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Chapter 1. Preamble

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This document contains extensions which are not ratified by Khronos, and as such is not a ratified Specification, though it contains text from (and is a superset of) the ratified Vulkan Specification. The ratified versions of the Vulkan Specification can be found at https://registry.khronos.org/vulkan/specs/1.3/html/vkspec.html (core only) and https://registry.khronos.org/vulkan/specs/1.3-khr-extensions/html/vkspec.html (core with all ratified extensions).

This Specification contains substantially unmodified functionality from, and is a successor to, Khronos specifications including OpenGL, OpenGL ES and OpenCL.

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Chapter 2. Introduction

This document, referred to as the “Vulkan Specification” or just the “Specification” hereafter, describes the Vulkan Application Programming Interface (API). Vulkan is a C99 API designed for explicit control of low-level graphics and compute functionality.

The canonical version of the Specification is available in the official Vulkan Registry (https://registry.khronos.org/vulkan/). The source files used to generate the Vulkan specification are stored in the Vulkan Documentation Repository (https://github.com/KhronosGroup/Vulkan-Docs).

The source repository additionally has a public issue tracker and allows the submission of pull requests that improve the specification.

2.1. Document Conventions

The Vulkan specification is intended for use by both implementors of the API and application developers seeking to make use of the API, forming a contract between these parties. Specification text may address either party; typically the intended audience can be inferred from context, though some sections are defined to address only one of these parties. (For example, Valid Usage sections only address application developers). Any requirements, prohibitions, recommendations or options defined by normative terminology are imposed only on the audience of that text.

Note
Structure and enumerated types defined in extensions that were promoted to core in a later version of Vulkan are now defined in terms of the equivalent Vulkan core interfaces. This affects the Vulkan Specification, the Vulkan header files, and the corresponding XML Registry.

2.1.1. Informative Language

Some language in the specification is purely informative, intended to give background or suggestions to implementors or developers.

If an entire chapter or section contains only informative language, its title will be suffixed with “(Informative)”.

All NOTEs are implicitly informative.

2.1.2. Normative Terminology

Within this specification, the key words must, required, should, recommended, may, and optional are to be interpreted as described in RFC 2119 - Key words for use in RFCs to Indicate Requirement Levels (https://www.ietf.org/rfc/rfc2119.txt). The additional key word optionally is an alternate form of optional, for use where grammatically appropriate.

These key words are highlighted in the specification for clarity. In text addressing application developers, their use expresses requirements that apply to application behavior. In text addressing implementors, their use expresses requirements that apply to implementations.
In text addressing application developers, the additional key words **can** and **cannot** are to be interpreted as describing the capabilities of an application, as follows:

**can**

This word means that the application is able to perform the action described.

**cannot**

This word means that the API and/or the execution environment provide no mechanism through which the application can express or accomplish the action described.

These key words are never used in text addressing implementors.

---

**Note**

There is an important distinction between **cannot** and **must not**, as used in this Specification. **Cannot** means something the application literally is unable to express or accomplish through the API, while **must not** means something that the application is capable of expressing through the API, but that the consequences of doing so are undefined and potentially unrecoverable for the implementation (see Valid Usage).

---

Unless otherwise noted in the section heading, all sections and appendices in this document are normative.

### 2.1.3. Technical Terminology

The Vulkan Specification makes use of common engineering and graphics terms such as **Pipeline**, **Shader**, and **Host** to identify and describe Vulkan API constructs and their attributes, states, and behaviors. The **Glossary** defines the basic meanings of these terms in the context of the Specification. The Specification text provides fuller definitions of the terms and may elaborate, extend, or clarify the **Glossary** definitions. When a term defined in the **Glossary** is used in normative language within the Specification, the definitions within the Specification govern and supersede any meanings the terms may have in other technical contexts (i.e. outside the Specification).

### 2.1.4. Normative References

References to external documents are considered normative references if the Specification uses any of the normative terms defined in **Normative Terminology** to refer to them or their requirements, either as a whole or in part.

The following documents are referenced by normative sections of the specification:


Chapter 3. Fundamentals

This chapter introduces fundamental concepts including the Vulkan architecture and execution model, API syntax, queues, pipeline configurations, numeric representation, state and state queries, and the different types of objects and shaders. It provides a framework for interpreting more specific descriptions of commands and behavior in the remainder of the Specification.

3.1. Host and Device Environment

The Vulkan Specification assumes and requires: the following properties of the host environment with respect to Vulkan implementations:

- The host must have runtime support for 8, 16, 32 and 64-bit signed and unsigned two-complement integers, all addressable at the granularity of their size in bytes.
- The host must have runtime support for 32- and 64-bit floating-point types satisfying the range and precision constraints in the Floating Point Computation section.
- The representation and endianness of these types on the host must match the representation and endianness of the same types on every physical device supported.

Note
Since a variety of data types and structures in Vulkan may be accessible by both host and physical device operations, the implementation should be able to access such data efficiently in both paths in order to facilitate writing portable and performant applications.

3.2. Execution Model

This section outlines the execution model of a Vulkan system.

Vulkan exposes one or more devices, each of which exposes one or more queues which may process work asynchronously to one another. The set of queues supported by a device is partitioned into families. Each family supports one or more types of functionality and may contain multiple queues with similar characteristics. Queues within a single family are considered compatible with one another, and work produced for a family of queues can be executed on any queue within that family. This specification defines the following types of functionality that queues may support: graphics, compute, video decode, video encode, protected memory management, sparse memory management, and transfer.

Note
A single device may report multiple similar queue families rather than, or as well as, reporting multiple members of one or more of those families. This indicates that while members of those families have similar capabilities, they are not directly compatible with one another.

Device memory is explicitly managed by the application. Each device may advertise one or more
heaps, representing different areas of memory. Memory heaps are either device-local or host-local, but are always visible to the device. Further detail about memory heaps is exposed via memory types available on that heap. Examples of memory areas that may be available on an implementation include:

- **device-local** is memory that is physically connected to the device.
- **device-local, host visible** is device-local memory that is visible to the host.
- **host-local, host visible** is memory that is local to the host and visible to the device and host.

On other architectures, there may only be a single heap that can be used for any purpose.

### 3.2.1. Queue Operation

Vulkan queues provide an interface to the execution engines of a device. Commands for these execution engines are recorded into command buffers ahead of execution time, and then submitted to a queue for execution. Once submitted to a queue, command buffers will begin and complete execution without further application intervention, though the order of this execution is dependent on a number of implicit and explicit ordering constraints.

Work is submitted to queues using *queue submission commands* that typically take the form `vkQueue*` (e.g. `vkQueueSubmit`, `vkQueueBindSparse`), and can take a list of semaphores upon which to wait before work begins and a list of semaphores to signal once work has completed. The work itself, as well as signaling and waiting on the semaphores are all *queue operations*. Queue submission commands return control to the application once queue operations have been submitted - they do not wait for completion.

There are no implicit ordering constraints between queue operations on different queues, or between queues and the host, so these may operate in any order with respect to each other. Explicit ordering constraints between different queues or with the host can be expressed with *semaphores* and *fences*.

Command buffer submissions to a single queue respect *submission order* and other implicit ordering guarantees, but otherwise may overlap or execute out of order. Other types of batches and queue submissions against a single queue (e.g. sparse memory binding) have no implicit ordering constraints with any other queue submission or batch. Additional explicit ordering constraints between queue submissions and individual batches can be expressed with *semaphores* and *fences*.

Before a fence or semaphore is signaled, it is guaranteed that any previously submitted queue operations have completed execution, and that memory writes from those queue operations are available to future queue operations. Waiting on a signaled semaphore or fence guarantees that previous writes that are available are also visible to subsequent commands.

Command buffer boundaries, both between primary command buffers of the same or different batches or submissions as well as between primary and secondary command buffers, do not introduce any additional ordering constraints. In other words, submitting the set of command buffers (which can include executing secondary command buffers) between any semaphore or fence operations execute the recorded commands as if they had all been recorded into a single primary command buffer, except that the current state is reset on each boundary. Explicit ordering constraints can be expressed with *explicit synchronization primitives*. 
There are a few **implicit ordering guarantees** between commands within a command buffer, but only covering a subset of execution. Additional explicit ordering constraints can be expressed with the various **explicit synchronization primitives**.

**Note**

Implementations have significant freedom to overlap execution of work submitted to a queue, and this is common due to deep pipelining and parallelism in Vulkan devices.

Commands recorded in command buffers can perform actions, set state that persists across commands, synchronize other commands, or indirectly launch other commands, with some commands fulfilling several of these roles. The “Command Properties” section for each such command lists which of these roles the command takes. State setting commands update the **current state** of the command buffer. Some commands that perform actions (e.g. draw/dispatch) do so based on the current state set cumulatively since the start of the command buffer. The work involved in performing action commands is often allowed to overlap or to be reordered, but doing so **must** not alter the state to be used by each action command. In general, action commands are those commands that alter framebuffer attachments, read/write buffer or image memory, or write to query pools.

Synchronization commands introduce explicit execution and memory dependencies between two sets of action commands, where the second set of commands depends on the first set of commands. These dependencies enforce both that the execution of certain pipeline stages in the later set occurs after the execution of certain stages in the source set, and that the effects of memory accesses performed by certain pipeline stages occur in order and are visible to each other. When not enforced by an explicit dependency or **implicit ordering guarantees**, action commands **may** overlap execution or execute out of order, and **may** not see the side effects of each other's memory accesses.

### 3.3. Object Model

The devices, queues, and other entities in Vulkan are represented by Vulkan objects. At the API level, all objects are referred to by handles. There are two classes of handles, dispatchable and non-dispatchable. **Dispatchable** handle types are a pointer to an opaque type. This pointer **may** be used by layers as part of intercepting API commands, and thus each API command takes a dispatchable type as its first parameter. Each object of a dispatchable type **must** have a unique handle value during its lifetime.

**Non-dispatchable** handle types are a 64-bit integer type whose meaning is implementation-dependent. If the privateData feature is enabled for a **VkDevice**, each object of a non-dispatchable type created on that device **must** have a handle value that is unique among objects created on that device, for the duration of the object's lifetime. Otherwise, non-dispatchable handles **may** encode object information directly in the handle rather than acting as a reference to an underlying object, and thus **may** not have unique handle values. If handle values are not unique, then destroying one such handle **must** not cause identical handles of other types to become invalid, and **must** not cause identical handles of the same type to become invalid if that handle value has been created more times than it has been destroyed.
All objects created or allocated from a VkDevice (i.e. with a VkDevice as the first parameter) are private to that device, and must not be used on other devices.

### 3.3.1. Object Lifetime

Objects are created or allocated by vkCreate* and vkAllocate* commands, respectively. Once an object is created or allocated, its “structure” is considered to be immutable, though the contents of certain object types is still free to change. Objects are destroyed or freed by vkDestroy* and vkFree* commands, respectively.

Objects that are allocated (rather than created) take resources from an existing pool object or memory heap, and when freed return resources to that pool or heap. While object creation and destruction are generally expected to be low-frequency occurrences during runtime, allocating and freeing objects can occur at high frequency. Pool objects help accommodate improved performance of the allocations and frees.

It is an application’s responsibility to track the lifetime of Vulkan objects, and not to destroy them while they are still in use.

The ownership of application-owned memory is immediately acquired by any Vulkan command it is passed into. Ownership of such memory must be released back to the application at the end of the duration of the command, unless that command was deferred, so that the application can alter or free this memory as soon as all the commands that acquired it have returned. If the command was deferred, ownership of such memory is released back to the application when the deferred operation is complete.

The following object types are consumed when they are passed into a Vulkan command and not further accessed by the objects they are used to create. They must not be destroyed in the duration of any API command they are passed into:

- VkShaderModule
- VkPipelineCache
- VkValidationCacheEXT

A VkRenderPass or VkPipelineLayout object passed as a parameter to create another object is not further accessed by that object after the duration of the command it is passed into. A VkRenderPass used in a command buffer follows the rules described below.

VkDescriptorSetLayout objects may be accessed by commands that operate on descriptor sets allocated using that layout, and those descriptor sets must not be updated with vkUpdateDescriptorSets after the descriptor set layout has been destroyed. Otherwise, a VkDescriptorSetLayout object passed as a parameter to create another object is not further accessed by that object after the duration of the command it is passed into.

The application must not destroy any other type of Vulkan object until all uses of that object by the device (such as via command buffer execution) have completed.

The following Vulkan objects must not be destroyed while any command buffers using the object are in the pending state:
• VkEvent
• VkQueryPool
• VkBuffer
• VkBufferView
• VkImage
• VkImageView
• VkPipeline
• VkSampler
• VkSamplerYcbcrConversion
• VkDescriptorPool
• VkFramebuffer
• VkRenderPass
• VkCommandBuffer
• VkCommandPool
• VkDeviceMemory
• VkDescriptorSet
• VkIndirectCommandsLayoutNV
• VkAccelerationStructureNV
• VkAccelerationStructureKHR
• VkVideoSessionKHR
• VkVideoSessionParametersKHR

Destroying these objects will move any command buffers that are in the **recording or executable state**, and are using those objects, to the **invalid state**.

The following Vulkan objects **must** not be destroyed while any queue is executing commands that use the object:

• VkFence
• VkSemaphore
• VkCommandBuffer
• VkCommandPool

In general, objects **can** be destroyed or freed in any order, even if the object being freed is involved in the use of another object (e.g. use of a resource in a view, use of a view in a descriptor set, use of a pipeline library in another pipeline, use of a referenced pipeline for additional graphics shader groups in another pipeline, use of a bottom level acceleration structure in an instance referenced by a top level acceleration structure, use of an object in a command buffer, binding of a memory allocation to a resource), as long as any object that uses the freed object is not further used in any way except to be destroyed or to be reset in such a way that it no longer uses the other object (such
as resetting a command buffer). If the object has been reset, then it **can** be used as if it never used the freed object. An exception to this is when there is a parent/child relationship between objects. In this case, the application **must** not destroy a parent object before its children, except when the parent is explicitly defined to free its children when it is destroyed (e.g. for pool objects, as defined below).

**VkCommandPool** objects are parents of **VkCommandBuffer** objects. **VkDescriptorPool** objects are parents of **VkDescriptorSet** objects. **VkDevice** objects are parents of many object types (all that take a **VkDevice** as a parameter to their creation).

The following Vulkan objects have specific restrictions for when they **can** be destroyed:

- **VkQueue** objects **cannot** be explicitly destroyed. Instead, they are implicitly destroyed when the **VkDevice** object they are retrieved from is destroyed.
- Destroying a pool object implicitly frees all objects allocated from that pool. Specifically, destroying **VkCommandPool** frees all **VkCommandBuffer** objects that were allocated from it, and destroying **VkDescriptorPool** frees all **VkDescriptorSet** objects that were allocated from it.
- **VkDevice** objects **can** be destroyed when all **VkQueue** objects retrieved from them are idle, and all objects created from them have been destroyed.
  - This includes the following objects:
    - **VkFence**
    - **VkSemaphore**
    - **VkEvent**
    - **VkQueryPool**
    - **VkBuffer**
    - **VkBufferView**
    - **VkImage**
    - **VkImageView**
    - **VkShaderModule**
    - **VkPipelineCache**
    - **VkPipeline**
    - **VkPipelineLayout**
    - **VkSampler**
    - **VkSamplerYcbcrConversion**
    - **VkDescriptorSetLayout**
    - **VkDescriptorPool**
    - **VkFramebuffer**
    - **VkRenderPass**
    - **VkCommandPool**
The scope of external handles and their associated resources may vary according to their type, but they can generally be shared across process and API boundaries.

3.4. Application Binary Interface

The mechanism by which Vulkan is made available to applications is platform- or implementation-defined. On many platforms, the C interface described in this Specification is provided by a shared library. Since shared libraries can be changed independently of the applications that use them, they present particular compatibility challenges, and this Specification places some requirements on them.

Shared library implementations must use the default Application Binary Interface (ABI) of the standard C compiler for the platform, or provide customized API headers that cause application code to use the implementation’s non-default ABI. An ABI in this context means the size, alignment, and layout of C data types; the procedure calling convention; and the naming convention for shared library symbols corresponding to C functions. Customizing the calling convention for a platform is usually accomplished by defining calling convention macros appropriately in vk_platform.h.

On platforms where Vulkan is provided as a shared library, library symbols beginning with “vk” and followed by a digit or uppercase letter are reserved for use by the implementation. Applications which use Vulkan must not provide definitions of these symbols. This allows the Vulkan shared library to be updated with additional symbols for new API versions or extensions without causing symbol conflicts with existing applications.
Shared library implementations should provide library symbols for commands in the highest version of this Specification they support, and for Window System Integration extensions relevant to the platform. They may also provide library symbols for commands defined by additional extensions.

Note
These requirements and recommendations are intended to allow implementors to take advantage of platform-specific conventions for SDKs, ABIs, library versioning mechanisms, etc. while still minimizing the code changes necessary to port applications or libraries between platforms. Platform vendors, or providers of the de facto standard Vulkan shared library for a platform, are encouraged to document what symbols the shared library provides and how it will be versioned when new symbols are added.

Applications should only rely on shared library symbols for commands in the minimum core version required by the application. vkGetInstanceProcAddr and vkGetDeviceProcAddr should be used to obtain function pointers for commands in core versions beyond the application's minimum required version.

3.5. Command Syntax and Duration

The Specification describes Vulkan commands as functions or procedures using C99 syntax. Language bindings for other languages such as C++ and JavaScript may allow for stricter parameter passing, or object-oriented interfaces.

Vulkan uses the standard C types for the base type of scalar parameters (e.g. types from <stdint.h>), with exceptions described below, or elsewhere in the text when appropriate:

VkBool32 represents boolean True and False values, since C does not have a sufficiently portable built-in boolean type:

```c
// Provided by VK_VERSION_1_0
typedef uint32_t VkBool32;
```

VK_TRUE represents a boolean True (unsigned integer 1) value, and VK_FALSE a boolean False (unsigned integer 0) value.

All values returned from a Vulkan implementation in a VkBool32 will be either VK_TRUE or VK_FALSE.

Applications must not pass any other values than VK_TRUE or VK_FALSE into a Vulkan implementation where a VkBool32 is expected.

VK_TRUE is a constant representing a VkBool32 True value.

```c
#define VK_TRUE 1U
```

VK_FALSE is a constant representing a VkBool32 False value.


VkDeviceSize represents device memory size and offset values:

```c
// Provided by VK_VERSION_1_0
typedef uint64_t VkDeviceSize;
```

VkDeviceAddress represents device buffer address values:

```c
// Provided by VK_VERSION_1_0
typedef uint64_t VkDeviceAddress;
```

Commands that create Vulkan objects are of the form `vkCreate*` and take `Vk*CreateInfo` structures with the parameters needed to create the object. These Vulkan objects are destroyed with commands of the form `vkDestroy*`.

The last in-parameter to each command that creates or destroys a Vulkan object is `pAllocator`. The `pAllocator` parameter can be set to a non-`NULL` value such that allocations for the given object are delegated to an application provided callback; refer to the Memory Allocation chapter for further details.

Commands that allocate Vulkan objects owned by pool objects are of the form `vkAllocate*`, and take `Vk*AllocateInfo` structures. These Vulkan objects are freed with commands of the form `vkFree*`. These objects do not take allocators; if host memory is needed, they will use the allocator that was specified when their parent pool was created.

Commands are recorded into a command buffer by calling API commands of the form `vkCmd*`. Each such command may have different restrictions on where it can be used: in a primary and/or secondary command buffer, inside and/or outside a render pass, and in one or more of the supported queue types. These restrictions are documented together with the definition of each such command.

The duration of a Vulkan command refers to the interval between calling the command and its return to the caller.

### 3.5.1. Lifetime of Retrieved Results

Information is retrieved from the implementation with commands of the form `vkGet*` and `vkEnumerate*`.

Unless otherwise specified for an individual command, the results are invariant; that is, they will remain unchanged when retrieved again by calling the same command with the same parameters, so long as those parameters themselves all remain valid.
3.6. Threading Behavior

Vulkan is intended to provide scalable performance when used on multiple host threads. All commands support being called concurrently from multiple threads, but certain parameters, or components of parameters are defined to be externally synchronized. This means that the caller **must** guarantee that no more than one thread is using such a parameter at a given time.

More precisely, Vulkan commands use simple stores to update the state of Vulkan objects. A parameter declared as externally synchronized **may** have its contents updated at any time during the host execution of the command. If two commands operate on the same object and at least one of the commands declares the object to be externally synchronized, then the caller **must** guarantee not only that the commands do not execute simultaneously, but also that the two commands are separated by an appropriate memory barrier (if needed).

**Note**

Memory barriers are particularly relevant for hosts based on the ARM CPU architecture, which is more weakly ordered than many developers are accustomed to from x86/x64 programming. Fortunately, most higher-level synchronization primitives (like the pthread library) perform memory barriers as a part of mutual exclusion, so muting Vulkan objects via these primitives will have the desired effect.

Similarly the application **must** avoid any potential data hazard of application-owned memory that has its ownership temporarily acquired by a Vulkan command. While the ownership of application-owned memory remains acquired by a command the implementation **may** read the memory at any point, and it **may** write non-**const** qualified memory at any point. Parameters referring to non-**const** qualified application-owned memory are not marked explicitly as externally synchronized in the Specification.

If an application is using deferred host operations in a command, and that operation is successfully deferred, object parameters and application-owned memory passed to that command **may** be accessed at any time until the deferred operation is complete.

Many object types are immutable, meaning the objects cannot change once they have been created. These types of objects never need external synchronization, except that they **must** not be destroyed while they are in use on another thread. In certain special cases mutable object parameters are internally synchronized, making external synchronization unnecessary. Any command parameters that are not labeled as externally synchronized are either not mutated by the command or are internally synchronized. Additionally, certain objects related to a command’s parameters (e.g. command pools and descriptor pools) **may** be affected by a command, and **must** also be externally synchronized. These implicit parameters are documented as described below.

Parameters of commands that are externally synchronized are listed below.

**Externally Synchronized Parameters**

- The instance parameter in `vkDestroyInstance`
• The `device` parameter in `vkDestroyDevice`
• The `queue` parameter in `vkQueueSubmit`
• The `fence` parameter in `vkQueueSubmit`
• The `queue` parameter in `vkQueueWaitIdle`
• The `memory` parameter in `vkFreeMemory`
• The `memory` parameter in `vkMapMemory`
• The `memory` parameter in `vkUnmapMemory`
• The `buffer` parameter in `vkBindBufferMemory`
• The `image` parameter in `vkBindImageMemory`
• The `queue` parameter in `vkQueueBindSparse`
• The `fence` parameter in `vkQueueBindSparse`
• The `fence` parameter in `vkDestroyFence`
• The `semaphore` parameter in `vkDestroySemaphore`
• The `event` parameter in `vkDestroyEvent`
• The `event` parameter in `vkSetEvent`
• The `event` parameter in `vkResetEvent`
• The `queryPool` parameter in `vkDestroyQueryPool`
• The `buffer` parameter in `vkDestroyBuffer`
• The `bufferView` parameter in `vkDestroyBufferView`
• The `image` parameter in `vkDestroyImage`
• The `imageView` parameter in `vkDestroyImageView`
• The `shaderModule` parameter in `vkDestroyShaderModule`
• The `pipelineCache` parameter in `vkDestroyPipelineCache`
• The `dstCache` parameter in `vkMergePipelineCaches`
• The `pipeline` parameter in `vkDestroyPipeline`
• The `pipelineLayout` parameter in `vkDestroyPipelineLayout`
• The `sampler` parameter in `vkDestroySampler`
• The `descriptorSetLayout` parameter in `vkDestroyDescriptorSetLayout`
• The `descriptorPool` parameter in `vkDestroyDescriptorPool`
• The `descriptorPool` parameter in `vkResetDescriptorPool`
• The `descriptorPool` member of the `pAllocateInfo` parameter in `vkAllocateDescriptorSets`
• The `descriptorPool` parameter in `vkFreeDescriptorSets`
• The `framebuffer` parameter in `vkDestroyFramebuffer`
• The `renderPass` parameter in `vkDestroyRenderPass`
• The `commandPool` parameter in `vkDestroyCommandPool`
- The `commandPool` parameter in `vkResetCommandPool`
- The `commandPool` member of the `pAllocateInfo` parameter in `vkAllocateCommandBuffers`
- The `commandPool` parameter in `vkFreeCommandBuffers`
- The `commandBuffer` parameter in `vkBeginCommandBuffer`
- The `commandBuffer` parameter in `vkEndCommandBuffer`
- The `commandBuffer` parameter in `vkResetCommandBuffer`
- The `commandBuffer` parameter in `vkCmdBindPipeline`
- The `commandBuffer` parameter in `vkCmdSetViewport`
- The `commandBuffer` parameter in `vkCmdSetScissor`
- The `commandBuffer` parameter in `vkCmdSetLineWidth`
- The `commandBuffer` parameter in `vkCmdSetDepthBias`
- The `commandBuffer` parameter in `vkCmdSetBlendConstants`
- The `commandBuffer` parameter in `vkCmdSetDepthBounds`
- The `commandBuffer` parameter in `vkCmdSetStencilCompareMask`
- The `commandBuffer` parameter in `vkCmdSetStencilWriteMask`
- The `commandBuffer` parameter in `vkCmdSetStencilReference`
- The `commandBuffer` parameter in `vkCmdBindDescriptorSets`
- The `commandBuffer` parameter in `vkCmdBindIndexBuffer`
- The `commandBuffer` parameter in `vkCmdBindVertexBuffers`
- The `commandBuffer` parameter in `vkCmdDraw`
- The `commandBuffer` parameter in `vkCmdDrawIndexed`
- The `commandBuffer` parameter in `vkCmdDrawIndirect`
- The `commandBuffer` parameter in `vkCmdDrawIndexedIndirect`
- The `commandBuffer` parameter in `vkCmdDispatch`
- The `commandBuffer` parameter in `vkCmdDispatchIndirect`
- The `commandBuffer` parameter in `vkCmdCopyBuffer`
- The `commandBuffer` parameter in `vkCmdCopyImage`
- The `commandBuffer` parameter in `vkCmdBlitImage`
- The `commandBuffer` parameter in `vkCmdCopyBufferToImage`
- The `commandBuffer` parameter in `vkCmdCopyImageToBuffer`
- The `commandBuffer` parameter in `vkCmdUpdateBuffer`
- The `commandBuffer` parameter in `vkCmdFillBuffer`
- The `commandBuffer` parameter in `vkCmdClearColorImage`
- The `commandBuffer` parameter in `vkCmdClearDepthStencilImage`
- The `commandBuffer` parameter in `vkCmdClearAttachments`
• The `commandBuffer` parameter in `vkCmdResolveImage`
• The `commandBuffer` parameter in `vkCmdSetEvent`
• The `commandBuffer` parameter in `vkCmdResetEvent`
• The `commandBuffer` parameter in `vkCmdWaitEvents`
• The `commandBuffer` parameter in `vkCmdPipelineBarrier`
• The `commandBuffer` parameter in `vkCmdBeginQuery`
• The `commandBuffer` parameter in `vkCmdEndQuery`
• The `commandBuffer` parameter in `vkCmdResetQueryPool`
• The `commandBuffer` parameter in `vkCmdWriteTimestamp`
• The `commandBuffer` parameter in `vkCmdCopyQueryPoolResults`
• The `commandBuffer` parameter in `vkCmdPushConstants`
• The `commandBuffer` parameter in `vkCmdBeginRenderPass`
• The `commandBuffer` parameter in `vkCmdNextSubpass`
• The `commandBuffer` parameter in `vkCmdEndRenderPass`
• The `commandBuffer` parameter in `vkCmdExecuteCommands`
• The `commandBuffer` parameter in `vkCmdSetDeviceMask`
• The `commandBuffer` parameter in `vkCmdDispatchBase`
• The `commandPool` parameter in `vkTrimCommandPool`
• The `ycbcrConversion` parameter in `vkDestroySamplerYcbcrConversion`
• The `descriptorUpdateTemplate` parameter in `vkDestroyDescriptorUpdateTemplate`
• The `commandBuffer` parameter in `vkCmdDrawIndirectCount`
• The `commandBuffer` parameter in `vkCmdDrawIndexedIndirectCount`
• The `commandBuffer` parameter in `vkCmdBeginRenderPass2`
• The `commandBuffer` parameter in `vkCmdNextSubpass2`
• The `commandBuffer` parameter in `vkCmdEndRenderPass2`
• The `privateDataSlot` parameter in `vkDestroyPrivateDataSlot`
• The `commandBuffer` parameter in `vkCmdSetEvent2`
• The `commandBuffer` parameter in `vkCmdResetEvent2`
• The `commandBuffer` parameter in `vkCmdWaitEvents2`
• The `commandBuffer` parameter in `vkCmdPipelineBarrier2`
• The `commandBuffer` parameter in `vkCmdWriteTimestamp2`
• The `queue` parameter in `vkQueueSubmit2`
• The `fence` parameter in `vkQueueSubmit2`
• The `commandBuffer` parameter in `vkCmdCopyBuffer2`
• The `commandBuffer` parameter in `vkCmdCopyImage2`
- The `commandBuffer` parameter in `vkCmdCopyBufferToImage2`
- The `commandBuffer` parameter in `vkCmdCopyImageToBuffer2`
- The `commandBuffer` parameter in `vkCmdBlitImage2`
- The `commandBuffer` parameter in `vkCmdResolveImage2`
- The `commandBuffer` parameter in `vkCmdBeginRendering`
- The `commandBuffer` parameter in `vkCmdEndRendering`
- The `commandBuffer` parameter in `vkCmdSetCullMode`
- The `commandBuffer` parameter in `vkCmdSetFrontFace`
- The `commandBuffer` parameter in `vkCmdSetPrimitiveTopology`
- The `commandBuffer` parameter in `vkCmdSetViewportWithCount`
- The `commandBuffer` parameter in `vkCmdSetScissorWithCount`
- The `commandBuffer` parameter in `vkCmdBindVertexBuffers2`
- The `commandBuffer` parameter in `vkCmdSetDepthTestEnable`
- The `commandBuffer` parameter in `vkCmdSetDepthWriteEnable`
- The `commandBuffer` parameter in `vkCmdSetDepthCompareOp`
- The `commandBuffer` parameter in `vkCmdSetDepthBoundsTestEnable`
- The `commandBuffer` parameter in `vkCmdSetStencilTestEnable`
- The `commandBuffer` parameter in `vkCmdSetStencilOp`
- The `commandBuffer` parameter in `vkCmdSetRasterizerDiscardEnable`
- The `commandBuffer` parameter in `vkCmdSetDepthBiasEnable`
- The `commandBuffer` parameter in `vkCmdSetPrimitiveRestartEnable`
- The `surface` parameter in `vkDestroySurfaceKHR`
- The `surface` member of the `pCreateInfo` parameter in `vkCreateSwapchainKHR`
- The `oldSwapchain` member of the `pCreateInfo` parameter in `vkCreateSwapchainKHR`
- The `swapchain` parameter in `vkDestroySwapchainKHR`
- The `swapchain` parameter in `vkAcquireNextImageKHR`
- The `semaphore` parameter in `vkAcquireNextImageKHR`
- The `fence` parameter in `vkQueuePresentKHR`
- The `surface` parameter in `vkGetDeviceGroupSurfacePresentModesKHR`
- The `surface` parameter in `vkGetPhysicalDevicePresentRectanglesKHR`
- The `display` parameter in `vkCreateDisplayModeKHR`
- The `mode` parameter in `vkGetDisplayPlaneCapabilitiesKHR`
- The `videoSession` parameter in `vkDestroyVideoSessionKHR`
- The `videoSession` parameter in `vkBindVideoSessionMemoryKHR`
- The `videoSessionParameters` parameter in `vkDestroyVideoSessionParametersKHR`
- The `commandBuffer` parameter in `vkCmdBeginVideoCodingKHR`
- The `commandBuffer` parameter in `vkCmdEndVideoCodingKHR`
- The `commandBuffer` parameter in `vkCmdControlVideoCodingKHR`
- The `commandBuffer` parameter in `vkCmdDecodeVideoKHR`
- The `commandBuffer` parameter in `vkCmdBeginRenderingKHR`
- The `commandBuffer` parameter in `vkCmdEndRenderingKHR`
- The `commandBuffer` parameter in `vkCmdSetDeviceMaskKHR`
- The `commandBuffer` parameter in `vkCmdDispatchBaseKHR`
- The `commandPool` parameter in `vkTrimCommandPoolKHR`
- The `commandBuffer` parameter in `vkCmdPushDescriptorSetKHR`
- The `commandBuffer` parameter in `vkCmdPushDescriptorSetWithTemplateKHR`
- The `descriptorUpdateTemplate` parameter in `vkDestroyDescriptorUpdateTemplateKHR`
- The `commandBuffer` parameter in `vkCmdBeginRenderPass2KHR`
- The `commandBuffer` parameter in `vkCmdNextSubpass2KHR`
- The `commandBuffer` parameter in `vkCmdEndRenderPass2KHR`
- The `swapchain` parameter in `vkGetSwapchainStatusKHR`
- The `ycbcrConversion` parameter in `vkDestroySamplerYcbcrConversionKHR`
- The `commandBuffer` parameter in `vkCmdDrawIndirectCountKHR`
- The `commandBuffer` parameter in `vkCmdDrawIndexedIndirectCountKHR`
- The `swapchain` parameter in `vkWaitForPresentKHR`
- The `operation` parameter in `vkDestroyDeferredOperationKHR`
- The `commandBuffer` parameter in `vkCmdEncodeVideoKHR`
- The `commandBuffer` parameter in `vkCmdSetEvent2KHR`
- The `commandBuffer` parameter in `vkCmdResetEvent2KHR`
- The `commandBuffer` parameter in `vkCmdWaitEvents2KHR`
- The `commandBuffer` parameter in `vkCmdPipelineBarrier2KHR`
- The `commandBuffer` parameter in `vkCmdWriteTimestamp2KHR`
- The `queue` parameter in `vkQueueSubmit2KHR`
- The `fence` parameter in `vkQueueSubmit2KHR`
- The `commandBuffer` parameter in `vkCmdWriteBufferMarker2AMD`
- The `commandBuffer` parameter in `vkCmdCopyBuffer2KHR`
- The `commandBuffer` parameter in `vkCmdCopyImage2KHR`
- The `commandBuffer` parameter in `vkCmdCopyBufferToImage2KHR`
• The `commandBuffer` parameter in `vkCmdCopyImageToBuffer2KHR`  
• The `commandBuffer` parameter in `vkCmdBlitImage2KHR`  
• The `commandBuffer` parameter in `vkCmdResolveImage2KHR`  
• The `commandBuffer` parameter in `vkCmdTraceRaysIndirect2KHR`  
• The `commandBuffer` parameter in `vkCmdBindIndexBuffer2KHR`  
• The `callback` parameter in `vkDestroyDebugReportCallbackEXT`  
• The `object` member of the `pTagInfo` parameter in `vkDebugMarkerSetObjectTagEXT`  
• The `object` member of the `pNameInfo` parameter in `vkDebugMarkerSetObjectNameEXT`  
• The `commandBuffer` parameter in `vkCmdDebugMarkerBeginEXT`  
• The `commandBuffer` parameter in `vkCmdDebugMarkerEndEXT`  
• The `commandBuffer` parameter in `vkCmdDebugMarkerInsertEXT`  
• The `commandBuffer` parameter in `vkCmdBindTransformFeedbackBuffersEXT`  
• The `commandBuffer` parameter in `vkCmdBeginTransformFeedbackEXT`  
• The `commandBuffer` parameter in `vkCmdEndTransformFeedbackEXT`  
• The `commandBuffer` parameter in `vkCmdBeginQueryIndexedEXT`  
• The `commandBuffer` parameter in `vkCmdEndQueryIndexedEXT`  
• The `commandBuffer` parameter in `vkCmdDrawIndirectByteCountEXT`  
• The `commandBuffer` parameter in `vkCmdDrawIndirectCountAMD`  
• The `commandBuffer` parameter in `vkCmdBeginConditionalRenderingEXT`  
• The `commandBuffer` parameter in `vkCmdEndConditionalRenderingEXT`  
• The `commandBuffer` parameter in `vkCmdSetViewportWScalingNV`  
• The `swapchain` parameter in `vkGetRefreshCycleDurationGOOGLE`  
• The `swapchain` parameter in `vkGetPastPresentationTimingGOOGLE`  
• The `commandBuffer` parameter in `vkCmdSetDiscardRectangleEXT`  
• The `commandBuffer` parameter in `vkCmdSetDiscardRectangleEnableEXT`  
• The `commandBuffer` parameter in `vkCmdSetDiscardRectangleModeEXT`  
• The `objectHandle` member of the `pNameInfo` parameter in `vkSetDebugUtilsObjectNameEXT`  
• The `objectHandle` member of the `pTagInfo` parameter in `vkSetDebugUtilsObjectTagEXT`  
• The `commandBuffer` parameter in `vkCmdBeginDebugUtilsLabelEXT`  
• The `commandBuffer` parameter in `vkCmdEndDebugUtilsLabelEXT`  
• The `commandBuffer` parameter in `vkCmdInsertDebugUtilsLabelEXT`  
• The `messenger` parameter in `vkDestroyDebugUtilsMessengerEXT`  
• The `commandBuffer` parameter in `vkCmdSetSampleLocationsEXT`  
• The `validationCache` parameter in `vkDestroyValidationCacheEXT`
The dstCache parameter in `vkMergeValidationCachesEXT`

The commandBuffer parameter in `vkCmdBindShadingRateImageNV`

The commandBuffer parameter in `vkCmdSetViewportShadingRatePaletteNV`

The commandBuffer parameter in `vkCmdSetCoarseSampleOrderNV`

The accelerationStructure parameter in `vkDestroyAccelerationStructureNV`

The commandBuffer parameter in `vkCmdBuildAccelerationStructureNV`

The commandBuffer parameter in `vkCmdCopyAccelerationStructureNV`

The commandBuffer parameter in `vkCmdTraceRaysNV`

The commandBuffer parameter in `vkCmdWriteAccelerationStructuresPropertiesNV`

The commandBuffer parameter in `vkCmdWriteBufferMarkerAMD`

The commandBuffer parameter in `vkCmdDrawMeshTasksNV`

The commandBuffer parameter in `vkCmdDrawMeshTasksIndirectNV`

The commandBuffer parameter in `vkCmdDrawMeshTasksIndirectCountNV`

The commandBuffer parameter in `vkCmdSetExclusiveScissorEnableNV`

The commandBuffer parameter in `vkCmdSetExclusiveScissorNV`

The commandBuffer parameter in `vkCmdSetCheckpointNV`

The commandBuffer parameter in `vkCmdSetPerformanceMarkerINTEL`

The commandBuffer parameter in `vkCmdSetPerformanceStreamMarkerINTEL`

The commandBuffer parameter in `vkCmdSetPerformanceOverrideINTEL`

The configuration parameter in `vkReleasePerformanceConfigurationINTEL`

The commandBuffer parameter in `vkCmdSetLineStippleEXT`

The commandBuffer parameter in `vkCmdSetCullModeEXT`

The commandBuffer parameter in `vkCmdSetFrontFaceEXT`

The commandBuffer parameter in `vkCmdSetPrimitiveTopologyEXT`

The commandBuffer parameter in `vkCmdSetViewportWithCountEXT`

The commandBuffer parameter in `vkCmdSetScissorWithCountEXT`

The commandBuffer parameter in `vkCmdBindVertexBuffers2EXT`

The commandBuffer parameter in `vkCmdSetDepthTestEnableEXT`

The commandBuffer parameter in `vkCmdSetDepthWriteEnableEXT`

The commandBuffer parameter in `vkCmdSetDepthCompareOpEXT`

The commandBuffer parameter in `vkCmdSetDepthBoundsTestEnableEXT`

The commandBuffer parameter in `vkCmdSetStencilTestEnableEXT`

The commandBuffer parameter in `vkCmdSetStencilOpEXT`

The commandBuffer parameter in `vkCmdPreprocessGeneratedCommandsNV`

The commandBuffer parameter in `vkCmdExecuteGeneratedCommandsNV`
• The `commandBuffer` parameter in `vkCmdBindPipelineShaderGroupNV`
• The `indirectCommandsLayout` parameter in `vkDestroyIndirectCommandsLayoutNV`
• The `commandBuffer` parameter in `vkCmdSetDepthBias2EXT`
• The `privateDataSlot` parameter in `vkDestroyPrivateDataSlotEXT`
• The `commandBuffer` parameter in `vkCmdBindDescriptorBuffersEXT`
• The `commandBuffer` parameter in `vkCmdSetDescriptorBufferOffsetsEXT`
• The `commandBuffer` parameter in `vkCmdBindDescriptorBufferEmbeddedSamplersEXT`
• The `commandBuffer` parameter in `vkCmdSetFragmentShadingRateEnumNV`
• The `commandBuffer` parameter in `vkCmdSetVertexInputEXT`
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• The `commandBuffer` parameter in `vkCmdSetPatchControlPointsEXT`
• The `commandBuffer` parameter in `vkCmdSetRasterizerDiscardEnableEXT`
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• The `commandBuffer` parameter in `vkCmdUpdatePipelineIndirectBufferNV`
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• The `commandBuffer` parameter in `vkCmdSetRasterizationStreamEXT`
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• The `commandBuffer` parameter in `vkCmdSetExtraPrimitiveOverestimationSizeEXT`
• The `commandBuffer` parameter in `vkCmdSetDepthClipEnableEXT`
• The `commandBuffer` parameter in `vkCmdSetSampleLocationsEnableEXT`
• The `commandBuffer` parameter in `vkCmdSetColorBlendAdvancedEXT`
• The `commandBuffer` parameter in `vkCmdSetProvokingVertexModeEXT`
• The `commandBuffer` parameter in `vkCmdSetLineRasterizationModeEXT`
• The `commandBuffer` parameter in `vkCmdSetLineStippleEnableEXT`
• The `commandBuffer` parameter in `vkCmdSetDepthClipNegativeOneToOneEXT`
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• The `commandBuffer` parameter in `vkCmdSetViewportSwizzleNV`
• The `commandBuffer` parameter in `vkCmdSetCoverageToColorEnableNV`
• The `commandBuffer` parameter in `vkCmdSetCoverageToColorLocationNV`
• The `commandBuffer` parameter in `vkCmdSetCoverageModulationModeNV`
• The `commandBuffer` parameter in `vkCmdSetCoverageModulationTableEnableNV`
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• The `commandBuffer` parameter in `vkCmdSetShadingRateImageEnableNV`
• The `commandBuffer` parameter in `vkCmdSetRepresentativeFragmentTestEnableNV`
• The `commandBuffer` parameter in `vkCmdSetCoverageReductionModeNV`
• The `shader` parameter in `vkDestroyShaderEXT`
• The `commandBuffer` parameter in `vkCmdBindShadersEXT`
• The `commandBuffer` parameter in `vkCmdSetAttachmentFeedbackLoopEnableEXT`
• The `accelerationStructure` parameter in `vkDestroyAccelerationStructureKHR`
• The `commandBuffer` parameter in `vkCmdBuildAccelerationStructuresKHR`
• The `commandBuffer` parameter in `vkCmdBuildAccelerationStructuresIndirectKHR`
• The `commandBuffer` parameter in `vkCmdCopyAccelerationStructureKHR`
• The commandBuffer parameter in vkCmdCopyAccelerationStructureToMemoryKHR
• The commandBuffer parameter in vkCmdCopyMemoryToAccelerationStructureKHR
• The commandBuffer parameter in vkCmdWriteAccelerationStructuresPropertiesKHR
• The commandBuffer parameter in vkCmdTraceRaysKHR
• The commandBuffer parameter in vkCmdTraceRaysIndirectKHR
• The commandBuffer parameter in vkCmdSetRayTracingPipelineStackSizeKHR
• The commandBuffer parameter in vkCmdDrawMeshTasksEXT
• The commandBuffer parameter in vkCmdDrawMeshTasksIndirectEXT
• The commandBuffer parameter in vkCmdDrawMeshTasksIndirectCountEXT

For VkPipelineCache objects created with flags containing VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT, the above table is extended with the pipelineCache parameter to vkCreate*Pipelines being externally synchronized.

There are also a few instances where a command can take in a user allocated list whose contents are externally synchronized parameters. In these cases, the caller must guarantee that at most one thread is using a given element within the list at a given time. These parameters are listed below.

**Externally Synchronized Parameter Lists**

• Each element of the pFences parameter in vkResetFences
• Each element of the pDescriptorSets parameter in vkFreeDescriptorSets
• Each element of the pCommandBuffers parameter in vkFreeCommandBuffers
• Each element of the pWaitSemaphores member of the pPresentInfo parameter in vkQueuePresentKHR
• Each element of the pSwapchains member of the pPresentInfo parameter in vkQueuePresentKHR
• The surface member of each element of the pCreateInfos parameter in vkCreateSharedSwapchainsKHR
• The oldSwapchain member of each element of the pCreateInfos parameter in vkCreateSharedSwapchainsKHR

In addition, there are some implicit parameters that need to be externally synchronized. For example, when a commandBuffer parameter needs to be externally synchronized, it implies that the commandPool from which that command buffer was allocated also needs to be externally synchronized. The implicit parameters and their associated object are listed below.

**Implicit Externally Synchronized Parameters**

• All VkPhysicalDevice objects enumerated from instance in vkDestroyInstance
• All VkQueue objects created from device in vkDestroyDevice
• All VkQueue objects created from device in vkDeviceWaitIdle
• Any VkDescriptorSet objects allocated from descriptorPool in vkResetDescriptorPool
• The VkCommandPool that commandBuffer was allocated from in vkBeginCommandBuffer
• The VkCommandPool that commandBuffer was allocated from in vkEndCommandBuffer
• The VkCommandPool that commandBuffer was allocated from in vkResetCommandBuffer
• The VkCommandPool that commandBuffer was allocated from, in vkCmdBindPipeline
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetViewport
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetScissor
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetLineWidth
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetDepthBias
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetBlendConstants
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetDepthBounds
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetStencilCompareMask
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetStencilWriteMask
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetStencilReference
• The VkCommandPool that commandBuffer was allocated from, in vkCmdBindDescriptorSets
• The VkCommandPool that commandBuffer was allocated from, in vkCmdBindIndexBuffer
• The VkCommandPool that commandBuffer was allocated from, in vkCmdBindVertexBuffers
• The VkCommandPool that commandBuffer was allocated from, in vkCmdDraw
• The VkCommandPool that commandBuffer was allocated from, in vkCmdDrawIndexed
• The VkCommandPool that commandBuffer was allocated from, in vkCmdDrawIndexedIndirect
• The VkCommandPool that commandBuffer was allocated from, in vkCmdDispatch
• The VkCommandPool that commandBuffer was allocated from, in vkCmdDispatchIndirect
• The VkCommandPool that commandBuffer was allocated from, in vkCmdCopyBuffer
• The VkCommandPool that commandBuffer was allocated from, in vkCmdCopyImage
• The VkCommandPool that commandBuffer was allocated from, in vkCmdBlitImage
• The VkCommandPool that commandBuffer was allocated from, in vkCmdCopyBufferToImage
• The VkCommandPool that commandBuffer was allocated from, in vkCmdCopyImageToBuffer
• The VkCommandPool that commandBuffer was allocated from, in vkCmdUpdateBuffer
• The VkCommandPool that commandBuffer was allocated from, in vkCmdFillBuffer
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• The VkCommandPool that commandBuffer was allocated from, in
The VkCommandPool that commandBuffer was allocated from, in vkCmdClearAttachments
The VkCommandPool that commandBuffer was allocated from, in vkCmdResolveImage
The VkCommandPool that commandBuffer was allocated from, in vkCmdSetEvent
The VkCommandPool that commandBuffer was allocated from, in vkCmdResetEvent
The VkCommandPool that commandBuffer was allocated from, in vkCmdWaitEvents
The VkCommandPool that commandBuffer was allocated from, in vkCmdPipelineBarrier
The VkCommandPool that commandBuffer was allocated from, in vkCmdBeginQuery
The VkCommandPool that commandBuffer was allocated from, in vkCmdEndQuery
The VkCommandPool that commandBuffer was allocated from, in vkCmdResetQueryPool
The VkCommandPool that commandBuffer was allocated from, in vkCmdWriteTimestamp
The VkCommandPool that commandBuffer was allocated from, in vkCmdCopyQueryPoolResults
The VkCommandPool that commandBuffer was allocated from, in vkCmdPushConstants
The VkCommandPool that commandBuffer was allocated from, in vkCmdBeginRenderPass
The VkCommandPool that commandBuffer was allocated from, in vkCmdNextSubpass
The VkCommandPool that commandBuffer was allocated from, in vkCmdEndRenderPass
The VkCommandPool that commandBuffer was allocated from, in vkCmdExecuteCommands
The VkCommandPool that commandBuffer was allocated from, in vkCmdSetDeviceMask
The VkCommandPool that commandBuffer was allocated from, in vkCmdDispatchBase
The VkCommandPool that commandBuffer was allocated from, in vkCmdDrawIndirectCount
The VkCommandPool that commandBuffer was allocated from, in vkCmdDrawIndexedIndirectCount
The VkCommandPool that commandBuffer was allocated from, in vkCmdBeginRenderPass2
The VkCommandPool that commandBuffer was allocated from, in vkCmdNextSubpass2
The VkCommandPool that commandBuffer was allocated from, in vkCmdEndRenderPass2
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The VkCommandPool that commandBuffer was allocated from, in vkCmdCopyImageToBuffer2
The VkCommandPool that commandBuffer was allocated from, in vkCmdBlitImage2
• The VkCommandPool that commandBuffer was allocated from, in vkCmdResolveImage2
• The VkCommandPool that commandBuffer was allocated from, in vkCmdBeginRendering
• The VkCommandPool that commandBuffer was allocated from, in vkCmdEndRendering
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetCullMode
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetFrontFace
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetPrimitiveTopology
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetViewportWithCount
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetScissorWithCount
• The VkCommandPool that commandBuffer was allocated from, in vkCmdBindVertexBuffers2
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetDepthTestEnable
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetDepthWriteEnable
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetDepthCompareOp
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetDepthBoundsTestEnable
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetStencilTestEnable
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetStencilOp
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetRasterizerDiscardEnable
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetDepthBiasEnable
• The VkCommandPool that commandBuffer was allocated from, in vkCmdSetPrimitiveRestartEnable
• The VkCommandPool that commandBuffer was allocated from, in vkCmdBeginVideoCodingKHR
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• The VkCommandPool that commandBuffer was allocated from, in vkCmdDecodeVideoKHR
• The VkCommandPool that commandBuffer was allocated from, in vkCmdBeginRenderingKHR
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<td>• The VkCommandPool that commandBuffer was allocated from, in</td>
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<td><code>vkCmdSetCoverageModulationModeNV</code></td>
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<td>• The VkCommandPool that commandBuffer was allocated from, in</td>
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<td><code>vkCmdSetCoverageModulationTableEnableNV</code></td>
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<td>• The VkCommandPool that commandBuffer was allocated from, in</td>
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<td><code>vkCmdSetCoverageModulationTableNV</code></td>
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<td>• The VkCommandPool that commandBuffer was allocated from, in</td>
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<td><code>vkCmdSetShadingRateImageEnableNV</code></td>
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<tr>
<td></td>
<td>• The VkCommandPool that commandBuffer was allocated from, in</td>
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<tr>
<td></td>
<td><code>vkCmdSetRepresentativeFragmentTestEnableNV</code></td>
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</tbody>
</table>
3.7. Valid Usage

Valid usage defines a set of conditions which **must** be met in order to achieve well-defined runtime behavior in an application. These conditions depend only on Vulkan state, and the parameters or objects whose usage is constrained by the condition.

The core layer assumes applications are using the API correctly. Except as documented elsewhere in the Specification, the behavior of the core layer to an application using the API incorrectly is undefined, and **may** include program termination. However, implementations **must** ensure that incorrect usage by an application does not affect the integrity of the operating system, the Vulkan implementation, or other Vulkan client applications in the system. In particular, any guarantees made by an operating system about whether memory from one process **can** be visible to another process or not **must** not be violated by a Vulkan implementation for **any memory allocation**.
Vulkan implementations are not required to make additional security or integrity guarantees beyond those provided by the OS unless explicitly directed by the application's use of a particular feature or extension.

Note

For instance, if an operating system guarantees that data in all its memory allocations are set to zero when newly allocated, the Vulkan implementation must make the same guarantees for any allocations it controls (e.g. VkDeviceMemory).

Similarly, if an operating system guarantees that use-after-free of host allocations will not result in values written by another process becoming visible, the same guarantees must be made by the Vulkan implementation for device memory.

If the protectedMemory feature is supported, the implementation provides additional guarantees when invalid usage occurs to prevent values in protected memory from being accessed or inferred outside of protected operations, as described in Protected Memory Access Rules.

Some valid usage conditions have dependencies on runtime limits or feature availability. It is possible to validate these conditions against Vulkan's minimum supported values for these limits and features, or some subset of other known values.

Valid usage conditions do not cover conditions where well-defined behavior (including returning an error code) exists.

Valid usage conditions should apply to the command or structure where complete information about the condition would be known during execution of an application. This is such that a validation layer or linter can be written directly against these statements at the point they are specified.

Note

This does lead to some non-obvious places for valid usage statements. For instance, the valid values for a structure might depend on a separate value in the calling command. In this case, the structure itself will not reference this valid usage as it is impossible to determine validity from the structure that it is invalid - instead this valid usage would be attached to the calling command.

Another example is draw state - the state setters are independent, and can cause a legitimately invalid state configuration between draw calls; so the valid usage statements are attached to the place where all state needs to be valid - at the drawing command.

Valid usage conditions are described in a block labelled “Valid Usage” following each command or structure they apply to.

3.7.1. Usage Validation

Vulkan is a layered API. The lowest layer is the core Vulkan layer, as defined by this Specification. The application can use additional layers above the core for debugging, validation, and other
One of the core principles of Vulkan is that building and submitting command buffers should be highly efficient. Thus error checking and validation of state in the core layer is minimal, although more rigorous validation can be enabled through the use of layers.

Validation of correct API usage is left to validation layers. Applications should be developed with validation layers enabled, to help catch and eliminate errors. Once validated, released applications should not enable validation layers by default.

3.7.2. Implicit Valid Usage

Some valid usage conditions apply to all commands and structures in the API, unless explicitly denoted otherwise for a specific command or structure. These conditions are considered implicit, and are described in a block labelled “Valid Usage (Implicit)” following each command or structure they apply to. Implicit valid usage conditions are described in detail below.

Valid Usage for Object Handles

Any input parameter to a command that is an object handle must be a valid object handle, unless otherwise specified. An object handle is valid if:

- It has been created or allocated by a previous, successful call to the API. Such calls are noted in the Specification.
- It has not been deleted or freed by a previous call to the API. Such calls are noted in the Specification.
- Any objects used by that object, either as part of creation or execution, must also be valid.

The reserved values VK_NULL_HANDLE and NULL can be used in place of valid non-dispatchable handles and dispatchable handles, respectively, when explicitly called out in the Specification. Any command that creates an object successfully must not return these values. It is valid to pass these values to vkDestroy* or vkFree* commands, which will silently ignore these values.

Valid Usage for Pointers

Any parameter that is a pointer must be a valid pointer only if it is explicitly called out by a Valid Usage statement.

A pointer is “valid” if it points at memory containing values of the number and type(s) expected by the command, and all fundamental types accessed through the pointer (e.g. as elements of an array or as members of a structure) satisfy the alignment requirements of the host processor.

Valid Usage for Strings

Any parameter that is a pointer to char must be a finite sequence of values terminated by a null character, or if explicitly called out in the Specification, can be NULL.
Valid Usage for Enumerated Types

Any parameter of an enumerated type must be a valid enumerant for that type. Use of an enumerant is valid if the following conditions are true:

- The enumerant is defined as part of the enumerated type.
- The enumerant is not a value suffixed with _MAX_ENUM.
  - This value exists only to ensure that C enum types are 32 bits in size and must not be used by applications.
- If the enumerant is used in a function that has a VkInstance as its first parameter and either:
  - it was added by a core version that is supported (as reported by vkEnumerateInstanceVersion) and the value of VkApplicationInfo::apiVersion is greater than or equal to the version that added it; or
  - it was added by an instance extension that was enabled for the instance.
- If the enumerant is used in a function that has a VkPhysicalDevice object as its first parameter and either:
  - it was added by a core version that is supported by that device (as reported by VkPhysicalDeviceProperties::apiVersion); or
  - it was added by an instance extension that was enabled for the instance; or
  - it was added by a device extension that is supported by that device.
- If the enumerant is used in a function that has any other dispatchable object as its first parameter and either:
  - it was added by a core version that is supported for the device (as reported by VkPhysicalDeviceProperties::apiVersion); or
  - it was added by a device extension that was enabled for the device.

Additionally, if maintenance5 is supported, any integer value representable in the range valid for the defined type is valid when used in a function that has a VkPhysicalDevice object as its first parameter. Physical device queries will either return results indicating lack of support, or ignore unsupported values when used as a bit flag in a Vk*Flags* parameter.

Any enumerated type returned from a query command or otherwise output from Vulkan to the application must not have a reserved value. Reserved values are values not defined by any extension for that enumerated type.

Note

In some special cases, an enumerant is only meaningful if a feature defined by an extension is also enabled, as well as the extension itself. The global “valid enumerant” rule described here does not address such cases.

Note

This language is intended to accommodate cases such as “hidden” extensions known only to driver internals, or layers enabling extensions without knowledge
of the application, without allowing return of values not defined by any extension.

**Note**

Application developers are encouraged to be careful when using `switch` statements with Vulkan API enums. This is because new extensions can add new values to existing enums. Using a `default:` statement within a `switch` may avoid future compilation issues.

This is particularly true for enums such as `VkDriverId`, which may have values added that do not belong to a corresponding new extension.

### Valid Usage for Flags

A collection of flags is represented by a bitmask using the type `VkFlags`:

```c
// Provided by VK_VERSION_1_0
typedef uint32_t VkFlags;
```

Bitmasks are passed to many commands and structures to compactly represent options, but `VkFlags` is not used directly in the API. Instead, a `Vk*Flags` type which is an alias of `VkFlags`, and whose name matches the corresponding `Vk*FlagBits` that are valid for that type, is used.

Any `Vk*Flags` member or parameter used in the API as an input **must** be a valid combination of bit flags. A valid combination is either zero or the bitwise OR of valid bit flags.

An individual bit flag is valid for a `Vk*Flags` type if it would be a valid enumerant when used with the equivalent `Vk*FlagBits` type, where the bits type is obtained by taking the flag type and replacing the trailing `Flags` with `FlagBits`. For example, a flag value of type `VkColorComponentFlags` **must** contain only bit flags defined by `VkColorComponentFlagBits`.

Any `Vk*Flags` member or parameter returned from a query command or otherwise output from Vulkan to the application **may** contain bit flags undefined in its corresponding `Vk*FlagBits` type. An application **cannot** rely on the state of these unspecified bits.

Only the low-order 31 bits (bit positions zero through 30) are available for use as flag bits.

**Note**

This restriction is due to poorly defined behavior by C compilers given a C enumerant value of `0x80000000`. In some cases adding this enumerant value may increase the size of the underlying `Vk*FlagBits` type, breaking the ABI.

A collection of 64-bit flags is represented by a bitmask using the type `VkFlags64`:

```c
// Provided by VK_VERSION_1_3, VK_KHR_synchronization2
typedef uint64_t VkFlags64;
```

When the 31 bits available in `VkFlags` are insufficient, the `VkFlags64` type can be passed to
commands and structures to represent up to 64 options. VkFlags64 is not used directly in the API. Instead, a Vk*Flags2 type which is an alias of VkFlags64, and whose name matches the corresponding VkFlagBits2 that are valid for that type, is used.

Any Vk*Flags2 member or parameter used in the API as an input must be a valid combination of bit flags. A valid combination is either zero or the bitwise OR of valid bit flags.

An individual bit flag is valid for a Vk*Flags2 type if it would be a valid enumerant when used with the equivalent Vk*FlagBits2 type, where the bits type is obtained by taking the flag type and replacing the trailing Flags2 with FlagBits2. For example, a flag value of type VkAccessFlags2KHR must contain only bit flags defined by VkAccessFlagBits2KHR.

Any Vk*Flags2 member or parameter returned from a query command or otherwise output from Vulkan to the application may contain bit flags undefined in its corresponding Vk*FlagBits2 type. An application cannot rely on the state of these unspecified bits.

<table>
<thead>
<tr>
<th>Note</th>
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<tbody>
<tr>
<td>Both the Vk<em>FlagBits2 type, and the individual bits defined for that type, are defined as uint64_t integers in the C API. This is in contrast to the 32-bit types, where the Vk</em>FlagBits type is defined as a C enum and the individual bits as enumerants belonging to that enum. As a result, there is less compile time type checking possible for the 64-bit types. This is unavoidable since there is no sufficiently portable way to define a 64-bit enum type in C99.</td>
</tr>
</tbody>
</table>

**Valid Usage for Structure Types**

Any parameter that is a structure containing a sType member must have a value of sType which is a valid VkStructureType value matching the type of the structure.

**Valid Usage for Structure Pointer Chains**

Any parameter that is a structure containing a void* pNext member must have a value of pNext that is either NULL, or is a pointer to a valid extending structure, containing sType and pNext members as described in the Vulkan Documentation and Extensions document in the section “Extending Structures”. The set of structures connected by pNext pointers is referred to as a pNext chain.

Each structure included in the pNext chain must be defined at runtime by either:

- a core version which is supported
- an extension which is enabled
- a supported device extension in the case of physical-device-level functionality added by the device extension

Each type of extending structure must not appear more than once in a pNext chain, including any aliases. This general rule may be explicitly overridden for specific structures.

Any component of the implementation (the loader, any enabled layers, and drivers) must skip over, without processing (other than reading the sType and pNext members) any extending structures in the chain not defined by core versions or extensions supported by that component.
As a convenience to implementations and layers needing to iterate through a structure pointer chain, the Vulkan API provides two base structures. These structures allow for some type safety, and can be used by Vulkan API functions that operate on generic inputs and outputs.

The \texttt{VkBaseInStructure} structure is defined as:

\begin{verbatim}
// Provided by VK_VERSION_1_0
typedef struct VkBaseInStructure {
    VkStructureType sType;
    const struct VkBaseInStructure* pNext;
} VkBaseInStructure;
\end{verbatim}

- \texttt{sType} is the structure type of the structure being iterated through.
- \texttt{pNext} is NULL or a pointer to the next structure in a structure chain.

\texttt{VkBaseInStructure} can be used to facilitate iterating through a read-only structure pointer chain.

The \texttt{VkBaseOutStructure} structure is defined as:

\begin{verbatim}
// Provided by VK_VERSION_1_0
typedef struct VkBaseOutStructure {
    VkStructureType sType;
    struct VkBaseOutStructure* pNext;
} VkBaseOutStructure;
\end{verbatim}

- \texttt{sType} is the structure type of the structure being iterated through.
- \texttt{pNext} is NULL or a pointer to the next structure in a structure chain.

\texttt{VkBaseOutStructure} can be used to facilitate iterating through a structure pointer chain that returns data back to the application.

**Valid Usage for Nested Structures**

The above conditions also apply recursively to members of structures provided as input to a command, either as a direct argument to the command, or themselves a member of another structure.

Specifics on valid usage of each command are covered in their individual sections.

**Valid Usage for Extensions**

Instance-level functionality or behavior added by an instance extension to the API must not be used unless that extension is supported by the instance as determined by \texttt{vkEnumerateInstanceExtensionProperties}, and that extension is enabled in \texttt{VkInstanceCreateInfo}.

Physical-device-level functionality or behavior added by an instance extension to the API must not be used unless that extension is supported by the instance as determined by \texttt{vkEnumerateInstanceExtensionProperties}, and that extension is enabled in \texttt{VkInstanceCreateInfo}.
Physical-device-level functionality or behavior added by a device extension to the API must not be used unless the conditions described in Extending Physical Device Core Functionality are met.

Device-level functionality added by a device extension that is dispatched from a VkDevice, or from a child object of a VkDevice must not be used unless that extension is supported by the device as determined by vkEnumerateDeviceExtensionProperties, and that extension is enabled in VkDeviceCreateInfo.

Valid Usage for Newer Core Versions

Instance-level functionality or behavior added by a new core version of the API must not be used unless it is supported by the instance as determined by vkEnumerateInstanceVersion and the specified version of VkApplicationInfo::apiVersion.

Physical-device-level functionality or behavior added by a new core version of the API must not be used unless it is supported by the physical device as determined by VkPhysicalDeviceProperties::apiVersion and the specified version of VkApplicationInfo::apiVersion.

Device-level functionality or behavior added by a new core version of the API must not be used unless it is supported by the device as determined by VkPhysicalDeviceProperties::apiVersion and the specified version of VkApplicationInfo::apiVersion.

3.8. VkResult Return Codes

While the core Vulkan API is not designed to capture incorrect usage, some circumstances still require return codes. Commands in Vulkan return their status via return codes that are in one of two categories:

- Successful completion codes are returned when a command needs to communicate success or status information. All successful completion codes are non-negative values.
- Run time error codes are returned when a command needs to communicate a failure that could only be detected at runtime. All runtime error codes are negative values.

All return codes in Vulkan are reported via VkResult return values. The possible codes are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkResult {
    VK_SUCCESS = 0,
    VK_NOT_READY = 1,
    VK_TIMEOUT = 2,
    VK_EVENT_SET = 3,
    VK_EVENT_RESET = 4,
    VK_INCOMPLETE = 5,
    VK_ERROR_OUT_OF_HOST_MEMORY = -1,
    VK_ERROR_OUT_OFDEVICE_MEMORY = -2,
    VK_ERROR_INITIALIZATION_FAILED = -3,
    VK_ERROR_DEVICE_LOST = -4,
    VK_ERROR_MEMORY_MAP_FAILED = -5,
    VK_ERROR_LAYER_NOT_PRESENT = -6,
} VkResult;
```
VK_ERROR_EXTENSION_NOT_PRESENT = -7,
VK_ERROR_FEATURE_NOT_PRESENT = -8,
VK_ERROR_INCOMPATIBLE_DRIVER = -9,
VK_ERROR_TOO_MANY_OBJECTS = -10,
VK_ERROR_FORMAT_NOT_SUPPORTED = -11,
VK_ERROR_FRAGMENTED_POOL = -12,
VK_ERROR_UNKNOWN = -13,
  // Provided by VK_VERSION_1_1
VK_ERROR_OUT_OF_POOL_MEMORY = -1000069000,
  // Provided by VK_VERSION_1_1
VK_ERROR_INVALID_EXTERNAL_HANDLE = -1000072003,
  // Provided by VK_VERSION_1_2
VK_ERROR_FRAGMENTATION = -1000161000,
  // Provided by VK_VERSION_1_2
VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS = -1000257000,
  // Provided by VK_VERSION_1_3
VK_PIPELINE_COMPILE_REQUIRED = 1000297000,
  // Provided by VK_KHR_surface
VK_ERROR_SURFACE_LOST_KHR = -1000000000,
  // Provided by VK_KHR_surface
VK_ERROR_NATIVE_WINDOW_IN_USE_KHR = -1000000001,
  // Provided by VK_KHR_swapchain
VK_SUBOPTIMAL_KHR = 1000001003,
  // Provided by VK_KHR_swapchain
VK_ERROR_OUT_OF_DATE_KHR = -1000001004,
  // Provided by VK_KHR_display_swapchain
VK_ERROR_INCOMPATIBLE_DISPLAY_KHR = -1000003001,
  // Provided by VK_EXT_debug_report
VK_ERROR_VALIDATION_FAILED_EXT = -1000011001,
  // Provided by VK_NV_glsl_shader
VK_ERROR_INVALID_SHADER_NV = -1000012000,
  // Provided by VK_KHR_video_queue
VK_ERROR_IMAGE_USAGE_NOT_SUPPORTED_KHR = -1000023000,
  // Provided by VK_KHR_video_queue
VK_ERROR_VIDEO_PICTURE_LAYOUT_NOT_SUPPORTED_KHR = -1000023001,
  // Provided by VK_KHR_video_queue
VK_ERROR_VIDEO_PROFILE_OPERATION_NOT_SUPPORTED_KHR = -1000023002,
  // Provided by VK_KHR_video_queue
VK_ERROR_VIDEO_PROFILE_FORMAT_NOT_SUPPORTED_KHR = -1000023003,
  // Provided by VK_KHR_video_queue
VK_ERROR_VIDEO_PROFILE_CODEC_NOT_SUPPORTED_KHR = -1000023004,
  // Provided by VK_KHR_video_queue
VK_ERROR_VIDEO_STD_VERSION_NOT_SUPPORTED_KHR = -1000023005,
  // Provided by VK_EXT_image_drm_format_modifier
VK_ERROR_INVALID_DRM_FORMAT_MODIFIER_PLANE_LAYOUT_EXT = -1000158000,
  // Provided by VK_KHR_global_priority
VK_ERROR_NOT_PERMITTED_KHR = -1000174001,
  // Provided by VK_EXT_full_screen_exclusive
VK_ERROR_FULL_SCREEN_EXCLUSIVE_MODE_LOST_EXT = -1000255000,
  // Provided by VK_KHR_deferred_host_operations
VK_THREAD_IDLE_KHR = 1000268000,
// Provided by VK_KHR_deferred_host_operations
VK_THREAD_DONE_KHR = 1000268001,
// Provided by VK_KHR_deferred_host_operations
VK_OPERATION_DEFERRED_KHR = 1000268002,
// Provided by VK_KHR_deferred_host_operations
VK_OPERATION_NOT_DEFERRED_KHR = 1000268003,
#endif
// Provided by VK_KHR_video_encode_queue
VK_ERROR_INVALID_VIDEO_STD_PARAMETERS_KHR = -1000299000,
// Provided by VK_KHR_image_compression_control
VK_ERROR_COMPRESSION_EXHAUSTED_EXT = -1000338000,
// Provided by VK_KHR_shader_object
VK_ERROR_INCOMPATIBLE_SHADER_BINARY_EXT = 1000482000,
// Provided by VK_KHR_maintenance1
VK_ERROR_OUT_OF_POOL_MEMORY_KHR = VK_ERROR_OUT_OF_POOL_MEMORY,
// Provided by VK_KHR_external_memory
VK_ERROR_INVALID_EXTERNAL_HANDLE_KHR = VK_ERROR_INVALID_EXTERNAL_HANDLE,
// Provided by VK_EXT_descriptor_indexing
VK_ERROR_FRAGMENTATION_EXT = VK_ERROR_FRAGMENTATION,
// Provided by VK_KHR_global_priority
VK_ERROR_NOT_PERMITTED_EXT = VK_ERROR_NOT_PERMITTED_KHR,
// Provided by VK_KHR_buffer_device_address
VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS_KHR = VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS,
// Provided by VK_KHR_buffer_device_address
VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS_KHR = VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS,
// Provided by VK_KHR_pipeline_creation_cache_control
VK_PIPELINE_COMPILE_REQUIRED_EXT = VK_PIPELINE_COMPILE_REQUIRED,
// Provided by VK_KHR_buffer_device_address
VK_ERROR_PIPELINE_COMPILE_REQUIRED_EXT = VK_PIPELINE_COMPILE_REQUIRED,
} VkResult;

Success Codes

- **VK_SUCCESS** Command successfully completed
- **VK_NOT_READY** A fence or query has not yet completed
- **VK_TIMEOUT** A wait operation has not completed in the specified time
- **VK_EVENT_SET** An event is signaled
- **VK_EVENT_RESET** An event is unsignaled
- **VK_INCOMPLETE** A return array was too small for the result
- **VK_SUBOPTIMAL_KHR** A swapchain no longer matches the surface properties exactly, but can still be used to present to the surface successfully.
- **VK_THREAD_IDLE_KHR** A deferred operation is not complete but there is currently no work for this thread to do at the time of this call.
- **VK_THREAD_DONE_KHR** A deferred operation is not complete but there is no work remaining to assign to additional threads.
• **VK_OPERATION_DEFERRED_KHR** A deferred operation was requested and at least some of the work was deferred.

• **VK_OPERATION_NOT_DEFERRED_KHR** A deferred operation was requested and no operations were deferred.

• **VK_PIPELINE_COMPILE_REQUIRED** A requested pipeline creation would have required compilation, but the application requested compilation to not be performed.

**Error codes**

• **VK_ERROR_OUT_OF_HOST_MEMORY** A host memory allocation has failed.

• **VK_ERROR_OUT_OF_DEVICE_MEMORY** A device memory allocation has failed.

• **VK_ERROR_INITIALIZATION_FAILED** Initialization of an object could not be completed for implementation-specific reasons.

• **VK_ERROR_DEVICE_LOST** The logical or physical device has been lost. See Lost Device

• **VK_ERROR_MEMORY_MAP_FAILED** Mapping of a memory object has failed.

• **VK_ERROR_LAYER_NOT_PRESENT** A requested layer is not present or could not be loaded.

• **VK_ERROR_EXTENSION_NOT_PRESENT** A requested extension is not supported.

• **VK_ERROR_FEATURE_NOT_PRESENT** A requested feature is not supported.

• **VK_ERROR_INCOMPATIBLE_DRIVER** The requested version of Vulkan is not supported by the driver or is otherwise incompatible for implementation-specific reasons.

• **VK_ERROR_TOO_MANY_OBJECTS** Too many objects of the type have already been created.

• **VK_ERROR_FORMAT_NOT_SUPPORTED** A requested format is not supported on this device.

• **VK_ERROR_FRAGMENTED_POOL** A pool allocation has failed due to fragmentation of the pool’s memory. This **must** only be returned if no attempt to allocate host or device memory was made to accommodate the new allocation. This **should** be returned in preference to **VK_ERROR_OUT_OF_POOL_MEMORY**, but only if the implementation is certain that the pool allocation failure was due to fragmentation.

• **VK_ERROR_SURFACE_LOST_KHR** A surface is no longer available.

• **VK_ERROR_NATIVE_WINDOW_IN_USE_KHR** The requested window is already in use by Vulkan or another API in a manner which prevents it from being used again.

• **VK_ERROR_OUT_OF_DATE_KHR** A surface has changed in such a way that it is no longer compatible with the swapchain, and further presentation requests using the swapchain will fail. Applications **must** query the new surface properties and recreate their swapchain if they wish to continue presenting to the surface.

• **VK_ERROR_INCOMPATIBLE_DISPLAY_KHR** The display used by a swapchain does not use the same presentable image layout, or is incompatible in a way that prevents sharing an image.

• **VK_ERROR_INVALID_SHADER_NV** One or more shaders failed to compile or link. More details are reported back to the application via **VK_EXT_DEBUG_REPORT** if enabled.

• **VK_ERROR_OUT_OF_POOL_MEMORY** A pool memory allocation has failed. This **must** only be returned if no attempt to allocate host or device memory was made to accommodate the new allocation. If the failure was definitely due to fragmentation of the pool, **VK_ERROR_FRAGMENTED_POOL** **should** be
• VK_ERROR_INVALID_EXTERNAL_HANDLE An external handle is not a valid handle of the specified type.
• VK_ERROR_FRAGMENTATION A descriptor pool creation has failed due to fragmentation.
• VK_ERROR_INVALID_DEVICE_ADDRESS_EXT A buffer creation failed because the requested address is not available.
• VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS A buffer creation or memory allocation failed because the requested address is not available. A shader group handle assignment failed because the requested shader group handle information is no longer valid.
• VK_ERROR_FULL_SCREEN_EXCLUSIVE_MODE_LOST_EXT An operation on a swapchain created with VK_FULL_SCREEN_EXCLUSIVE_APPLICATION_CONTROLLED_EXT failed as it did not have exclusive full-screen access. This may occur due to implementation-dependent reasons, outside of the application’s control.
• VK_ERROR_VALIDATION_FAILED_EXT A command failed because invalid usage was detected by the implementation or a validation-layer.
• VK_ERROR_COMPRESSION_EXHAUSTED_EXT An image creation failed because internal resources required for compression are exhausted. This must only be returned when fixed-rate compression is requested.
• VK_ERROR_IMAGE_USAGE_NOT_SUPPORTED_KHR The requested VkImageUsageFlags are not supported.
• VK_ERROR_VIDEO_PICTURE_LAYOUT_NOT_SUPPORTED_KHR The requested video picture layout is not supported.
• VK_ERROR_VIDEO_PROFILE_OPERATION_NOT_SUPPORTED_KHR A video profile operation specified via VkVideoProfileInfoKHR::videoCodecOperation is not supported.
• VK_ERROR_VIDEO_PROFILE_FORMAT_NOT_SUPPORTED_KHR Format parameters in a requested VkVideoProfileInfoKHR chain are not supported.
• VK_ERROR_VIDEO_PROFILE_CODEC_NOT_SUPPORTED_KHR Codec-specific parameters in a requested VkVideoProfileInfoKHR chain are not supported.
• VK_ERROR_VIDEO_STD_VERSION_NOT_SUPPORTED_KHR The specified video Std header version is not supported.
• VK_ERROR_VIDEO_STD_PARAMETERS_KHR The specified Video Std parameters do not adhere to the syntactic or semantic requirements of the used video compression standard, or values derived from parameters according to the rules defined by the used video compression standard do not adhere to the capabilities of the video compression standard or the implementation.
• VK_ERROR_INCOMPATIBLE_SHADER_BINARY_EXT The provided binary shader code is not compatible with this device.
• VK_ERROR_UNKNOWN An unknown error has occurred; either the application has provided invalid input, or an implementation failure has occurred.

If a command returns a runtime error, unless otherwise specified any output parameters will have undefined contents, except that if the output parameter is a structure with sType and pNext fields, those fields will be unmodified. Any structures chained from pNext will also have undefined contents, except that sType and pNext will be unmodified.
**Note**

As a general rule, Free, Release, and Reset commands do not return VK_ERROR_OUT_OF_HOST_MEMORY, while any other command with a return code may return it. Any exceptions from this rule are described for those commands.

**Note**

VK_ERROR_UNKNOWN is not expected to ever be returned if the application behavior is valid, and if the implementation is bug-free. If VK_ERROR_UNKNOWN is received, the application should be checked against the latest validation layers to verify correct behavior as much as possible. If no issues are identified it could be an implementation issue, and the implementor should be contacted for support.

Any command returning a VkResult may return VK_ERROR_VALIDATION_FAILED_EXT if a violation of valid usage is detected, even though commands do not explicitly list this as a possible return code.

Performance-critical commands generally do not have return codes. If a runtime error occurs in such commands, the implementation will defer reporting the error until a specified point. For commands that record into command buffers (vkCmd*) runtime errors are reported by vkEndCommandBuffer.

### 3.9. Numeric Representation and Computation

Implementations normally perform computations in floating-point, and must meet the range and precision requirements defined under “Floating-Point Computation” below.

These requirements only apply to computations performed in Vulkan operations outside of shader execution, such as texture image specification and sampling, and per-fragment operations. Range and precision requirements during shader execution differ and are specified by the Precision and Operation of SPIR-V Instructions section.

In some cases, the representation and/or precision of operations is implicitly limited by the specified format of vertex or texel data consumed by Vulkan. Specific floating-point formats are described later in this section.

#### 3.9.1. Floating-Point Computation

Most floating-point computation is performed in SPIR-V shader modules. The properties of computation within shaders are constrained as defined by the Precision and Operation of SPIR-V Instructions section.

Some floating-point computation is performed outside of shaders, such as viewport and depth...
range calculations. For these computations, we do not specify how floating-point numbers are to be represented, or the details of how operations on them are performed, but only place minimal requirements on representation and precision as described in the remainder of this section.

We require simply that numbers’ floating-point parts contain enough bits and that their exponent fields are large enough so that individual results of floating-point operations are accurate to about 1 part in $10^5$. The maximum representable magnitude for all floating-point values must be at least $2^{32}$.

$$x \times 0 = 0 \times x = 0$$
for any non-infinite and non-NaN $x$.

$$1 \times x = x \times 1 = x.$$  

$$x + 0 = 0 + x = x.$$  

$$0^0 = 1.$$  

Occasionally, further requirements will be specified. Most single-precision floating-point formats meet these requirements.

The special values Inf and -Inf encode values with magnitudes too large to be represented; the special value NaN encodes “Not A Number” values resulting from undefined arithmetic operations such as $0 / 0$. Implementations may support Inf and NaN in their floating-point computations. Any computation which does not support either Inf or NaN, for which that value is an input or output will yield an undefined value.

### 3.9.2. Floating-Point Format Conversions

When a value is converted to a defined floating-point representation, finite values falling between two representable finite values are rounded to one or the other. The rounding mode is not defined. Finite values whose magnitude is larger than that of any representable finite value may be rounded either to the closest representable finite value or to the appropriately signed infinity. For unsigned destination formats any negative values are converted to zero. Positive infinity is converted to positive infinity; negative infinity is converted to negative infinity in signed formats and to zero in unsigned formats; and any NaN is converted to a NaN.

### 3.9.3. 16-Bit Floating-Point Numbers

16-bit floating point numbers are defined in the “16-bit floating point numbers” section of the Khronos Data Format Specification.

### 3.9.4. Unsigned 11-Bit Floating-Point Numbers

Unsigned 11-bit floating point numbers are defined in the “Unsigned 11-bit floating point numbers” section of the Khronos Data Format Specification.
3.9.5. Unsigned 10-Bit Floating-Point Numbers

Unsigned 10-bit floating point numbers are defined in the “Unsigned 10-bit floating point numbers” section of the Khronos Data Format Specification.

3.9.6. General Requirements

Any representable floating-point value in the appropriate format is legal as input to a Vulkan command that requires floating-point data. The result of providing a value that is not a floating-point number to such a command is unspecified, but must not lead to Vulkan interruption or termination. For example, providing a negative zero (where applicable) or a denormalized number to a Vulkan command must yield deterministic results, while providing a NaN or Inf yields unspecified results.

Some calculations require division. In such cases (including implied divisions performed by vector normalization), division by zero produces an unspecified result but must not lead to Vulkan interruption or termination.

3.10. Fixed-Point Data Conversions

When generic vertex attributes and pixel color or depth components are represented as integers, they are often (but not always) considered to be normalized. Normalized integer values are treated specially when being converted to and from floating-point values, and are usually referred to as normalized fixed-point.

In the remainder of this section, b denotes the bit width of the fixed-point integer representation. When the integer is one of the types defined by the API, b is the bit width of that type. When the integer comes from an image containing color or depth component texels, b is the number of bits allocated to that component in its specified image format.

The signed and unsigned fixed-point representations are assumed to be b-bit binary two’s-complement integers and binary unsigned integers, respectively.

3.10.1. Conversion from Normalized Fixed-Point to Floating-Point

Unsigned normalized fixed-point integers represent numbers in the range [0,1). The conversion from an unsigned normalized fixed-point value c to the corresponding floating-point value f is defined as

\[ f = \frac{c}{2^b - 1} \]

Signed normalized fixed-point integers represent numbers in the range [-1,1]. The conversion from a signed normalized fixed-point value c to the corresponding floating-point value f is performed using

\[ f = \max\left(\frac{c}{2^b - 1} - 1.0, -1.0\right) \]

Only the range \([-2^{b-1} + 1, 2^{b-1} - 1]\) is used to represent signed fixed-point values in the range [-1,1]. For
example, if \( b = 8 \), then the integer value -127 corresponds to -1.0 and the value 127 corresponds to 1.0. This equation is used everywhere that signed normalized fixed-point values are converted to floating-point.

Note that while zero is exactly expressible in this representation, one value (-128 in the example) is outside the representable range, and implementations must clamp it to -1.0. Where the value is subject to further processing by the implementation, e.g., during texture filtering, values less than -1.0 may be used but the result must be clamped before the value is returned to shaders.

### 3.10.2. Conversion from Floating-Point to Normalized Fixed-Point

The conversion from a floating-point value \( f \) to the corresponding unsigned normalized fixed-point value \( c \) is defined by first clamping \( f \) to the range \([0,1]\), then computing

\[
c = \text{convertFloatToUint}(f \times (2^b - 1), b)
\]

where \text{convertFloatToUint}(r,b) returns one of the two unsigned binary integer values with exactly \( b \) bits which are closest to the floating-point value \( r \). Implementations should round to nearest. If \( r \) is equal to an integer, then that integer value must be returned. In particular, if \( f \) is equal to 0.0 or 1.0, then \( c \) must be assigned 0 or \( 2^b - 1 \), respectively.

The conversion from a floating-point value \( f \) to the corresponding signed normalized fixed-point value \( c \) is performed by clamping \( f \) to the range \([-1,1]\), then computing

\[
c = \text{convertFloatToInt}(f \times (2^{b-1} - 1), b)
\]

where \text{convertFloatToInt}(r,b) returns one of the two signed two's-complement binary integer values with exactly \( b \) bits which are closest to the floating-point value \( r \). Implementations should round to nearest. If \( r \) is equal to an integer, then that integer value must be returned. In particular, if \( f \) is equal to -1.0, 0.0, or 1.0, then \( c \) must be assigned \(-(2^{b-1} - 1)\), 0, or \( 2^{b-1} - 1 \), respectively.

This equation is used everywhere that floating-point values are converted to signed normalized fixed-point.

### 3.11. Common Object Types

Some types of Vulkan objects are used in many different structures and command parameters, and are described here. These types include offsets, extents, and rectangles.

#### 3.11.1. Offsets

Offsets are used to describe a pixel location within an image or framebuffer, as an \((x,y)\) location for two-dimensional images, or an \((x,y,z)\) location for three-dimensional images.

A two-dimensional offset is defined by the structure:

```c
// Provided by VK_VERSION_1_0
```
typedef struct VkOffset2D {
    int32_t x;
    int32_t y;
} VkOffset2D;

• x is the x offset.
• y is the y offset.

A three-dimensional offset is defined by the structure:

// Provided by VK_VERSION_1_0
typedef struct VkOffset3D {
    int32_t x;
    int32_t y;
    int32_t z;
} VkOffset3D;

• x is the x offset.
• y is the y offset.
• z is the z offset.

3.11.2. Extents

Extents are used to describe the size of a rectangular region of pixels within an image or framebuffer, as (width,height) for two-dimensional images, or as (width,height,depth) for three-dimensional images.

A two-dimensional extent is defined by the structure:

// Provided by VK_VERSION_1_0
typedef struct VkExtent2D {
    uint32_t width;
    uint32_t height;
} VkExtent2D;

• width is the width of the extent.
• height is the height of the extent.

A three-dimensional extent is defined by the structure:

// Provided by VK_VERSION_1_0
typedef struct VkExtent3D {
    uint32_t width;
    uint32_t height;
    uint32_t depth;
} VkExtent3D;
• width is the width of the extent.
• height is the height of the extent.
• depth is the depth of the extent.

3.11.3. Rectangles

Rectangles are used to describe a specified rectangular region of pixels within an image or framebuffer. Rectangles include both an offset and an extent of the same dimensionality, as described above. Two-dimensional rectangles are defined by the structure

```c
// Provided by VK_VERSION_1_0
typedef struct VkRect2D {
    VkOffset2D offset;
    VkExtent2D extent;
} VkRect2D;
```

• offset is a VkOffset2D specifying the rectangle offset.
• extent is a VkExtent2D specifying the rectangle extent.

3.11.4. Structure Types

Each value corresponds to a particular structure with a sType member with a matching name. As a general rule, the name of each VkStructureType value is obtained by taking the name of the structure, stripping the leading Vk, prefixing each capital letter with _, converting the entire resulting string to upper case, and prefixing it with VK_STRUCTURE_TYPE_. For example, structures of type VkImageCreateInfo correspond to a VkStructureType value of VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO, and thus a structure of this type must have its sType member set to this value before it is passed to the API.

The values VK_STRUCTURE_TYPE_LOADER_INSTANCE_CREATE_INFO and VK_STRUCTURE_TYPE_LOADER_DEVICE_CREATE_INFO are reserved for internal use by the loader, and do not have corresponding Vulkan structures in this Specification.

Structure types supported by the Vulkan API include:

```c
// Provided by VK_VERSION_1_0
typedef enum VkStructureType {
    VK_STRUCTURE_TYPE_APPLICATION_INFO = 0,
    VK_STRUCTURE_TYPE_INSTANCE_CREATE_INFO = 1,
    VK_STRUCTURE_TYPE_DEVICE_QUEUE_CREATE_INFO = 2,
    VK_STRUCTURE_TYPE_DEVICE_CREATE_INFO = 3,
    VK_STRUCTURE_TYPE_SUBMIT_INFO = 4,
    VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO = 5,
    VK_STRUCTURE_TYPE_MAPPED_MEMORY_RANGE = 6,
};
```
VK_STRUCTURE_TYPE_BIND_SPARSE_INFO = 7,
VK_STRUCTURE_TYPE_FENCE_CREATE_INFO = 8,
VK_STRUCTURE_TYPE_SEMAPHORE_CREATE_INFO = 9,
VK_STRUCTURE_TYPE_EVENT_CREATE_INFO = 10,
VK_STRUCTURE_TYPE_QUERY_POOL_CREATE_INFO = 11,
VK_STRUCTURE_TYPE_BUFFER_CREATE_INFO = 12,
VK_STRUCTURE_TYPE_BUFFER_VIEW_CREATE_INFO = 13,
VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO = 14,
VK_STRUCTURE_TYPE_IMAGE_VIEW_CREATE_INFO = 15,
VK_STRUCTURE_TYPE_SHADER_MODULE_CREATE_INFO = 16,
VK_STRUCTURE_TYPE_PIPELINE_CACHE_CREATE_INFO = 17,
VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_CREATE_INFO = 18,
VK_STRUCTURE_TYPE_PIPELINE_VERTEX_INPUT_STATE_CREATE_INFO = 19,
VK_STRUCTURE_TYPE_PIPELINE_INPUT_ASSEMBLY_STATE_CREATE_INFO = 20,
VK_STRUCTURE_TYPE_PIPELINE_TESSELLATION_STATE_CREATE_INFO = 21,
VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_STATE_CREATE_INFO = 22,
VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_STATE_CREATE_INFO = 23,
VK_STRUCTURE_TYPE_PIPELINE_MULTISAMPLE_STATE_CREATE_INFO = 24,
VK_STRUCTURE_TYPE_PIPELINE_DEPTH_STENCIL_STATE_CREATE_INFO = 25,
VK_STRUCTURE_TYPE_PIPELINE_COLOR_BLEND_STATE_CREATE_INFO = 26,
VK_STRUCTURE_TYPE_PIPELINE_DYNAMIC_STATE_CREATE_INFO = 27,
VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_CREATE_INFO = 28,
VK_STRUCTURE_TYPE_COMPUTE_PIPELINE_CREATE_INFO = 29,
VK_STRUCTURE_TYPE_PIPELINE_LAYOUT_CREATE_INFO = 30,
VK_STRUCTURE_TYPE_SAMPLER_CREATE_INFO = 31,
VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_CREATE_INFO = 32,
VK_STRUCTURE_TYPE_DESCRIPTOR_POOL_CREATE_INFO = 33,
VK_STRUCTURE_TYPE_DESCRIPTOR_SET_ALLOCATE_INFO = 34,
VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET = 35,
VK_STRUCTURE_TYPE_COPY_DESCRIPTOR_SET = 36,
VK_STRUCTURE_TYPE_FRAMEBUFFER_CREATE_INFO = 37,
VK_STRUCTURE_TYPE_RENDER_PASS_CREATE_INFO = 38,
VK_STRUCTURE_TYPE_COMMAND_POOL_CREATE_INFO = 39,
VK_STRUCTURE_TYPE_COMMAND_BUFFER_ALLOCATE_INFO = 40,
VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_INFO = 41,
VK_STRUCTURE_TYPE_COMMAND_BUFFER_BEGIN_INFO = 42,
VK_STRUCTURE_TYPE_RENDER_PASS_BEGIN_INFO = 43,
VK_STRUCTURE_TYPE_BUFFER_MEMORY_BARRIER = 44,
VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER = 45,
VK_STRUCTURE_TYPE_MEMORY_BARRIER = 46,
VK_STRUCTURE_TYPE_LOADER_INSTANCE_CREATE_INFO = 47,
VK_STRUCTURE_TYPE_LOADER_DEVICE_CREATE_INFO = 48,

// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBGROUP_PROPERTIES = 1000094000,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_BIND_BUFFER_MEMORY_INFO = 1000157000,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_INFO = 1000157001,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_16BIT_STORAGE_FEATURES = 1000083000,
VK_STRUCTURE_TYPE_MEMORY_DEDICATED_REQUIREMENTS = 1000127000,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_MEMORY_DEDICATED_ALLOCATE_INFO = 1000127001,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_FLAGS_INFO = 1000060000,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_DEVICE_GROUP_RENDER_PASS_BEGIN_INFO = 1000060003,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_DEVICE_GROUP_COMMAND_BUFFER_BEGIN_INFO = 1000060004,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_DEVICE_GROUP_SUBMIT_INFO = 1000060005,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_DEVICE_GROUP_BIND_SPARSE_INFO = 1000060006,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_BIND_BUFFER_MEMORY_DEVICE_GROUP_INFO = 1000060013,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_DEVICE_GROUP_INFO = 1000060014,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GROUP_PROPERTIES = 1000070000,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_DEVICE_GROUP_DEVICE_CREATE_INFO = 1000070001,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_BUFFER_MEMORY_REQUIREMENTS_INFO_2 = 1000146000,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_IMAGE_MEMORY_REQUIREMENTS_INFO_2 = 1000146001,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_IMAGE_SPARSE_MEMORY_REQUIREMENTS_INFO_2 = 1000146002,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_MEMORY_REQUIREMENTS_2 = 1000146003,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_SPARSE_IMAGE_MEMORY_REQUIREMENTS_2 = 1000146004,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FEATURES_2 = 1000059000,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PROPERTIES_2 = 1000059001,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_FORMAT_PROPERTIES_2 = 1000059002,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_IMAGE_FORMAT_PROPERTIES_2 = 1000059003,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_FORMAT_INFO_2 = 1000059004,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_QUEUE_FAMILY_PROPERTIES_2 = 1000059005,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_PROPERTIES_2 = 1000059006,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_SPARSE_IMAGE_FORMAT_PROPERTIES_2 = 1000059007,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SPARSE_IMAGE_FORMAT_INFO_2 = 1000059008,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_POINT_CLIPPING_PROPERTIES = 1000117000,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_EXPORT_MEMORY_ALLOCATE_INFO = 1000072002,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_FENCE_INFO = 1000112000,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_EXTERNAL_FENCE_PROPERTIES = 1000112001,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_EXPORT_FENCE_CREATE_INFO = 1000113000,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_EXPORT_SEMAPHORE_CREATE_INFO = 1000077000,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_SEMAPHORE_INFO = 1000076000,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_EXTERNAL_SEMAPHORE_PROPERTIES = 1000076001,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_3_PROPERTIES = 1000168000,
// Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_SUPPORT = 1000168001,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_1_FEATURES = 49,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_1_PROPERTIES = 50,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_2_FEATURES = 51,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_2_PROPERTIES = 52,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_IMAGE_FORMAT_LIST_CREATE_INFO = 1000147000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_2 = 1000109000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_2 = 1000109001,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_SUBPASS_DESCRIPTION_2 = 1000109002,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_SUBPASS_DEPENDENCY_2 = 1000109003,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_RENDER_PASS_CREATE_INFO_2 = 1000109004,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_SUBPASS_BEGIN_INFO = 1000109005,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_SUBPASS_END_INFO = 1000109006,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_8BIT_STORAGE_FEATURES = 1000177000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DRIVER_PROPERTIES = 1000196000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ATOMIC_INT64_FEATURES = 1000180000,
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_FLOAT16_INT8_FEATURES = 1000082000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FLOAT_CONTROLS_PROPERTIES = 1000197000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_BINDING_FLAGS_CREATE_INFO = 1000161000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_INDEXING_FEATURES = 1000161001,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_INDEXING_PROPERTIES = 1000161002,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_DESCRIPTOR_SET_VARIABLE_DESCRIPTOR_COUNT_ALLOCATE_INFO = 1000161003,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_DESCRIPTOR_SET_VARIABLE_DESCRIPTOR_COUNT_LAYOUT_SUPPORT = 1000161004,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_STENCIL_RESOLVE_PROPERTIES = 1000199000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_SUBPASS_DESCRIPTION_DEPTH_STENCIL_RESOLVE = 1000199001,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SCALAR_BLOCK_LAYOUT_FEATURES = 1000221000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_IMAGE_STENCIL_USAGE_CREATE_INFO = 1000246000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SAMPLER_FILTER_MINMAX_PROPERTIES = 1000130000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_SAMPLER_REDUCTION_MODE_CREATE_INFO = 1000130001,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_MEMORY_MODEL_FEATURES = 1000211000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGELESS_FRAMEBUFFER_FEATURES = 1000108000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_FRAMEBUFFER_ATTACHMENTS_CREATE_INFO = 1000108001,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_FRAMEBUFFER_ATTACHMENT_IMAGE_INFO = 1000108002,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_RENDER_PASS_ATTACHMENT_BEGIN_INFO = 1000108003,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_UNIFORM_BUFFER_STANDARD_LAYOUT_FEATURES = 1000253000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_SUBGROUP_EXTENDED_TYPES_FEATURES = 1000175000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SEPARATE_DEPTH_STENCIL_LAYOUTS_FEATURES = 1000241000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_STENCIL_LAYOUT = 1000241001,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_STENCIL_LAYOUT = 1000241002,
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_HOST_QUERY_RESET_FEATURES = 1000261000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TIMELINE_SEMAPHORE_FEATURES = 1000207000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TIMELINE_SEMAPHORE_PROPERTIES = 1000207001,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_SEMAPHORE_TYPE_CREATE_INFO = 1000207002,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_TIMELINE_SEMAPHORE_SUBMIT_INFO = 1000207003,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_SEMAPHORE_WAIT_INFO = 1000207004,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_SEMAPHORE_SIGNAL_INFO = 1000207005,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BUFFER_DEVICE_ADDRESS_FEATURES = 1000257000,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_BUFFER_DEVICE_ADDRESS_INFO = 1000244001,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_BUFFER_OPAQUE_CAPTURE_ADDRESS_CREATE_INFO = 1000257002,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_MEMORY_OPAQUE_CAPTURE_ADDRESS_ALLOCATE_INFO = 1000257003,
// Provided by VK_VERSION_1_2
VK_STRUCTURE_TYPE_DEVICE_MEMORY_OPAQUE_CAPTURE_ADDRESS_INFO = 1000257004,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_3_FEATURES = 53,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_3_PROPERTIES = 54,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PIPELINE_CREATION_FEEDBACK_CREATE_INFO = 1000192000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_TERMINATE_INVOCATION_FEATURES = 1000215000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TOOL_PROPERTIES = 1000245000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_DEMOTE_TO_HELPER_INVOCATION_FEATURES = 1000276000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRIVATE_DATA_FEATURES = 1000295000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_DEVICE_PRIVATE_DATA_CREATE_INFO = 1000295001,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PRIVATE_DATA_SLOT_CREATE_INFO = 1000295002,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_CREATION_CACHE_CONTROL_FEATURES = 1000297000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_BUFFER_MEMORY_BARRIER_2 = 1000314000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_BUFFER_MEMORY_BARRIER_2 = 1000314001,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_MEMORY_BARRIER_2 = 1000314000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_MEMORY_BARRIER_2 = 1000314001,
VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER_2 = 1000314002,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_DEPENDENCY_INFO = 1000314003,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_SUBMIT_INFO_2 = 1000314004,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_SEMAPHORE_SUBMIT_INFO = 1000314005,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_COMMAND_BUFFER_SUBMIT_INFO = 1000314006,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SYNCHRONIZATION_2_FEATURES = 1000314007,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ZERO_INITIALIZE_WORKGROUP_MEMORY_FEATURES = 1000325000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_ROBUSTNESS_FEATURES = 1000335000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_COPY_BUFFER_INFO_2 = 1000337000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_COPY_IMAGE_INFO_2 = 1000337001,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_COPY_BUFFER_TO_IMAGE_INFO_2 = 1000337002,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_COPY_IMAGE_TO_BUFFER_INFO_2 = 1000337003,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_BLIT_IMAGE_INFO_2 = 1000337004,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_RESOLVE_IMAGE_INFO_2 = 1000337005,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_BUFFER_COPY_2 = 1000337006,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_IMAGE_COPY_2 = 1000337007,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_IMAGE_BLIT_2 = 1000337008,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_BUFFER_IMAGE_COPY_2 = 1000337009,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_IMAGE_RESOLVE_2 = 1000337010,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBGROUP_SIZE_CONTROL_PROPERTIES = 1000225000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_REQUIRED_SUBGROUP_SIZE_CREATE_INFO = 1000225001,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBGROUP_SIZE_CONTROL_FEATURES = 1000225002,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INLINE_UNIFORM_BLOCK_FEATURES = 1000138000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INLINE_UNIFORM_BLOCK_PROPERTIES = 1000138001,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET_INLINE_UNIFORM_BLOCK = 1000138002,
// Provided by VK_VERSION_1_3
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_DESCRIPTOR_POOL_INLINE_UNIFORM_BLOCK_CREATE_INFO = 1000138003,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXTURE_COMPRESSION_ASTC_HDR_FEATURES = 1000066000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_RENDERING_INFO = 1000044000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_RENDERING_ATTACHMENT_INFO = 1000044001,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PIPELINE_RENDERING_CREATE_INFO = 1000044002,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DYNAMIC_RENDERING_FEATURES = 1000044003,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_RENDERING_INFO = 1000044004,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_INTEGER_DOT_PRODUCT_FEATURES = 1000280000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_INTEGER_DOT_PRODUCT_PROPERTIES = 1000280001,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXEL_BUFFER_ALIGNMENT_PROPERTIES = 1000281001,
// Provided by VK_STRUCTURE_TYPE_FORMAT_PROPERTIES_3 = 1000360000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_4_FEATURES = 1000413000,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_4_PROPERTIES = 1000413001,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_DEVICE_BUFFER_MEMORY_REQUIREMENTS = 1000413002,
// Provided by VK_VERSION_1_3
VK_STRUCTURE_TYPE_DEVICE_IMAGE_MEMORY_REQUIREMENTS = 1000413003,
// Provided by VK_KHR_swapchain
VK_STRUCTURE_TYPE_SWAPCHAIN_CREATE_INFO_KHR = 1000001000,
// Provided by VK_KHR_swapchain
VK_STRUCTURE_TYPE_PRESENT_INFO_KHR = 1000001001,
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with VK_KHR_surface
VK_STRUCTURE_TYPE_DEVICE_GROUP_PRESENT_CAPABILITIES_KHR = 1000060007,
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with VK_KHR_swapchain
VK_STRUCTURE_TYPE_IMAGE_SWAPCHAIN_CREATE_INFO_KHR = 1000060008,
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with VK_KHR_swapchain
VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_SWAPCHAIN_INFO_KHR = 1000060009,
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with VK_KHR_swapchain
VK_STRUCTURE_TYPE_ACQUIRE_NEXT_IMAGE_INFO_KHR = 1000060010,
VK_STRUCTURE_TYPE_DEVICE_GROUP_PRESENT_INFO_KHR = 1000060011,
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with
VK_KHR_swapchain
VK_STRUCTURE_TYPE_DEVICE_GROUP_SWAPCHAIN_CREATE_INFO_KHR = 1000060012,
// Provided by VK_KHR_display
VK_STRUCTURE_TYPE_DISPLAY_MODE_CREATE_INFO_KHR = 1000002000,
// Provided by VK_KHR_display
VK_STRUCTURE_TYPE_DISPLAY_SURFACE_CREATE_INFO_KHR = 1000002001,
// Provided by VK_KHR_display_swapchain
VK_STRUCTURE_TYPE_DISPLAY_PRESENT_INFO_KHR = 1000003000,
// Provided by VK_KHR_xlib_surface
VK_STRUCTURE_TYPE_XLIB_SURFACE_CREATE_INFO_KHR = 1000004000,
// Provided by VK_KHR_xcb_surface
VK_STRUCTURE_TYPE_XCB_SURFACE_CREATE_INFO_KHR = 1000005000,
// Provided by VK_KHR_wayland_surface
VK_STRUCTURE_TYPE_WAYLAND_SURFACE_CREATE_INFO_KHR = 1000006000,
// Provided by VK_KHR_android_surface
VK_STRUCTURE_TYPE_ANDROID_SURFACE_CREATE_INFO_KHR = 1000008000,
// Provided by VK_KHR_win32_surface
VK_STRUCTURE_TYPE_WIN32_SURFACE_CREATE_INFO_KHR = 1000009000,
// Provided by VK_EXT_debug_report
VK_STRUCTURE_TYPE_DEBUG_REPORT_CALLBACK_CREATE_INFO_EXT = 1000011000,
// Provided by VK_AMD_rasterization_order
VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_STATE_RASTERIZATION_ORDER_AMD = 1000018000,
// Provided by VK_EXT_debug_marker
VK_STRUCTURE_TYPE_DEBUG_MARKER_OBJECT_NAME_INFO_EXT = 1000022000,
// Provided by VK_EXT_debug_marker
VK_STRUCTURE_TYPE_DEBUG_MARKER_OBJECT_TAG_INFO_EXT = 1000022001,
// Provided by VK_EXT_debug_marker
VK_STRUCTURE_TYPE_DEBUG_MARKER_MARKER_INFO_EXT = 1000022002,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_VIDEO_PROFILE_INFO_KHR = 1000023000,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_VIDEO_CAPABILITIES_KHR = 1000023001,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_VIDEO_PICTURE_RESOURCE_INFO_KHR = 1000023002,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_BIND_VIDEO_SESSION_MEMORY_INFO_KHR = 1000023003,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_VIDEO_SESSION_CREATE_INFO_KHR = 1000023005,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_VIDEO_SESSION_PARAMETERS_CREATE_INFO_KHR = 1000023006,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_VIDEO_SESSION_PARAMETERS_UPDATE_INFO_KHR = 1000023007,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_VIDEO_BEGIN_CODING_INFO_KHR = 1000023008,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_VIDEO_END_CODING_INFO_KHR = 1000023009,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_VIDEO_CODING_CONTROL_INFO_KHR = 1000023010,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_VIDEO_REFERENCE_SLOT_INFO_KHR = 1000023011,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_QUEUE_FAMILY_VIDEO_PROPERTIES_KHR = 1000023012,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_VIDEO_PROFILE_LIST_INFO_KHR = 1000023013,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VIDEO_FORMAT_INFO_KHR = 1000023014,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_VIDEO_FORMAT_PROPERTIES_KHR = 1000023015,
// Provided by VK_KHR_video_queue
VK_STRUCTURE_TYPE_QUEUE_FAMILY_QUERY_RESULT_STATUS_PROPERTIES_KHR = 1000023016,
// Provided by VK_KHR_video_decode_queue
VK_STRUCTURE_TYPE_VIDEO_DECODE_INFO_KHR = 1000024000,
// Provided by VK_KHR_video_decode_queue
VK_STRUCTURE_TYPE_VIDEO_DECODE_CAPABILITIES_KHR = 1000024001,
// Provided by VK_KHR_video_decode_queue
VK_STRUCTURE_TYPE_VIDEO_DECODE_USAGE_INFO_KHR = 1000024002,
// Provided by VK_NV_dedicated_allocation
VK_STRUCTURE_TYPE_DEDICATED_ALLOCATION_IMAGE_CREATE_INFO_NV = 1000026000,
// Provided by VK_NV_dedicated_allocation
VK_STRUCTURE_TYPE_DEDICATED_ALLOCATION_BUFFER_CREATE_INFO_NV = 1000026001,
// Provided by VK_NV_dedicated_allocation
VK_STRUCTURE_TYPE_DEDICATED_ALLOCATION_MEMORY_ALLOCATE_INFO_NV = 1000026002,
// Provided by VK_EXT_transform_feedback
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TRANSFORM_FEEDBACK_FEATURES_EXT = 1000028000,
// Provided by VK_EXT_transform_feedback
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TRANSFORM_FEEDBACK_PROPERTIES_EXT = 1000028001,
// Provided by VK_EXT_transform_feedback
VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_STATE_STREAM_CREATE_INFO_EXT = 1000028002,
// Provided by VK_NVX_binary_import
VK_STRUCTURE_TYPE_CU_MODULE_CREATE_INFO_NVX = 1000029000,
// Provided by VK_NVX_binary_import
VK_STRUCTURE_TYPE_CU_FUNCTION_CREATE_INFO_NVX = 1000029001,
// Provided by VK_NVX_binary_import
VK_STRUCTURE_TYPE_CU_LAUNCH_INFO_NVX = 1000029002,
// Provided by VK_NVX_image_view_handle
VK_STRUCTURE_TYPE_IMAGE_VIEW_HANDLE_INFO_NVX = 1000030000,
// Provided by VK_NVX_image_view_handle
VK_STRUCTURE_TYPE_IMAGE_VIEW_ADDRESS_PROPERTIES_NVX = 1000030001,
#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_EXT_video_encode_h264
VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_CAPABILITIES_EXT = 1000038000,
#endif
#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_EXT_video_encode_h264
VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_PARAMETERS_CREATE_INFO_EXT = 1000038001,
#endif
#ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h264
    VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_PARAMETERS_ADD_INFO_EXT = 1000038002,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h264
    VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_PICTURE_INFO_EXT = 1000038003,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h264
    VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_DPB_SLOT_INFO_EXT = 1000038004,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h264
    VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_NALU_SLICE_INFO_EXT = 1000038005,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h264
    VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_GOP_REMAINING_FRAME_INFO_EXT = 1000038006,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h264
    VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_PROFILE_INFO_EXT = 1000038007,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h264
    VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_RATE_CONTROL_INFO_EXT = 1000038008,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h264
    VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_RATE_CONTROL_LAYER_INFO_EXT = 1000038009,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h264
    VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_CREATE_INFO_EXT = 1000038010,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h264
    VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_QUALITY_LEVEL_PROPERTIES_EXT = 1000038011,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h264
    VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_PARAMETERS_GET_INFO_EXT = 1000038012,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h264
    VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_PARAMETERS_FEEDBACK_INFO_EXT = 1000038013,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h264
    VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_PARAMETERS_ADD_INFO_EXT = 1000038002,
#endif
// Provided by VK_EXT_video_encode_h265
VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_CAPABILITIES_EXT = 1000039000,
#endif

// Provided by VK_EXT_videoEncodeH265
VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_PARAMETERS_CREATE_INFO_EXT = 1000039001,
#endif

// Provided by VK_EXT_video_encode_h265
VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_PARAMETERS_ADD_INFO_EXT = 1000039002,
#endif

// Provided by VK_EXT_video_encode_h265
VK_STRUCTURE_TYPEVIDEO_ENCODE_H265_PICTURE_INFO_EXT = 1000039003,
#endif

// Provided by VK_EXT_videoEncodeH265
VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_DPB_SLOT_INFO_EXT = 1000039004,
#endif

// Provided by VK_EXT_video_encode_h265
VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_NALU_SLICE_SEGMENT_INFO_EXT = 1000039005,
#endif

// Provided by VK_EXT_videoEncodeH265
VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_GOP_REMAINING_FRAME_INFO_EXT = 1000039006,
#endif

// Provided by VK_EXT_video_encode_h265
VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_PROFILE_INFO_EXT = 1000039007,
#endif

// Provided by VK_EXT_videoEncodeH265
VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_RATE_CONTROL_INFO_EXT = 1000039009,
#endif

// Provided by VK_EXT_video_encode_h265
VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_RATE_CONTROL_LAYER_INFO_EXT = 1000039010,
#endif

// Provided by VK_EXT_videoEncodeH265
VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_CREATE_INFO_EXT = 1000039011,
#endif

// Provided by VK_EXT_video_encode_h265
VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_QUALITY_LEVEL_PROPERTIES_EXT = 1000039012,
#endif

// Provided by VK_EXT_videoEncodeH265
VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_PARAMETERS_GET_INFO_EXT = 1000039013,
#ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h265
    VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_PARAMETERS_FEEDBACK_INFO_EXT = 1000039014,
#endif

// Provided by VK_KHR_video_decode_h264
    VK_STRUCTURE_TYPE_VIDEO_DECODE_H264_CAPABILITIES_KHR = 1000040000,
    VK_STRUCTURE_TYPE_VIDEO_DECODE_H264_PICTURE_INFO_KHR = 1000040001,
    VK_STRUCTURE_TYPE_VIDEO_DECODE_H264_PROFILE_INFO_KHR = 1000040003,
    VK_STRUCTURE_TYPE_VIDEO_DECODE_H264_SESSION_PARAMETERS_CREATE_INFO_KHR = 1000040004,
    VK_STRUCTURE_TYPE_VIDEO_DECODE_H264_SESSION_PARAMETERS_ADD_INFO_KHR = 1000040005,
    VK_STRUCTURE_TYPE_VIDEO_DECODE_H264_DPB_SLOT_INFO_KHR = 1000040006,
    VK_STRUCTURE_TYPE_TEXTURE_LOD_GATHER_FORMAT_PROPERTIES_AMD = 1000041000
    // Provided by VK_KHR_dynamic_rendering with VK_KHR_fragment_shading_rate
    VK_STRUCTURE_TYPE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_INFO_KHR = 1000044006,
    VK_STRUCTURE_TYPE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_INFO_EXT = 1000044007
    // Provided by VK_KHR_dynamic_rendering with VK_AMD_mixed_attachment_samples
    VK_STRUCTURE_TYPE_ATTACHMENT_SAMPLE_COUNT_INFO_AMD = 1000044008,
    // Provided by VK_NVX_multiview_per_view_attributes
    VK_STRUCTURE_TYPE_MULTIVIEW_PER_VIEW_ATTRIBUTES_INFO_NVX = 1000044009
    // Provided by VK_GGP_stream_descriptor_surface
    VK_STRUCTURE_TYPE_STREAM_DESCRIPTOR_SURFACE_CREATE_INFO_GGP = 1000049000
    // Provided by VK_NV_corner_sampled_image
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CORNER_SAMPLED_IMAGE_FEATURES_NV = 1000050000
    // Provided by VK_NV_external_memory
    VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_IMAGE_CREATE_INFO_NV = 1000056000
    VK_STRUCTURE_TYPE_EXPORT_MEMORY_ALLOCATE_INFO_NV = 1000056001
    VK_STRUCTURE_TYPE_IMPORT_MEMORY_WIN32_HANDLE_INFO_NV = 1000057000
    // Provided by VK_NV_win32_keyed_mutex
    VK_STRUCTURE_TYPE_WIN32_KEYED_MUTEX_ACQUIRE_RELEASE_INFO_NV = 1000058000
    // Provided by VK_EXT_validation_flags
    VK_STRUCTURE_TYPE_VALIDATION_FLAGS_EXT = 1000061000
    // Provided by VK_NN_vi_surface
    VK_STRUCTURE_TYPE_VI_SURFACE_CREATE_INFO_NN = 1000062000
    // Provided by VK_EXT_astc_decode_mode
    VK_STRUCTURE_TYPE_IMAGE_VIEW_ASTC_DECODE_MODE_EXT = 1000067000
}
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ASTC.Decode.Features_EXT = 100067001,
// Provided by VK_EXT_pipeline_robustness
VK_STRUCTURE_TYPE_PIPELINE_ROBUSTNESS_CREATE_INFO_EXT = 100068000,
// Provided by VK_EXT_pipeline_robustness
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_ROBUSTNESS_FEATURES_EXT = 100068001,
// Provided by VK_EXT_pipeline_robustness
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_ROBUSTNESS_PROPERTIES_EXT = 100068002,
// Provided by VK_KHR_external_memory_win32
VK_STRUCTURE_TYPE_IMPORT_MEMORY_WIN32_HANDLE_INFO_KHR = 1000073000,
// Provided by VK_KHR_external_memory_win32
VK_STRUCTURE_TYPE_EXPORT_MEMORY_WIN32_HANDLE_INFO_KHR = 1000073001,
// Provided by VK_KHR_external_memory_win32
VK_STRUCTURE_TYPE_MEMORY_WIN32_HANDLE_PROPERTIES_KHR = 1000073002,
// Provided by VK_KHR_external_memory_win32
VK_STRUCTURE_TYPE_MEMORY_GET_WIN32_HANDLE_INFO_KHR = 1000073003,
// Provided by VK_KHR_win32_keyed_mutex
VK_STRUCTURE_TYPE_D3D12_FENCE_SUBMIT_INFO_KHR = 1000078002,
// Provided by VK_KHR_external_semaphore_win32
VK_STRUCTURE_TYPE_SEMAPHORE_GET_WIN32_HANDLE_INFO_KHR = 1000078003,
// Provided by VK_KHR_push_descriptor
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PUSH_DESCRIPTOR_PROPERTIES_KHR = 1000080000,
// Provided by VK_EXT_conditional_rendering
VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_CONDITIONAL_RENDERING_INFO_EXT = 1000081000,
// Provided by VK_KHR_incremental_present
VK_STRUCTURE_TYPE_PRESENT_REGIONS_KHR = 1000084000,
// Provided by VK_NV_clip_space_w_scaling
VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_W_SCALING_STATE_CREATE_INFO_NV = 1000087000,
// Provided by VK_EXT_display_surface_counter
VK_STRUCTURE_TYPE_SURFACE_CAPABILITIES_2_EXT = 1000090000,
// Provided by VK_EXT_display_control
VK_STRUCTURE_TYPE_DISPLAY_POWER_INFO_EXT = 0x100091000,
    // Provided by VK_EXT_display_control
VK_STRUCTURE_TYPE_DEVICE_EVENT_INFO_EXT = 0x100091001,
    // Provided by VK_EXT_display_control
VK_STRUCTURE_TYPE_DISPLAY_EVENT_INFO_EXT = 0x100091002,
    // Provided by VK_EXT_display_control
VK_STRUCTURE_TYPE_SWAPCHAIN_COUNTER_CREATE_INFO_EXT = 0x100091003,
    // Provided by VK_GOOGLE_display_timing
VK_STRUCTURE_TYPE_PRESENT_TIMES_INFO_GOOGLE = 0x1000092000,
    // Provided by VK_NVX_multiview_per_view_attributes
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_PER_VIEW_ATTRIBUTES_PROPERTIES_NVX = 0x1000097000,
    // Provided by VK_NV_viewport_swizzle
VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_SWIZZLE_STATE_CREATE_INFO_NV = 0x1000098000,
    // Provided by VK_EXT_discard_rectangles
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DISCARD_RECTANGLE_PROPERTIES_EXT = 0x1000099000,
    // Provided by VK_EXT_discard_rectangles
VK_STRUCTURE_TYPE_PIPELINE_DISCARD_RECTANGLE_STATE_CREATE_INFO_EXT = 0x1000099001,
    // Provided by VK_EXT_conservative_rasterization
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CONSERVATIVE_RASTERIZATION_PROPERTIES_EXT = 0x1000101000,
    // Provided by VK_EXT_conservative_rasterization
VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_CONSERVATIVE_STATE_CREATE_INFO_EXT = 0x1000101001,
    // Provided by VK_EXT_depth_clip_enable
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_CLIP_ENABLE_FEATURES_EXT = 0x1000102000,
    // Provided by VK_KHR_performance_query
VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_DEPTH_CLIP_STATE_CREATE_INFO_EXT = 0x1000102001,
    // Provided by VK_KHR_performance_query
VK_STRUCTURE_TYPE_HDR_METADATA_EXT = 0x10000105000,
    // Provided by VK_KHR_performance_query
VK_STRUCTURE_TYPE_SHARED_PRESENT_SURFACE_CAPABILITIES_KHR = 0x1000111000,
    // Provided by VK_KHR_performance_query
VK_STRUCTURE_TYPE_IMPORT_FENCE_WIN32_HANDLE_INFO_KHR = 0x1000114000,
    // Provided by VK_KHR_performance_query
VK_STRUCTURE_TYPE_EXPORT_FENCE_WIN32_HANDLE_INFO_KHR = 0x1000114001,
    // Provided by VK_KHR_performance_query
VK_STRUCTURE_TYPE_FENCE_GET_WIN32_HANDLE_INFO_KHR = 0x1000114002,
    // Provided by VK_KHR_performance_query
VK_STRUCTURE_TYPE_IMPORT_FENCE_FD_INFO_KHR = 0x1000115000,
    // Provided by VK_KHR_performance_query
VK_STRUCTURE_TYPE_FENCE_GET_FD_INFO_KHR = 0x1000115001,
    // Provided by VK_KHR_performance_query
VK_STRUCTURE_TYPE_QUERY_POOL_PERFORMANCE_CREATE_INFO_KHR = 0x1000116002,
    // Provided by VK_KHR_performance_query
VK_STRUCTURE_TYPE_PERFORMANCE_QUERY_SUBMIT_INFO_KHR = 0x1000116003,
// Provided by VK_KHR_performance_query
VK_STRUCTURE_TYPE_ACQUIRE_PROFILING_LOCK_INFO_KHR = 1000116004,
// Provided by VK_KHR_performance_query
VK_STRUCTURE_TYPE_PERFORMANCE_COUNTER_KHR = 1000116005,
// Provided by VK_KHR_performance_query
VK_STRUCTURE_TYPE_PERFORMANCE_COUNTER_DESCRIPTION_KHR = 1000116006,
// Provided by VK_KHR_get_surface_capabilities2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SURFACE_INFO_2_KHR = 1000119000,
// Provided by VK_KHR_get_surface_capabilities2
VK_STRUCTURE_TYPE_SURFACE_CAPABILITIES_2_KHR = 1000119001,
// Provided by VK_KHR_get_surface_capabilities2
VK_STRUCTURE_TYPE_SURFACE_FORMAT_2_KHR = 1000119002,
// Provided by VK_KHR_get_display_properties2
VK_STRUCTURE_TYPE_DISPLAY_PROPERTIES_2_KHR = 1000121000,
// Provided by VK_KHR_get_display_properties2
VK_STRUCTURE_TYPE_DISPLAY_PLANE_PROPERTIES_2_KHR = 1000121001,
// Provided by VK_KHR_get_display_properties2
VK_STRUCTURE_TYPE_DISPLAY_MODE_PROPERTIES_2_KHR = 1000121002,
// Provided by VK_KHR_get_display_properties2
VK_STRUCTURE_TYPE_DISPLAY_PLANE_INFO_2_KHR = 1000121003,
// Provided by VK_KHR_get_display_properties2
VK_STRUCTURE_TYPE_DISPLAY_PLANE_CAPABILITIES_2_KHR = 1000121004,
// Provided by VK_MVK_ios_surface
VK_STRUCTURE_TYPE_IOS_SURFACE_CREATE_INFO_MVK = 1000122000,
// Provided by VK_MVK_macos_surface
VK_STRUCTURE_TYPE_MACOS_SURFACE_CREATE_INFO_MVK = 1000123000,
// Provided by VK_EXT_debug_utils
VK_STRUCTURE_TYPE_DEBUG_UTILS_OBJECT_NAME_INFO_EXT = 1000128000,
// Provided by VK_EXT_debug_utils
VK_STRUCTURE_TYPE_DEBUG_UTILS_OBJECT_TAG_INFO_EXT = 1000128001,
// Provided by VK_EXT_debug_utils
VK_STRUCTURE_TYPE_DEBUG_UTILS_LABEL_EXT = 1000128002,
// Provided by VK_EXT_debug_utils
VK_STRUCTURE_TYPE_DEBUG_UTILS_MESSENGER_CALLBACK_DATA_EXT = 1000128003,
// Provided by VK_EXT_debug_utils
VK_STRUCTURE_TYPE_DEBUG_UTILS_MESSENGER_CREATE_INFO_EXT = 1000128004,
// Provided by VK_ANDROID_external_memory_android_hardware_buffer
VK_STRUCTURE_TYPE_ANDROID_HARDWARE_BUFFER_USAGE_ANDROID = 1000129000,
// Provided by VK_ANDROID_external_memory_android_hardware_buffer
VK_STRUCTURE_TYPE_ANDROID_HARDWARE_BUFFER_PROPERTIES_ANDROID = 1000129001,
// Provided by VK_ANDROID_external_memory_android_hardware_buffer
VK_STRUCTURE_TYPE_ANDROID_HARDWARE_BUFFER_FORMAT_PROPERTIES_ANDROID = 1000129002,
// Provided by VK_ANDROID_external_memory_android_hardware_buffer
VK_STRUCTURE_TYPE_IMPORT_ANDROID_HARDWARE_BUFFER_INFO_ANDROID = 1000129003,
// Provided by VK_ANDROID_external_memory_android_hardware_buffer
VK_STRUCTURE_TYPE_MEMORY_GET_ANDROID_HARDWARE_BUFFER_INFO_ANDROID = 1000129004,
// Provided by VK_KHR_format_feature_flags2 with
VK_ANDROID_external_memory_android_hardware_buffer
VK_STRUCTURE_TYPE_ANDROID_HARDWARE_BUFFER_FORMAT_PROPERTIES_2_ANDROID = 1000129005,
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1000129006,
#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_AMDX_shader_enqueue
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ENQUEUE_FEATURES_AMDX = 1000134000,
#endif
#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_AMDX_shader_enqueue
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ENQUEUE_PROPERTIES_AMDX = 1000134001,
#endif
#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_AMDX_shader_enqueue
    VK_STRUCTURE_TYPE_EXECUTION_GRAPH_PIPELINE_SCRATCH_SIZE_AMDX = 1000134002,
#endif
#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_AMDX_shader_enqueue
    VK_STRUCTURE_TYPE_EXECUTION_GRAPH_PIPELINE_CREATE_INFO_AMDX = 1000134003,
#endif
#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_AMDX_shader_enqueue
    VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_NODE_CREATE_INFO_AMDX = 1000134004,
#endif
// Provided by VK_EXT_sample_locations
    VK_STRUCTURE_TYPE_SAMPLE_LOCATIONS_INFO_EXT = 1000143000,
// Provided by VK_EXT_sample_locations
    VK_STRUCTURE_TYPE_RENDER_PASS_SAMPLE_LOCATIONS_BEGIN_INFO_EXT = 1000143001,
// Provided by VK_EXT_sample_locations
    VK_STRUCTURE_TYPE_PIPELINE_SAMPLE_LOCATIONS_STATE_CREATE_INFO_EXT = 1000143002,
// Provided by VK_EXT_sample_locations
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SAMPLE_LOCATIONS_PROPERTIES_EXT = 1000143003,
// Provided by VK_EXT_sample_locations
    VK_STRUCTURE_TYPE_MULTISAMPLE_PROPERTIES_EXT = 1000143004,
// Provided by VK_EXT_blend_operation_advanced
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BLEND_OPERATION_ADVANCED_FEATURES_EXT = 1000148000,
// Provided by VK_EXT_blend_operation_advanced
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BLEND_OPERATION_ADVANCED_PROPERTIES_EXT = 1000148001,
// Provided by VK_EXT_blend_operation_advanced
    VK_STRUCTURE_TYPE_PIPELINE_COLOR_BLEND_ADVANCED_STATE_CREATE_INFO_EXT = 1000148002,
// Provided by VK_NV_fragment_coverage_to_color
    VK_STRUCTURE_TYPE_PIPELINE_COVERAGE_TO_COLOR_STATE_CREATE_INFO_NV = 1000149000,
// Provided by VK_KHR_acceleration_structure
    VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET_ACCELERATION_STRUCTURE_KHR = 1000150007,
// Provided by VK_KHR_acceleration_structure
    VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_BUILD_GEOMETRY_INFO_KHR = 1000150000,
// Provided by VK_KHR_acceleration_structure
    VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_DEVICE_ADDRESS_INFO_KHR = 1000150002,
// Provided by VK_KHR_acceleration_structure
    VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_GEOMETRY_AABBS_DATA_KHR = 1000150003,
// Provided by VK_KHR_acceleration_structure
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VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_GEOMETRY_INSTANCES_DATA_KHR = 1000150004,
// Provided by VK_KHR_acceleration_structure
VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_GEOMETRY_TRIANGLES_DATA_KHR = 1000150005,
// Provided by VK_KHR_acceleration_structure
VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_GEOMETRY_KHR = 1000150006,
// Provided by VK_KHR_acceleration_structure
VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_VERSION_INFO_KHR = 1000150009,
// Provided by VK_KHR_acceleration_structure
VK_STRUCTURE_TYPE_COPY_ACCELERATION_STRUCTURE_INFO_KHR = 1000150010,
// Provided by VK_KHR_acceleration_structure
VK_STRUCTURE_TYPE_COPY_ACCELERATION_STRUCTURE_TO_MEMORY_INFO_KHR = 1000150011,
// Provided by VK_KHR_acceleration_structure
VK_STRUCTURE_TYPE_COPY_MEMORY_TO_ACCELERATION_STRUCTURE_INFO_KHR = 1000150012,
// Provided by VK_KHR_acceleration_structure
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ACCELERATION_STRUCTURE_FEATURES_KHR = 1000150013,
// Provided by VK_KHR_acceleration_structure
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ACCELERATION_STRUCTURE_PROPERTIES_KHR = 1000150014,
// Provided by VK_KHR_acceleration_structure
VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_CREATE_INFO_KHR = 1000150017,
// Provided by VK_KHR_acceleration_structure
VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_BUILD_SIZES_INFO_KHR = 1000150020,
// Provided by VK_KHR_ray_tracing_pipeline
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_PIPELINE_FEATURES_KHR = 1000347000,
// Provided by VK_KHR_ray_tracing_pipeline
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_PIPELINE_PROPERTIES_KHR = 1000347001,
// Provided by VK_KHR_ray_tracing_pipeline
VK_STRUCTURE_TYPE_RAY_TRACING_PIPELINE_CREATE_INFO_KHR = 1000150015,
// Provided by VK_KHR_ray_tracing_pipeline
VK_STRUCTURE_TYPE_RAY_TRACING_SHADER_GROUP_CREATE_INFO_KHR = 1000150016,
// Provided by VK_KHR_ray_tracing_pipeline
VK_STRUCTURE_TYPE_RAY_TRACING_PIPELINE_INTERFACE_CREATE_INFO_KHR = 1000150018,
// Provided by VK_KHR_ray_query
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_QUERY_FEATURES_KHR = 1000348013,
// Provided by VK_NV_framebuffer_mixed_samples
VK_STRUCTURE_TYPE_PIPELINE_COVERAGE_MODULATION_STATE_CREATE_INFO_NV = 1000152000,
// Provided by VK_NV_shader_sm_builtins
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_SM_BUILTINS_FEATURES_NV = 1000154000,
// Provided by VK_NV_shader_sm_builtins
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_SM_BUILTINS_PROPERTIES_NV = 1000154001,
// Provided by VK_EXT_image_drm_format_modifier
VK_STRUCTURE_TYPE_DRM_FORMAT_MODIFIER_PROPERTIES_LIST_EXT = 1000158000,
// Provided by VK_EXT_image_drm_format_modifier
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_DRM_FORMAT_MODIFIER_INFO_EXT = 1000158002,
// Provided by VK_EXT_image_drm_format_modifier
VK_STRUCTURE_TYPE_IMAGE_DRM_FORMAT_MODIFIER_LIST_CREATE_INFO_EXT = 1000158003,
// Provided by VK_EXT_image_drm_format_modifier
VK_STRUCTURE_TYPE_IMAGE_DRM_FORMAT_MODIFIER_EXPLICIT_CREATE_INFO_EXT = 1000158004,
// Provided by VK_EXT_image_drm_format_modifier
VK_STRUCTURE_TYPE_IMAGE_DRM_FORMAT_MODIFIER_PROPERTIES_EXT = 1000158005,
// Provided by VK_KHR_format_feature_flags2 with VK_EXT_image_drm_format_modifier
VK_STRUCTURE_TYPE_IMAGE_DRM_FORMAT_MODIFIER_PROPERTIES_LIST_2_EXT = 1000158006,
// Provided by VK_EXT_validation_cache
VK_STRUCTURE_TYPE_VALIDATION_CACHE_CREATE_INFO_EXT = 1000160000,
// Provided by VK_EXT_validation_cache
VK_STRUCTURE_TYPE_SHADER_MODULE_VALIDATION_CACHE_CREATE_INFO_EXT = 1000160001,
// Provided by VK_KHR_portability_subset
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PORTABILITY_SUBSET_FEATURES_KHR = 1000163000,
#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_portability_subset
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PORTABILITY_SUBSET_PROPERTIES_KHR = 1000163001,
#endif
#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_portability_subset
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PORTABILITY_SUBSET_PROPERTIES_KHR = 1000163001,
#endif
// Provided by VK_NV_shading_rate_image
VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_SHADING_RATE_IMAGE_STATE_CREATE_INFO_NV = 1000164000,
// Provided by VK_NV_shading_rate_image
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADING_RATE_IMAGE_FEATURES_NV = 1000164001,
// Provided by VK_NV_shading_rate_image
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADING_RATE_IMAGE_PROPERTIES_NV = 1000164002,
// Provided by VK_NV_shading_rate_image
VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_COARSE_SAMPLE_ORDER_STATE_CREATE_INFO_NV = 1000164005,
// Provided by VK_NV_ray_tracing
VK_STRUCTURE_TYPE_RAY_TRACING_PIPELINE_CREATE_INFO_NV = 1000165000,
// Provided by VK_NV_ray_tracing
VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_CREATE_INFO_NV = 1000165001,
// Provided by VK_NV_ray_tracing
VK_STRUCTURE_TYPE_GEOMETRY_NV = 1000165003,
// Provided by VK_NV_ray_tracing
VK_STRUCTURE_TYPE_GEOMETRY_TRIANGLES_NV = 1000165004,
// Provided by VK_NV_ray_tracing
VK_STRUCTURE_TYPE_GEOMETRY_AABB_NV = 1000165005,
// Provided by VK_NV_ray_tracing
VK_STRUCTURE_TYPE_BIND_ACCELERATION_STRUCTURE_MEMORY_INFO_NV = 1000165006,
// Provided by VK_NV_ray_tracing
VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET_ACCELERATION_STRUCTURE_NV = 1000165007,
// Provided by VK_NV_ray_tracing
VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_INFO_NV = 1000165012,
// Provided by VK_NV_representative_fragment_test
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_REPRESENTATIVE_FRAGMENT_TEST_FEATURES_NV = 1000166000,
// Provided by VK_NV_representative_fragment_test
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VK_STRUCTURE_TYPE_PIPELINE_REPRESENTATIVE_FRAGMENT_TEST_STATE_CREATE_INFO_NV =
1000166001,
// Provided by VK_EXT_filter_cubic
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_VIEW_IMAGE_FORMAT_INFO_EXT =
1000170000,
// Provided by VK_EXT_filter_cubic
VK_STRUCTURE_TYPE_FILTER_CUBIC_IMAGE_VIEW_IMAGE_FORMAT_PROPERTIES_EXT =
1000170001,
// Provided by VK_EXT_external_memory_host
VK_STRUCTURE_TYPE_IMPORT_MEMORY_HOST_POINTER_INFO_EXT =
1000178000,
// Provided by VK_EXT_external_memory_host
VK_STRUCTURE_TYPE_MEMORY_HOST_POINTER_PROPERTIES_EXT =
1000178001,
// Provided by VK_EXT_external_memory_host
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_MEMORY_HOST_PROPERTIES_EXT =
1000178002,
// Provided by VK_KHR_shader_clock
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CLOCK_FEATURES_KHR =
1000181000,
// Provided by VK_AMD_pipeline_compiler_control
VK_STRUCTURE_TYPE_PIPELINE_COMPILER_CONTROL_CREATE_INFO_AMD =
1000183000,
// Provided by VK_KHR_video_decode_h265
VK_STRUCTURE_TYPE_VIDEO_DECODE_H265_PROFILE_INFO_KHR =
1000187003,
// Provided by VK_KHR_video_decode_h265
VK_STRUCTURE_TYPE_VIDEO_DECODE_H265_SESSION_PARAMETERS_CREATE_INFO_KHR =
1000187001,
// Provided by VK_KHR_video_decode_h265
VK_STRUCTURE_TYPE_VIDEO_DECODE_H265_SESSION_PARAMETERS_ADD_INFO_KHR =
1000187002,
// Provided by VK_KHR_video_decode_h265
VK_STRUCTURE_TYPE_VIDEO_DECODE_H265_DPB_SLOT_INFO_KHR =
1000187005,
// Provided by VK_KHR_global_priority
VK_STRUCTURE_TYPE_DEVICE_QUEUE_GLOBAL_PRIORITY_CREATE_INFO_KHR =
1000174000,
// Provided by VK_KHR_global_priority
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_QUEUE_GLOBAL_PRIORITY_QUERY_FEATURES_KHR =
1000388000,
// Provided by VK_KHR_global_priority
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_OVERALLOCATION_CREATE_INFO_AMD =
1000189000,
// Provided by VK_AMD_memory_overallocation_behavior
VK_STRUCTURE_TYPE_PIPELINE_VERTEX_INPUT_DIVISOR_STATE_CREATE_INFO_EXT =
1000190001,
// Provided by VK_EXT_vertex_attribute_divisor
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VERTEX_ATTRIBUTE_DIVISOR_FEATURES_EXT =
1000190001,
// Provided by VK_GGP_frame_token
VK_STRUCTURE_TYPE_PRESENT_FRAME_TOKEN_GGP = 1000190002,
// Provided by VK_NV_compute_shader_derivatives
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COMPUTE_SHADER_DERIVATIVES_FEATURES_NV = 1000201000,
// Provided by VK_NV_mesh_shader
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MESH_SHADER_FEATURES_NV = 1000202000,
// Provided by VK_NV_mesh_shader
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MESH_SHADER_PROPERTIES_NV = 1000202001,
// Provided by VK_NV_shader_image_footprint
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_IMAGE_FOOTPRINT_FEATURES_NV = 1000204000,
// Provided by VK_NV_scissor_exclusive
VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_EXCLUSIVE_SCISSOR_STATE_CREATE_INFO_NV = 1000205000,
// Provided by VK_NV_scissor_exclusive
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXCLUSIVE_SCISSOR_FEATURES_NV = 1000205002,
// Provided by VK_INTEL_shader_integer_functions2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_INTEGER_FUNCTIONS_2_FEATURES_INTEL = 1000209000,
// Provided by VK_INTEL_performance_query
VK_STRUCTURE_TYPE_QUERY_POOL_PERFORMANCE_QUERY_CREATE_INFO_INTEL = 1000210000,
// Provided by VK_INTEL_performance_query
VK_STRUCTURE_TYPE_INITIALIZE_PERFORMANCE_API_INFO_INTEL = 1000210001,
// Provided by VK_INTEL_performance_query
VK_STRUCTURE_TYPE_PERFORMANCE_MARKER_INFO_INTEL = 1000210002,
// Provided by VK_INTEL_performance_query
VK_STRUCTURE_TYPE_PERFORMANCE_STREAM_MARKER_INFO_INTEL = 1000210003,
// Provided by VK_INTEL_performance_query
VK_STRUCTURE_TYPE_PERFORMANCE_OVERRIDE_INFO_INTEL = 1000210004,
// Provided by VK_INTEL_performance_query
VK_STRUCTURE_TYPE_PERFORMANCE_CONFIGURATION_ACQUIRE_INFO_INTEL = 1000210005,
// Provided by VK_EXT_pci_bus_info
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PCI_BUS_INFO_PROPERTIES_EXT = 1000212000,
// Provided by VK_AMD_display_native_hdr
VK_STRUCTURE_TYPE_DISPLAY_NATIVE_HDR_SURFACE_CAPABILITIES_AMD = 1000213000,
// Provided by VK_AMD_display_native_hdr
VK_STRUCTURE_TYPE_SWAPCHAIN_DISPLAY_NATIVE_HDR_CREATE_INFO_AMD = 1000213001,
// Provided by VK_FUCHSIA_imagepipe_surface
VK_STRUCTURE_TYPE_IMAGEPIPE_SURFACE_CREATE_INFO_FUCHSIA = 1000214000,
// Provided by VK_EXT_metal_surface
VK_STRUCTURE_TYPE_METAL_SURFACE_CREATE_INFO_EXT = 1000217000,
// Provided by VK_EXT_fragment_density_map
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_FEATURES_EXT = 1000218000,
// Provided by VK_EXT_fragment_density_map
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_PROPERTIES_EXT = 1000218001,
// Provided by VK_EXT_fragment_density_map
VK_STRUCTURE_TYPE_RENDER_PASS_FRAGMENT_DENSITY_MAP_CREATE_INFO_EXT = 1000218002,
// Provided by VK_KHR_fragment_shading_rate
VK_STRUCTURE_TYPE_FRAGMENT_SHADING_RATE_ATTACHMENT_INFO_KHR = 1000226000,
// Provided by VK_KHR_fragment_shading_rate
VK_STRUCTURE_TYPE_PIPELINE_FRAGMENT_SHADING_RATE_STATE_CREATE_INFO_KHR = 1000226001,
// Provided by VK_KHR_fragment_shading_rate
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADING_RATE_PROPERTIES_KHR = 1000226002,
// Provided by VK_KHR_fragment_shading_rate
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADING_RATE_FEATURES_KHR = 1000226003,
// Provided by VK_KHR_fragment_shading_rate
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADING_RATE_KHR = 1000226004,
// Provided by VK_AMD_shader_core_properties2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CORE_PROPERTIES_2_AMD = 1000227000,
// Provided by VK_AMD_device_coherent_memory
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COHERENT_MEMORY_FEATURES_AMD = 1000229000,
// Provided by VK_EXT_shader_image_atomic_int64
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_IMAGE_ATOMIC_INT64_FEATURES_EXT = 1000234000,
// Provided by VK_EXT_memory_budget
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_BUDGET_PROPERTIES_EXT = 1000237000,
// Provided by VK_EXT_memory_priority
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_PRIORITY_FEATURES_EXT = 1000238000,
// Provided by VK_KHR_surface_protected_capabilities
VK_STRUCTURE_TYPE_SURFACE_PROTECTED_CAPABILITIES_KHR = 1000239000,
// Provided by VK_NV_dedicated_allocation_image_aliasing
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEDICATED_ALLOCATION_IMAGE_ALIASING_FEATURES_NV = 1000240000,
// Provided by VK_EXT_buffer_device_address
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BUFFER_DEVICE_ADDRESS_FEATURES_EXT = 1000244000,
// Provided by VK_EXT_buffer_device_address
VK_STRUCTURE_TYPE_BUFFER_DEVICE_ADDRESS_CREATE_INFO_EXT = 1000244002,
// Provided by VK_KHR_validation_features
VK_STRUCTURE_TYPE_VALIDATION_FEATURES_EXT = 1000247000,
// Provided by VK_KHR_present_wait
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRESENT_WAIT_FEATURES_KHR = 1000248000,
// Provided by VK_NV_cooperative_matrix
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COOPERATIVE_MATRIX_FEATURES_NV = 1000249000,
// Provided by VK_NV_cooperative_matrix
VK_STRUCTURE_TYPE_COOPERATIVE_MATRIX_PROPERTIES_NV = 1000249001,
// Provided by VK_NV_cooperative_matrix
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COOPERATIVE_MATRIX_PROPERTIES_NV = 1000249002,
// Provided by VK_NV_coverage_reduction_mode
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COVERAGE_REDUCTION_MODE_FEATURES_NV = 1000250000,
// Provided by VK_NV_coverage_reduction_mode
VK_STRUCTURE_TYPE_PIPELINE_COVERAGE_REDUCTION_STATE_CREATE_INFO_NV = 1000250001,
// Provided by VK_NV_coverage_reduction_mode
VK_STRUCTURE_TYPE_FRAMEBUFFER_MIXED_SAMPLES_COMBINATION_NV = 1000250002,
// Provided by VK_EXT_fragment_shader_interlock
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADER_INTERLOCK_FEATURES_EXT = 1000251000,
// Provided by VK_EXT_ycbcr_image_arrays
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_YCBCR_IMAGE_ARRAYS_FEATURES_EXT = 1000252000,
// Provided by VK_EXT_provoking_vertex
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PROVOKING_VERTEX_FEATURES_EXT = 1000254000,
VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_PROVOKING_VERTEX_STATE_CREATE_INFO_EXT = 1000254001,
// Provided by VK_EXT_provoking_vertex
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PROVOKING_VERTEX_PROPERTIES_EXT = 1000254002,
// Provided by VK_KHR_win32_surface with VK_EXT_full_screen_exclusive
VK_STRUCTURE_TYPE_SURFACE_FULL_SCREEN_EXCLUSIVE_WIN32_INFO_EXT = 1000255001,
// Provided by VK_EXT_headless_surface
VK_STRUCTURE_TYPE_HEADLESS_SURFACE_CREATE_INFO_EXT = 1000256000,
// Provided by VK_EXT_line_rasterization
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_LINE_RASTERIZATION_FEATURES_EXT = 1000259000,
VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_LINE_STATE_CREATE_INFO_EXT = 1000259001,
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_LINE_RASTERIZATION_PROPERTIES_EXT = 1000259002,
// Provided by VK_KHR_pipeline_executable_properties
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_EXECUTABLE_PROPERTIES_FEATURES_KHR = 1000269000,
VK_STRUCTURE_TYPE_PIPELINE_INFO_KHR = 1000269001,
VK_STRUCTURE_TYPE_PIPELINE_EXECUTABLE_PROPERTIES_KHR = 1000269002,
VK_STRUCTURE_TYPE_PIPELINE_EXECUTABLE_INFO_KHR = 1000269003,
VK_STRUCTURE_TYPE_PIPELINE_EXECUTABLE_STATISTIC_KHR = 1000269004,
VK_STRUCTURE_TYPE_PIPELINE_EXECUTABLE_INTERNAL_REPRESENTATION_KHR = 1000269005,
// Provided by VK_EXT_host_image_copy
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_HOST_IMAGE_COPY_FEATURES_EXT = 1000270000.
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_HOST_IMAGE_COPY_PROPERTIES_EXT = 1000270001,
// Provided by VK_EXT_host_image_copy
VK_STRUCTURE_TYPE_MEMORY_TO_IMAGE_COPY_EXT = 1000270002,
// Provided by VK_EXT_host_image_copy
VK_STRUCTURE_TYPE_IMAGE_TO_MEMORY_COPY_EXT = 1000270003,
// Provided by VK_EXT_host_image_copy
VK_STRUCTURE_TYPE_COPY_IMAGE_TO_MEMORY_INFO_EXT = 1000270004,
// Provided by VK_EXT_host_image_copy
VK_STRUCTURE_TYPE_COPY_MEMORY_TO_IMAGE_INFO_EXT = 1000270005,
// Provided by VK_EXT_host_image_copy
VK_STRUCTURE_TYPE_HOST_IMAGE_LAYOUT_TRANSITION_INFO_EXT = 1000270006,
// Provided by VK_EXT_host_image_copy
VK_STRUCTURE_TYPE_COPY_IMAGE_TO_IMAGE_INFO_EXT = 1000270007,
// Provided by VK_EXT_host_image_copy
VK_STRUCTURE_TYPE_SUBRESOURCE_HOST_MEMCPY_SIZE_EXT = 1000270008,
// Provided by VK_EXT_host_image_copy
VK_STRUCTURE_TYPE_HOST_IMAGE_COPY_DEVICE_PERFORMANCE_QUERY_EXT = 1000270009,
// Provided by VK_KHR_map_memory2
VK_STRUCTURE_TYPE_MEMORY_MAP_INFO_KHR = 1000271000,
// Provided by VK_KHR_map_memory2
VK_STRUCTURE_TYPE_MEMORY_UNMAP_INFO_KHR = 1000271001,
// Provided by VK_EXT_shader_atomic_float2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ATOMIC_FLOAT_2_FEATURES_EXT = 1000273000,
// Provided by VK_EXT_surface_maintenance1
VK_STRUCTURE_TYPE_SURFACE_PRESENT_MODE_EXT = 1000274000,
// Provided by VK_EXT_surface_maintenance1
VK_STRUCTURE_TYPE_SURFACE_PRESENT_SCALING_CAPABILITIES_EXT = 1000274001,
// Provided by VK_EXT_surface_maintenance1
VK_STRUCTURE_TYPE_SURFACE_PRESENT_MODE_COMPATIBILITY_EXT = 1000274002,
// Provided by VK_EXT_swapchain_maintenance1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SWAPCHAIN_MAINTENANCE_1_FEATURES_EXT = 1000275000,
// Provided by VK_EXT_swapchain_maintenance1
VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_FENCE_INFO_EXT = 1000275001,
// Provided by VK_EXT_swapchain_maintenance1
VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_MODES_CREATE_INFO_EXT = 1000275002,
// Provided by VK_EXT_swapchain_maintenance1
VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_MODE_INFO_EXT = 1000275003,
// Provided by VK_EXT_swapchain_maintenance1
VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_SCALING_CREATE_INFO_EXT = 1000275004,
// Provided by VK_EXT_swapchain_maintenance1
VK_STRUCTURE_TYPE_RELEASE_SWAPCHAIN_IMAGES_INFO_EXT = 1000275005,
// Provided by VK_NV_device_generated_commands
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEVICE_GENERATED_COMMANDS_PROPERTIES_NV = 1000277000,
// Provided by VK_NV_device_generated_commands
VK_STRUCTURE_TYPE_GRAPHICS_SHADER_GROUP_CREATE_INFO_NV = 1000277001,
// Provided by VK_NV_device_generated_commands
VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_SHADER_GROUPS_CREATE_INFO_NV = 1000277002,
// Provided by VK_NV_device_generated_commands
VK_STRUCTURE_TYPE_INDIRECT_COMMANDS_LAYOUT_TOKEN_NV = 1000277003,
// Provided by VK_NV_device_generated_commands
VK_STRUCTURE_TYPE_INDIRECT_COMMANDS_LAYOUT_CREATE_INFO_NV = 1000277004,
// Provided by VK_NV_device_generated_commands
VK_STRUCTURE_TYPE_GENERATED_COMMANDS_INFO_NV = 1000277005,
// Provided by VK_NV_device_generated_commands
VK_STRUCTURE_TYPE_GENERATED_COMMANDS_MEMORY_REQUIREMENTS_INFO_NV = 1000277006,
// Provided by VK_NV_device_generated_commands
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEVICE_GENERATED_COMMANDS/features_NV = 1000277007,
// Provided by VK_NV.inherited_viewport_scissor
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INHERITED_VIEWPORT_SCISSOR_FEATURES_NV = 1000278000,
// Provided by VK_NV.inherited_viewport_scissor
VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_VIEWPORT_SCISSOR_INFO_NV = 1000278001,
// Provided by VK_EXT_texel_buffer_alignment
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXEL_BUFFER_ALIGNMENT_FEATURES_EXT = 1000281000,
// Provided by VK_QCOM_render_pass_transform
VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_RENDER_PASS_TRANSFORM_INFO_QCOM = 1000282000,
// Provided by VK_QCOM_render_pass_transform
VK_STRUCTURE_TYPE_RENDER_PASS_TRANSFORM_BEGIN_INFO_QCOM = 1000282001,
// Provided by VK_EXT_depth_bias_control
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_BIAS_CONTROL_FEATURES_EXT = 1000283000,
// Provided by VK_EXT_depth_bias_control
VK_STRUCTURE_TYPE_DEPTH_BIAS_INFO_EXT = 1000283001,
// Provided by VK_EXT_depth_bias_control
VK_STRUCTURE_TYPE_DEPTH_BIAS_REPRESENTATION_INFO_EXT = 1000283002,
// Provided by VK_EXT_device_memory_report
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEVICE_MEMORY_REPORT_FEATURES_EXT = 1000284000,
// Provided by VK_EXT_device_memory_report
VK_STRUCTURE_TYPE_DEVICE_DEVICE_MEMORY_REPORT_CREATE_INFO_EXT = 1000284001,
// Provided by VK_EXT_device_memory_report
VK_STRUCTURE_TYPE_DEVICE_MEMORY_REPORT_CALLBACK_DATA_EXT = 1000284002,
// Provided by VK_EXT_robustness2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ROBUSTNESS_2_FEATURES_EXT = 1000286000,
// Provided by VK_EXT_robustness2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ROBUSTNESS_2_PROPERTIES_EXT = 1000286001,
// Provided by VK_EXT_custom_border_color
VK_STRUCTURE_TYPE_SAMPLER_CUSTOM_BORDER_COLOR_CREATE_INFO_EXT = 1000287000,
// Provided by VK_EXT_custom_border_color
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CUSTOM_BORDER_COLOR_PROPERTIES_EXT = 1000287001,
// Provided by VK_EXT_custom_border_color
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CUSTOM_BORDER_COLOR_FEATURES_EXT = 1000287002,
// Provided by VK_KHR_pipeline_library
VK_STRUCTURE_TYPE_PIPELINE_LIBRARY_CREATE_INFO_KHR = 1000290000,
// Provided by VK_NV_present_barrier
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRESENT_BARRIER_FEATURES_NV = 1000292000,
// Provided by VK_NV_present_barrier
VK_STRUCTURE_TYPE_SURFACE_CAPABILITIES_PRESENT_BARRIER_NV = 1000292001,
// Provided by VK_NV_present_barrier
VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_BARRIER_CREATE_INFO_NV = 1000292002,

// Provided by VK_KHR_present_id
VK_STRUCTURE_TYPE_PRESENT_ID_KHR = 1000294000,

// Provided by VK_KHR_present_id
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRESENT_ID_FEATURES_KHR = 1000294001,

#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_video_encode_queue
VK_STRUCTURE_TYPE_VIDEO_ENCODE_INFO_KHR = 1000299000,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_video_encode_queue
VK_STRUCTURE_TYPE_VIDEO_ENCODE_RATE_CONTROL_INFO_KHR = 1000299001,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_video_encode_queue
VK_STRUCTURE_TYPE_VIDEO_ENCODE_RATE_CONTROL_LAYER_INFO_KHR = 1000299002,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_video_encode_queue
VK_STRUCTURE_TYPE_VIDEO_ENCODE_CAPABILITIES_KHR = 1000299003,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_video_encode_queue
VK_STRUCTURE_TYPE_VIDEO_ENCODE_USAGE_INFO_KHR = 1000299004,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_video_encode_queue
VK_STRUCTURE_TYPE_QUERY_POOL_VIDEO_ENCODE_FEEDBACK_CREATE_INFO_KHR = 1000299005,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_video_encode_queue
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VIDEO_ENCODE_QUALITY_LEVEL_INFO_KHR = 1000299006,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_video_encode_queue
VK_STRUCTURE_TYPE_VIDEO_ENCODE_QUALITY_LEVEL_PROPERTIES_KHR = 1000299007,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_video_encode_queue
VK_STRUCTURE_TYPE_VIDEO_ENCODE_QUALITY_LEVEL_INFO_KHR = 1000299008,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_video_encode_queue
VK_STRUCTURE_TYPE_VIDEO_ENCODE_SESSION_PARAMETERS_GET_INFO_KHR = 1000299009,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_video_encode_queue
VK_STRUCTURE_TYPE_VIDEO_ENCODE_SESSION_PARAMETERS_FEEDBACK_INFO_KHR = 1000299010,
#endif
// Provided by VK_NV_device_diagnostics_config
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DIAGNOSTICS_CONFIG_FEATURES_NV = 1000300000,
// Provided by VK_NV_device_diagnostics_config
VK_STRUCTURE_TYPE_DEVICE_DIAGNOSTICS_CONFIG_CREATE_INFO_NV = 1000300001,
// Provided by VK_NV_low_latency
VK_STRUCTURE_TYPE_QUERY_LOW_LATENCY_SUPPORT_NV = 1000310000,
// Provided by VK_EXT_metal_objects
VK_STRUCTURE_TYPE_EXPORT_METAL_OBJECT_CREATE_INFO_EXT = 1000311000,
// Provided by VK_EXT_metal_objects
VK_STRUCTURE_TYPE_EXPORT_METAL_OBJECTS_INFO_EXT = 1000311001,
// Provided by VK_EXT_metal_objects
VK_STRUCTURE_TYPE_EXPORT_METAL_DEVICE_INFO_EXT = 1000311002,
// Provided by VK_EXT_metal_objects
VK_STRUCTURE_TYPE_EXPORT_METAL_COMMAND_QUEUE_INFO_EXT = 1000311003,
// Provided by VK_EXT_metal_objects
VK_STRUCTURE_TYPE_EXPORT_METAL_BUFFER_INFO_EXT = 1000311004,
// Provided by VK_EXT_metal_objects
VK_STRUCTURE_TYPE_IMPORT_METAL_BUFFER_INFO_EXT = 1000311005,
// Provided by VK_EXT_metal_objects
VK_STRUCTURE_TYPE_EXPORT_METAL_TEXTURE_INFO_EXT = 1000311006,
// Provided by VK_EXT_metal_objects
VK_STRUCTURE_TYPE_IMPORT_METAL_TEXTURE_INFO_EXT = 1000311007,
// Provided by VK_EXT_metal_objects
VK_STRUCTURE_TYPE_EXPORT_METAL_IO_SURFACE_INFO_EXT = 1000311008,
// Provided by VK_EXT_metal_objects
VK_STRUCTURE_TYPE_IMPORT_METAL_IO_SURFACE_INFO_EXT = 1000311009,
// Provided by VK_KHR_synchronization2 with VK_NV_device_diagnostic_checkpoints
VK_STRUCTURE_TYPE_QUEUE_FAMILY_CHECKPOINT_PROPERTIES_2_NV = 1000314008,
// Provided by VK_KHR_synchronization2 with VK_NV_device_diagnostic_checkpoints
VK_STRUCTURE_TYPE_CHECKPOINT_DATA_2_NV = 1000314009,
// Provided by VK_EXT_descriptor_buffer
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_BUFFER_PROPERTIES_EXT = 1000316000,
// Provided by VK_EXT_descriptor_buffer
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_BUFFER_DENSITY_MAP_PROPERTIES_EXT = 1000316001,
// Provided by VK_EXT_descriptor_buffer
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_BUFFER_FEATURES_EXT = 1000316002,
// Provided by VK_EXT_descriptor_buffer
VK_STRUCTURE_TYPE_DESCRIPTOR_ADDRESS_INFO_EXT = 1000316003,
// Provided by VK_EXT_descriptor_buffer
VK_STRUCTURE_TYPE_DESCRIPTOR_GET_INFO_EXT = 1000316004,
// Provided by VK_EXT_descriptor_buffer
VK_STRUCTURE_TYPE_BUFFER_CAPTURE_DESCRIPTOR_DATA_INFO_EXT = 1000316005,
// Provided by VK_EXT_descriptor_buffer
VK_STRUCTURE_TYPE_IMAGE_CAPTURE_DESCRIPTOR_DATA_INFO_EXT = 1000316006,
// Provided by VK_EXT_descriptor_buffer
VK_STRUCTURE_TYPE_IMAGE_VIEW_CAPTURE_DESCRIPTOR_DATA_INFO_EXT = 1000316007,
// Provided by VK_EXT_descriptor_buffer
VK_STRUCTURE_TYPE_SAMPLER_CAPTURE_DESCRIPTOR_DATA_INFO_EXT = 1000316008,
// Provided by VK_EXT_descriptor_buffer
VK_STRUCTURE_TYPE_OPAQUE_CAPTURE_DESCRIPTOR_DATA_CREATE_INFO_EXT = 1000316010,
// Provided by VK_EXT_descriptor_buffer
VK_STRUCTURE_TYPE_DESCRIPTOR_BUFFER_BINDING_INFO_EXT = 1000316011,
// Provided by VK_EXT_descriptor_buffer
VK_STRUCTURE_TYPE_DESCRIPTOR_BUFFER_BINDING_PUSH_DESCRIPTOR_BUFFER_HANDLE_EXT = 1000316012,
// Provided by VK_EXT_descriptor_buffer with VK_KHR_acceleration_structure or
VK_NV_ray_tracing
VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_CAPTURE_DESCRIPTOR_DATA_INFO_EXT = 1000316009,
// Provided by VK_EXT_graphics_pipeline_library
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GRAPHICS_PIPELINE_LIBRARY_FEATURES_EXT = 1000320000,
// Provided by VK_EXT_graphics_pipeline_library
VK_STRUCTURE_TYPE_PHYSICALDEVICE_GRAPHICS_PIPELINE_LIBRARY_PROPERTIES_EXT = 1000320001,
// Provided by VK_EXT_graphics_pipeline_library
VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_LIBRARY_CREATE_INFO_EXT = 1000320002,
// Provided by VK_AMD_shader_early_and_late_fragment_tests
VK_STRUCTURE_TYPE_PHYSICALDEVICE_SHADER_EARLY_AND_LATE_FRAGMENT_TESTS_FEATURES_AMD = 1000321000,
// Provided by VK_KHR_fragment_shader_barycentric
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADER_BARYCENTRIC_FEATURES_KHR = 1000203000,
// Provided by VK_KHR_fragment_shader_barycentric
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADER_BARYCENTRIC_PROPERTIES_KHR = 1000322000,
// Provided by VK_KHR_shader_subgroup_uniform_control_flow
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_SUBGROUP_UNIFORM_CONTROL_FLOW_FEATURES_KHR = 1000323000,
// Provided by VK_NV_fragment_shading_rate_enums
VK_STRUCTURE_TYPE_PHYSICALDEVICE_FRAGMENT_SHADING_RATE_ENUMS_PROPERTIES_NV = 1000326000,
// Provided by VK_NV_fragment_shading_rate_enums
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADING_RATE_ENUMS_FEATURES_NV = 1000326001,
// Provided by VK_NV_fragment_shading_rate_enums
VK_STRUCTURE_TYPE_PIPELINE_FRAGMENT_SHADING_RATE_ENUM_STATE_CREATE_INFO_NV = 1000326002,
// Provided by VK_NV_ray_tracing_motion_blur
VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_GEOMETRY_MOTION_TRIANGLES_DATA_NV = 1000327000,
// Provided by VK_NV_ray_tracing_motion_blur
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_MOTION_BLUR_FEATURES_NV = 1000327001,
// Provided by VK_NV_ray_tracing_motion_blur
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VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_MOTION_INFO_NV = 1000327002,
// Provided by VK_EXT_mesh_shader
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MESH_SHADER_FEATURES_EXT = 1000328000,
// Provided by VK_EXT_mesh_shader
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MESH_SHADER_PROPERTIES_EXT = 1000328001,
// Provided by VK_EXT_ycbcr_2plane_444_formats
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_YCBCR_2_PLANE_444_FORMATS_FEATURES_EXT = 1000330000,
// Provided by VK_EXT_fragment_density_map2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_2_FEATURES_EXT = 1000332000,
// Provided by VK_EXT_fragment_density_map2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_2_PROPERTIES_EXT = 1000338001,
// Provided by VK_QCOM_rotated_copy_commands
VK_STRUCTURE_TYPE_COPY_COMMAND_TRANSFORM_INFO_QCOM = 1000333000,
// Provided by VK_KHR_workgroup_memory_explicit_layout
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_WORKGROUP_MEMORY_EXPLICIT_LAYOUT_FEATURES_KHR = 1000336000,
// Provided by VK_EXT_image_compression_control
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_COMPRESSION_CONTROL_FEATURES_EXT = 1000338000,
// Provided by VK_EXT_image_compression_control
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_COMPRESSION_CONTROL_EXT = 1000338001,
// Provided by VK_EXT_image_compression_control
VK_STRUCTURE_TYPE_IMAGE_COMPRESSION_CONTROL_EXT = 1000338004,
// Provided by VK_EXT_image_compression_control
VK_STRUCTURE_TYPE_IMAGE_COMPRESSION_PROPERTIES_EXT = 1000338004,
// Provided by VK_EXT_attachment_feedback_loop_layout
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ATTACHMENT_FEEDBACK_LOOP_LAYOUT_FEATURES_EXT = 1000339000,
// Provided by VK_EXT_4444_formats
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_4444_FORMATS_FEATURES_EXT = 1000340000,
// Provided by VK_EXT_device_fault
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FAULT_FEATURES_EXT = 1000341000,
// Provided by VK_EXT_device_fault
VK_STRUCTURE_TYPE_DEVICE_FAULT_COUNTS_EXT = 1000341001,
// Provided by VK_EXT_device_fault
VK_STRUCTURE_TYPE_DEVICE_FAULT_INFO_EXT = 1000341002,
// Provided by VK_EXT_rgba10x6_formats
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RGBA10X6_FORMATS_FEATURES_EXT = 1000344000,
// Provided by VK_EXT_directfb_surface
VK_STRUCTURE_TYPE_DIRECTFB_SURFACE_CREATE_INFO_EXT = 1000346000,
// Provided by VK_EXT_vertex_input_dynamic_state
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VERTEX_INPUT_DYNAMIC_STATE_FEATURES_EXT = 1000352000,
// Provided by VK_EXT_vertex_input_dynamic_state
VK_STRUCTURE_TYPE_VERTEX_INPUT_BINDING_DESCRIPTION_2_EXT = 1000352001,
// Provided by VK_EXT_vertex_input_dynamic_state
VK_STRUCTURE_TYPE_VERTEX_INPUT_ATTRIBUTE_DESCRIPTION_2_EXT = 1000352002,
// Provided by VK_EXT_physical_device_drm
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DRM_PROPERTIES_EXT = 1000353000,
VK_STRUCTURE_TYPE_MEMORY_GET_REMOTE_ADDRESS_INFO_NV = 1000371000,
// Provided by VK_NV_external_memory_rdma
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_MEMORY_RDMA_FEATURES_NV = 1000371001,
// Provided by VK_EXT_pipeline_properties
VK_STRUCTURE_TYPE_PIPELINE_PROPERTIES_IDENTIFIER_EXT = 1000372000,
// Provided by VK_EXT_pipeline_properties
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_PROPERTIES_FEATURES_EXT = 1000372001,
// Provided by VK_EXT_frame_boundary
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAME_BOUNDARY_FEATURES_EXT = 1000375000,
// Provided by VK_EXT_frame_boundary
VK_STRUCTURE_TYPE_FRAME_BOUNDARY_EXT = 1000375001,
// Provided by VK_EXT_multisampled_render_to_single_sampled
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_FEATURES_EXT = 1000376000,
// Provided by VK_EXT_multisampled_render_to_single_sampled
VK_STRUCTURE_TYPE_SUBPASS_RESOLVE_PERFORMANCE_QUERY_EXT = 1000376001,
// Provided by VK_EXT_multisampled_render_to_single_sampled
VK_STRUCTURE_TYPE_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_INFO_EXT = 1000376002,
// Provided by VK_EXT_extended_dynamic_state2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTENDED_DYNAMIC_STATE_2_FEATURES_EXT = 1000377000,
// Provided by VK_QNX_screen_surface
VK_STRUCTURE_TYPE_SCREEN_SURFACE_CREATE_INFO_QNX = 1000378000,
// Provided by VK_EXT_color_write_enable
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COLOR_WRITE_ENABLE_FEATURES_EXT = 1000381000,
// Provided by VK_EXT_color_write_enable
VK_STRUCTURE_TYPE_PIPELINE_COLOR_WRITE_CREATE_INFO_EXT = 1000381001,
// Provided by VK_EXT_primitives_generated_query
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRIMITIVES_GENERATED_QUERY_FEATURES_EXT = 1000382000,
// Provided by VK_KHR_ray_tracing_maintenance1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_MAINTENANCE_1_FEATURES_KHR = 1000386000,
// Provided by VK_EXT_image_view_min_lod
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_VIEW_MIN_LOD_FEATURES_EXT = 1000391000,
// Provided by VK_EXT_image_view_min_lod
VK_STRUCTURE_TYPE_IMAGE_VIEW_MIN_LOD_CREATE_INFO_EXT = 1000391001,
// Provided by VK_EXT_multi_draw
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTI_DRAW_FEATURES_EXT = 1000392000,
// Provided by VK_EXT_multi_draw
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTI_DRAW_PROPERTIES_EXT = 1000392001,
// Provided by VK_EXT_image_2d_view_of_3d
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_2D_VIEW_OF_3D_FEATURES_EXT = 1000393000,
// Provided by VK_EXT_shader_tile_image
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_TILE_IMAGE_FEATURES_EXT = 1000395000,
// Provided by VK_EXT_shader_tile_image
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_TILE_IMAGE_PROPERTIES_EXT = 1000395001,
// Provided by VK_KHR_opacity_micromap
VK_STRUCTURE_TYPE_MICROMAP_BUILD_INFO_EXT = 1000396000,
VK_STRUCTURE_TYPE_MICROMAP_VERSION_INFO_EXT = 1000396001,
// Provided by VK_EXT_opacity_micromap
VK_STRUCTURE_TYPE_COPY_MICROMAP_INFO_EXT = 1000396002,
// Provided by VK_EXT_opacity_micromap
VK_STRUCTURE_TYPE_COPY_MICROMAP_TO_MEMORY_INFO_EXT = 1000396003,
// Provided by VK_EXT_opacity_micromap
VK_STRUCTURE_TYPE_COPY_MEMORY_TO_MICROMAP_INFO_EXT = 1000396004,
// Provided by VK_EXT_opacity_micromap
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_OPACITY_MICROMAP_FEATURES_EXT = 1000396005,
// Provided by VK_EXT_opacity_micromap
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_OPACITY_MICROMAP_PROPERTIES_EXT = 1000396006,
// Provided by VK_EXT_opacity_micromap
VK_STRUCTURE_TYPE_MICROMAP_CREATE_INFO_EXT = 1000396007,
// Provided by VK_EXT_opacity_micromap
VK_STRUCTURE_TYPE_MICROMAP_BUILD_SIZES_INFO_EXT = 1000396008,
// Provided by VK_EXT_opacity_micromap

#ifdef VK_ENABLE_BETA_EXTENSIONS
  // Provided by VK_NV_displacement_micromap
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DISPLACEMENT_MICROMAP_FEATURES_NV = 1000397000,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
  // Provided by VK_NV_displacement_micromap
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DISPLACEMENT_MICROMAP_PROPERTIES_NV = 1000397001,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
  // Provided by VK_NV_displacement_micromap
  VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_TRIANGLES_DISPLACEMENT_MICROMAP_NV = 1000397002,
#endif

// Provided by VK_HUAWEI_cluster_culling_shader
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CLUSTER_CULLING_SHADER_FEATURES_HUAWEI = 1000404000,
// Provided by VK_HUAWEI_cluster_culling_shader
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CLUSTER_CULLING_SHADER_PROPERTIES_HUAWEI = 1000404001,
// Provided by VK_EXT_border_color_swizzle
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BORDER_COLOR_SWIZZLE_FEATURES_EXT = 1000411000,
// Provided by VK_EXT_border_color_swizzle
VK_STRUCTURE_TYPE_SAMPLER_BORDER_COLOR_COMPONENT_MAPPING_CREATE_INFO_EXT = 1000411001,
// Provided by VK_EXT_pageable_device_local_memory
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PAGEABLE_DEVICE_LOCAL_MEMORY_FEATURES_EXT = 1000412000,
// Provided by VK_ARM_shader_core_properties
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CORE_PROPERTIES_ARM = 1000415000,
// Provided by VK_EXT_image_sliced_view_of_3d
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_SLICED_VIEW_OF_3D_FEATURES_EXT = 1000418000,
// Provided by VK_EXT_image_sliced_view_of_3d
VK_STRUCTURE_TYPE_IMAGE_VIEW_SLICED_CREATE_INFO_EXT = 1000418001,
// Provided by VK_VALVE_descriptor_set_host_mapping
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_SET_HOST_MAPPING_FEATURES_VALVE = 1000420000,
// Provided by VK_VALVE_descriptor_set_host_mapping
VK_STRUCTURE_TYPE_DESCRIPTOR_SET_BINDING_REFERENCE_VALVE = 1000420001,
// Provided by VK_VALVE_descriptor_set_host_mapping
VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_HOST_MAPPING_INFO_VALVE = 1000420002,
// Provided by VK_EXT_depth_clamp_zero_one
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_CLAMP_ZERO_ONE_FEATURES_EXT = 1000421000,
// Provided by VK_EXT_non_seamless_cube_map
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_NON_SEAMLESS_CUBE_MAP_FEATURES_EXT = 1000422000,
// Provided by VK_QCOM_fragment_density_map_offset
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_OFFSET_FEATURES_QCOM = 1000425000,
// Provided by VK_QCOM_fragment_density_map_offset
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_OFFSET_PROPERTIES_QCOM = 1000425001,
// Provided by VK_QCOM_fragment_density_map_offset
VK_STRUCTURE_TYPE_SUBPASS_FRAGMENT_DENSITY_MAP_OFFSET_END_INFO_QCOM = 1000425002,
// Provided by VK_NV_copy_memory_indirect
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COPY_MEMORY_INDIRECT_FEATURES_NV = 1000426000,
// Provided by VK_NV_copy_memory_indirect
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COPY_MEMORY_INDIRECT_PROPERTIES_NV = 1000426001,
// Provided by VK_NV_memory_decompression
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_DECOMPRESSION_FEATURES_NV = 1000427000,
// Provided by VK_NV_memory_decompression
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_DECOMPRESSION_PROPERTIES_NV = 1000427001,
// Provided by VK_NV_device_generated_commands_compute
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEVICE_GENERATED_COMMANDS_COMPUTE_FEATURES_NV = 1000428000,
// Provided by VK_NV_device_generated_commands_compute
VK_STRUCTURE_TYPE_COMPUTE_PIPELINE_INDIRECT_BUFFER_INFO_NV = 1000428001,
// Provided by VK_NV_device_generated_commands_compute
VK_STRUCTURE_TYPE_PIPELINE_INDIRECT_DEVICE_ADDRESS_INFO_NV = 1000428002,
// Provided by VK_NV_linear_color_attachment
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_LINEAR_COLOR_ATTACHMENT_FEATURES_NV = 1000430000,
// Provided by VK_EXT_image_compression_control_swapchain
VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_ACQUIRE_UNMODIFIED_EXT = 1000453000,
// Provided by VK_EXT_extended_dynamic_state3
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VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTENDED_DYNAMIC_STATE_3_FEATURES_EXT = 1000455000,
// Provided by VK_EXT_extended_dynamic_state3
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTENDED_DYNAMIC_STATE_3_PROPERTIES_EXT = 1000455001,
// Provided by VK_EXT_subpass_merge_feedback
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBPASS_MERGE_FEEDBACK_FEATURES_EXT = 1000458000,
// Provided by VK_EXT_subpass_merge_feedback
VK_STRUCTURE_TYPE_RENDER_PASS_CREATION_CONTROL_EXT = 1000458001,
// Provided by VK_EXT_subpass_merge_feedback
VK_STRUCTURE_TYPE_RENDER_PASS_CREATION_FEEDBACK_CREATE_INFO_EXT = 1000458002,
// Provided by VK_EXT_subpass_merge_feedback
VK_STRUCTURE_TYPE_RENDER_PASS_SUBPASS_FEEDBACK_CREATE_INFO_EXT = 1000458003,
// Provided by VK_LUNARG_direct_driver_loading
VK_STRUCTURE_TYPE_DIRECT_DRIVER_LOADING_INFO_LUNARG = 1000459000,
// Provided by VK_LUNARG_direct_driver_loading
VK_STRUCTURE_TYPE_DIRECT_DRIVER_LOADING_LIST_LUNARG = 1000459001,
// Provided by VK_EXT_shader_module_identifier
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_MODULE_IDENTIFIER_FEATURES_EXT = 1000462000,
// Provided by VK_EXT_shader_module_identifier
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_MODULE_IDENTIFIER_PROPERTIES_EXT = 1000462001,
// Provided by VK_EXT_shader_module_identifier
VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_MODULE_IDENTIFIER_CREATE_INFO_EXT = 1000462002,
// Provided by VK_EXT_shader_module_identifier
VK_STRUCTURE_TYPE_SHADER_MODULE_IDENTIFIER_EXT = 1000462003,
// Provided by VK_EXT_rasterization_order_attachment_access
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_FEATURES_EXT = 1000342000,
// Provided by VK_NV_optical_flow
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_OPTICAL_FLOW_FEATURES_NV = 1000464000,
// Provided by VK_NV_optical_flow
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_OPTICAL_FLOW_PROPERTIES_NV = 1000464001,
// Provided by VK_NV_optical_flow
VK_STRUCTURE_TYPE_OPTICAL_FLOW_IMAGE_FORMAT_INFO_NV = 1000464002,
// Provided by VK_NV_optical_flow
VK_STRUCTURE_TYPE_OPTICAL_FLOW_IMAGE_FORMAT_PROPERTIES_NV = 1000464003,
// Provided by VK_NV_optical_flow
VK_STRUCTURE_TYPE_OPTICAL_FLOW_SESSION_CREATE_INFO_NV = 1000464004,
// Provided by VK_NV_optical_flow
VK_STRUCTURE_TYPE_OPTICAL_FLOW_EXECUTE_INFO_NV = 1000464005,
// Provided by VK_NV_optical_flow
VK_STRUCTURE_TYPE_OPTICAL_FLOW_SESSION_CREATE_PRIVATE_DATA_INFO_NV = 1000464006,
// Provided by VK_EXT_legacy_dithering
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_LEGACY_DITHERING_FEATURES_EXT = 1000465000,
// Provided by VK_EXT_pipeline_protected_access
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_PROTECTED_ACCESS_FEATURES_EXT = 1000466000.
1000466000,
// Provided by VK_KHR_maintenance5
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_5_FEATURES_KHR = 1000470000,
// Provided by VK_KHR_maintenance5
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_5_PROPERTIES_KHR = 1000470001,
// Provided by VK_KHR_maintenance5
  VK_STRUCTURE_TYPE_RENDERING_AREA_INFO_KHR = 1000470003,
// Provided by VK_KHR_maintenance5
  VK_STRUCTURE_TYPE_DEVICE_IMAGE_SUBRESOURCE_INFO_KHR = 1000470004,
// Provided by VK_KHR_maintenance5
  VK_STRUCTURE_TYPE_SUBRESOURCE_LAYOUT_2_KHR = 1000338002,
// Provided by VK_KHR_maintenance5
  VK_STRUCTURE_TYPE_IMAGE_SUBRESOURCE_2_KHR = 1000338003,
// Provided by VK_KHR_maintenance5
  VK_STRUCTURE_TYPE_PIPELINE_CREATE_FLAGS_2_CREATE_INFO_KHR = 1000470005,
// Provided by VK_KHR_maintenance5
  VK_STRUCTURE_TYPE_BUFFER_USAGE_FLAGS_2_CREATE_INFO_KHR = 1000470006,
// Provided by VK_KHR_ray_tracing_position_fetch
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_POSITION_FETCH_FEATURES_KHR = 1000481000,
// Provided by VK_EXT_shader_object
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_OBJECT_FEATURES_EXT = 1000482000,
// Provided by VK_EXT_shader_object
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_OBJECT_PROPERTIES_EXT = 1000482001,
// Provided by VK_EXT_shader_object
  VK_STRUCTURE_TYPE_SHADER_CREATE_INFO_EXT = 1000482002,
// Provided by VK_QCOM_tile_properties
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TILE_PROPERTIES_FEATURES_QCOM = 1000484000,
// Provided by VK_QCOM_tile_properties
  VK_STRUCTURE_TYPE_TILE_PROPERTIES_QCOM = 1000484001,
// Provided by VK_SEC_amigo_profiling
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_AMIGO_PROFILING_FEATURES_SEC = 1000485000,
// Provided by VK_SEC_amigo_profiling
  VK_STRUCTURE_TYPE_AMIGO_PROFILING_SUBMIT_INFO_SEC = 1000485001,
// Provided by VK_QCOM_multiview_per_view_viewports
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_PER_VIEW_VIEWPORTS_FEATURES_QCOM = 1000488000,
// Provided by VK_NV_ray_tracing_invocation_reorder
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_INVOCATION_REORDER_FEATURES_NV = 1000490000,
// Provided by VK_NV_ray_tracing_invocation_reorder
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_INVOCATION_REORDER_PROPERTIES_NV = 1000490001,
// Provided by VK_EXT_mutable_descriptor_type
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MUTABLE_DESCRIPTOR_TYPE_FEATURES_EXT = 1000351000,
// Provided by VK_EXT_mutable_descriptor_type
  VK_STRUCTURE_TYPE_MUTABLE_DESCRIPTOR_TYPE_CREATE_INFO_EXT = 1000351002,
// Provided by VK_ARM_shader_core_builtins
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CORE_BUILTINS_FEATURES_ARM = 1000497000,
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CORE_BUILTINS_PROPERTIES_ARM = 1000497001,
// Provided by VK_EXT_pipeline_library_group_handles
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_LIBRARY_GROUP_HANDLES_FEATURES_EXT = 1000498000,
// Provided by VK_EXT_dynamic_rendering_unused_attachments

VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DYNAMIC_RENDERING_UNUSED_ATTACHMENTS_FEATURES_EXT = 1000499000,
// Provided by VK_KHR_cooperative_matrix
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COOPERATIVE_MATRIX_FEATURES_KHR = 1000506000,
// Provided by VK_KHR_cooperative_matrix
VK_STRUCTURE_TYPE_COOPERATIVE_MATRIX_PROPERTIES_KHR = 1000506001,
// Provided by VK_KHR_cooperative_matrix
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COOPERATIVE_MATRIX_PROPERTIES_KHR = 1000506002,
// Provided by VK_QCOM_multiview_per_view_render_areas
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_PER_VIEW_RENDER_AREAS_FEATURES_QCOM = 1000510000,
// Provided by VK_QCOM_multiview_per_view_render_areas
VK_STRUCTURE_TYPE_MULTIVIEW_PER_VIEW_RENDER_AREAS_RENDER_PASS_BEGIN_INFO_QCOM = 1000510001,
// Provided by VK_QCOM_image_processing2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_PROCESSING_2_FEATURES_QCOM = 1000518000,
// Provided by VK_QCOM_image_processing2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_PROCESSING_2_PROPERTIES_QCOM = 1000518001,
// Provided by VK_QCOM_image_processing2
VK_STRUCTURE_TYPE_SAMPLER_BLOCK_MATCH_WINDOW_CREATE_INFO_QCOM = 1000518002,
// Provided by VK_QCOM_filter_cubic_weights
VK_STRUCTURE_TYPE_SAMPLER_CUBIC_WEIGHTS_CREATE_INFO_QCOM = 1000519000,
// Provided by VK_QCOM_filter_cubic_weights
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CUBIC_WEIGHTS_FEATURES_QCOM = 1000519001,
// Provided by VK_QCOM_filter_cubic_clamp
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CUBIC_CLAMP_FEATURES_QCOM = 1000521000,
// Provided by VK_EXT_attachment_feedback_loop_dynamic_state
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ATTACHMENT_FEEDBACK_LOOP_DYNAMIC_STATE_FEATURES_EXT = 1000524000,
// Provided by VK_QNX_external_memory_screen_buffer
VK_STRUCTURE_TYPE_SCREEN_BUFFER_PROPERTIES_QNX = 1000529000,
// Provided by VK_QNX_external_memory_screen_buffer
VK_STRUCTURE_TYPE_SCREEN_BUFFER_FORMAT_PROPERTIES_QNX = 1000529001,
// Provided by VK_QNX_external_memory_screen_buffer
VK_STRUCTURE_TYPE_IMPORT_SCREEN_BUFFER_INFO_QNX = 1000529002,
VK_STRUCTURE_TYPE_EXTERNAL_FORMAT_QNX = 1000529003,
    // Provided by VK_QNX_external_memory_screen_buffer
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_MEMORY_SCREEN_BUFFER_FEATURES_QNX = 1000529004,
    // Provided by VK_MSFT_layered_driver
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_LAYERED_DRIVER_PROPERTIES_MSFT = 1000530000,
    // Provided by VK_NV_descriptor_pool_overallocation
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_POOL_OVERALLOCATION_FEATURES_NV = 1000546000,
    // Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VARIABLE_POINTER_FEATURES = VK_STRUCTURE_TYPE_PHYSICALDEVICE_VARIABLE_POINTERFEATURES,
    // Provided by VK_VERSION_1_1
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_DRAW_PARAMETER_FEATURES = VK_STRUCTURE_TYPE_PHYSICALDEVICE_SHADERDRAWPARAMETERFEATURES,
    // Provided by VK_EXT_debug_report
VK_STRUCTURE_TYPE_DEBUG_REPORT_CREATE_INFO_EXT = VK_STRUCTURE_TYPE_DEBUGREPORT_CALLBACK_CREATE_INFO_EXT,
    // Provided by VK_KHR_dynamic_rendering
VK_STRUCTURE_TYPE_RENDERING_INFO_KHR = VK_STRUCTURE_TYPE_RENDERING_INFO,
    // Provided by VK_KHR_dynamic_rendering
VK_STRUCTURE_TYPE_RENDERING_ATTACHMENT_INFO_KHR = VK_STRUCTURE_TYPE_RENDERING_ATTACHMENT_INFO,
    // Provided by VK_KHR_dynamic_rendering
VK_STRUCTURE_TYPE_PIPELINE_RENDERING_CREATE_INFO_KHR = VK_STRUCTURE_TYPE_PIPELINE_RENDERING_CREATE_INFO,
    // Provided by VK_KHR_dynamic_rendering
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DYNAMIC_RENDERING_FEATURES_KHR = VK_STRUCTURE_TYPE_PHYSICALDEVICE_DYNAMIC_RENDERINGFEATURES,
    // Provided by VK_KHR_dynamic_rendering with VK_NV_framebuffer_mixed_samples
VK_STRUCTURE_TYPE_ATTACHMENT_SAMPLE_COUNT_INFO_NV = VK_STRUCTURE_TYPE_ATTACHMENT_SAMPLE_COUNT_INFO_AMD,
    // Provided by VK_KHR_multiview
VK_STRUCTURE_TYPE_RENDER_PASS_MULTIVIEW_CREATE_INFO_KHR = VK_STRUCTURE_TYPE_RENDER_PASS_MULTIVIEW_CREATE_INFO,
    // Provided by VK_KHR_multiview
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_FEATURES_KHR = VK_STRUCTURE_TYPE_PHYSICALDEVICE_MULTIVIEWFEATURES,
    // Provided by VK_KHR_multiview
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_PROPERTIES_KHR = VK_STRUCTURE_TYPE_PHYSICALDEVICE_MULTIVIEWPROPERTIES,
    // Provided by VK_KHR_get_physical_device_properties2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_PROPERTIES_2_KHR = VK_STRUCTURE_TYPE_PHYSICALDEVICE_MULTIVIEWPROPERTIES_2,
    // Provided by VK_KHR_get_physical_device_properties2
VK_STRUCTURE_TYPE_PHYSICALDEVICE_MULTIVIEWPROPERTIES_2_KHR = VK_STRUCTURE_TYPE_PHYSICALDEVICE_MULTIVIEWPROPERTIES_2,
VK_STRUCTURE_TYPE_FORMAT_PROPERTIES_2_KHR = VK_STRUCTURE_TYPE_FORMAT_PROPERTIES_2,
    // Provided by VK_KHR_get_physical_device_properties2
VK_STRUCTURE_TYPE_IMAGE_FORMAT_PROPERTIES_2_KHR =
    VK_STRUCTURE_TYPE_IMAGE_FORMAT_PROPERTIES_2,
    // Provided by VK_KHR_get_physical_device_properties2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_FORMAT_INFO_2_KHR =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_FORMAT_INFO_2,
    // Provided by VK_KHR_get_physical_device_properties2
VK_STRUCTURE_TYPE_QUEUE_FAMILY_PROPERTIES_2_KHR =
    VK_STRUCTURE_TYPE_QUEUE_FAMILY_PROPERTIES_2,
    // Provided by VK_KHR_get_physical_device_properties2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_PROPERTIES_2_KHR =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_PROPERTIES_2,
    // Provided by VK_KHR_get_physical_device_properties2
VK_STRUCTURE_TYPE_SPARSE_IMAGE_FORMAT_PROPERTIES_2_KHR =
    VK_STRUCTURE_TYPE_SPARSE_IMAGE_FORMAT_PROPERTIES_2,
    // Provided by VK_KHR_get_physical_device_properties2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SPARSE_IMAGE_FORMAT_INFO_2_KHR =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SPARSE_IMAGE_FORMAT_INFO_2,
    // Provided by VK_KHR_device_group
VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_FLAGS_INFO_KHR =
    VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_FLAGS_INFO,
    // Provided by VK_KHR_device_group
VK_STRUCTURE_TYPE_DEVICE_GROUP_RENDER_PASS_BEGIN_INFO_KHR =
    VK_STRUCTURE_TYPE_DEVICE_GROUP_RENDER_PASS_BEGIN_INFO,
    // Provided by VK_KHR_device_group
VK_STRUCTURE_TYPE_DEVICE_GROUP_COMMAND_BUFFER_BEGIN_INFO_KHR =
    VK_STRUCTURE_TYPE_DEVICE_GROUP_COMMAND_BUFFER_BEGIN_INFO,
    // Provided by VK_KHR_device_group
VK_STRUCTURE_TYPE_DEVICE_GROUP_SUBMIT_INFO_KHR =
    VK_STRUCTURE_TYPEDEVICE GROUP_SUBMIT_INFO,
    // Provided by VK_KHR_device_group
VK_STRUCTURE_TYPE_DEVICE_GROUP_BIND_SPARSE_INFO_KHR =
    VK_STRUCTURE_TYPE_DEVICE_GROUP_BIND_SPARSE_INFO,
    // Provided by VK_KHR_bind_memory2 with VK_KHR_device_group
VK_STRUCTURE_TYPE_BIND_BUFFER_MEMORY_DEVICE_GROUP_INFO_KHR =
    VK_STRUCTURE_TYPE_BIND_BUFFER_MEMORY_DEVICE_GROUP_INFO,
    // Provided by VK_KHR_bind_memory2 with VK_KHR_device_group
VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_DEVICE_GROUP_INFO_KHR =
    VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORYDEVICE_GROUP_INFO,
    // Provided by VK_EXT_texture_compression_astc_hdr
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXTURE_COMPRESSION_ASTC_HDR_FEATURES_EXT =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXTURE_COMPRESSION_ASTC_HDR_FEATURES,
    // Provided by VK_KHR_device_group_creation
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GROUP_PROPERTIES_KHR =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GROUP_PROPERTIES,
    // Provided by VK_KHR_device_group_creation
VK_STRUCTURE_TYPE_DEVICE_GROUP_DEVICE_CREATE_INFO_KHR =
    VK_STRUCTURE_TYPEDEVICE_GROUP_DEVICE_CREATE_INFO,
    // Provided by VK_KHR_external_memory_capabilities
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_IMAGE_FORMAT_INFO_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_IMAGE_FORMAT_INFO,
// Provided by VK_KHR_external_memory_capabilities
VK_STRUCTURE_TYPE_EXTERNAL_IMAGE_FORMAT_PROPERTIES_KHR =
VK_STRUCTURE_TYPE_EXTERNAL_IMAGE_FORMAT_PROPERTIES,
// Provided by VK_KHR_external_memory_capabilities
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_BUFFER_INFO_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_BUFFER_INFO,
// Provided by VK_KHR_external_memory_capabilities
VK_STRUCTURE_TYPE_EXTERNAL_BUFFER_PROPERTIES_KHR =
VK_STRUCTURE_TYPE_EXTERNAL_BUFFER_PROPERTIES,
// Provided by VK_KHR_external_fence_capabilities,
VK_KHR_external_memory_capabilities, VK_KHR_external_semaphore_capabilities
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ID_PROPERTIES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ID_PROPERTIES,
// Provided by VK_KHR_external_memory
VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_BUFFER_CREATE_INFO_KHR =
VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_BUFFER_CREATE_INFO,
// Provided by VK_KHR External_memory
VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_IMAGE_CREATE_INFO_KHR =
VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_IMAGE_CREATE_INFO,
// Provided by VK_KHR_external_memory
VK_STRUCTURE_TYPE_EXPORT_MEMORY_ALLOCATE_INFO_KHR =
VK_STRUCTURE_TYPE_EXPORT_MEMORY_ALLOCATE_INFO,
// Provided by VK_KHR_external_semaphore_capabilities
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_SEMAPHORE_INFO_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_SEMAPHORE_INFO,
// Provided by VK_KHR_external_semaphore_capabilities
VK_STRUCTURE_TYPE_EXTERNAL_SEMAPHORE_PROPERTIES_KHR =
VK_STRUCTURE_TYPE_EXTERNAL_SEMAPHORE_PROPERTIES,
// Provided by VK_KHR_external_semaphore
VK_STRUCTURE_TYPE_EXPORT_SEMAPHORE_CREATE_INFO_KHR =
VK_STRUCTURE_TYPE_EXPORT_SEMAPHORE_CREATE_INFO,
// Provided by VK_KHR_shader_float16_int8
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_FLOAT16_INT8_FEATURES_KHR =
VK_STRUCTURE_TYPE_PHYSICALDEVICE_SHADER_FLOAT16_INT8_FEATURES,
// Provided by VK_KHR_shader_float16_int8
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FLOAT16_INT8_FEATURES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FLOAT16_INT8_FEATURES,
// Provided by VK_KHR_16bit_storage
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_16BIT_STORAGE_FEATURES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_16BIT_STORAGE_FEATURES,
// Provided by VK_KHR_descriptor_update_template
VK_STRUCTURE_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_CREATE_INFO_KHR =
VK_STRUCTURE_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_CREATE_INFO,
// Provided by VK_KHR_imageless_framebuffer
VK_STRUCTURE_TYPE_SURFACE_CAPABILITIES2_EXT =
VK_STRUCTURE_TYPE_SURFACE_CAPABILITIES2_EXT,
// Provided by VK_KHR_imageless_framebuffer
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGELESS_FRAMEBUFFER_FEATURES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGELESS_FRAMEBUFFER_FEATURES,
// Provided by VK_KHR_variable_pointers
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VARIABLE_POINTER_FEATURES_KHR = VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VARIABLE_POINTERS_FEATURES_KHR,
// Provided by VK_KHR_dedicated_allocation
VK_STRUCTURE_TYPE_MEMORY_DEDICATED_REQUIREMENTS_KHR = VK_STRUCTURE_TYPE_MEMORY_DEDICATED_REQUIREMENTS,
// Provided by VK_KHR_dedicated_allocation
VK_STRUCTURE_TYPE_MEMORY_DEDICATED_ALLOCATE_INFO_KHR = VK_STRUCTURE_TYPE_MEMORY_DEDICATED_ALLOCATE_INFO,
// Provided by VK_EXT_sampler_filter_minmax
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SAMPLER_FILTER_MINMAX_PROPERTIES_EXT = VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SAMPLER_FILTER_MINMAX_PROPERTIES,
// Provided by VK_EXT_sampler_filter_minmax
VK_STRUCTURE_TYPE_SAMPLER_REDUCTION_MODE_CREATE_INFO_EXT = VK_STRUCTURE_TYPE_SAMPLER_REDUCTION_MODE_CREATE_INFO,
// Provided by VK_EXT_inline_uniform_block
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INLINE_UNIFORM_BLOCK_FEATURES_EXT = VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INLINE_UNIFORM_BLOCK_FEATURES,
// Provided by VK_EXT_inline_uniform_block
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INLINE_UNIFORM_BLOCK_PROPERTIES_EXT = VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INLINE_UNIFORM_BLOCK_PROPERTIES,
// Provided by VK_EXT_inline_uniform_block
VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET_INLINE_UNIFORM_BLOCK_EXT = VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET_INLINE_UNIFORM_BLOCK,
// Provided by VK_EXT_inline_uniform_block
VK_STRUCTURE_TYPE_DESCRIPTOR_POOL_INLINE_UNIFORM_BLOCK_CREATE_INFO_EXT = VK_STRUCTURE_TYPE_DESCRIPTOR_POOL_INLINE_UNIFORM_BLOCK_CREATE_INFO,
// Provided by VK_KHR_get_memory_requirements2
VK_STRUCTURE_TYPE_BUFFER_MEMORY_REQUIREMENTS_INFO_2_KHR = VK_STRUCTURE_TYPE_BUFFER_MEMORY_REQUIREMENTS_INFO_2,
// Provided by VK_KHR_get_memory_requirements2
VK_STRUCTURE_TYPE_IMAGE_MEMORY_REQUIREMENTS_INFO_2_KHR = VK_STRUCTURE_TYPE_IMAGE_MEMORY_REQUIREMENTS_INFO_2,
// Provided by VK_KHR_get_memory_requirements2
VK_STRUCTURE_TYPE_IMAGE_SPARSE_MEMORY_REQUIREMENTS_INFO_2_KHR = VK_STRUCTURE_TYPE_IMAGE_SPARSE_MEMORY_REQUIREMENTS_INFO_2,
// Provided by VK_KHR_get_memory_requirements2
VK_STRUCTURE_TYPE_MEMORY_REQUIREMENTS_2_KHR = VK_STRUCTURE_TYPE_MEMORY_REQUIREMENTS_2,
// Provided by VK_KHR_get_memory_requirements2
VK_STRUCTURE_TYPE_SPARSE_IMAGE_MEMORY_REQUIREMENTS_2_KHR = VK_STRUCTURE_TYPE_SPARSE_IMAGE_MEMORY_REQUIREMENTS_2,
// Provided by VK_KHR_image_format_list
VK_STRUCTURE_TYPE_IMAGE_FORMAT_LIST_CREATE_INFO_KHR = VK_STRUCTURE_TYPE_IMAGE_FORMAT_LIST_CREATE_INFO,
// Provided by VK_KHR_sampler_ycbcr_conversion
VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_CREATE_INFO_KHR = VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_CREATE_INFO,
// Provided by VK_KHR_sampler_ycbcr_conversion
VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_INFO_KHR = VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_INFO,
VK_STRUCTURE_TYPE_BIND_IMAGE_PLANE_MEMORY_INFO_KHR

VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_INFO_KHR

VK_STRUCTURE_TYPE_BIND_BUFFER_MEMORY_INFO_KHR

VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_BINDING_FLAGS_CREATE_INFO_EXT

VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_BINDING_FLAGS_CREATE_INFO_KHR

VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_SUPPORT_KHR

VK_STRUCTURE_TYPE_DESCRIPTOR_SET_VARIABLE_DESCRIPTOR_COUNT_ALLOCATE_INFO_EXT

VK_STRUCTURE_TYPE_DESCRIPTOR_SET_VARIABLE_DESCRIPTOR_COUNT_LAYOUT_SUPPORT_EXT

VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_3_PROPERTIES_KHR

VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_8BIT_STORAGE_FEATURES_KHR

VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ATOMIC_INT64_FEATURES_KHR

VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_SUBGROUP_EXTENDED_TYPES_FEATURES_KHR
// Provided by VK_EXT_pipeline_creation_feedback
VK_STRUCTURE_TYPE_PIPELINE_CREATION_FEEDBACK_CREATE_INFO_EXT =
VK_STRUCTURE_TYPE_PIPELINE_CREATION_FEEDBACK_CREATE_INFO,
// Provided by VK_KHR_driver_properties
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DRIVER_PROPERTIES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DRIVER_PROPERTIES,
// Provided by VK_KHR_shader_float_controls
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FLOAT CONTROLS_PROPERTIES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FLOAT CONTROLS_PROPERTIES,
// Provided by VK_KHR_depth_stencil_resolve
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_STENCIL_RESOLVE_PROPERTIES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_STENCIL_RESOLVE_PROPERTIES,
// Provided by VK_KHR_depth_stencil_resolve
VK_STRUCTURE_TYPE_SUBPASS_DESCRIPTION_DEPTH_STENCIL_RESOLVE_KHR =
VK_STRUCTURE_TYPE_SUBPASS_DESCRIPTION_DEPTH_STENCIL_RESOLVE,
// Provided by VK_NV_fragment_shader_barycentric
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADER_BARYCENTRIC_FEATURES_NV =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADER_BARYCENTRIC_FEATURES_KHR,
// Provided by VK_KHR_timeline_semaphore
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TIMELINE_SEMAPHORE_FEATURES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TIMELINE_SEMAPHORE_FEATURES,
// Provided by VK_KHR_timeline_semaphore
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TIMELINE_SEMAPHORE_PROPERTIES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL DEVICE_TIMELINE_SEMAPHORE_PROPERTIES,
// Provided by VK_KHR_timeline_semaphore
VK_STRUCTURE_TYPE_SEMAPHORE_TYPE_CREATE_INFO_KHR =
VK_STRUCTURE_TYPE_SEMAPHORE_TYPE_CREATE_INFO,
// Provided by VK_KHR_timeline_semaphore
VK_STRUCTURE_TYPE_TIMELINE_SEMAPHORE_SUBMIT_INFO_KHR =
VK_STRUCTURE_TYPE_TIMELINE_SEMAPHORE_SUBMIT_INFO,
// Provided by VK_KHR_timeline_semaphore
VK_STRUCTURE_TYPE_SEMAPHORE_WAIT_INFO_KHR = VK_STRUCTURE_TYPE_SEMAPHORE_WAIT_INFO,
// Provided by VK_KHR_timeline_semaphore
VK_STRUCTURE_TYPE_SEMAPHORE_SIGNAL_INFO_KHR =
VK_STRUCTURE_TYPE_SEMAPHORE_SIGNAL_INFO,
// Provided by VK_INTEL_performance_query
VK_STRUCTURE_TYPE_QUERY_POOL_CREATE_INFO_INTEL =
VK_STRUCTURE_TYPE_QUERY_POOL_PERFORMANCE_QUERY_CREATE_INFO_INTEL,
// Provided by VK_KHR_vulkan_memory_model
VK_STRUCTURE_TYPE_PHYSICAL DEVICE_VULKAN_MEMORY_MODEL_FEATURES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL DEVICE_VULKAN_MEMORY_MODEL_FEATURES,
// Provided by VK_KHR_shader_terminate_invocation
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_TERMINATE_INVOCATION_FEATURES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL DEVICE_SHADER_TERMINATE_INVOCATION_FEATURES,
// Provided by VK_EXT_scalar_block_layout
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SCALAR BLOCK_LAYOUT_FEATURES_EXT =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SCALAR BLOCK_LAYOUT_FEATURES,
// Provided by VK_EXT_subgroup_size_control
VK_STRUCTURE_TYPE_PHYSICAL DEVICE_SUBGROUP_SIZE_CONTROL_PROPERTIES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL DEVICE_SUBGROUP_SIZE_CONTROL_PROPERTIES,
VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_REQUIRED_SUBGROUP_SIZE_CREATE_INFO_EXT =
VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_REQUIRED_SUBGROUP_SIZE_CREATE_INFO,
// Provided by VK_EXT_subgroup_size_control
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBGROUP_SIZE_CONTROL_FEATURES_EXT =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBGROUP_SIZE_CONTROL_FEATURES,
// Provided by VK_KHR_separate_depthStencil_layouts
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SEPARATE_DEPTH_STENCIL_LAYERS_FEATURES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SEPARATE_DEPTH_STENCIL_LAYERS_FEATURES,
// Provided by VK_KHR_separate_depthStencil_layouts
VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_STENCIL_LAYOUT_KHR =
VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_STENCIL_LAYOUT,
// Provided by VK_KHR_separate_depthStencil_layouts
VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_STENCIL_LAYOUT_KHR =
VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_STENCIL_LAYOUT,
// Provided by VK_KHR_uniform_buffer_standard_layout
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_UNIFORM_BUFFER_STANDARD_LAYOUT_FEATURES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_UNIFORM_BUFFER_STANDARD_LAYOUT_FEATURES,
// Provided by VK_KHR_buffer_device_address
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BUFFER_ADDRESS_FEATURES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BUFFER_ADDRESS_FEATURES,
// Provided by VK_KHR_buffer_device_address
VK_STRUCTURE_TYPE_BUFFER_OPAQUE_CAPTURE_ADDRESS_CREATE_INFO_KHR =
VK_STRUCTURE_TYPE_BUFFER_OPAQUE_CAPTURE_ADDRESS_CREATE_INFO,
// Provided by VK_KHR_buffer_device_address
VK_STRUCTURE_TYPE_MEMORY_OPAQUE_CAPTURE_ADDRESS_ALLOCATE_INFO_KHR =
VK_STRUCTURE_TYPE_MEMORY_OPAQUE_CAPTURE_ADDRESS_ALLOCATE_INFO,
// Provided by VK_KHR_buffer_device_address
VK_STRUCTURE_TYPE_DEVICE_MEMORY_OPAQUE_CAPTURE_ADDRESS_INFO_KHR =
VK_STRUCTURE_TYPE_DEVICE_MEMORY_OPAQUE_CAPTURE_ADDRESS_INFO,
// Provided by VK_KHR_host_query_reset
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_HOST_QUERY_RESET_FEATURES_EXT =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_HOST_QUERY_RESET_FEATURES,
// Provided by VK_KHR_shader_integer_dot_product
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_DEMOTE_TO_HELPER_INVOCATION_FEATURES_EXT =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_DEMOTE_TO_HELPER_INVOCATION_FEATURES,
// Provided by VK_KHR_shader_integer_dot_product
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_INTEGER_DOT_PRODUCT_FEATURES_KHR =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_INTEGER_DOT_PRODUCT_FEATURES,
    // Provided by VK_KHR_shader_integer_dot_product
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_INTEGER_DOT_PRODUCT_PROPERTIES_KHR =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_INTEGER_DOT_PRODUCT_PROPERTIES,
    // Provided by VK_KHR_shader_integer_dot_product
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXEL_BUFFER_ALIGNMENT_PROPERTIES_EXT =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXEL_BUFFER_ALIGNMENT_PROPERTIES,
    // Provided by VK_EXT_texel_buffer_alignment
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRIVATE_DATA_FEATURES_EXT =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRIVATE_DATA_FEATURES,
    // Provided by VK_EXT_private_data
VK_STRUCTURE_TYPE_DEVICE_PRIVATE_DATA_CREATE_INFO_EXT =
    VK_STRUCTURE_TYPE_DEVICE_PRIVATE_DATA_CREATE_INFO,
    // Provided by VK_EXT_private_data
VK_STRUCTURE_TYPE_PRIVATE_DATA_SLOT_CREATE_INFO_EXT =
    VK_STRUCTURE_TYPE_PRIVATE_DATA_SLOT_CREATE_INFO,
    // Provided by VK_EXT_private_data
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_CREATION_CACHE_CONTROL_FEATURES_EXT =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_CREATION_CACHE_CONTROL_FEATURES,
    // Provided by VK_EXT_pipeline_creation_cache_control
VK_STRUCTURE_TYPE_MEMORY_BARRIER_2_KHR =
    VK_STRUCTURE_TYPE_MEMORY_BARRIER_2,
    // Provided by VK_KHR_synchronization2
VK_STRUCTURE_TYPE_BUFFER_MEMORY_BARRIER_2_KHR =
    VK_STRUCTURE_TYPE_BUFFER_MEMORY_BARRIER_2,
    // Provided by VK_KHR_synchronization2
VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER_2_KHR =
    VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER_2,
    // Provided by VK_KHR_synchronization2
VK_STRUCTURE_TYPE_DEPENDENCY_INFO_KHR =
    VK_STRUCTURE_TYPE_DEPENDENCY_INFO,
    // Provided by VK_KHR_synchronization2
VK_STRUCTURE_TYPE_SUBMIT_INFO_2_KHR =
    VK_STRUCTURE_TYPE_SUBMIT_INFO_2,
    // Provided by VK_KHR_synchronization2
VK_STRUCTURE_TYPE_SEMAPHORE_SUBMIT_INFO_KHR =
    VK_STRUCTURE_TYPE_SEMAPHORE_SUBMIT_INFO,
    // Provided by VK_KHR_synchronization2
VK_STRUCTURE_TYPE_COMMAND_BUFFER_SUBMIT_INFO_KHR =
    VK_STRUCTURE_TYPE_COMMAND_BUFFER_SUBMIT_INFO,
    // Provided by VK_KHR_synchronization2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SYNCHRONIZATION_2_FEATURES_KHR =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SYNCHRONIZATION_2_FEATURES,
    // Provided by VK_KHR_zero_initialize_workgroup_memory
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ZERO_INITIALIZE_WORKGROUP_MEMORY_FEATURES_KHR =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ZERO_INITIALIZE_WORKGROUP_MEMORY_FEATURES,
    // Provided by VK_KHR_zero_initialize_workgroup_memory
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_ROBUSTNESS_FEATURES_EXT =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_ROBUSTNESS_FEATURES,
    // Provided by VK_EXT_image_robustness
VK_STRUCTURE_TYPE_COPY_BUFFER_INFO_2_KHR =
    VK_STRUCTURE_TYPE_COPY_BUFFER_INFO_2,
    // Provided by VK_KHR_copy_commands2
VK_STRUCTURE_TYPE_COPY_IMAGE_INFO_2_KHR =
    VK_STRUCTURE_TYPE_COPY_IMAGE_INFO_2,
    // Provided by VK_KHR_copy_commands2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_ROBUSTNESS_FEATURES =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_ROBUSTNESS_FEATURES,
    // Provided by VK_KHR_copy_commands2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_ROBUSTNESS_FEATURES_EXT =
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_ROBUSTNESS_FEATURES,
    // Provided by VK_KHR_copy_commands2
VK_STRUCTURE_TYPE_COPY_BUFFER_INFO_2_KHR =
    VK_STRUCTURE_TYPE_COPY_BUFFER_INFO_2,
    // Provided by VK_KHR_copy_commands2
VK_STRUCTURE_TYPE_COPY_IMAGE_INFO_2_KHR =
    VK_STRUCTURE_TYPE_COPY_IMAGE_INFO_2,
// Provided by VK_KHR_copy_commands2
VK_STRUCTURE_TYPE_COPY_BUFFER_TO_IMAGE_INFO_2_KHR =
VK_STRUCTURE_TYPE_COPY_BUFFER_TO_IMAGE_INFO_2,
// Provided by VK_KHR_copy_commands2
VK_STRUCTURE_TYPE_COPY_IMAGE_TO_BUFFER_INFO_2_KHR =
VK_STRUCTURE_TYPE_COPY_IMAGE_TO_BUFFER_INFO_2,
// Provided by VK_KHR_copy_commands2
VK_STRUCTURE_TYPE_BLIT_IMAGE_INFO_2_KHR = VK_STRUCTURE_TYPE_BLIT_IMAGE_INFO_2,
// Provided by VK_KHR_copy_commands2
VK_STRUCTURE_TYPE_RESOLVE_IMAGE_INFO_2_KHR =
VK_STRUCTURE_TYPE_RESOLVE_IMAGE_INFO_2,
// Provided by VK_KHR_copy_commands2
VK_STRUCTURE_TYPE_BUFFER_COPY_2_KHR = VK_STRUCTURE_TYPE_BUFFER_COPY_2,
// Provided by VK_KHR_copy_commands2
VK_STRUCTURE_TYPE_IMAGE_COPY_2_KHR = VK_STRUCTURE_TYPE_IMAGE_COPY_2,
// Provided by VK_KHR_copy_commands2
VK_STRUCTURE_TYPE_IMAGE_BLIT_2_KHR = VK_STRUCTURE_TYPE_IMAGE_BLIT_2,
// Provided by VK_KHR_copy_commands2
VK_STRUCTURE_TYPE_BUFFER_IMAGE_COPY_2_KHR = VK_STRUCTURE_TYPE_BUFFER_IMAGE_COPY_2,
// Provided by VK_KHR_copy_commands2
VK_STRUCTURE_TYPE_IMAGE_RESOLVE_2_KHR = VK_STRUCTURE_TYPE_IMAGE_RESOLVE_2,
// Provided by VK_EXT_image_compression_control
VK_STRUCTURE_TYPE_SUBRESOURCE_LAYOUT_2_EXT =
VK_STRUCTURE_TYPE_SUBRESOURCE_LAYOUT_2_KHR,
// Provided by VK_EXT_image_compression_control
VK_STRUCTURE_TYPE_IMAGE_SUBRESOURCE_2_EXT =
VK_STRUCTURE_TYPE_IMAGE_SUBRESOURCE_2_KHR,
// Provided by VK_ARM_rasterization_order_attachment_access
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_FEATURES_ARM =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_FEATURES_EXT,
// Provided by VK_VALVE_mutable_descriptor_type
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MUTABLE_DESCRIPTOR_TYPE_FEATURES_VALVE =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MUTABLE_DESCRIPTOR_TYPE_FEATURES_EXT,
// Provided by VK_VALVE_mutable_descriptor_type
VK_STRUCTURE_TYPE_MUTABLE_DESCRIPTOR_TYPE_CREATE_INFO_VALVE =
VK_STRUCTURE_TYPE_MUTABLE_DESCRIPTOR_TYPE_CREATE_INFO_EXT,
// Provided by VK_KHR_format_feature_flags2
VK_STRUCTURE_TYPE_FORMAT_PROPERTIES_3_KHR = VK_STRUCTURE_TYPE_FORMAT_PROPERTIES_3,
// Provided by VK_EXT_pipeline_properties
VK_STRUCTURE_TYPE_PIPELINE_INFO_EXT = VK_STRUCTURE_TYPE_PIPELINE_INFO_KHR,
// Provided by VK_EXT_global_priority_query
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GLOBAL_PRIORITY_QUERY_FEATURES_EXT =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GLOBAL_PRIORITY_QUERY_FEATURES_KHR,
// Provided by VK_KHR_maintenance4
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_4_FEATURES_KHR =
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_4_FEATURES,
3.12. API Name Aliases

A small number of APIs did not follow the naming conventions when initially defined. For consistency, when we discover an API name that violates the naming conventions, we rename it in the Specification, XML, and header files. For backwards compatibility, the original (incorrect) name is retained as a “typo alias”. The alias is deprecated and should not be used, but will be retained indefinitely.

Note

VK_STENCIL_FRONT_AND_BACK is an example of a typo alias. It was initially defined as part of VkStencilFaceFlagBits. Once the naming inconsistency was noticed, it was renamed to VK_STENCIL_FACE_FRONT_AND_BACK, and the old name was aliased to the correct name.
Chapter 4. Initialization

Before using Vulkan, an application must initialize it by loading the Vulkan commands, and creating a VkInstance object.

4.1. Command Function Pointers

Vulkan commands are not necessarily exposed by static linking on a platform. Commands to query function pointers for Vulkan commands are described below.

Note

When extensions are promoted or otherwise incorporated into another extension or Vulkan core version, command aliases may be included. Whilst the behavior of each command alias is identical, the behavior of retrieving each alias's function pointer is not. A function pointer for a given alias can only be retrieved if the extension or version that introduced that alias is supported and enabled, irrespective of whether any other alias is available.

Function pointers for all Vulkan commands can be obtained with the command:

```c
// Provided by VK_VERSION_1_0
PFN_vkVoidFunction vkGetInstanceProcAddr(
    VkInstance instance,
    const char* pName);
```

- `instance` is the instance that the function pointer will be compatible with, or NULL for commands not dependent on any instance.
- `pName` is the name of the command to obtain.

`vkGetInstanceProcAddr` itself is obtained in a platform- and loader- specific manner. Typically, the loader library will export this command as a function symbol, so applications can link against the loader library, or load it dynamically and look up the symbol using platform-specific APIs.

The table below defines the various use cases for `vkGetInstanceProcAddr` and expected return value (“fp” is “function pointer”) for each case. A valid returned function pointer (“fp”) must not be NULL.

The returned function pointer is of type `PFN_vkVoidFunction`, and must be cast to the type of the command being queried before use.

<table>
<thead>
<tr>
<th><code>instance</code></th>
<th><code>pName</code></th>
<th><code>return value</code></th>
</tr>
</thead>
<tbody>
<tr>
<td>*¹</td>
<td>NULL</td>
<td>undefined</td>
</tr>
<tr>
<td>invalid non-NULL instance</td>
<td>*¹</td>
<td>undefined</td>
</tr>
<tr>
<td>NULL</td>
<td><code>global command</code>²</td>
<td>fp</td>
</tr>
</tbody>
</table>
### Table 1. Function Pointer Return Values

<table>
<thead>
<tr>
<th>instance</th>
<th>pName</th>
<th>return value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NULL</td>
<td>vkGetInstanceProcAddr</td>
<td>fp&lt;sup&gt;5&lt;/sup&gt;</td>
</tr>
<tr>
<td>instance</td>
<td>vkGetInstanceProcAddr</td>
<td>fp</td>
</tr>
<tr>
<td>instance</td>
<td>core dispatchable command</td>
<td>fp&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>instance</td>
<td>enabled instance extension dispatchable command for instance</td>
<td>fp&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>instance</td>
<td>available device extension&lt;sup&gt;4&lt;/sup&gt; dispatchable command for instance</td>
<td>fp&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>any other case, not covered above</td>
<td>NULL</td>
<td>NULL</td>
</tr>
</tbody>
</table>

1

"*" means any representable value for the parameter (including valid values, invalid values, and NULL).

2

The global commands are: vkEnumerateInstanceVersion, vkEnumerateInstanceExtensionProperties, vkEnumerateInstanceLayerProperties, and vkCreateInstance. Dispatchable commands are all other commands which are not global.

3

The returned function pointer **must** only be called with a dispatchable object (the first parameter) that is instance or a child of instance, e.g. VkInstance, VkPhysicalDevice, VkDevice, VkQueue, or VkCommandBuffer.

4

An “available device extension” is a device extension supported by any physical device enumerated by instance.

5

Starting with Vulkan 1.2, vkGetInstanceProcAddr can resolve itself with a NULL instance pointer.

#### Valid Usage (Implicit)

- VUID-vkGetInstanceProcAddr-instance-parameter
  
  If instance is not NULL, instance **must** be a valid VkInstance handle

- VUID-vkGetInstanceProcAddr-pName-parameter
  
  pName **must** be a null-terminated UTF-8 string

In order to support systems with multiple Vulkan implementations, the function pointers returned by vkGetInstanceProcAddr **may** point to dispatch code that calls a different real implementation for different VkDevice objects or their child objects. The overhead of the internal dispatch for VkDevice
objects can be avoided by obtaining device-specific function pointers for any commands that use a device or device-child object as their dispatchable object. Such function pointers can be obtained with the command:

```c
// Provided by VK_VERSION_1_0
PFN_vkVoidFunction vkGetDeviceProcAddr(
    VkDevice device,
    const char* pName);
```

The table below defines the various use cases for `vkGetDeviceProcAddr` and expected return value (“fp” is “function pointer”) for each case. A valid returned function pointer (“fp”) must not be `NULL`.

The returned function pointer is of type `PFN_vkVoidFunction`, and must be cast to the type of the command being queried before use. The function pointer must only be called with a dispatchable object (the first parameter) that is `device` or a child of `device`.

### Table 2. `vkGetDeviceProcAddr` behavior

<table>
<thead>
<tr>
<th>device</th>
<th>pName</th>
<th>return value</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>NULL</code></td>
<td>*¹</td>
<td>undefined</td>
</tr>
<tr>
<td>invalid device</td>
<td>*¹</td>
<td>undefined</td>
</tr>
<tr>
<td>device</td>
<td><code>NULL</code></td>
<td>undefined</td>
</tr>
<tr>
<td>device</td>
<td>requested core version²</td>
<td><code>fp</code>³</td>
</tr>
<tr>
<td></td>
<td>device-level dispatchable</td>
<td></td>
</tr>
<tr>
<td></td>
<td>command³</td>
<td></td>
</tr>
<tr>
<td>device</td>
<td>enabled extension</td>
<td><code>fp</code>⁴</td>
</tr>
<tr>
<td></td>
<td>device-level dispatchable</td>
<td></td>
</tr>
<tr>
<td></td>
<td>command³</td>
<td></td>
</tr>
<tr>
<td>any other case, not covered above</td>
<td></td>
<td><code>NULL</code></td>
</tr>
</tbody>
</table>

1  
“*” means any representable value for the parameter (including valid values, invalid values, and `NULL`).

2  
Device-level commands which are part of the core version specified by `VkApplicationInfo::apiVersion` when creating the instance will always return a valid function pointer. If the `maintenance5` feature is enabled, core commands beyond that version which are supported by the implementation will return `NULL`, otherwise the implementation may either return `NULL` or a function pointer. If a function pointer is returned, it must not be called.

3  
In this function, device-level excludes all physical-device-level commands.

4  
The returned function pointer must only be called with a dispatchable object (the first
parameter) that is device or a child of device e.g. VkDevice, VkQueue, or VkCommandBuffer.

<table>
<thead>
<tr>
<th>Valid Usage (Implicit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• VUID-vkGetDeviceProcAddr-device-parameter</td>
</tr>
<tr>
<td>device must be a valid VkDevice handle</td>
</tr>
<tr>
<td>• VUID-vkGetDeviceProcAddr-pName-parameter</td>
</tr>
<tr>
<td>pName must be a null-terminated UTF-8 string</td>
</tr>
</tbody>
</table>

The definition ofPFN_vkVoidFunctionis:

```c
// Provided by VK_VERSION_1_0
typedef void (VKAPI_PTR *PFN_vkVoidFunction)(void);
```

This type is returned from command function pointer queries, and must be cast to an actual command function pointer before use.

### 4.1.1. Extending Physical Device Core Functionality

New core physical-device-level functionality can be used when the physical-device version is greater than or equal to the version of Vulkan that added the new functionality. The Vulkan version supported by a physical device can be obtained by calling vkGetPhysicalDeviceProperties.

### 4.1.2. Extending Physical Device From Device Extensions

When the VK_KHR_get_physical_device_properties2 extension is enabled, or when both the instance and the physical-device versions are at least 1.1, physical-device-level functionality of a device extension can be used with a physical device if the corresponding extension is enumerated by vkEnumerateDeviceExtensionProperties for that physical device, even before a logical device has been created.

To obtain a function pointer for a physical-device-level command from a device extension, an application can use vkGetInstanceProcAddr. This function pointer may point to dispatch code, which calls a different real implementation for different VkPhysicalDevice objects. Applications must not use a VkPhysicalDevice in any command added by an extension or core version that is not supported by that physical device.

Device extensions may define structures that can be added to the pNext chain of physical-device-level commands.

### 4.2. Instances

There is no global state in Vulkan and all per-application state is stored in a VkInstance object. Creating a VkInstance object initializes the Vulkan library and allows the application to pass information about itself to the implementation.
Instances are represented by VkInstance handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_HANDLE(VkInstance)
```

To query the version of instance-level functionality supported by the implementation, call:

```c
// Provided by VK_VERSION_1_1
VkResult vkEnumerateInstanceVersion(
    uint32_t* pApiVersion);
```

- `pApiVersion` is a pointer to a `uint32_t`, which is the version of Vulkan supported by instance-level functionality, encoded as described in Version Numbers.

**Note**
The intended behaviour of `vkEnumerateInstanceVersion` is that an implementation **should** not need to perform memory allocations and **should** unconditionally return `VK_SUCCESS`. The loader, and any enabled layers, **may** return `VK_ERROR_OUT_OF_HOST_MEMORY` in the case of a failed memory allocation.

### Valid Usage (Implicit)
- VUID-vkEnumerateInstanceVersion-pApiVersion-parameter `pApiVersion` must be a valid pointer to a `uint32_t` value

### Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`

To create an instance object, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkCreateInstance(
    const VkInstanceCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkInstance* pInstance);
```

- `pCreateInfo` is a pointer to a `VkInstanceCreateInfo` structure controlling creation of the instance.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
• `pInstance` points a `VkInstance` handle in which the resulting instance is returned.

`vkCreateInstance` verifies that the requested layers exist. If not, `vkCreateInstance` will return `VK_ERROR_LAYER_NOT_PRESENT`. Next, `vkCreateInstance` verifies that the requested extensions are supported (e.g., in the implementation or in any enabled instance layer) and if any requested extension is not supported, `vkCreateInstance` must return `VK_ERROR_EXTENSION_NOT_PRESENT`. After verifying and enabling the instance layers and extensions, the `VkInstance` object is created and returned to the application. If a requested extension is only supported by a layer, both the layer and the extension need to be specified at `vkCreateInstance` time for the creation to succeed.

### Valid Usage

- VUID-vkCreateInstance-ppEnabledExtensionNames-01388
  All required extensions for each extension in the `VkInstanceCreateInfo::ppEnabledExtensionNames` list must also be present in that list

### Valid Usage (Implicit)

- VUID-vkCreateInstance-pCreateInfo-parameter
  `pCreateInfo` must be a valid pointer to a valid `VkInstanceCreateInfo` structure
- VUID-vkCreateInstance-pAllocator-parameter
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure
- VUID-vkCreateInstance-pInstance-parameter
  `pInstance` must be a valid pointer to a `VkInstance` handle

### Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_INITIALIZATION_FAILED`
- `VK_ERROR_LAYER_NOT_PRESENT`
- `VK_ERROR_EXTENSION_NOT_PRESENT`
- `VK_ERROR_INCOMPATIBLE_DRIVER`

The `VkInstanceCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
```
typedef struct VkInstanceCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkInstanceCreateFlags flags;
    const VkApplicationInfo* pApplicationInfo;
    uint32_t enabledLayerCount;
    const char* const* ppEnabledLayerNames;
    uint32_t enabledExtensionCount;
    const char* const* ppEnabledExtensionNames;
} VkInstanceCreateInfo;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkInstanceCreateFlagBits` indicating the behavior of the instance.
- `pApplicationInfo` is `NULL` or a pointer to a `VkApplicationInfo` structure. If not `NULL`, this information helps implementations recognize behavior inherent to classes of applications. `VkApplicationInfo` is defined in detail below.
- `enabledLayerCount` is the number of global layers to enable.
- `ppEnabledLayerNames` is a pointer to an array of `enabledLayerCount` null-terminated UTF-8 strings containing the names of layers to enable for the created instance. The layers are loaded in the order they are listed in this array, with the first array element being the closest to the application, and the last array element being the closest to the driver. See the Layers section for further details.
- `enabledExtensionCount` is the number of global extensions to enable.
- `ppEnabledExtensionNames` is a pointer to an array of `enabledExtensionCount` null-terminated UTF-8 strings containing the names of extensions to enable.

To capture events that occur while creating or destroying an instance, an application can link a `VkDebugReportCallbackCreateInfoEXT` structure or a `VkDebugUtilsMessengerCreateInfoEXT` structure to the `pNext` element of the `VkInstanceCreateInfo` structure given to `vkCreateInstance`. This callback is only valid for the duration of the `vkCreateInstance` and the `vkDestroyInstance` call. Use `vkCreateDebugReportCallbackEXT` or `vkCreateDebugUtilsMessengerEXT` to create persistent callback objects.

An application can add additional drivers by including the `VkDirectDriverLoadingListLUNARG` struct to the `pNext` element of the `VkInstanceCreateInfo` structure given to `vkCreateInstance`.

**Note**

`VkDirectDriverLoadingListLUNARG` allows applications to ship drivers with themselves. Only drivers that are designed to work with it should be used, such as drivers that implement Vulkan in software or that implement Vulkan by translating it to a different API. Any driver that requires installation should not be used, such as hardware drivers.
Valid Usage

- VUID-VkInstanceCreateInfo-pNext-04925
  If the `pNext` chain of `VkInstanceCreateInfo` includes a `VkDebugReportCallbackCreateInfoEXT` structure, the list of enabled extensions in `ppEnabledExtensionNames` must contain `VK_EXT_debug_report`

- VUID-VkInstanceCreateInfo-pNext-04926
  If the `pNext` chain of `VkInstanceCreateInfo` includes a `VkDebugUtilsMessengerCreateInfoEXT` structure, the list of enabled extensions in `ppEnabledExtensionNames` must contain `VK_EXT_debug_utils`

- VUID-VkInstanceCreateInfo-pNext-06779
  If the `pNext` chain includes a `VkExportMetalObjectCreateInfoEXT` structure, its `exportObjectType` member must be either `VK_EXPORT_METAL_OBJECT_TYPE_METAL_DEVICE_BIT_EXT` or `VK.Export.Metal.Object.Type.Metal.Command.Queue.Bit_EXT`

- VUID-VkInstanceCreateInfo-flags-06559
  If `flags` has the `VK_INSTANCE_CREATE_ENUMERATE_PORTABILITY_BIT_KHR` bit set, the list of enabled extensions in `ppEnabledExtensionNames` must contain `VK_KHR_portability_enumeration`

- VUID-VkInstanceCreateInfo-pNext
  If the `pNext` chain of `VkInstanceCreateInfo` includes a `VkDirectDriverLoadingListLUNARG` structure, the list of enabled extensions in `ppEnabledExtensionNames` must contain `VK_LUNARG_direct_driver_loading`

Valid Usage (Implicit)

- VUID-VkInstanceCreateInfo-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_INSTANCE_CREATE_INFO`

- VUID-VkInstanceCreateInfo-pNext-pNext
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkDebugReportCallbackCreateInfoEXT`, `VkDebugUtilsMessengerCreateInfoEXT`, `VkDirectDriverLoadingListLUNARG`, `VkExportMetalObjectCreateInfoEXT`, `VkValidationFeaturesEXT`, or `VkValidationFlagsEXT`

- VUID-VkInstanceCreateInfo-sType-unique
  The `sType` value of each struct in the `pNext` chain must be unique, with the exception of structures of type `VkDebugUtilsMessengerCreateInfoEXT` or `VkExportMetalObjectCreateInfoEXT`

- VUID-VkInstanceCreateInfo-flags-parameter
  `flags` must be a valid combination of `VkInstanceCreateFlagBits` values

- VUID-VkInstanceCreateInfo-pApplicationInfo-parameter
  If `pApplicationInfo` is not `NULL`, `pApplicationInfo` must be a valid pointer to a valid `VkApplicationInfo` structure
• **VUID-VkInstanceCreateInfo-ppEnabledLayerNames-parameter**
  If `enabledLayerCount` is not 0, `ppEnabledLayerNames` must be a valid pointer to an array of `enabledLayerCount` null-terminated UTF-8 strings.

• **VUID-VkInstanceCreateInfo-ppEnabledExtensionNames-parameter**
  If `enabledExtensionCount` is not 0, `ppEnabledExtensionNames` must be a valid pointer to an array of `enabledExtensionCount` null-terminated UTF-8 strings.

```c
// Provided by VK_VERSION_1_0
typedef enum VkInstanceCreateFlagBits {
    // Provided by VK_KHR_portability_enumeration
    VK_INSTANCE_CREATE_ENUMERATE_PORTABILITY_BIT_KHR = 0x00000001,
} VkInstanceCreateFlagBits;
```

• **VK_INSTANCE_CREATE_ENUMERATE_PORTABILITY_BIT_KHR** specifies that the instance will enumerate available Vulkan Portability-compliant physical devices and groups in addition to the Vulkan physical devices and groups that are enumerated by default.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkInstanceCreateFlags;
```

*VkInstanceCreateFlags* is a bitmask type for setting a mask of zero or more *VkInstanceCreateFlagBits*.

When creating a Vulkan instance for which you wish to disable validation checks, add a *VkValidationFlagsEXT* structure to the `pNext` chain of the *VkInstanceCreateInfo* structure, specifying the checks to be disabled.

```c
// Provided by VK_EXT_validation_flags
typedef struct VkValidationFlagsEXT {
    VkStructureType sType;
    const void* pNext;
    uint32_t disabledValidationCheckCount;
    const VkValidationCheckEXT* pDisabledValidationChecks;
} VkValidationFlagsEXT;
```

• **sType** is a *VkStructureType* value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **disabledValidationCheckCount** is the number of checks to disable.

• **pDisabledValidationChecks** is a pointer to an array of *VkValidationCheckEXT* values specifying the validation checks to be disabled.
Valid Usage (Implicit)

• VUID-VkValidationFlagsEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_VALIDATION_FLAGS_EXT

• VUID-VkValidationFlagsEXT-pDisabledValidationChecks-parameter
  pDisabledValidationChecks must be a valid pointer to an array of
disabledValidationCheckCount valid VkValidationCheckEXT values

• VUID-VkValidationFlagsEXT-disabledValidationCheckCount-arraylength
  disabledValidationCheckCount must be greater than 0

Possible values of elements of the VkValidationFlagsEXT::pDisabledValidationChecks array, specifying validation checks to be disabled, are:

```c
// Provided by VK_EXT_validation_flags
typedef enum VkValidationCheckEXT {
    VK_VALIDATION_CHECK_ALL_EXT = 0,
    VK_VALIDATION_CHECK_SHADERS_EXT = 1,
} VkValidationCheckEXT;
```

• VK_VALIDATION_CHECK_ALL_EXT specifies that all validation checks are disabled.
• VK_VALIDATION_CHECK_SHADERS_EXT specifies that shader validation is disabled.

When creating a Vulkan instance for which you wish to enable or disable specific validation features, add a VkValidationFeaturesEXT structure to the pNext chain of the VkInstanceCreateInfo structure, specifying the features to be enabled or disabled.

```c
// Provided by VK_EXT_validation_features
typedef struct VkValidationFeaturesEXT {
    VkStructureType sType;
    const void* pNext;
    uint32_t enabledValidationFeatureCount;
    const VkValidationFeatureEnableEXT* pEnabledValidationFeatures;
    uint32_t disabledValidationFeatureCount;
    const VkValidationFeatureDisableEXT* pDisabledValidationFeatures;
} VkValidationFeaturesEXT;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• enabledValidationFeatureCount is the number of features to enable.
• pEnabledValidationFeatures is a pointer to an array of VkValidationFeatureEnableEXT values specifying the validation features to be enabled.
• disabledValidationFeatureCount is the number of features to disable.
• pDisabledValidationFeatures is a pointer to an array of VkValidationFeatureDisableEXT values
specifying the validation features to be disabled.

Valid Usage

- VUID-VkValidationFeaturesEXT-pEnabledValidationFeatures-02967
  If the `pEnabledValidationFeatures` array contains `VK_VALIDATION_FEATURE_ENABLE_GPU_ASSISTED_RESERVE_BINDING_SLOT_EXT`, then it must also contain `VK_VALIDATION_FEATURE_ENABLE_GPU_ASSISTED_EXT`

- VUID-VkValidationFeaturesEXT-pEnabledValidationFeatures-02968
  If the `pEnabledValidationFeatures` array contains `VK_VALIDATION_FEATURE_ENABLE_DEBUG_PRINTF_EXT`, then it must not contain `VK_VALIDATION_FEATURE_ENABLE_GPU_ASSISTED_EXT`

Valid Usage (Implicit)

- VUID-VkValidationFeaturesEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_VALIDATION_FEATURES_EXT`

- VUID-VkValidationFeaturesEXT-pEnabledValidationFeatures-parameter
  If `enabledValidationFeatureCount` is not 0, `pEnabledValidationFeatures` must be a valid pointer to an array of `enabledValidationFeatureCount` valid `VkValidationFeatureEnableEXT` values

- VUID-VkValidationFeaturesEXT-pDisabledValidationFeatures-parameter
  If `disabledValidationFeatureCount` is not 0, `pDisabledValidationFeatures` must be a valid pointer to an array of `disabledValidationFeatureCount` valid `VkValidationFeatureDisableEXT` values

Possible values of elements of the `VkValidationFeaturesEXT::pEnabledValidationFeatures` array, specifying validation features to be enabled, are:

```c
// Provided by VK_EXT_validation_features
typedef enum VkValidationFeatureEnableEXT {
    VK_VALIDATION_FEATURE_ENABLE_GPU_ASSISTED_EXT = 0,
    VK_VALIDATION_FEATURE_ENABLE_GPU_ASSISTED_RESERVE_BINDING_SLOT_EXT = 1,
    VK_VALIDATION_FEATURE_ENABLE_BEST_PRACTICES_EXT = 2,
    VK_VALIDATION_FEATURE_ENABLE_DEBUG_PRINTF_EXT = 3,
    VK_VALIDATION_FEATURE_ENABLE_SYNCHRONIZATION_VALIDATION_EXT = 4,
} VkValidationFeatureEnableEXT;
```

- `VK_VALIDATION_FEATURE_ENABLE_GPU_ASSISTED_EXT` specifies that GPU-assisted validation is enabled. Activating this feature instruments shader programs to generate additional diagnostic data. This feature is disabled by default.

- `VK_VALIDATION_FEATURE_ENABLE_GPU_ASSISTED_RESERVE_BINDING_SLOT_EXT` specifies that the validation layers reserve a descriptor set binding slot for their own use. The layer reports a value for `VkPhysicalDeviceLimits::maxBoundDescriptorSets` that is one less than the value
reported by the device. If the device supports the binding of only one descriptor set, the validation layer does not perform GPU-assisted validation. This feature is disabled by default.

• **VK_VALIDATION_FEATURE_ENABLE_BEST_PRACTICES_EXT** specifies that Vulkan best-practices validation is enabled. Activating this feature enables the output of warnings related to common misuse of the API, but which are not explicitly prohibited by the specification. This feature is disabled by default.

• **VK_VALIDATION_FEATURE_ENABLE_DEBUG_PRINTF_EXT** specifies that the layers will process `debugPrintfEXT` operations in shaders and send the resulting output to the debug callback. This feature is disabled by default.

• **VK_VALIDATION_FEATURE_ENABLE_SYNCHRONIZATION_VALIDATION_EXT** specifies that Vulkan synchronization validation is enabled. This feature reports resource access conflicts due to missing or incorrect synchronization operations between actions (Draw, Copy, Dispatch, Blit) reading or writing the same regions of memory. This feature is disabled by default.

Possible values of elements of the `VkValidationFeaturesEXT::pDisabledValidationFeatures` array, specifying validation features to be disabled, are:

```c
// Provided by VK_EXT_validation_features
typedef enum VkValidationFeatureDisableEXT {
    VK_VALIDATION_FEATURE_DISABLE_ALL_EXT = 0,
    VK_VALIDATION_FEATURE_DISABLE_SHADERS_EXT = 1,
    VK_VALIDATION_FEATURE_DISABLE_THREAD_SAFETY_EXT = 2,
    VK_VALIDATION_FEATURE_DISABLE_API_PARAMETERS_EXT = 3,
    VK_VALIDATION_FEATURE_DISABLE_OBJECT_LIFETIMES_EXT = 4,
    VK_VALIDATION_FEATURE_DISABLE_CORE_CHECKS_EXT = 5,
    VK_VALIDATION_FEATURE_DISABLE_UNIQUE_HANDLES_EXT = 6,
    VK_VALIDATION_FEATURE_DISABLE_SHADER_VALIDATION_CACHE_EXT = 7,
} VkValidationFeatureDisableEXT;
```

• **VK_VALIDATION_FEATURE_DISABLE_ALL_EXT** specifies that all validation checks are disabled.

• **VK_VALIDATION_FEATURE_DISABLE_SHADERS_EXT** specifies that shader validation is disabled. This feature is enabled by default.

• **VK_VALIDATION_FEATURE_DISABLE_THREAD_SAFETY_EXT** specifies that thread safety validation is disabled. This feature is enabled by default.

• **VK_VALIDATION_FEATURE_DISABLE_API_PARAMETERS_EXT** specifies that stateless parameter validation is disabled. This feature is enabled by default.

• **VK_VALIDATION_FEATURE_DISABLE_OBJECT_LIFETIMES_EXT** specifies that object lifetime validation is disabled. This feature is enabled by default.

• **VK_VALIDATION_FEATURE_DISABLE_CORE_CHECKS_EXT** specifies that core validation checks are disabled. This feature is enabled by default. If this feature is disabled, the shader validation and GPU-assisted validation features are also disabled.

• **VK_VALIDATION_FEATURE_DISABLE_UNIQUE_HANDLES_EXT** specifies that protection against duplicate non-dispatchable object handles is disabled. This feature is enabled by default.

• **VK_VALIDATION_FEATURE_DISABLE_SHADER_VALIDATION_CACHE_EXT** specifies that there will be no
The caching of shader validation results and every shader will be validated on every application execution. Shader validation caching is enabled by default.

**Note**
Disabling checks such as parameter validation and object lifetime validation prevents the reporting of error conditions that can cause other validation checks to behave incorrectly or crash. Some validation checks assume that their inputs are already valid and do not always revalidate them.

**Note**
The [VK_EXT_validation_features] extension subsumes all the functionality provided in the [VK_EXT_validation_flags] extension.

The `VkDirectDriverLoadingListLUNARG` structure is defined as:

```c
// Provided by VK_LUNARG_direct_driver_loading
typedef struct VkDirectDriverLoadingListLUNARG {
    VkStructureType sType;
    void* pNext;
    VkDirectDriverLoadingModeLUNARG mode;
    uint32_t driverCount;
    const VkDirectDriverLoadingInfoLUNARG* pDrivers;
} VkDirectDriverLoadingListLUNARG;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **mode** controls the mode in which to load the provided drivers.
- **driverCount** is the number of driver manifest paths.
- **pDrivers** is a pointer to an array of `driverCount` `VkDirectDriverLoadingInfoLUNARG` structures.

When creating a Vulkan instance for which additional drivers are to be included, add a `VkDirectDriverLoadingListLUNARG` structure to the pNext chain of the `VkInstanceCreateInfo` structure, and include in it the list of `VkDirectDriverLoadingInfoLUNARG` structures which contain the information necessary to load additional drivers.

### Valid Usage (Implicit)

- **VUID-VkDirectDriverLoadingListLUNARG-sType-sType**
  sType must be `VK_STRUCTURE_TYPE_DIRECT_DRIVER_LOADING_LIST_LUNARG`

- **VUID-VkDirectDriverLoadingListLUNARG-mode-parameter**
  mode must be a valid `VkDirectDriverLoadingModeLUNARG` value

- **VUID-VkDirectDriverLoadingListLUNARG-pDrivers-parameter**
  pDrivers must be a valid pointer to an array of `driverCount` valid `VkDirectDriverLoadingInfoLUNARG` structures
The `VkDirectDriverLoadingInfoLUNARG` structure is defined as:

```
// Provided by VK_LUNARG_direct_driver_loading
typedef struct VkDirectDriverLoadingInfoLUNARG {
    VkStructureType sType;
    void* pNext;
    VkDirectDriverLoadingFlagsLUNARG flags;
    PFN_vkGetInstanceProcAddrLUNARG pfnGetInstanceProcAddr;
} VkDirectDriverLoadingInfoLUNARG;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **pfnGetInstanceProcAddr** is a `PFN_vkGetInstanceProcAddrLUNARG` pointer to the driver `vkGetInstanceProcAddr` function.

### Valid Usage (Implicit)

- VUID-VkDirectDriverLoadingInfoLUNARG-sType-sType must be `VK_STRUCTURE_TYPE_DIRECT_DRIVER_LOADING_INFO_LUNARG`
- VUID-VkDirectDriverLoadingInfoLUNARG-flags-zerobitmask flags must be 0

Possible values of `VkDirectDriverLoadingListLUNARG::mode`, specifying the mode in which drivers are used, are:

```
// Provided by VK_LUNARG_direct_driver_loading
typedef enum VkDirectDriverLoadingModeLUNARG {
    VK_DIRECT_DRIVER_LOADING_MODE_EXCLUSIVE_LUNARG = 0,
    VK_DIRECT_DRIVER>Loading_MODE_INCLUSIVE_LUNARG = 1,
} VkDirectDriverLoadingModeLUNARG;
```

- **VK_DIRECT_DRIVER_LOADING_MODE_EXCLUSIVE_LUNARG** specifies that the provided drivers are used instead of the system-loaded drivers.
- **VK_DIRECT_DRIVER_LOADING_MODE_INCLUSIVE_LUNARG** specifies that the provided drivers are used in addition to the system-loaded drivers.

```
// Provided by VK_LUNARG_direct_driver_loading
typedef VkFlags VkDirectDriverLoadingFlagsLUNARG;
```
VkDirectDriverLoadingFlagsLUNARG is a bitmask type for setting a mask, but is currently reserved for future use.

The type of PFN_vkGetInstanceProcAddrLUNARG is:

```c
// Provided by VK_LUNARG_direct_driver_loading
typedef PFN_vkVoidFunction (VKAPI_PTR *PFN_vkGetInstanceProcAddrLUNARG)(
    VkInstance instance, const char* pName);
```

- `instance` is a VkInstance handle.
- `pName` is the name of a Vulkan command.

This type is compatible with the type of a pointer to the `vkGetInstanceProcAddr` command, but is used only to specify device driver addresses in VkDirectDriverLoadingInfoLUNARG::pfnGetInstanceProcAddr.

Note

This type exists only because of limitations in the XML schema and processing scripts, and its name may change in the future. Ideally we would use the PFN_vkGetInstanceProcAddr type generated in the vulkan_core.h header.

The VkApplicationInfo structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkApplicationInfo {
    VkStructureType  sType;
    const void*      pNext;
    const char*      pApplicationName;
    uint32_t         applicationVersion;
    const char*      pEngineName;
    uint32_t         engineVersion;
    uint32_t         apiVersion;
} VkApplicationInfo;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `pApplicationName` is NULL or is a pointer to a null-terminated UTF-8 string containing the name of the application.
- `applicationVersion` is an unsigned integer variable containing the developer-supplied version number of the application.
- `pEngineName` is NULL or is a pointer to a null-terminated UTF-8 string containing the name of the engine (if any) used to create the application.
- `engineVersion` is an unsigned integer variable containing the developer-supplied version number of the engine used to create the application.
• **apiVersion** must be the highest version of Vulkan that the application is designed to use, encoded as described in Version Numbers. The patch version number specified in **apiVersion** is ignored when creating an instance object. The variant version of the instance must match that requested in **apiVersion**.

Vulkan 1.0 implementations were required to return **VK_ERROR_INCOMPATIBLE_DRIVER** if **apiVersion** was larger than 1.0. Implementations that support Vulkan 1.1 or later must not return **VK_ERROR_INCOMPATIBLE_DRIVER** for any value of **apiVersion**.

**Note**
Because Vulkan 1.0 implementations may fail with **VK_ERROR_INCOMPATIBLE_DRIVER**, applications should determine the version of Vulkan available before calling **vkCreateInstance**. If the **vkGetInstanceProcAddr** returns **NULL** for **vkEnumerateInstanceVersion**, it is a Vulkan 1.0 implementation. Otherwise, the application can call **vkEnumerateInstanceVersion** to determine the version of Vulkan.

As long as the instance supports at least Vulkan 1.1, an application can use different versions of Vulkan with an instance than it does with a device or physical device.

**Note**
The Khronos validation layers will treat **apiVersion** as the highest API version the application targets, and will validate API usage against the minimum of that version and the implementation version (instance or device, depending on context). If an application tries to use functionality from a greater version than this, a validation error will be triggered.

For example, if the instance supports Vulkan 1.1 and three physical devices support Vulkan 1.0, Vulkan 1.1, and Vulkan 1.2, respectively, and if the application sets **apiVersion** to 1.2, the application can use the following versions of Vulkan:

- **Vulkan 1.0** can be used with the instance and with all physical devices.
- **Vulkan 1.1** can be used with the instance and with the physical devices that support Vulkan 1.1 and Vulkan 1.2.
- **Vulkan 1.2** can be used with the physical device that supports Vulkan 1.2.

If we modify the above example so that the application sets **apiVersion** to 1.1, then the application must not use Vulkan 1.2 functionality on the physical device that supports Vulkan 1.2.

**Note**
Providing a **NULL** **VkInstanceCreateInfo::pApplicationInfo** or providing an **apiVersion** of 0 is equivalent to providing an **apiVersion** of **VK_MAKE_API_VERSION(0,1,0,0)**.
Valid Usage

- VUID-VkApplicationInfo-apiVersion-04010
  If `apiVersion` is not 0, then it **must** be greater than or equal to `VK_API_VERSION_1_0`

Valid Usage (Implicit)

- VUID-VkApplicationInfo-sType-sType
  `sType` **must** be `VK_STRUCTURE_TYPE_APPLICATION_INFO`

- VUID-VkApplicationInfo-pNext-pNext
  `pNext` **must** be `NULL`

- VUID-VkApplicationInfo-pApplicationName-parameter
  If `pApplicationName` is not `NULL`, `pApplicationName` **must** be a null-terminated UTF-8 string

- VUID-VkApplicationInfo-pEngineName-parameter
  If `pEngineName` is not `NULL`, `pEngineName` **must** be a null-terminated UTF-8 string

To destroy an instance, call:

```c
// Provided by VK_VERSION_1_0
void vkDestroyInstance(
    VkInstance instance,
    const VkAllocationCallbacks* pAllocator);
```

- `instance` is the handle of the instance to destroy.

- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

Valid Usage

- VUID-vkDestroyInstance-instance-00629
  All child objects created using `instance` **must** have been destroyed prior to destroying `instance`

- VUID-vkDestroyInstance-instance-00630
  If `VkAllocationCallbacks` were provided when `instance` was created, a compatible set of callbacks **must** be provided here

- VUID-vkDestroyInstance-instance-00631
  If no `VkAllocationCallbacks` were provided when `instance` was created, `pAllocator` **must** be `NULL`

Valid Usage (Implicit)

- VUID-vkDestroyInstance-instance-parameter
If `instance` is not `NULL`, `instance` must be a valid `VkInstance` handle

- VUID-vkDestroyInstance-pAllocator-parameter
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

### Host Synchronization

- Host access to `instance` must be externally synchronized
- Host access to all `VkPhysicalDevice` objects enumerated from `instance` must be externally synchronized
Chapter 5. Devices and Queues

Once Vulkan is initialized, devices and queues are the primary objects used to interact with a Vulkan implementation.

Vulkan separates the concept of physical and logical devices. A physical device usually represents a single complete implementation of Vulkan (excluding instance-level functionality) available to the host, of which there are a finite number. A logical device represents an instance of that implementation with its own state and resources independent of other logical devices.

Physical devices are represented by VkPhysicalDevice handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_HANDLE(VkPhysicalDevice)
```

### 5.1. Physical Devices

To retrieve a list of physical device objects representing the physical devices installed in the system, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkEnumeratePhysicalDevices(
    VkInstance instance,
    uint32_t* pPhysicalDeviceCount,
    VkPhysicalDevice* pPhysicalDevices);
```

- `instance` is a handle to a Vulkan instance previously created with `vkCreateInstance`.
- `pPhysicalDeviceCount` is a pointer to an integer related to the number of physical devices available or queried, as described below.
- `pPhysicalDevices` is either `NULL` or a pointer to an array of `VkPhysicalDevice` handles.

If `pPhysicalDevices` is `NULL`, then the number of physical devices available is returned in `pPhysicalDeviceCount`. Otherwise, `pPhysicalDeviceCount` must point to a variable set by the user to the number of elements in the `pPhysicalDevices` array, and on return the variable is overwritten with the number of handles actually written to `pPhysicalDevices`. If `pPhysicalDeviceCount` is less than the number of physical devices available, at most `pPhysicalDeviceCount` structures will be written, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available physical devices were returned.

**Valid Usage (Implicit)**

- VUID-vkEnumeratePhysicalDevices-instance-parameter
  `instance` must be a valid `VkInstance` handle
- VUID-vkEnumeratePhysicalDevices-pPhysicalDeviceCount-parameter
**pPhysicalDeviceCount must** be a valid pointer to a `uint32_t` value

- **VUID-vkEnumeratePhysicalDevices-pPhysicalDevices-parameter**
  If the value referenced by `pPhysicalDeviceCount` is not `0`, and `pPhysicalDevices` is not `NULL`, `pPhysicalDevices` must be a valid pointer to an array of `pPhysicalDeviceCount` `VkPhysicalDevice` handles.

---

### Return Codes

**Success**
- `VK_SUCCESS`
- `VK_INCOMPLETE`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_INITIALIZATION_FAILED`

To query general properties of physical devices once enumerated, call:

```c
// Provided by VK_VERSION_1_0
void vkGetPhysicalDeviceProperties(VkPhysicalDevice physicalDevice, VkPhysicalDeviceProperties* pProperties);
```

- `physicalDevice` is the handle to the physical device whose properties will be queried.
- `pProperties` is a pointer to a `VkPhysicalDeviceProperties` structure in which properties are returned.

---

### Valid Usage (Implicit)

- **VUID-vkGetPhysicalDeviceProperties-physicalDevice-parameter**
  `physicalDevice` must be a valid `VkPhysicalDevice` handle

- **VUID-vkGetPhysicalDeviceProperties-pProperties-parameter**
  `pProperties` must be a valid pointer to a `VkPhysicalDeviceProperties` structure

The `VkPhysicalDeviceProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPhysicalDeviceProperties {
  uint32_t apiVersion;
  uint32_t driverVersion;
  uint32_t vendorID;
} VkPhysicalDeviceProperties;
```
struct VkPhysicalDeviceProperties {
    uint32_t deviceID;
    VkPhysicalDeviceType deviceType;
    char deviceName[VK_MAX_PHYSICAL_DEVICE_NAME_SIZE];
    uint8_t pipelineCacheUUID[VK_UUID_SIZE];
    VkPhysicalDeviceLimits limits;
    VkPhysicalDeviceSparseProperties sparseProperties;
} VkPhysicalDeviceProperties;

• **apiVersion** is the version of Vulkan supported by the device, encoded as described in Version Numbers.

• **driverVersion** is the vendor-specified version of the driver.

• **vendorID** is a unique identifier for the vendor (see below) of the physical device.

• **deviceID** is a unique identifier for the physical device among devices available from the vendor.

• **deviceType** is a VkPhysicalDeviceType specifying the type of device.

• **deviceName** is an array of VK_MAX_PHYSICAL_DEVICE_NAME_SIZE char containing a null-terminated UTF-8 string which is the name of the device.

• **pipelineCacheUUID** is an array of VK_UUID_SIZE uint8_t values representing a universally unique identifier for the device.

• **limits** is the VkPhysicalDeviceLimits structure specifying device-specific limits of the physical device. See Limits for details.

• **sparseProperties** is the VkPhysicalDeviceSparseProperties structure specifying various sparse related properties of the physical device. See Sparse Properties for details.

Note

The value of apiVersion may be different than the version returned by vkEnumerateInstanceVersion; either higher or lower. In such cases, the application must not use functionality that exceeds the version of Vulkan associated with a given object. The pApiVersion parameter returned by vkEnumerateInstanceVersion is the version associated with a VkInstance and its children, except for a VkPhysicalDevice and its children. VkPhysicalDeviceProperties::apiVersion is the version associated with a VkPhysicalDevice and its children.

Note

The encoding of driverVersion is implementation-defined. It may not use the same encoding as apiVersion. Applications should follow information from the vendor on how to extract the version information from driverVersion.

On implementations that claim support for the Roadmap 2022 profile, the major and minor version expressed by apiVersion must be at least Vulkan 1.3.

The vendorID and deviceID fields are provided to allow applications to adapt to device characteristics that are not adequately exposed by other Vulkan queries.
Note
These may include performance profiles, hardware errata, or other characteristics.

The vendor identified by vendorID is the entity responsible for the most salient characteristics of the underlying implementation of the VkPhysicalDevice being queried.

Note
For example, in the case of a discrete GPU implementation, this should be the GPU chipset vendor. In the case of a hardware accelerator integrated into a system-on-chip (SoC), this should be the supplier of the silicon IP used to create the accelerator.

If the vendor has a PCI vendor ID, the low 16 bits of vendorID must contain that PCI vendor ID, and the remaining bits must be set to zero. Otherwise, the value returned must be a valid Khronos vendor ID, obtained as described in the Vulkan Documentation and Extensions: Procedures and Conventions document in the section “Registering a Vendor ID with Khronos”. Khronos vendor IDs are allocated starting at 0x10000, to distinguish them from the PCI vendor ID namespace. Khronos vendor IDs are symbolically defined in the VkVendorId type.

The vendor is also responsible for the value returned in deviceID. If the implementation is driven primarily by a PCI device with a PCI device ID, the low 16 bits of deviceID must contain that PCI device ID, and the remaining bits must be set to zero. Otherwise, the choice of what values to return may be dictated by operating system or platform policies - but should uniquely identify both the device version and any major configuration options (for example, core count in the case of multicore devices).

Note
The same device ID should be used for all physical implementations of that device version and configuration. For example, all uses of a specific silicon IP GPU version and configuration should use the same device ID, even if those uses occur in different SoCs.

Khronos vendor IDs which may be returned in VkPhysicalDeviceProperties::vendorID are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkVendorId {
    VK_VENDOR_ID_VIV = 0x10001,
    VK_VENDOR_ID_VSI = 0x10002,
    VK_VENDOR_ID_KAZAN = 0x10003,
    VK_VENDOR_ID_CODEPLAY = 0x10004,
    VK_VENDOR_ID_MESA = 0x10005,
    VK_VENDOR_ID_POCL = 0x10006,
    VK_VENDOR_ID_MOBILEYE = 0x10007,
} VkVendorId;
```
Khronos vendor IDs may be allocated by vendors at any time. Only the latest canonical versions of this Specification, of the corresponding `vk.xml` API Registry, and of the corresponding `vulkan_core.h` header file must contain all reserved Khronos vendor IDs.

Only Khronos vendor IDs are given symbolic names at present. PCI vendor IDs returned by the implementation can be looked up in the PCI-SIG database.

`VK_MAX_PHYSICAL_DEVICE_NAME_SIZE` is the length in `char` values of an array containing a physical device name string, as returned in `VkPhysicalDeviceProperties::deviceName`.

```c
#define VK_MAX_PHYSICAL_DEVICE_NAME_SIZE  256U
```

The physical device types which may be returned in `VkPhysicalDeviceProperties::deviceType` are:

```c
typedef enum VkPhysicalDeviceType {
    VK_PHYSICAL_DEVICE_TYPE_OTHER         = 0,
    VK_PHYSICAL_DEVICE_TYPE_INTEGRATED_GPU = 1,
    VK_PHYSICAL_DEVICE_TYPE_DISCRETE_GPU  = 2,
    VK_PHYSICAL_DEVICE_TYPE_VIRTUAL_GPU   = 3,
    VK_PHYSICAL_DEVICE_TYPE_CPU           = 4,
} VkPhysicalDeviceType;
```

- **VK_PHYSICAL_DEVICE_TYPE_OTHER** - the device does not match any other available types.
- **VK_PHYSICAL_DEVICE_TYPE_INTEGRATED_GPU** - the device is typically one embedded in or tightly coupled with the host.
- **VK_PHYSICAL_DEVICE_TYPE_DISCRETE_GPU** - the device is typically a separate processor connected to the host via an interlink.
- **VK_PHYSICAL_DEVICE_TYPE_VIRTUAL_GPU** - the device is typically a virtual node in a virtualization environment.
- **VK_PHYSICAL_DEVICE_TYPE_CPU** - the device is typically running on the same processors as the host.

The physical device type is advertised for informational purposes only, and does not directly affect the operation of the system. However, the device type may correlate with other advertised properties or capabilities of the system, such as how many memory heaps there are.

To query general properties of physical devices once enumerated, call:

```c
void vkGetPhysicalDeviceProperties2(
    VkPhysicalDevice physicalDevice,
    VkPhysicalDeviceProperties2* pProperties);
```
or the equivalent command

```c
// Provided by VK_KHR_get_physical_device_properties2
void vkGetPhysicalDeviceProperties2KHR(
    VkPhysicalDevice physicalDevice,
    VkPhysicalDeviceProperties2* pProperties);
```

- `physicalDevice` is the handle to the physical device whose properties will be queried.
- `pProperties` is a pointer to a `VkPhysicalDeviceProperties2` structure in which properties are returned.

Each structure in `pProperties` and its `pNext` chain contains members corresponding to implementation-dependent properties, behaviors, or limits. `vkGetPhysicalDeviceProperties2` fills in each member to specify the corresponding value for the implementation.

### Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceProperties2-physicalDevice-parameter
  - `physicalDevice` must be a valid `VkPhysicalDevice` handle
- VUID-vkGetPhysicalDeviceProperties2-pProperties-parameter
  - `pProperties` must be a valid pointer to a `VkPhysicalDeviceProperties2` structure

The `VkPhysicalDeviceProperties2` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceProperties2 {
    VkStructureType sType;
    void* pNext;
    VkPhysicalDeviceProperties properties;
} VkPhysicalDeviceProperties2;
```

or the equivalent

```c
// Provided by VK_KHR_get_physical_device_properties2
typedef VkPhysicalDeviceProperties2 VkPhysicalDeviceProperties2KHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `properties` is a `VkPhysicalDeviceProperties` structure describing properties of the physical device. This structure is written with the same values as if it were written by `vkGetPhysicalDeviceProperties`.

The `pNext` chain of this structure is used to extend the structure with properties defined by extensions.
Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceProperties2-sType-sType**
  
  *sType* must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PROPERTIES_2**

- **VUID-VkPhysicalDeviceProperties2-pNext-pNext**
  
  Each *pNext* member of any structure (including this one) in the *pNext* chain must be either **NULL** or a pointer to a valid instance of:
  
  - VkPhysicalDeviceAccelerationStructurePropertiesKHR,
  - VkPhysicalDeviceBlendOperationAdvancedPropertiesEXT,
  - VkPhysicalDeviceClusterCullingShaderPropertiesHUAWEI,
  - VkPhysicalDeviceConservativeRasterizationPropertiesEXT,
  - VkPhysicalDeviceCooperativeMatrixPropertiesKHR,
  - VkPhysicalDeviceCooperativeMatrixPropertiesNV,
  - VkPhysicalDeviceCopyMemoryIndirectPropertiesNV,
  - VkPhysicalDeviceCustomBorderColorPropertiesEXT,
  - VkPhysicalDeviceDepthStencilResolveProperties,
  - VkPhysicalDeviceDescriptorBufferDensityMapPropertiesEXT,
  - VkPhysicalDeviceDescriptorBufferPropertiesEXT,
  - VkPhysicalDeviceDiscardRectanglePropertiesEXT,
  - VkPhysicalDeviceDisplacementMicromapPropertiesNV,
  - VkPhysicalDeviceDriverProperties,
  - VkPhysicalDeviceDrmPropertiesEXT,
  - VkPhysicalDeviceExtendedDynamicState3PropertiesEXT,
  - VkPhysicalDeviceExternalMemoryHostPropertiesEXT,
  - VkPhysicalDeviceFloatControlsProperties,
  - VkPhysicalDeviceFragmentDensityMap2PropertiesEXT,
  - VkPhysicalDeviceFragmentDensityMapOffsetPropertiesQCOM,
  - VkPhysicalDeviceFragmentDensityMapPropertiesEXT,
  - VkPhysicalDeviceFragmentShaderBarycentricPropertiesKHR,
  - VkPhysicalDeviceFragmentShadingRate EnumsPropertiesNV,
  - VkPhysicalDeviceFragmentShadingRatePropertiesKHR,
  - VkPhysicalDeviceGraphicsPipelineLibraryPropertiesEXT,
  - VkPhysicalDeviceHostImageCopyPropertiesEXT,
  - VkPhysicalDeviceIDProperties,
  - VkPhysicalDeviceImageProcessing2PropertiesQCOM,
  - VkPhysicalDeviceImageProcessingPropertiesQCOM,
  - VkPhysicalDeviceInlineUniformBlockProperties,
  - VkPhysicalDeviceLayeredDriverPropertiesMSFT,
  - VkPhysicalDeviceLineRasterizationPropertiesEXT,
  - VkPhysicalDeviceMaintenance3Properties,
  - VkPhysicalDeviceMaintenance4Properties,
  - VkPhysicalDeviceMaintenance5PropertiesKHR,
  - VkPhysicalDeviceMemoryDecompressionPropertiesNV,
  - VkPhysicalDeviceMeshShaderPropertiesEXT,
  - VkPhysicalDeviceMeshShaderPropertiesNV,
  - VkPhysicalDeviceMultiDrawPropertiesEXT,
  - VkPhysicalDeviceMultiviewPerViewAttributesPropertiesNVX,
  - VkPhysicalDeviceMultiviewProperties,
  - VkPhysicalDeviceOpacityMicromapPropertiesEXT,
  - VkPhysicalDeviceOpticalFlowPropertiesNV,
  - VkPhysicalDevicePCIBusInfoPropertiesEXT,
The `VkPhysicalDeviceVulkan11Properties` structure is defined as:

```c
typedef struct VkPhysicalDeviceVulkan11Properties {
    VkStructureType sType;
    void* pNext;
    uint8_t deviceUUID[VK_UUID_SIZE];
    uint8_t driverUUID[VK_UUID_SIZE];
    uint8_t deviceLUID[VK_LUID_SIZE];
    uint32_t deviceNodeMask;
    VkBool32 deviceLUIDValid;
    uint32_t subgroupSize;
    VkShaderStageFlags subgroupSupportedStages;
} VkPhysicalDeviceVulkan11Properties;
```
VkSubgroupFeatureFlags subgroupSupportedOperations;
VkBool32 subgroupQuadOperationsInAllStages;
VkPointClippingBehavior pointClippingBehavior;
uint32_t maxMultiviewViewCount;
uint32_t maxMultiviewInstanceIndex;
VkBool32 protectedNoFault;
uint32_t maxPerSetDescriptors;
VkDeviceSize maxMemoryAllocationSize;
}

• **sType** is a *VkStructureType* value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **deviceUUID** is an array of *VK_UUID_SIZE* uint8_t values representing a universally unique identifier for the device.

• **driverUUID** is an array of *VK_UUID_SIZE* uint8_t values representing a universally unique identifier for the driver build in use by the device.

• **deviceLUID** is an array of *VK_LUID_SIZE* uint8_t values representing a locally unique identifier for the device.

• **deviceNodeMask** is a uint32_t bitfield identifying the node within a linked device adapter corresponding to the device.

• **deviceLUIDValid** is a boolean value that will be VK_TRUE if deviceLUID contains a valid LUID and deviceNodeMask contains a valid node mask, and VK_FALSE if they do not.

• **subgroupSize** is the default number of invocations in each subgroup. subgroupSize is at least 1 if any of the physical device's queues support VK_QUEUE_GRAPHICS_BIT or VK_QUEUE_COMPUTE_BIT. subgroupSize is a power-of-two.

• **subgroupSupportedStages** is a bitfield of *VkShaderStageFlagBits* describing the shader stages that group operations with subgroup scope are supported in. subgroupSupportedStages will have the VK_SHADER_STAGE_COMPUTE_BIT bit set if any of the physical device's queues support VK_QUEUE_COMPUTE_BIT.

• **subgroupSupportedOperations** is a bitmask of *VkSubgroupFeatureFlagBits* specifying the sets of group operations with subgroup scope supported on this device. subgroupSupportedOperations will have the VK_SUBGROUP_FEATURE_BASIC_BIT bit set if any of the physical device's queues support VK_QUEUE_GRAPHICS_BIT or VK_QUEUE_COMPUTE_BIT.

• **subgroupQuadOperationsInAllStages** is a boolean specifying whether quad group operations are available in all stages, or are restricted to fragment and compute stages.

• **pointClippingBehavior** is a *VkPointClippingBehavior* value specifying the point clipping behavior supported by the implementation.

• **maxMultiviewViewCount** is one greater than the maximum view index that can be used in a subpass.

• **maxMultiviewInstanceIndex** is the maximum valid value of instance index allowed to be generated by a drawing command recorded within a subpass of a multiview render pass instance.
• **protectedNoFault** specifies how an implementation behaves when an application attempts to write to unprotected memory in a protected queue operation, read from protected memory in an unprotected queue operation, or perform a query in a protected queue operation. If this limit is **VK_TRUE**, such writes will be discarded or have undefined values written, reads and queries will return undefined values. If this limit is **VK_FALSE**, applications must not perform these operations. See Protected Memory Access Rules for more information.

• **maxPerSetDescriptors** is a maximum number of descriptors (summed over all descriptor types) in a single descriptor set that is guaranteed to satisfy any implementation-dependent constraints on the size of a descriptor set itself. Applications can query whether a descriptor set that goes beyond this limit is supported using `vkGetDescriptorSetLayoutSupport`.

• **maxMemoryAllocationSize** is the maximum size of a memory allocation that can be created, even if there is more space available in the heap.

If the `VkPhysicalDeviceVulkan11Properties` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

These properties correspond to Vulkan 1.1 functionality.

The members of `VkPhysicalDeviceVulkan11Properties` have the same values as the corresponding members of `VkPhysicalDeviceIDProperties`, `VkPhysicalDeviceSubgroupProperties`, `VkPhysicalDevicePointClippingProperties`, `VkPhysicalDeviceMultiviewProperties`, `VkPhysicalDeviceProtectedMemoryProperties`, and `VkPhysicalDeviceMaintenance3Properties`.

---

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceVulkan11Properties-sType-sType

  `sType` must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_1_PROPERTIES**

---

The `VkPhysicalDeviceVulkan12Properties` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceVulkan12Properties {
    VkStructureType sType;
    void* pNext;
    VkDriverId driverID;
    char driverName[VK_MAX_DRIVER_NAME_SIZE];
    char driverInfo[VK_MAX_DRIVER_INFO_SIZE];
    VkConformanceVersion conformanceVersion;
    VkShaderFloatControlsIndependence denormBehaviorIndependence;
    VkShaderFloatControlsIndependence roundingModeIndependence;
    VkBool32 shaderSignedZeroInfNanPreserveFloat16;
    VkBool32 shaderSignedZeroInfNanPreserveFloat32;
    VkBool32 shaderSignedZeroInfNanPreserveFloat64;
    VkBool32 shaderDenormPreserveFloat16;
    VkBool32 shaderDenormPreserveFloat32;
    VkBool32 shaderDenormPreserveFloat64;
} VkPhysicalDeviceVulkan12Properties;
```
VkBool32 shaderDenormFlushToZeroFloat16;
VkBool32 shaderDenormFlushToZeroFloat32;
VkBool32 shaderDenormFlushToZeroFloat64;
VkBool32 shaderRoundingModeRTEFloat16;
VkBool32 shaderRoundingModeRTEFloat32;
VkBool32 shaderRoundingModeRTEFloat64;
VkBool32 shaderRoundingModeRTZFloat16;
VkBool32 shaderRoundingModeRTZFloat32;
VkBool32 shaderRoundingModeRTZFloat64;
uint32_t maxUpdateAfterBindDescriptorsInAllPools;
VkBool32 shaderUniformBufferArrayNonUniformIndexingNative;
VkBool32 shaderSampledImageArrayNonUniformIndexingNative;
VkBool32 shaderStorageBufferArrayNonUniformIndexingNative;
VkBool32 shaderStorageImageArrayNonUniformIndexingNative;
VkBool32 shaderInputAttachmentArrayNonUniformIndexingNative;
VkBool32 robustBufferAccessUpdateAfterBind;
VkBool32 quadDivergentImplicitLod;
uint32_t maxPerStageDescriptorUpdateAfterBindSamplers;
uint32_t maxPerStageDescriptorUpdateAfterBindUniformBuffers;
uint32_t maxPerStageDescriptorUpdateAfterBindStorageBuffers;
uint32_t maxPerStageDescriptorUpdateAfterBindSampledImages;
uint32_t maxPerStageDescriptorUpdateAfterBindStorageImages;
uint32_t maxPerStageDescriptorUpdateAfterBindInputAttachments;
uint32_t maxPerStageUpdateAfterBindResources;
uint32_t maxDescriptorSetUpdateAfterBindSamplers;
uint32_t maxDescriptorSetUpdateAfterBindUniformBuffers;
uint32_t maxDescriptorSetUpdateAfterBindUniformBuffersDynamic;
uint32_t maxDescriptorSetUpdateAfterBindStorageBuffers;
uint32_t maxDescriptorSetUpdateAfterBindStorageBuffersDynamic;
uint32_t maxDescriptorSetUpdateAfterBindSampledImages;
uint32_t maxDescriptorSetUpdateAfterBindStorageImages;
uint32_t maxDescriptorSetUpdateAfterBindInputAttachments;
VkResolveModeFlags supportedDepthResolveModes;
VkResolveModeFlags supportedStencilResolveModes;
VkBool32 independentResolveNone;
VkBool32 independentResolve;

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VkBool32 filterMinmaxSingleComponentFormats;
VkBool32 filterMinmaxImageComponentMapping;
uint64_t maxTimelineSemaphoreValueDifference;
VkSampleCountFlags framebufferIntegerColorSampleCounts;
}

VkPhysicalDeviceVulkan12Properties

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• driverID is a unique identifier for the driver of the physical device.
• driverName is an array of VK_MAX_DRIVER_NAME_SIZE char containing a null-terminated UTF-8 string which is the name of the driver.
• driverInfo is an array of VK_MAX_DRIVER_INFO_SIZE char containing a null-terminated UTF-8 string with additional information about the driver.
• conformanceVersion is the version of the Vulkan conformance test this driver is conformant against (see VkConformanceVersion).
• denormBehaviorIndependence is a VkShaderFloatControlsIndependence value indicating whether, and how, denorm behavior can be set independently for different bit widths.
• roundingModeIndependence is a VkShaderFloatControlsIndependence value indicating whether, and how, rounding modes can be set independently for different bit widths.
• shaderSignedZeroInfNanPreserveFloat16 is a boolean value indicating whether sign of a zero, Nans and ±∞ can be preserved in 16-bit floating-point computations. It also indicates whether the SignedZeroInfNanPreserve execution mode can be used for 16-bit floating-point types.
• shaderSignedZeroInfNanPreserveFloat32 is a boolean value indicating whether sign of a zero, Nans and ±∞ can be preserved in 32-bit floating-point computations. It also indicates whether the SignedZeroInfNanPreserve execution mode can be used for 32-bit floating-point types.
• shaderSignedZeroInfNanPreserveFloat64 is a boolean value indicating whether sign of a zero, Nans and ±∞ can be preserved in 64-bit floating-point computations. It also indicates whether the SignedZeroInfNanPreserve execution mode can be used for 64-bit floating-point types.
• shaderDenormPreserveFloat16 is a boolean value indicating whether denormals can be preserved in 16-bit floating-point computations. It also indicates whether the DenormPreserve execution mode can be used for 16-bit floating-point types.
• shaderDenormPreserveFloat32 is a boolean value indicating whether denormals can be preserved in 32-bit floating-point computations. It also indicates whether the DenormPreserve execution mode can be used for 32-bit floating-point types.
• shaderDenormPreserveFloat64 is a boolean value indicating whether denormals can be preserved in 64-bit floating-point computations. It also indicates whether the DenormPreserve execution mode can be used for 64-bit floating-point types.
• shaderDenormFlushToZeroFloat16 is a boolean value indicating whether denormals can be flushed to zero in 16-bit floating-point computations. It also indicates whether the DenormFlushToZero execution mode can be used for 16-bit floating-point types.
• shaderDenormFlushToZeroFloat32 is a boolean value indicating whether denormals can be flushed
to zero in 32-bit floating-point computations. It also indicates whether the `DenormFlushToZero` execution mode can be used for 32-bit floating-point types.

- `shaderDenormFlushToZeroFloat64` is a boolean value indicating whether denormals can be flushed to zero in 64-bit floating-point computations. It also indicates whether the `DenormFlushToZero` execution mode can be used for 64-bit floating-point types.

- `shaderRoundingModeRTEFloat16` is a boolean value indicating whether an implementation supports the round-to-nearest-even rounding mode for 16-bit floating-point arithmetic and conversion instructions. It also indicates whether the `RoundingModeRTE` execution mode can be used for 16-bit floating-point types.

- `shaderRoundingModeRTEFloat32` is a boolean value indicating whether an implementation supports the round-to-nearest-even rounding mode for 32-bit floating-point arithmetic and conversion instructions. It also indicates whether the `RoundingModeRTE` execution mode can be used for 32-bit floating-point types.

- `shaderRoundingModeRTEFloat64` is a boolean value indicating whether an implementation supports the round-to-nearest-even rounding mode for 64-bit floating-point arithmetic and conversion instructions. It also indicates whether the `RoundingModeRTE` execution mode can be used for 64-bit floating-point types.

- `shaderRoundingModeRTZFloat16` is a boolean value indicating whether an implementation supports the round-towards-zero rounding mode for 16-bit floating-point arithmetic and conversion instructions. It also indicates whether the `RoundingModeRTZ` execution mode can be used for 16-bit floating-point types.

- `shaderRoundingModeRTZFloat32` is a boolean value indicating whether an implementation supports the round-towards-zero rounding mode for 32-bit floating-point arithmetic and conversion instructions. It also indicates whether the `RoundingModeRTZ` execution mode can be used for 32-bit floating-point types.

- `shaderRoundingModeRTZFloat64` is a boolean value indicating whether an implementation supports the round-towards-zero rounding mode for 64-bit floating-point arithmetic and conversion instructions. It also indicates whether the `RoundingModeRTZ` execution mode can be used for 64-bit floating-point types.

- `maxUpdateAfterBindDescriptorsInAllPools` is the maximum number of descriptors (summed over all descriptor types) that can be created across all pools that are created with the `VK_DESCRIPTOR_POOL_CREATE_UPDATE_AFTER_BIND_BIT` bit set. Pool creation may fail when this limit is exceeded, or when the space this limit represents is unable to satisfy a pool creation due to fragmentation.

- `shaderUniformBufferArrayNonUniformIndexingNative` is a boolean value indicating whether uniform buffer descriptors natively support nonuniform indexing. If this is `VK_FALSE`, then a single dynamic instance of an instruction that nonuniformly indexes an array of uniform buffers may execute multiple times in order to access all the descriptors.

- `shaderSampledImageArrayNonUniformIndexingNative` is a boolean value indicating whether sampler and image descriptors natively support nonuniform indexing. If this is `VK_FALSE`, then a single dynamic instance of an instruction that nonuniformly indexes an array of samplers or images may execute multiple times in order to access all the descriptors.

- `shaderStorageBufferArrayNonUniformIndexingNative` is a boolean value indicating whether
storage buffer descriptors natively support nonuniform indexing. If this is \texttt{VK_FALSE}, then a single dynamic instance of an instruction that nonuniformly indexes an array of storage buffers may execute multiple times in order to access all the descriptors.

- \texttt{shaderStorageImageArrayNonUniformIndexingNative} is a boolean value indicating whether storage image descriptors natively support nonuniform indexing. If this is \texttt{VK_FALSE}, then a single dynamic instance of an instruction that nonuniformly indexes an array of storage images may execute multiple times in order to access all the descriptors.

- \texttt{shaderInputAttachmentArrayNonUniformIndexingNative} is a boolean value indicating whether input attachment descriptors natively support nonuniform indexing. If this is \texttt{VK_FALSE}, then a single dynamic instance of an instruction that nonuniformly indexes an array of input attachments may execute multiple times in order to access all the descriptors.

- \texttt{robustBufferAccessUpdateAfterBind} is a boolean value indicating whether \texttt{robustBufferAccess} can be enabled on a device simultaneously with \texttt{descriptorBindingUniformBufferUpdateAfterBind}, \texttt{descriptorBindingStorageBufferUpdateAfterBind}, \texttt{descriptorBindingUniformTexelBufferUpdateAfterBind}, and/or \texttt{descriptorBindingStorageTexelBufferUpdateAfterBind}. If this is \texttt{VK_FALSE}, then either \texttt{robustBufferAccess} must be disabled or all of these update-after-bind features must be disabled.

- \texttt{quadDivergentImplicitLod} is a boolean value indicating whether implicit LOD calculations for image operations have well-defined results when the image and/or sampler objects used for the instruction are not uniform within a quad. See Derivative Image Operations.

- \texttt{maxPerStageDescriptorUpdateAfterBindSamplers} is similar to \texttt{maxPerStageDescriptorSamplers} but counts descriptors from descriptor sets created with or without the \texttt{VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT} bit set.

- \texttt{maxPerStageDescriptorUpdateAfterBindUniformBuffers} is similar to \texttt{maxPerStageDescriptorUniformBuffers} but counts descriptors from descriptor sets created with or without the \texttt{VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT} bit set.

- \texttt{maxPerStageDescriptorUpdateAfterBindStorageBuffers} is similar to \texttt{maxPerStageDescriptorStorageBuffers} but counts descriptors from descriptor sets created with or without the \texttt{VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT} bit set.

- \texttt{maxPerStageDescriptorUpdateAfterBindSamplerImages} is similar to \texttt{maxPerStageDescriptorSamplerImages} but counts descriptors from descriptor sets created with or without the \texttt{VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT} bit set.

- \texttt{maxPerStageDescriptorUpdateAfterBindStorageImages} is similar to \texttt{maxPerStageDescriptorStorageImages} but counts descriptors from descriptor sets created with or without the \texttt{VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT} bit set.

- \texttt{maxPerStageDescriptorUpdateAfterBindInputAttachments} is similar to \texttt{maxPerStageDescriptorInputAttachments} but counts descriptors from descriptor sets created with or without the \texttt{VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT} bit set.

- \texttt{maxPerStageUpdateAfterBindResources} is similar to \texttt{maxPerStageResources} but counts descriptors from descriptor sets created with or without the \texttt{VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT} bit set.

- \texttt{maxDescriptorSetUpdateAfterBindSamplers} is similar to \texttt{maxDescriptorSetSamplers} but counts descriptors from descriptor sets created with or without the
**VkDescriptorSetLayoutCreateUpdateAfterBindPoolBit** bit set.

- **maxDescriptorSetUpdateAfterBindUniformBuffers** is similar to **maxDescriptorSetUniformBuffers** but counts descriptors from descriptor sets created with or without the **VkDescriptorSetLayoutCreateUpdateAfterBindPoolBit** bit set.

- **maxDescriptorSetUpdateAfterBindUniformBuffersDynamic** is similar to **maxDescriptorSetUniformBuffersDynamic** but counts descriptors from descriptor sets created with or without the **VkDescriptorSetLayoutCreateUpdateAfterBindPoolBit** bit set. While an application can allocate dynamic uniform buffer descriptors from a pool created with the **VkDescriptorSetLayoutCreateUpdateAfterBindPoolBit**, bindings for these descriptors must not be present in any descriptor set layout that includes bindings created with **VkDescriptorBindingUpdateAfterBindBit**.

- **maxDescriptorSetUpdateAfterBindStorageBuffers** is similar to **maxDescriptorSetStorageBuffers** but counts descriptors from descriptor sets created with or without the **VkDescriptorSetLayoutCreateUpdateAfterBindPoolBit** bit set.

- **maxDescriptorSetUpdateAfterBindStorageBuffersDynamic** is similar to **maxDescriptorSetStorageBuffersDynamic** but counts descriptors from descriptor sets created with or without the **VkDescriptorSetLayoutCreateUpdateAfterBindPoolBit** bit set. While an application can allocate dynamic storage buffer descriptors from a pool created with the **VkDescriptorSetLayoutCreateUpdateAfterBindPoolBit**, bindings for these descriptors must not be present in any descriptor set layout that includes bindings created with **VkDescriptorBindingUpdateAfterBindBit**.

- **maxDescriptorSetUpdateAfterBindSampledImages** is similar to **maxDescriptorSetSampledImages** but counts descriptors from descriptor sets created with or without the **VkDescriptorSetLayoutCreateUpdateAfterBindPoolBit** bit set.

- **maxDescriptorSetUpdateAfterBindStorageImages** is similar to **maxDescriptorSetStorageImages** but counts descriptors from descriptor sets created with or without the **VkDescriptorSetLayoutCreateUpdateAfterBindPoolBit** bit set.

- **maxDescriptorSetUpdateAfterBindInputAttachments** is similar to **maxDescriptorSetInputAttachments** but counts descriptors from descriptor sets created with or without the **VkDescriptorSetLayoutCreateUpdateAfterBindPoolBit** bit set.

- **supportedDepthResolveModes** is a bitmask of **VkResolveModeFlagBits** indicating the set of supported depth resolve modes. **VkResolveModeSampleZeroBit** must be included in the set but implementations may support additional modes.

- **supportedStencilResolveModes** is a bitmask of **VkResolveModeFlagBits** indicating the set of supported stencil resolve modes. **VkResolveModeSampleZeroBit** must be included in the set but implementations may support additional modes. **VkResolveModeAverageBit** must not be included in the set.

- **independentResolveNone** is **VkTrue** if the implementation supports setting the depth and stencil resolve modes to different values when one of those modes is **VkResolveModeNone**. Otherwise the implementation only supports setting both modes to the same value.

- **independentResolve** is **VkTrue** if the implementation supports all combinations of the supported depth and stencil resolve modes, including setting either depth or stencil resolve mode to **VkResolveModeNone**. An implementation that supports **independentResolve** must also support
• `filterMinmaxSingleComponentFormats` is a boolean value indicating whether a minimum set of required formats support min/max filtering.

• `filterMinmaxImageComponentMapping` is a boolean value indicating whether the implementation supports non-identity component mapping of the image when doing min/max filtering.

• `maxTimelineSemaphoreValueDifference` indicates the maximum difference allowed by the implementation between the current value of a timeline semaphore and any pending signal or wait operations.

• `framebufferIntegerColorSampleCounts` is a bitmask of `VkSampleCountFlagBits` indicating the color sample counts that are supported for all framebuffer color attachments with integer formats.

If the `VkPhysicalDeviceVulkan12Properties` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

These properties correspond to Vulkan 1.2 functionality.

The members of `VkPhysicalDeviceVulkan12Properties` must have the same values as the corresponding members of `VkPhysicalDeviceDriverProperties`, `VkPhysicalDeviceFloatControlsProperties`, `VkPhysicalDeviceDescriptorIndexingProperties`, `VkPhysicalDeviceDepthStencilResolveProperties`, `VkPhysicalDeviceSamplerFilterMinmaxProperties`, `VkPhysicalDeviceTimelineSemaphoreProperties`, and `VkPhysicalDeviceVulkan13Properties`.

### Valid Usage (Implicit)

• **VUID-VkPhysicalDeviceVulkan12Properties-sType-sType**  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_2_PROPERTIES`

The `VkPhysicalDeviceVulkan13Properties` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceVulkan13Properties {
    VkStructureType sType;
    void* pNext;
    uint32_t minSubgroupSize;
    uint32_t maxSubgroupSize;
    uint32_t maxComputeWorkgroupSubgroups;
    VkShaderStageFlags requiredSubgroupSizeStages;
    uint32_t maxInlineUniformBlockSize;
    uint32_t maxPerStageDescriptorInlineUniformBlocks;
    uint32_t maxPerStageDescriptorUpdateAfterBindInlineUniformBlocks;
    uint32_t maxDescriptorSetInlineUniformBlocks;
    uint32_t maxDescriptorSetUpdateAfterBindInlineUniformBlocks;
    uint32_t maxInlineUniformTotalSize;
    VkBool32 integerDotProduct8BitUnsignedAccelerated;
    VkBool32 integerDotProduct8BitSignedAccelerated;
} VkPhysicalDeviceVulkan13Properties;
```
VkBool32 integerDotProduct8BitMixedSignednessAccelerated;
VkBool32 integerDotProduct4x8BitPackedUnsignedAccelerated;
VkBool32 integerDotProduct4x8BitPackedSignedAccelerated;
VkBool32 integerDotProduct4x8BitPackedMixedSignednessAccelerated;
VkBool32 integerDotProduct16BitUnsignedAccelerated;
VkBool32 integerDotProduct16BitSignedAccelerated;
VkBool32 integerDotProduct16BitMixedSignednessAccelerated;
VkBool32 integerDotProduct32BitUnsignedAccelerated;
VkBool32 integerDotProduct32BitSignedAccelerated;
VkBool32 integerDotProduct32BitMixedSignednessAccelerated;
VkBool32 integerDotProduct64BitUnsignedAccelerated;
VkBool32 integerDotProduct64BitSignedAccelerated;
VkBool32 integerDotProduct64BitMixedSignednessAccelerated;
int integerDotProductAccumulatingSaturating8BitUnsignedAccelerated;
int integerDotProductAccumulatingSaturating8BitSignedAccelerated;
int integerDotProductAccumulatingSaturating8BitMixedSignednessAccelerated;
int integerDotProductAccumulatingSaturating4x8BitPackedUnsignedAccelerated;
int integerDotProductAccumulatingSaturating4x8BitPackedSignedAccelerated;
int integerDotProductAccumulatingSaturating4x8BitPackedMixedSignednessAccelerated;
int integerDotProductAccumulatingSaturating16BitUnsignedAccelerated;
int integerDotProductAccumulatingSaturating16BitSignedAccelerated;
int integerDotProductAccumulatingSaturating16BitMixedSignednessAccelerated;
int integerDotProductAccumulatingSaturating32BitUnsignedAccelerated;
int integerDotProductAccumulatingSaturating32BitSignedAccelerated;
int integerDotProductAccumulatingSaturating32BitMixedSignednessAccelerated;
int integerDotProductAccumulatingSaturating64BitUnsignedAccelerated;
int integerDotProductAccumulatingSaturating64BitSignedAccelerated;
int integerDotProductAccumulatingSaturating64BitMixedSignednessAccelerated;
VkDeviceSize storageTexelBufferOffsetAlignmentBytes;
VkBool32 storageTexelBufferOffsetSingleTexelAlignment;
VkDeviceSize uniformTexelBufferOffsetAlignmentBytes;
VkBool32 uniformTexelBufferOffsetSingleTexelAlignment;
VkDeviceSize maxBufferSize;
} VkPhysicalDeviceVulkan13Properties;
• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **minSubgroupSize** is the minimum subgroup size supported by this device. `minSubgroupSize` is at least one if any of the physical device's queues support `VK_QUEUE_GRAPHICS_BIT` or `VK_QUEUE_COMPUTE_BIT`. `minSubgroupSize` is a power-of-two. `minSubgroupSize` is less than or equal to `maxSubgroupSize`. `minSubgroupSize` is less than or equal to `subgroupSize`.

• **maxSubgroupSize** is the maximum subgroup size supported by this device. `maxSubgroupSize` is at least one if any of the physical device's queues support `VK_QUEUE_GRAPHICS_BIT` or `VK_QUEUE_COMPUTE_BIT`. `maxSubgroupSize` is a power-of-two. `maxSubgroupSize` is greater than or equal to `minSubgroupSize`. `maxSubgroupSize` is greater than or equal to `subgroupSize`.

• **maxComputeWorkgroupSubgroups** is the maximum number of subgroups supported by the implementation within a workgroup.

• **requiredSubgroupSizeStages** is a bitfield of what shader stages support having a required subgroup size specified.

• **maxInlineUniformBlockSize** is the maximum size in bytes of an inline uniform block binding.

• **maxPerStageDescriptorInlineUniformBlocks** is the maximum number of inline uniform block bindings that can be accessible to a single shader stage in a pipeline layout. Descriptor bindings with a descriptor type of `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK` count against this limit. Only descriptor bindings in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set count against this limit.

• **maxPerStageDescriptorUpdateAfterBindInlineUniformBlocks** is similar to `maxPerStageDescriptorInlineUniformBlocks` but counts descriptor bindings from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.

• **maxDescriptorSetInlineUniformBlocks** is the maximum number of inline uniform block bindings that can be included in descriptor bindings in a pipeline layout across all pipeline shader stages and descriptor set numbers. Descriptor bindings with a descriptor type of `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK` count against this limit. Only descriptor bindings in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set count against this limit.

• **maxDescriptorSetUpdateAfterBindInlineUniformBlocks** is similar to `maxDescriptorSetInlineUniformBlocks` but counts descriptor bindings from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.

• **maxInlineUniformTotalSize** is the maximum total size in bytes of all inline uniform block bindings, across all pipeline shader stages and descriptor set numbers, that can be included in a pipeline layout. Descriptor bindings with a descriptor type of `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK` count against this limit.

• **integerDotProduct8BitUnsignedAccelerated** is a boolean that will be `VK_TRUE` if the support for 8-bit unsigned dot product operations using the `OpUDotKHR` SPIR-V instruction is accelerated as defined below.

• **integerDotProduct8BitSignedAccelerated** is a boolean that will be `VK_TRUE` if the support for 8-bit signed dot product operations using the `OpSDotKHR` SPIR-V instruction is accelerated as defined below.
• integerDotProduct8BitMixedSignednessAccelerated is a boolean that will be VK_TRUE if the support for 8-bit mixed signedness dot product operations using the OpSU DotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct4x8BitPackedUnsignedAccelerated is a boolean that will be VK_TRUE if the support for 8-bit unsigned dot product operations from operands packed into 32-bit integers using the OpUDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct4x8BitPackedSignedAccelerated is a boolean that will be VK_TRUE if the support for 8-bit signed dot product operations from operands packed into 32-bit integers using the OpSDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct4x8BitPackedMixedSignednessAccelerated is a boolean that will be VK_TRUE if the support for 8-bit mixed signedness dot product operations from operands packed into 32-bit integers using the OpSU DotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct16BitUnsignedAccelerated is a boolean that will be VK_TRUE if the support for 16-bit unsigned dot product operations using the OpUDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct16BitSignedAccelerated is a boolean that will be VK_TRUE if the support for 16-bit signed dot product operations using the OpSDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct16BitMixedSignednessAccelerated is a boolean that will be VK_TRUE if the support for 16-bit mixed signedness dot product operations using the OpSU DotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct32BitUnsignedAccelerated is a boolean that will be VK_TRUE if the support for 32-bit unsigned dot product operations using the OpUDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct32BitSignedAccelerated is a boolean that will be VK_TRUE if the support for 32-bit signed dot product operations using the OpSDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct32BitMixedSignednessAccelerated is a boolean that will be VK_TRUE if the support for 32-bit mixed signedness dot product operations using the OpSU DotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct64BitUnsignedAccelerated is a boolean that will be VK_TRUE if the support for 64-bit unsigned dot product operations using the OpUDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct64BitSignedAccelerated is a boolean that will be VK_TRUE if the support for 64-bit signed dot product operations using the OpSDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct64BitMixedSignednessAccelerated is a boolean that will be VK_TRUE if the support for 64-bit mixed signedness dot product operations using the OpSU DotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProductAccumulatingSaturating8BitUnsignedAccelerated is a boolean that will be VK_TRUE if the support for 8-bit unsigned accumulating saturating dot product operations using the OpUDotAccSatKHR SPIR-V instruction is accelerated as defined below.
• \texttt{integerDotProductAccumulatingSaturating8BitSignedAccelerated} is a boolean that will be \texttt{VK_TRUE} if the support for 8-bit signed accumulating saturating dot product operations using the \texttt{OpSDotAccSatKHR} SPIR-V instruction is accelerated \textcolor{red}{as defined below}.

• \texttt{integerDotProductAccumulatingSaturating8BitMixedSignednessAccelerated} is a boolean that will be \texttt{VK_TRUE} if the support for 8-bit mixed signedness accumulating saturating dot product operations using the \texttt{OpSUDotAccSatKHR} SPIR-V instruction is accelerated \textcolor{red}{as defined below}.

• \texttt{integerDotProductAccumulatingSaturating4x8BitPackedUnsignedAccelerated} is a boolean that will be \texttt{VK_TRUE} if the support for 8-bit unsigned accumulating saturating dot product operations from operands packed into 32-bit integers using the \texttt{OpUDotAccSatKHR} SPIR-V instruction is accelerated \textcolor{red}{as defined below}.

• \texttt{integerDotProductAccumulatingSaturating4x8BitPackedSignedAccelerated} is a boolean that will be \texttt{VK_TRUE} if the support for 8-bit signed accumulating saturating dot product operations from operands packed into 32-bit integers using the \texttt{OpSDotAccSatKHR} SPIR-V instruction is accelerated \textcolor{red}{as defined below}.

• \texttt{integerDotProductAccumulatingSaturating4x8BitPackedMixedSignednessAccelerated} is a boolean that will be \texttt{VK_TRUE} if the support for 8-bit mixed signedness accumulating saturating dot product operations from operands packed into 32-bit integers using the \texttt{OpSUDotAccSatKHR} SPIR-V instruction is accelerated \textcolor{red}{as defined below}.

• \texttt{integerDotProductAccumulatingSaturating16BitUnsignedAccelerated} is a boolean that will be \texttt{VK_TRUE} if the support for 16-bit unsigned accumulating saturating dot product operations using the \texttt{OpUDotAccSatKHR} SPIR-V instruction is accelerated \textcolor{red}{as defined below}.

• \texttt{integerDotProductAccumulatingSaturating16BitSignedAccelerated} is a boolean that will be \texttt{VK_TRUE} if the support for 16-bit signed accumulating saturating dot product operations using the \texttt{OpSDotAccSatKHR} SPIR-V instruction is accelerated \textcolor{red}{as defined below}.

• \texttt{integerDotProductAccumulatingSaturating16BitMixedSignednessAccelerated} is a boolean that will be \texttt{VK_TRUE} if the support for 16-bit mixed signedness accumulating saturating dot product operations using the \texttt{OpSUDotAccSatKHR} SPIR-V instruction is accelerated \textcolor{red}{as defined below}.

• \texttt{integerDotProductAccumulatingSaturating32BitUnsignedAccelerated} is a boolean that will be \texttt{VK_TRUE} if the support for 32-bit unsigned accumulating saturating dot product operations using the \texttt{OpUDotAccSatKHR} SPIR-V instruction is accelerated \textcolor{red}{as defined below}.

• \texttt{integerDotProductAccumulatingSaturating32BitSignedAccelerated} is a boolean that will be \texttt{VK_TRUE} if the support for 32-bit signed accumulating saturating dot product operations using the \texttt{OpSDotAccSatKHR} SPIR-V instruction is accelerated \textcolor{red}{as defined below}.

• \texttt{integerDotProductAccumulatingSaturating32BitMixedSignednessAccelerated} is a boolean that will be \texttt{VK_TRUE} if the support for 32-bit mixed signedness accumulating saturating dot product operations using the \texttt{OpSUDotAccSatKHR} SPIR-V instruction is accelerated \textcolor{red}{as defined below}.

• \texttt{integerDotProductAccumulatingSaturating64BitUnsignedAccelerated} is a boolean that will be \texttt{VK_TRUE} if the support for 64-bit unsigned accumulating saturating dot product operations using the \texttt{OpUDotAccSatKHR} SPIR-V instruction is accelerated \textcolor{red}{as defined below}.

• \texttt{integerDotProductAccumulatingSaturating64BitSignedAccelerated} is a boolean that will be \texttt{VK_TRUE} if the support for 64-bit signed accumulating saturating dot product operations using the \texttt{OpSDotAccSatKHR} SPIR-V instruction is accelerated \textcolor{red}{as defined below}.

• \texttt{integerDotProductAccumulatingSaturating64BitMixedSignednessAccelerated} is a boolean that will be \texttt{VK_TRUE} if the support for 64-bit mixed signedness accumulating saturating dot product operations using the \texttt{OpSUDotAccSatKHR} SPIR-V instruction is accelerated \textcolor{red}{as defined below}.
be `VK_TRUE` if the support for 64-bit mixed signedness accumulating saturating dot product operations using the `OpSUDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

- `storageTexelBufferOffsetAlignmentBytes` is a byte alignment that is sufficient for a storage texel buffer of any format. The value must be a power of two.
- `storageTexelBufferOffsetSingleTexelAlignment` indicates whether single texel alignment is sufficient for a storage texel buffer of any format.
- `uniformTexelBufferOffsetAlignmentBytes` is a byte alignment that is sufficient for a uniform texel buffer of any format. The value must be a power of two.
- `uniformTexelBufferOffsetSingleTexelAlignment` indicates whether single texel alignment is sufficient for a uniform texel buffer of any format.
- `maxBufferSize` is the maximum size `VkBuffer` that can be created.

If the `VkPhysicalDeviceVulkan13Properties` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

These properties correspond to Vulkan 1.3 functionality.

The members of `VkPhysicalDeviceVulkan13Properties` must have the same values as the corresponding members of `VkPhysicalDeviceInlineUniformBlockProperties` and `VkPhysicalDeviceSubgroupSizeControlProperties`.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceVulkan13Properties-sType-sType
  
sType must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_3_PROPERTIES`

The `VkPhysicalDeviceIDProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceIDProperties {
    VkStructureType sType;
    void* pNext;
    uint8_t deviceUUID[VK_UUID_SIZE];
    uint8_t driverUUID[VK_UUID_SIZE];
    uint8_t deviceLUID[VK_LUID_SIZE];
    uint32_t deviceNodeMask;
    VkBool32 deviceLUIDValid;
} VkPhysicalDeviceIDProperties;
```

or the equivalent

```c
// Provided by VK_KHR_external_fence_capabilities,
// VK_KHR_external_memory_capabilities, VK_KHR_external_semaphore_capabilities
```
typedef VkPhysicalDeviceIDProperties VkPhysicalDeviceIDPropertiesKHR;

• **sType** is a `VkStructureType` value identifying this structure.
• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **deviceUUID** is an array of `VK_UUID_SIZE uint8_t` values representing a universally unique identifier for the device.
• **driverUUID** is an array of `VK_UUID_SIZE uint8_t` values representing a universally unique identifier for the driver build in use by the device.
• **deviceLUID** is an array of `VK_LUID_SIZE uint8_t` values representing a locally unique identifier for the device.
• **deviceNodeMask** is a `uint32_t` bitfield identifying the node within a linked device adapter corresponding to the device.

• **deviceLUIDValid** is a boolean value that will be `VK_TRUE` if `deviceLUID` contains a valid LUID and `deviceNodeMask` contains a valid node mask, and `VK_FALSE` if they do not.

If the `VkPhysicalDeviceIDProperties` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

**deviceUUID** must be immutable for a given device across instances, processes, driver APIs, driver versions, and system reboots.

Applications can compare the **driverUUID** value across instance and process boundaries, and can make similar queries in external APIs to determine whether they are capable of sharing memory objects and resources using them with the device.

**deviceUUID** and/or **driverUUID** must be used to determine whether a particular external object can be shared between driver components, where such a restriction exists as defined in the compatibility table for the particular object type:

• External memory handle types compatibility
• External semaphore handle types compatibility
• External fence handle types compatibility

If **deviceLUIDValid** is `VK_FALSE`, the values of **deviceLUID** and **deviceNodeMask** are undefined. If **deviceLUIDValid** is `VK_TRUE` and Vulkan is running on the Windows operating system, the contents of **deviceLUID** can be cast to an `LUID` object and must be equal to the locally unique identifier of a `IDXGIAdapter1` object that corresponds to `physicalDevice`. If **deviceLUIDValid** is `VK_TRUE`, **deviceNodeMask** must contain exactly one bit. If Vulkan is running on an operating system that supports the Direct3D 12 API and `physicalDevice` corresponds to an individual device in a linked device adapter, **deviceNodeMask** identifies the Direct3D 12 node corresponding to `physicalDevice`. Otherwise, **deviceNodeMask** must be 1.

**Note**
Although they have identical descriptions, `VkPhysicalDeviceIDProperties`
deviceUUID may differ from VkPhysicalDeviceProperties2::pipelineCacheUUID. The former is intended to identify and correlate devices across API and driver boundaries, while the latter is used to identify a compatible device and driver combination to use when serializing and de-serializing pipeline state.

Implementations should return deviceUUID values which are likely to be unique even in the presence of multiple Vulkan implementations (such as a GPU driver and a software renderer; two drivers for different GPUs; or the same Vulkan driver running on two logically different devices).

Khronos' conformance testing is unable to guarantee that deviceUUID values are actually unique, so implementors should make their own best efforts to ensure this. In particular, hard-coded deviceUUID values, especially all-0 bits, should never be used.

A combination of values unique to the vendor, the driver, and the hardware environment can be used to provide a deviceUUID which is unique to a high degree of certainty. Some possible inputs to such a computation are:

- Information reported by vkGetPhysicalDeviceProperties
- PCI device ID (if defined)
- PCI bus ID, or similar system configuration information.
- Driver binary checksums.

**Note**
While VkPhysicalDeviceIDProperties::deviceUUID is specified to remain consistent across driver versions and system reboots, it is not intended to be usable as a serializable persistent identifier for a device. It may change when a device is physically added to, removed from, or moved to a different connector in a system while that system is powered down. Further, there is no reasonable way to verify with conformance testing that a given device retains the same UUID in a given system across all driver versions supported in that system. While implementations should make every effort to report consistent device UUIDs across driver versions, applications should avoid relying on the persistence of this value for uses other than identifying compatible devices for external object sharing purposes.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceIDProperties-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ID_PROPERTIES

VK_UUID_SIZE is the length in uint8_t values of an array containing a universally unique device or driver build identifier, as returned in VkPhysicalDeviceIDProperties::deviceUUID and VkPhysicalDeviceIDProperties::driverUUID.
VK_UUID_SIZE is the length in `uint8_t` values of an array containing a locally unique device identifier, as returned in `VkPhysicalDeviceIDProperties::deviceLUID`.

```
#define VK_LUID_SIZE                      16U
```

or the equivalent

```
#define VK_LUID_SIZE                      8U
```

or the equivalent

```
#define VK_LUID_SIZE_KHR                  VK_LUID_SIZE
```

The `VkPhysicalDeviceDriverProperties` structure is defined as:

```
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceDriverProperties {
    VkStructureType sType;
    void* pNext;
    VkDriverId driverID;
    char driverName[VK_MAX_DRIVER_NAME_SIZE];
    char driverInfo[VK_MAX_DRIVER_INFO_SIZE];
    VkConformanceVersion conformanceVersion;
} VkPhysicalDeviceDriverProperties;
```

or the equivalent

```
// Provided by VK_KHR_driver_properties
typedef VkPhysicalDeviceDriverProperties VkPhysicalDeviceDriverPropertiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `driverID` is a unique identifier for the driver of the physical device.
- `driverName` is an array of `VK_MAX_DRIVER_NAME_SIZE` `char` containing a null-terminated UTF-8 string which is the name of the driver.
- `driverInfo` is an array of `VK_MAX_DRIVER_INFO_SIZE` `char` containing a null-terminated UTF-8 string with additional information about the driver.
- `conformanceVersion` is the version of the Vulkan conformance test this driver is conformant against (see `VkConformanceVersion`).

If the `VkPhysicalDeviceDriverProperties` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.
These are properties of the driver corresponding to a physical device.

driverID must be immutable for a given driver across instances, processes, driver versions, and system reboots.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDriverProperties-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DRIVER_PROPERTIES

Khronos driver IDs which may be returned in VkPhysicalDeviceDriverProperties::driverID are:

```c
typedef enum VkDriverId {
    VK_DRIVER_ID_AMD_PROPRIETARY = 1,
    VK_DRIVER_ID_AMD_OPEN_SOURCE = 2,
    VK_DRIVER_ID_MESA_RADV = 3,
    VK_DRIVER_ID_NVIDIA_PROPRIETARY = 4,
    VK_DRIVER_ID_INTEL_PROPRIETARY_WINDOWS = 5,
    VK_DRIVER_ID_INTEL_OPEN_SOURCE_MESA = 6,
    VK_DRIVER_ID_IMAGINATION_PROPRIETARY = 7,
    VK_DRIVER_ID_QUALCOMM_PROPRIETARY = 8,
    VK_DRIVER_ID_ARM_PROPRIETARY = 9,
    VK_DRIVER_ID_GOOGLE_SWIFTSHADER = 10,
    VK_DRIVER_ID_GGP_PROPRIETARY = 11,
    VK_DRIVER_ID_BROADCOM_PROPRIETARY = 12,
    VK_DRIVER_ID_MESA_LLVMPIPE = 13,
    VK_DRIVER_ID_MOLTENVK = 14,
    VK_DRIVER_ID_COREAVI_PROPRIETARY = 15,
    VK_DRIVER_ID_JUICE_PROPRIETARY = 16,
    VK_DRIVER_ID_VERISILICON_PROPRIETARY = 17,
    VK_DRIVER_ID_MESA_TURNIP = 18,
    VK_DRIVER_ID_MESA_V3DV = 19,
    VK_DRIVER_ID_MESA_PANVK = 20,
    VK_DRIVER_ID_SAMSUNG_PROPRIETARY = 21,
    VK_DRIVER_ID_MESA_VENUS = 22,
    VK_DRIVER_ID_MESA_DOZEN = 23,
    VK_DRIVER_ID_MESA_NVK = 24,
    VK_DRIVER_ID_IMAGINATION_OPEN_SOURCE_MESA = 25,
} VkDriverId;
```

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VK_DRIVER_ID_INTEL_PROPRIETARY_WINDOWS,
   // Provided by VK_KHR_driver_properties
   VK_DRIVER_ID_INTEL_OPEN_SOURCE_MESA_KHR = VK_DRIVER_ID_INTEL_OPEN_SOURCE_MESA,
   // Provided by VK_KHR_driver_properties
   VK_DRIVER_ID_IMAGINATION_PROPRIETARY_KHR = VK_DRIVER_ID_IMAGINATION_PROPRIETARY,
   // Provided by VK_KHR_driver_properties
   VK_DRIVER_ID_QUALCOMM_PROPRIETARY_KHR = VK_DRIVER_ID_QUALCOMM_PROPRIETARY,
   // Provided by VK_KHR_driver_properties
   VK_DRIVER_ID_ARM_PROPRIETARY_KHR = VK_DRIVER_ID_ARM_PROPRIETARY,
   // Provided by VK_KHR_driver_properties
   VK_DRIVER_ID_GOOGLE_SWIFTSHADER_KHR = VK_DRIVER_ID_GOOGLE_SWIFTSHADER,
   // Provided by VK_KHR_driver_properties
   VK_DRIVER_ID_GGP_PROPRIETARY_KHR = VK_DRIVER_ID_GGP_PROPRIETARY,
   // Provided by VK_KHR_driver_properties
   VK_DRIVER_ID_BROADCOM_PROPRIETARY_KHR = VK_DRIVER_ID_BROADCOM_PROPRIETARY,
} VkDriverId;

or the equivalent

// Provided by VK_KHR_driver_properties
typedef VkDriverId VkDriverIdKHR;

Note
Khronos driver IDs may be allocated by vendors at any time. There may be multiple driver IDs for the same vendor, representing different drivers (for e.g. different platforms, proprietary or open source, etc.). Only the latest canonical versions of this Specification, of the corresponding \textit{vk.xml} API Registry, and of the corresponding \textit{vulkan_core.h} header file \textbf{must} contain all reserved Khronos driver IDs.

Only driver IDs registered with Khronos are given symbolic names. There \textbf{may be} unregistered driver IDs returned.

\textbf{VK\_MAX\_DRIVER\_NAME\_SIZE} is the length in \texttt{char} values of an array containing a driver name string, as returned in \texttt{VkPhysicalDeviceDriverProperties::driverName}.

\begin{verbatim}
#define VK_MAX_DRIVER_NAME_SIZE 256U
\end{verbatim}

or the equivalent

\begin{verbatim}
#define VK_MAX_DRIVER_NAME_SIZE_KHR VK_MAX_DRIVER_NAME_SIZE
\end{verbatim}

\textbf{VK\_MAX\_DRIVER\_INFO\_SIZE} is the length in \texttt{char} values of an array containing a driver information string, as returned in \texttt{VkPhysicalDeviceDriverProperties::driverInfo}.
```c
#define VK_MAX_DRIVER_INFO_SIZE           256U

or the equivalent

#define VK_MAX_DRIVER_INFO_SIZE_KHR       VK_MAX_DRIVER_INFO_SIZE

The conformance test suite version an implementation is compliant with is described with the `VkConformanceVersion` structure:

```c
// Provided by VK_VERSION_1_2
typedef struct VkConformanceVersion {
    uint8_t major;
    uint8_t minor;
    uint8_t subminor;
    uint8_t patch;
} VkConformanceVersion;
```

or the equivalent

```c
// Provided by VK_KHR_driver_properties
typedef VkConformanceVersion VkConformanceVersionKHR;
```

- **major** is the major version number of the conformance test suite.
- **minor** is the minor version number of the conformance test suite.
- **subminor** is the subminor version number of the conformance test suite.
- **patch** is the patch version number of the conformance test suite.

The `VkPhysicalDevicePCIBusInfoPropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_pci_bus_info
typedef struct VkPhysicalDevicePCIBusInfoPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t pciDomain;
    uint32_t pciBus;
    uint32_t pciDevice;
    uint32_t pciFunction;
} VkPhysicalDevicePCIBusInfoPropertiesEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **pciDomain** is the PCI bus domain.
• `pciBus` is the PCI bus identifier.
• `pciDevice` is the PCI device identifier.
• `pciFunction` is the PCI device function identifier.

If the `VkPhysicalDevicePCIBusInfoPropertiesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

These are properties of the PCI bus information of a physical device.

**Valid Usage (Implicit)**

• VUID-VkPhysicalDevicePCIBusInfoPropertiesEXT-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PCI_BUS_INFO_PROPERTIES_EXT`

The `VkPhysicalDeviceDrmPropertiesEXT` structure is defined as:

```
// Provided by VK_EXT_physical_device_drm
typedef struct VkPhysicalDeviceDrmPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 hasPrimary;
    VkBool32 hasRender;
    int64_t primaryMajor;
    int64_t primaryMinor;
    int64_t renderMajor;
    int64_t renderMinor;
} VkPhysicalDeviceDrmPropertiesEXT;
```

• `sType` is a `VkStructureType` value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.
• `hasPrimary` is a boolean indicating whether the physical device has a DRM primary node.
• `hasRender` is a boolean indicating whether the physical device has a DRM render node.
• `primaryMajor` is the DRM primary node major number, if any.
• `primaryMinor` is the DRM primary node minor number, if any.
• `renderMajor` is the DRM render node major number, if any.
• `renderMinor` is the DRM render node minor number, if any.

If the `VkPhysicalDeviceDrmPropertiesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

These are properties of the DRM information of a physical device.
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDrmPropertiesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DRM_PROPERTIES_EXT

The `VkPhysicalDeviceShaderIntegerDotProductProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceShaderIntegerDotProductProperties {
    VkStructureType sType;
    void* pNext;
    VkBool32 integerDotProduct8BitUnsignedAccelerated;
    VkBool32 integerDotProduct8BitSignedAccelerated;
    VkBool32 integerDotProduct8BitMixedSignednessAccelerated;
    VkBool32 integerDotProduct4x8BitPackedUnsignedAccelerated;
    VkBool32 integerDotProduct4x8BitPackedSignedAccelerated;
    VkBool32 integerDotProduct4x8BitPackedMixedSignednessAccelerated;
    VkBool32 integerDotProduct16BitUnsignedAccelerated;
    VkBool32 integerDotProduct16BitSignedAccelerated;
    VkBool32 integerDotProduct16BitMixedSignednessAccelerated;
    VkBool32 integerDotProduct32BitUnsignedAccelerated;
    VkBool32 integerDotProduct32BitSignedAccelerated;
    VkBool32 integerDotProduct32BitMixedSignednessAccelerated;
    VkBool32 integerDotProduct64BitUnsignedAccelerated;
    VkBool32 integerDotProduct64BitSignedAccelerated;
    VkBool32 integerDotProduct64BitMixedSignednessAccelerated;
    VkBool32 integerDotProductAccumulatingSaturating8BitUnsignedAccelerated;
    VkBool32 integerDotProductAccumulatingSaturating8BitSignedAccelerated;
    VkBool32 integerDotProductAccumulatingSaturating8BitMixedSignednessAccelerated;
    VkBool32 integerDotProductAccumulatingSaturating4x8BitPackedUnsignedAccelerated;
    VkBool32 integerDotProductAccumulatingSaturating4x8BitPackedSignedAccelerated;
    VkBool32 integerDotProductAccumulatingSaturating4x8BitPackedMixedSignednessAccelerated;
    VkBool32 integerDotProductAccumulatingSaturating16BitUnsignedAccelerated;
    VkBool32 integerDotProductAccumulatingSaturating16BitSignedAccelerated;
    VkBool32 integerDotProductAccumulatingSaturating16BitMixedSignednessAccelerated;
    VkBool32 integerDotProductAccumulatingSaturating32BitUnsignedAccelerated;
    VkBool32 integerDotProductAccumulatingSaturating32BitSignedAccelerated;
    VkBool32 integerDotProductAccumulatingSaturating32BitMixedSignednessAccelerated;
    VkBool32 integerDotProductAccumulatingSaturating64BitUnsignedAccelerated;
    VkBool32 integerDotProductAccumulatingSaturating64BitSignedAccelerated;
} VkPhysicalDeviceShaderIntegerDotProductProperties;
```
VkBool32 integerDotProductAccumulatingSaturating64BitMixedSignednessAccelerated;
} VkPhysicalDeviceShaderIntegerDotProductProperties;

or the equivalent

// Provided by VK_KHR_shader_integer_dot_product
typedef VkPhysicalDeviceShaderIntegerDotProductProperties
VkPhysicalDeviceShaderIntegerDotProductPropertiesKHR;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.

• integerDotProduct8BitUnsignedAccelerated is a boolean that will be VK_TRUE if the support for 8-bit unsigned dot product operations using the OpUDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct8BitSignedAccelerated is a boolean that will be VK_TRUE if the support for 8-bit signed dot product operations using the OpSDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct8BitMixedSignednessAccelerated is a boolean that will be VK_TRUE if the support for 8-bit mixed signedness dot product operations using the OpSUDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct4x8BitPackedUnsignedAccelerated is a boolean that will be VK_TRUE if the support for 8-bit unsigned dot product operations from operands packed into 32-bit integers using the OpUDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct4x8BitPackedSignedAccelerated is a boolean that will be VK_TRUE if the support for 8-bit signed dot product operations from operands packed into 32-bit integers using the OpSDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct4x8BitPackedMixedSignednessAccelerated is a boolean that will be VK_TRUE if the support for 8-bit mixed signedness dot product operations from operands packed into 32-bit integers using the OpSUDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct16BitUnsignedAccelerated is a boolean that will be VK_TRUE if the support for 16-bit unsigned dot product operations using the OpUDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct16BitSignedAccelerated is a boolean that will be VK_TRUE if the support for 16-bit signed dot product operations using the OpSDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct16BitMixedSignednessAccelerated is a boolean that will be VK_TRUE if the support for 16-bit mixed signedness dot product operations using the OpSUDotKHR SPIR-V instruction is accelerated as defined below.

• integerDotProduct32BitUnsignedAccelerated is a boolean that will be VK_TRUE if the support for 32-bit unsigned dot product operations using the OpUDotKHR SPIR-V instruction is accelerated as defined below.
• **integerDotProduct32BitSignedAccelerated** is a boolean that will be `VK_TRUE` if the support for 32-bit signed dot product operations using the `OpSDotKHR` SPIR-V instruction is accelerated as defined below.

• **integerDotProduct32BitMixedSignednessAccelerated** is a boolean that will be `VK_TRUE` if the support for 32-bit mixed signedness dot product operations using the `OpSUDotKHR` SPIR-V instruction is accelerated as defined below.

• **integerDotProduct64BitUnsignedAccelerated** is a boolean that will be `VK_TRUE` if the support for 64-bit unsigned dot product operations using the `OpUDotKHR` SPIR-V instruction is accelerated as defined below.

• **integerDotProduct64BitSignedAccelerated** is a boolean that will be `VK_TRUE` if the support for 64-bit signed dot product operations using the `OpSDotKHR` SPIR-V instruction is accelerated as defined below.

• **integerDotProduct64BitMixedSignednessAccelerated** is a boolean that will be `VK_TRUE` if the support for 64-bit mixed signedness dot product operations using the `OpSUDotKHR` SPIR-V instruction is accelerated as defined below.

• **integerDotProductAccumulatingSaturating8BitUnsignedAccelerated** is a boolean that will be `VK_TRUE` if the support for 8-bit unsigned accumulating saturating dot product operations using the `OpUDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

• **integerDotProductAccumulatingSaturating8BitSignedAccelerated** is a boolean that will be `VK_TRUE` if the support for 8-bit signed accumulating saturating dot product operations using the `OpSDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

• **integerDotProductAccumulatingSaturating8BitMixedSignednessAccelerated** is a boolean that will be `VK_TRUE` if the support for 8-bit mixed signedness accumulating saturating dot product operations using the `OpSUDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

• **integerDotProductAccumulatingSaturating4x8BitPackedUnsignedAccelerated** is a boolean that will be `VK_TRUE` if the support for 8-bit unsigned accumulating saturating dot product operations from operands packed into 32-bit integers using the `OpUDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

• **integerDotProductAccumulatingSaturating4x8BitPackedSignedAccelerated** is a boolean that will be `VK_TRUE` if the support for 8-bit signed accumulating saturating dot product operations from operands packed into 32-bit integers using the `OpSDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

• **integerDotProductAccumulatingSaturating4x8BitPackedMixedSignednessAccelerated** is a boolean that will be `VK_TRUE` if the support for 8-bit mixed signedness accumulating saturating dot product operations from operands packed into 32-bit integers using the `OpSUDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

• **integerDotProductAccumulatingSaturating16BitUnsignedAccelerated** is a boolean that will be `VK_TRUE` if the support for 16-bit unsigned accumulating saturating dot product operations using the `OpUDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

• **integerDotProductAccumulatingSaturating16BitSignedAccelerated** is a boolean that will be `VK_TRUE` if the support for 16-bit signed accumulating saturating dot product operations using the `OpSDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

• **integerDotProductAccumulatingSaturating16BitMixedSignednessAccelerated** is a boolean that will be `VK_TRUE` if the support for 16-bit mixed signedness accumulating saturating dot product operations using the `OpSUDotAccSatKHR` SPIR-V instruction is accelerated as defined below.
be **VK_TRUE** if the support for 16-bit mixed signedness accumulating saturating dot product operations using the `OpSUDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

- **integerDotProductAccumulatingSaturating32BitUnsignedAccelerated** is a boolean that will be **VK_TRUE** if the support for 32-bit unsigned accumulating saturating dot product operations using the `OpUDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

- **integerDotProductAccumulatingSaturating32BitSignedAccelerated** is a boolean that will be **VK_TRUE** if the support for 32-bit signed accumulating saturating dot product operations using the `OpSDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

- **integerDotProductAccumulatingSaturating32BitMixedSignednessAccelerated** is a boolean that will be **VK_TRUE** if the support for 32-bit mixed signedness accumulating saturating dot product operations using the `OpSUDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

- **integerDotProductAccumulatingSaturating64BitUnsignedAccelerated** is a boolean that will be **VK_TRUE** if the support for 64-bit unsigned accumulating saturating dot product operations using the `OpUDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

- **integerDotProductAccumulatingSaturating64BitSignedAccelerated** is a boolean that will be **VK_TRUE** if the support for 64-bit signed accumulating saturating dot product operations using the `OpSDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

- **integerDotProductAccumulatingSaturating64BitMixedSignednessAccelerated** is a boolean that will be **VK_TRUE** if the support for 64-bit mixed signedness accumulating saturating dot product operations using the `OpSUDotAccSatKHR` SPIR-V instruction is accelerated as defined below.

If the `VkPhysicalDeviceShaderIntegerDotProductProperties` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

These are properties of the integer dot product acceleration information of a physical device.

**Note**

A dot product operation is deemed accelerated if its implementation provides a performance advantage over application-provided code composed from elementary instructions and/or other dot product instructions, either because the implementation uses optimized machine code sequences whose generation from application-provided code cannot be guaranteed or because it uses hardware features that cannot otherwise be targeted from application-provided code.

**Valid Usage (Implicit)**

- **VUID-VkPhysicalDeviceShaderIntegerDotProductProperties-sType-sType**  
  **sType** must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_INTEGER_DOT_PRODUCT_PROPERTIES**

The `VkPhysicalDeviceImageProcessingPropertiesQCOM` structure is defined as:

```c
// Provided by VK_QCOM_image_processing
typedef struct VkPhysicalDeviceImageProcessingPropertiesQCOM {
```

```c
```
VkStructureType sType;  
void* pNext;  
uint32_t maxWeightFilterPhases;  
VkExtent2D maxWeightFilterDimension;  
VkExtent2D maxBlockMatchRegion;  
VkExtent2D maxBoxFilterBlockSize;
} VkPhysicalDeviceImageProcessingPropertiesQCOM;

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **maxWeightFilterPhases** is the maximum value that **can** be specified for *VkImageViewSampleWeightCreateInfoQCOM::numPhases* in weight image sampling operations.
- **maxWeightFilterDimension** is a *VkExtent2D* describing the largest dimensions (width and height) that **can** be specified for *VkImageViewSampleWeightCreateInfoQCOM::filterSize*.
- **maxBlockMatchRegion** is a *VkExtent2D* describing the largest dimensions (width and height) that **can** be specified for *blockSize* in block matching operations.
- **maxBoxFilterBlockSize** is a *VkExtent2D* describing the maximum dimensions (width and height) that **can** be specified for *blocksize* in box filter sampling operations.

If the *VkPhysicalDeviceImageProcessingPropertiesQCOM* structure is included in the **pNext** chain of the *VkPhysicalDeviceProperties2* structure passed to *vkGetPhysicalDeviceProperties2*, it is filled in with each corresponding implementation-dependent property.

These are properties of the image processing information of a physical device.

Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceImageProcessingPropertiesQCOM-sType-sType**
  
  **sType must be** [VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_PROCESSING_PROPERTIES_QCOM](#)

The *VkPhysicalDeviceShaderTileImagePropertiesEXT* structure is defined as:

```c
// Provided by VK_EXT_shader_tile_image
typedef struct VkPhysicalDeviceShaderTileImagePropertiesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderTileImageCoherentReadAccelerated;
    VkBool32 shaderTileImageReadSampleFromPixelRateInvocation;
    VkBool32 shaderTileImageReadFromHelperInvocation;
} VkPhysicalDeviceShaderTileImagePropertiesEXT;
```

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **shaderTileImageCoherentReadAccelerated** is a boolean that will be **VK_TRUE** if coherent reads of tile
image data is accelerated.

- `shaderTileImageReadSampleFromPixelRateInvocation` is a boolean that will be `VK_TRUE` if reading from samples from a pixel rate fragment invocation is supported when `VkPipelineMultisampleStateCreateInfo::rasterizationSamples > 1`.

- `shaderTileImageReadFromHelperInvocation` is a boolean that will be `VK_TRUE` if reads of tile image data from helper fragment invocations result in valid values.

If the `VkPhysicalDeviceShaderTileImagePropertiesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

These are properties of the tile image information of a physical device.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceShaderTileImagePropertiesEXT-sType-sType
  
  **sType** must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_TILE_IMAGE_PROPERTIES_EXT`

The `VkPhysicalDeviceImageProcessing2PropertiesQCOM` structure is defined as:

```c
// Provided by VK_QCOM_image_processing2
typedef struct VkPhysicalDeviceImageProcessing2PropertiesQCOM {
    VkStructureType sType;
    void* pNext;
    VkExtent2D maxBlockMatchWindow;
} VkPhysicalDeviceImageProcessing2PropertiesQCOM;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **maxBlockMatchWindow** is a `VkExtent2D` describing the largest dimensions (width and height) that can be specified for the block match window.

If the `VkPhysicalDeviceImageProcessing2PropertiesQCOM` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

These are properties of the image processing2 information of a physical device.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceImageProcessing2PropertiesQCOM-sType-sType
  
  **sType** must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_PROCESSING_2_PROPERTIES_QCOM`

The `VkPhysicalDeviceLayeredDriverPropertiesMSFT` structure is defined as:
typedef struct VkPhysicalDeviceLayeredDriverPropertiesMSFT {
    VkStructureType sType;
    void* pNext;
    VkLayeredDriverUnderlyingApiMSFT underlyingAPI;
} VkPhysicalDeviceLayeredDriverPropertiesMSFT;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• underlyingAPI is a VkLayeredDriverUnderlyingApiMSFT value indicating which underlying API is used to implement the layered driver, or VK_LAYERED_DRIVER_UNDERLYING_API_NONE_MSFT if the driver is not layered.

These are properties of the driver layering information of a physical device.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceLayeredDriverPropertiesMSFT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_LAYERED_DRIVER_PROPERTIES_MSFT

Underlying APIs which may be returned in VkPhysicalDeviceLayeredDriverPropertiesMSFT::underlyingAPI are:

typedef enum VkLayeredDriverUnderlyingApiMSFT {
    VK_LAYERED_DRIVER_UNDERLYING_API_NONE_MSFT = 0,
    VK_LAYERED_DRIVER_UNDERLYING_API_D3D12_MSFT = 1,
} VkLayeredDriverUnderlyingApiMSFT;

To query properties of queues available on a physical device, call:

void vkGetPhysicalDeviceQueueFamilyProperties(
    VkPhysicalDevice physicalDevice,
    uint32_t* pQueueFamilyPropertyCount,
    VkQueueFamilyProperties* pQueueFamilyProperties);

• physicalDevice is the handle to the physical device whose properties will be queried.
• pQueueFamilyPropertyCount is a pointer to an integer related to the number of queue families available or queried, as described below.
• pQueueFamilyProperties is either NULL or a pointer to an array of VkQueueFamilyProperties structures.

If pQueueFamilyProperties is NULL, then the number of queue families available is returned in
pQueueFamilyPropertyCount. Implementations must support at least one queue family. Otherwise, pQueueFamilyPropertyCount must point to a variable set by the user to the number of elements in the pQueueFamilyProperties array, and on return the variable is overwritten with the number of structures actually written to pQueueFamilyProperties. If pQueueFamilyPropertyCount is less than the number of queue families available, at most pQueueFamilyPropertyCount structures will be written.

Valid Usage (Implicit)

• VUID-vkGetPhysicalDeviceQueueFamilyProperties-physicalDevice-parameter
physicalDevice must be a valid VkPhysicalDevice handle

• VUID-vkGetPhysicalDeviceQueueFamilyProperties-pQueueFamilyPropertyCount-parameter
pQueueFamilyPropertyCount must be a valid pointer to a uint32_t value

• VUID-vkGetPhysicalDeviceQueueFamilyProperties-pQueueFamilyProperties-parameter
If the value referenced by pQueueFamilyPropertyCount is not 0, and pQueueFamilyProperties is not NULL, pQueueFamilyProperties must be a valid pointer to an array of pQueueFamilyPropertyCount VkQueueFamilyProperties structures

The VkQueueFamilyProperties structure is defined as:

```
// Provided by VK_VERSION_1_0
typedef struct VkQueueFamilyProperties {
    VkQueueFlags queueFlags;
    uint32_t queueCount;
    uint32_t timestampValidBits;
    VkExtent3D minImageTransferGranularity;
} VkQueueFamilyProperties;
```

• queueFlags is a bitmask of VkQueueFlagBits indicating capabilities of the queues in this queue family.

• queueCount is the unsigned integer count of queues in this queue family. Each queue family must support at least one queue.

• timestampValidBits is the unsigned integer count of meaningful bits in the timestamps written via vkCmdWriteTimestamp2 or vkCmdWriteTimestamp. The valid range for the count is 36 to 64 bits, or a value of 0, indicating no support for timestamps. Bits outside the valid range are guaranteed to be zeros.

• minImageTransferGranularity is the minimum granularity supported for image transfer operations on the queues in this queue family.

The value returned in minImageTransferGranularity has a unit of compressed texel blocks for images having a block-compressed format, and a unit of texels otherwise.

Possible values of minImageTransferGranularity are:

• (0,0,0) specifies that only whole mip levels must be transferred using the image transfer
operations on the corresponding queues. In this case, the following restrictions apply to all offset and extent parameters of image transfer operations:

- The $x$, $y$, and $z$ members of a VkOffset3D parameter must always be zero.
- The width, height, and depth members of a VkExtent3D parameter must always match the width, height, and depth of the image subresource corresponding to the parameter, respectively.

- $(A_x, A_y, A_z)$ where $A_x$, $A_y$, and $A_z$ are all integer powers of two. In this case the following restrictions apply to all image transfer operations:
  - $x$, $y$, and $z$ of a VkOffset3D parameter must be integer multiples of $A_x$, $A_y$, and $A_z$, respectively.
  - width of a VkExtent3D parameter must be an integer multiple of $A_x$, or else $x + \text{width}$ must equal the width of the image subresource corresponding to the parameter.
  - height of a VkExtent3D parameter must be an integer multiple of $A_y$, or else $y + \text{height}$ must equal the height of the image subresource corresponding to the parameter.
  - depth of a VkExtent3D parameter must be an integer multiple of $A_z$, or else $z + \text{depth}$ must equal the depth of the image subresource corresponding to the parameter.
  - If the format of the image corresponding to the parameters is one of the block-compressed formats then for the purposes of the above calculations the granularity must be scaled up by the compressed texel block dimensions.

Queues supporting graphics and/or compute operations must report $(1,1,1)$ in minImageTransferGranularity, meaning that there are no additional restrictions on the granularity of image transfer operations for these queues. Other queues supporting image transfer operations are only required to support whole mip level transfers, thus minImageTransferGranularity for queues belonging to such queue families may be $(0,0,0)$.

The Device Memory section describes memory properties queried from the physical device.

For physical device feature queries see the Features chapter.

Bits which may be set in VkQueueFamilyProperties::queueFlags, indicating capabilities of queues in a queue family are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkQueueFlagBits {
    VK_QUEUE_GRAPHICS_BIT = 0x00000001,
    VK_QUEUE_COMPUTE_BIT = 0x00000002,
    VK_QUEUE_TRANSFER_BIT = 0x00000004,
    VK_QUEUE_SPARSE_BINDING_BIT = 0x00000008,
    // Provided by VK_VERSION_1_1
    VK_QUEUE_PROTECTED_BIT = 0x00000010,
    // Provided by VK_KHR_video_decode_queue
    VK_QUEUE_VIDEO_DECODE_BIT_KHR = 0x00000020,
    #ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_KHR_video_encode_queue
    VK_QUEUE_VIDEO_ENCODE_BIT_KHR = 0x00000040,
    #endif
};
```
• **VK_QUEUE_GRAPHICS_BIT** specifies that queues in this queue family support graphics operations.

• **VK_QUEUE.Compute_BIT** specifies that queues in this queue family support compute operations.

• **VK_QUEUE_TRANSFER_BIT** specifies that queues in this queue family support transfer operations.

• **VK_QUEUE_SPARSE_BINDING_BIT** specifies that queues in this queue family support sparse memory management operations (see Sparse Resources). If any of the sparse resource features are enabled, then at least one queue family must support this bit.

• **VK_QUEUE_VIDEO DECODE_BIT_KHR** specifies that queues in this queue family support video decode operations.

• **VK_QUEUE_VIDEO_ENCODE_BIT_KHR** specifies that queues in this queue family support video encode operations.

• **VK_QUEUE_OPTICAL_FLOW_BIT_NV** specifies that queues in this queue family support optical flow operations.

• **VK_QUEUE_PROTECTED_BIT** specifies that queues in this queue family support the `VK_DEVICE_QUEUE_CREATE_PROTECTED_BIT` bit. (see Protected Memory). If the physical device supports the protectedMemory feature, at least one of its queue families must support this bit.

If an implementation exposes any queue family that supports graphics operations, at least one queue family of at least one physical device exposed by the implementation must support both graphics and compute operations.

Furthermore, if the protectedMemory physical device feature is supported, then at least one queue family of at least one physical device exposed by the implementation must support graphics operations, compute operations, and protected memory operations.

---

**Note**

All commands that are allowed on a queue that supports transfer operations are also allowed on a queue that supports either graphics or compute operations. Thus, if the capabilities of a queue family include **VK_QUEUE_GRAPHICS_BIT** or **VK_QUEUE_COMPUTE_BIT**, then reporting the **VK_QUEUE_TRANSFER_BIT** capability separately for that queue family is optional.

For further details see Queues.
void vkGetPhysicalDeviceQueueFamilyProperties2(
    VkPhysicalDevice physicalDevice,
    uint32_t* pQueueFamilyPropertyCount,
    VkQueueFamilyProperties2* pQueueFamilyProperties);

or the equivalent command

void vkGetPhysicalDeviceQueueFamilyProperties2KHR(
    VkPhysicalDevice physicalDevice,
    uint32_t* pQueueFamilyPropertyCount,
    VkQueueFamilyProperties2* pQueueFamilyProperties);

- physicalDevice is the handle to the physical device whose properties will be queried.
- pQueueFamilyPropertyCount is a pointer to an integer related to the number of queue families available or queried, as described in vkGetPhysicalDeviceQueueFamilyProperties.
- pQueueFamilyProperties is either NULL or a pointer to an array of VkQueueFamilyProperties2 structures.

vkGetPhysicalDeviceQueueFamilyProperties2 behaves similarly to vkGetPhysicalDeviceQueueFamilyProperties, with the ability to return extended information in a pNext chain of output structures.

**Valid Usage (Implicit)**

- VUID-vkGetPhysicalDeviceQueueFamilyProperties2-physicalDevice-parameter physicalDevice must be a valid VkPhysicalDevice handle
- VUID-vkGetPhysicalDeviceQueueFamilyProperties2-pQueueFamilyPropertyCount-parameter pQueueFamilyPropertyCount must be a valid pointer to a uint32_t value
- VUID-vkGetPhysicalDeviceQueueFamilyProperties2-pQueueFamilyProperties-parameter If the value referenced by pQueueFamilyPropertyCount is not 0, and pQueueFamilyProperties is not NULL, pQueueFamilyProperties must be a valid pointer to an array of pQueueFamilyPropertyCount VkQueueFamilyProperties2 structures

The VkQueueFamilyProperties2 structure is defined as:

typedef struct VkQueueFamilyProperties2 {
    VkStructureType sType;
    void* pNext;
    VkQueueFamilyProperties queueFamilyProperties;
};
} VkQueueFamilyProperties2;

or the equivalent

```c
// Provided by VK_KHR_get_physical_device_properties2
typedef VkQueueFamilyProperties2 VkQueueFamilyProperties2KHR;
```

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **queueFamilyProperties** is a *VkQueueFamilyProperties* structure which is populated with the same values as in *vkGetPhysicalDeviceQueueFamilyProperties*.

### Valid Usage (Implicit)

- **VUID-VkQueueFamilyProperties2-sType-sType**
  
  *sType* must be **VK_STRUCTURE_TYPE_QUEUE_FAMILY_PROPERTIES_2**

- **VUID-VkQueueFamilyProperties2-pNext-pNext**
  
  Each **pNext** member of any structure (including this one) in the **pNext** chain must be either **NULL** or a pointer to a valid instance of *VkQueueFamilyCheckpointProperties2NV*, *VkQueueFamilyCheckpointPropertiesNV*, *VkQueueFamilyGlobalPriorityPropertiesKHR*, *VkQueueFamilyQueryResultStatusPropertiesKHR*, or *VkQueueFamilyVideoPropertiesKHR*.

- **VUID-VkQueueFamilyProperties2-sType-unique**
  
  The **sType** value of each struct in the **pNext** chain must be unique.

The definition of *VkQueueFamilyGlobalPriorityPropertiesKHR* is:

```c
// Provided by VK_KHR_global_priority
typedef struct VkQueueFamilyGlobalPriorityPropertiesKHR {
    VkStructureType sType;
    void* pNext;
    uint32_t priorityCount;
    VkQueueGlobalPriorityKHR priorities[VK_MAX_GLOBAL_PRIORITY_SIZE_KHR];
} VkQueueFamilyGlobalPriorityPropertiesKHR;
```

or the equivalent

```c
// Provided by VK_EXT_global_priority_query
typedef VkQueueFamilyGlobalPriorityPropertiesKHR
VkQueueFamilyGlobalPriorityPropertiesEXT;
```

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
• priorityCount is the number of supported global queue priorities in this queue family, and it **must** be greater than 0.

• priorities is an array of `VK_MAX_GLOBAL_PRIORITY_SIZE_EXT` VkQueueGlobalPriorityEXT enums representing all supported global queue priorities in this queue family. The first priorityCount elements of the array will be valid.

If the `VkQueueFamilyGlobalPriorityPropertiesKHR` structure is included in the pNext chain of the `VkQueueFamilyProperties2` structure passed to `vkGetPhysicalDeviceQueueFamilyProperties2`, it is filled in with the list of supported global queue priorities for the indicated family.

The valid elements of priorities **must** not contain any duplicate values.

The valid elements of priorities **must** be a continuous sequence of VkQueueGlobalPriorityKHR enums in the ascending order.

**Note**

For example, returning priorityCount as 3 with supported priorities as VK_QUEUE_GLOBAL_PRIORITY_LOW_KHR, VK_QUEUE_GLOBAL_PRIORITY_MEDIUM_KHR and VK_QUEUE_GLOBAL_PRIORITY_REALTIME_KHR is not allowed.

**Valid Usage (Implicit)**

- VUID-VkQueueFamilyGlobalPriorityPropertiesKHR-sType-sType
  sType **must be** VK_STRUCTURE_TYPE_QUEUE_FAMILY_GLOBAL_PRIORITY_PROPERTIES_KHR

- VUID-VkQueueFamilyGlobalPriorityPropertiesKHR-priorities-parameter
  Each element of priorities **must be** a valid VkQueueGlobalPriorityKHR value

`VK_MAX_GLOBAL_PRIORITY_SIZE_KHR` is the length of an array of VkQueueGlobalPriorityKHR enumerants representing supported queue priorities, as returned in `VkQueueFamilyGlobalPriorityPropertiesKHR::priorities`.

```c
#define VK_MAX_GLOBAL_PRIORITY_SIZE_KHR   16U
```

or the equivalent

```c
#define VK_MAX_GLOBAL_PRIORITY_SIZE_EXT   VK_MAX_GLOBAL_PRIORITY_SIZE_KHR
```

The `VkQueueFamilyCheckpointProperties2NV` structure is defined as:

```c
// Provided by VK_KHR_synchronization2 with VK_NV_device_diagnostic_checkpoints
typedef struct VkQueueFamilyCheckpointProperties2NV {
    VkStructureType sType;
    void* pNext;
    VkPipelineStageFlags2 checkpointExecutionStageMask;
} VkQueueFamilyCheckpointProperties2NV;
```
• **sType** is a **VkStructureType** value identifying this structure.
• **pNext** is **NULL** or a pointer to a structure extending this structure.
• **checkpointExecutionStageMask** is a mask indicating which pipeline stages the implementation can execute checkpoint markers in.

Additional queue family information can be queried by setting `VkQueueFamilyProperties2::pNext` to point to a `VkQueueFamilyCheckpointProperties2NV` structure.

**Valid Usage (Implicit)**

• VUID-VkQueueFamilyCheckpointProperties2NV-sType-sType
  
  **sType** must be **VK_STRUCTURE_TYPE_QUEUE_FAMILY_CHECKPOINT_PROPERTIES_2_NV**

The **VkQueueFamilyCheckpointPropertiesNV** structure is defined as:

```c
// Provided by VK_NV_device_diagnostic_checkpoints
typedef struct VkQueueFamilyCheckpointPropertiesNV {
    VkStructureType sType;
    void* pNext;
    VkPipelineStageFlags checkpointExecutionStageMask;
} VkQueueFamilyCheckpointPropertiesNV;
```

• **sType** is a **VkStructureType** value identifying this structure.
• **pNext** is **NULL** or a pointer to a structure extending this structure.
• **checkpointExecutionStageMask** is a mask indicating which pipeline stages the implementation can execute checkpoint markers in.

Additional queue family information can be queried by setting `VkQueueFamilyProperties2::pNext` to point to a `VkQueueFamilyCheckpointPropertiesNV` structure.

**Valid Usage (Implicit)**

• VUID-VkQueueFamilyCheckpointPropertiesNV-sType-sType
  
  **sType** must be **VK_STRUCTURE_TYPE_QUEUE_FAMILY_CHECKPOINT_PROPERTIES_NV**

The **VkQueueFamilyVideoPropertiesKHR** structure is defined as:

```c
// Provided by VK_KHR_video_queue
typedef struct VkQueueFamilyVideoPropertiesKHR {
    VkStructureType sType;
    void* pNext;
    VkVideoCodecOperationFlagsKHR videoCodecOperations;
} VkQueueFamilyVideoPropertiesKHR;
```
• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• videoCodecOperations is a bitmask of VkVideoCodecOperationFlagBitsKHR that indicates the set of video codec operations supported by the queue family.

If this structure is included in the pNext chain of the VkQueueFamilyProperties2 structure passed to vkGetPhysicalDeviceQueueFamilyProperties2, then it is filled with the set of video codec operations supported by the specified queue family.

Valid Usage (Implicit)

• VUID-VkQueueFamilyVideoPropertiesKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_QUEUE_FAMILY_VIDEO_PROPERTIES_KHR

The VkQueueFamilyQueryResultStatusPropertiesKHR structure is defined as:

```c
// Provided by VK_KHR_video_queue
typedef struct VkQueueFamilyQueryResultStatusPropertiesKHR {
  VkStructureType sType;
  void* pNext;
  VkBool32 queryResultStatusSupport;
} VkQueueFamilyQueryResultStatusPropertiesKHR;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• queryResultStatusSupport reports VK_TRUE if query type VK_QUERY_TYPE_RESULT_STATUS_ONLY_KHR and use of VK_QUERY_RESULT_WITH_STATUS_BIT_KHR are supported.

If this structure is included in the pNext chain of the VkQueueFamilyProperties2 structure passed to vkGetPhysicalDeviceQueueFamilyProperties2, then it is filled with information about whether result status queries are supported by the specified queue family.

Valid Usage (Implicit)

• VUID-VkQueueFamilyQueryResultStatusPropertiesKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_QUEUE_FAMILY_QUERY_RESULT_STATUS_PROPERTIES_KHR

To enumerate the performance query counters available on a queue family of a physical device, call:

```c
// Provided by VK_KHR_performance_query
VkResult vkEnumeratePhysicalDeviceQueueFamilyPerformanceQueryCountersKHR(
```
**VkPhysicalDevice**

```c
uint32_t
VkPerformanceCounterKHR*
VkPerformanceCounterDescriptionKHR*` physicalDevice,
queueFamilyIndex,
pCounterCount,
pCounters,
pCounterDescriptions);
```

- **physicalDevice** is the handle to the physical device whose queue family performance query counter properties will be queried.
- **queueFamilyIndex** is the index into the queue family of the physical device we want to get properties for.
- **pCounterCount** is a pointer to an integer related to the number of counters available or queried, as described below.
- **pCounters** is either `NULL` or a pointer to an array of `VkPerformanceCounterKHR` structures.
- **pCounterDescriptions** is either `NULL` or a pointer to an array of `VkPerformanceCounterDescriptionKHR` structures.

If **pCounters** is `NULL` and **pCounterDescriptions** is `NULL`, then the number of counters available is returned in **pCounterCount**. Otherwise, **pCounterCount** must point to a variable set by the user to the number of elements in the **pCounters**, **pCounterDescriptions**, or both arrays and on return the variable is overwritten with the number of structures actually written out. If **pCounterCount** is less than the number of counters available, at most **pCounterCount** structures will be written, and **VK_INCOMPLETE** will be returned instead of **VK_SUCCESS**, to indicate that not all the available counters were returned.

### Valid Usage (Implicit)

- **VUID-vkEnumeratePhysicalDeviceQueueFamilyPerformanceQueryCountersKHR-physicalDevice-parameter**
  - **physicalDevice** must be a valid `VkPhysicalDevice` handle

- **VUID-vkEnumeratePhysicalDeviceQueueFamilyPerformanceQueryCountersKHR-pCounterCount-parameter**
  - **pCounterCount** must be a valid pointer to a `uint32_t` value

- **VUID-vkEnumeratePhysicalDeviceQueueFamilyPerformanceQueryCountersKHR-pCounters-parameter**
  - If the value referenced by **pCounterCount** is not `0`, and **pCounters** is not `NULL`, **pCounters** must be a valid pointer to an array of **pCounterCount** `VkPerformanceCounterKHR` structures

- **VUID-vkEnumeratePhysicalDeviceQueueFamilyPerformanceQueryCountersKHR-pCounterDescriptions-parameter**
  - If the value referenced by **pCounterCount** is not `0`, and **pCounterDescriptions** is not `NULL`, **pCounterDescriptions** must be a valid pointer to an array of **pCounterCount** `VkPerformanceCounterDescriptionKHR` structures
Return Codes

Success
• VK_SUCCESS
• VK_INCOMPLETE

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY
• VK_ERROR_INITIALIZATION_FAILED

The VkPerformanceCounterKHR structure is defined as:

```c
// Provided by VK_KHR_performance_query
typedef struct VkPerformanceCounterKHR {
    VkStructureType sType;
    void* pNext;
    VkPerformanceCounterUnitKHR unit;
    VkPerformanceCounterScopeKHR scope;
    VkPerformanceCounterStorageKHR storage;
    uint8_t uuid[VK_UUID_SIZE];
} VkPerformanceCounterKHR;
```

• **sType** is a VkStructureType value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.
• **unit** is a VkPerformanceCounterUnitKHR specifying the unit that the counter data will record.
• **scope** is a VkPerformanceCounterScopeKHR specifying the scope that the counter belongs to.
• **storage** is a VkPerformanceCounterStorageKHR specifying the storage type that the counter’s data uses.
• **uuid** is an array of size VK_UUID_SIZE, containing 8-bit values that represent a universally unique identifier for the counter of the physical device.

Valid Usage (Implicit)

• VUID-VkPerformanceCounterKHR-sType-sType
  **sType** must be VK_STRUCTURE_TYPE_PERFORMANCE_COUNTER_KHR
• VUID-VkPerformanceCounterKHR-pNext-pNext
  **pNext** must be NULL

Performance counters have an associated unit. This unit describes how to interpret the performance counter result.
The performance counter unit types which **may** be returned in `VkPerformanceCounterKHR::unit` are:

```c
// Provided by VK_KHR_performance_query
typedef enum VkPerformanceCounterUnitKHR {
    VK_PERFORMANCE_COUNTER_UNIT_GENERIC_KHR = 0,
    VK_PERFORMANCE_COUNTER_UNIT_PERCENTAGE_KHR = 1,
    VK_PERFORMANCE_COUNTER_UNIT_NANOSECONDS_KHR = 2,
    VK_PERFORMANCE_COUNTER_UNIT_BYTES_KHR = 3,
    VK_PERFORMANCE_COUNTER_UNIT_BYTES_PER_SECOND_KHR = 4,
    VK_PERFORMANCE_COUNTER_UNIT_KELVIN_KHR = 5,
    VK_PERFORMANCE_COUNTER_UNIT_WATTS_KHR = 6,
    VK_PERFORMANCE_COUNTER_UNIT_VOLTS_KHR = 7,
    VK_PERFORMANCE_COUNTER_UNIT_AMPS_KHR = 8,
    VK_PERFORMANCE_COUNTER_UNIT_HERTZ_KHR = 9,
    VK_PERFORMANCE_COUNTER_UNIT_CYCLES_KHR = 10,
} VkPerformanceCounterUnitKHR;
```

- **VK_PERFORMANCE_COUNTER_UNIT_GENERIC_KHR** - the performance counter unit is a generic data point.
- **VK_PERFORMANCE_COUNTER_UNIT_PERCENTAGE_KHR** - the performance counter unit is a percentage (%).
- **VK_PERFORMANCE_COUNTER_UNIT_NANOSECONDS_KHR** - the performance counter unit is a value of nanoseconds (ns).
- **VK_PERFORMANCE_COUNTER_UNIT_BYTES_KHR** - the performance counter unit is a value of bytes.
- **VK_PERFORMANCE_COUNTER_UNIT_BYTES_PER_SECOND_KHR** - the performance counter unit is a value of bytes/s.
- **VK_PERFORMANCE_COUNTER_UNIT_KELVIN_KHR** - the performance counter unit is a temperature reported in Kelvin.
- **VK_PERFORMANCE_COUNTER_UNIT_WATTS_KHR** - the performance counter unit is a value of watts (W).
- **VK_PERFORMANCE_COUNTER_UNIT_VOLTS_KHR** - the performance counter unit is a value of volts (V).
- **VK_PERFORMANCE_COUNTER_UNIT_AMPS_KHR** - the performance counter unit is a value of amps (A).
- **VK_PERFORMANCE_COUNTER_UNIT_HERTZ_KHR** - the performance counter unit is a value of hertz (Hz).
- **VK_PERFORMANCE_COUNTER_UNIT_CYCLES_KHR** - the performance counter unit is a value of cycles.

Performance counters have an associated scope. This scope describes the granularity of a performance counter.

The performance counter scope types which **may** be returned in `VkPerformanceCounterKHR::scope` are:

```c
// Provided by VK_KHR_performance_query
typedef enum VkPerformanceCounterScopeKHR {
    VK_PERFORMANCE_COUNTER_SCOPE_COMMAND_BUFFER_KHR = 0,
    VK_PERFORMANCE_COUNTER_SCOPE_RENDER_PASS_KHR = 1,
    VK_PERFORMANCE_COUNTER_SCOPE_COMMAND_KHR = 2,
    VkPerformanceCounterScopeKHR;
```

Performance counter unit types which may be returned in `VkPerformanceCounterKHR::unit` are:

- **VK_PERFORMANCE_COUNTER_UNIT_GENERIC_KHR** - the performance counter unit is a generic data point.
- **VK_PERFORMANCE_COUNTER_UNIT_PERCENTAGE_KHR** - the performance counter unit is a percentage (%).
- **VK_PERFORMANCE_COUNTER_UNIT_NANOSECONDS_KHR** - the performance counter unit is a value of nanoseconds (ns).
- **VK_PERFORMANCE_COUNTER_UNIT_BYTES_KHR** - the performance counter unit is a value of bytes.
- **VK_PERFORMANCE_COUNTER_UNIT_BYTES_PER_SECOND_KHR** - the performance counter unit is a value of bytes/s.
- **VK_PERFORMANCE_COUNTER_UNIT_KELVIN_KHR** - the performance counter unit is a temperature reported in Kelvin.
- **VK_PERFORMANCE_COUNTER_UNIT_WATTS_KHR** - the performance counter unit is a value of watts (W).
- **VK_PERFORMANCE_COUNTER_UNIT_VOLTS_KHR** - the performance counter unit is a value of volts (V).
- **VK_PERFORMANCE_COUNTER_UNIT_AMPS_KHR** - the performance counter unit is a value of amps (A).
- **VK_PERFORMANCE_COUNTER_UNIT_HERTZ_KHR** - the performance counter unit is a value of hertz (Hz).
- **VK_PERFORMANCE_COUNTER_UNIT_CYCLES_KHR** - the performance counter unit is a value of cycles.

Performance counters have an associated scope. This scope describes the granularity of a performance counter.

The performance counter scope types which may be returned in `VkPerformanceCounterKHR::scope` are:
vk_query_scope_command_buffer_khr =
vk_performance_counter_scope_command_buffer_khr,
vk_query_scope_render_pass_khr = vk_performance_counter_scope_render_pass_khr,
vk_query_scope_command_khr = vk_performance_counter_scope_command_khr,
} VkPerformanceCounterScopeKHR;

- **VK_PERFORMANCE_COUNTER_SCOPE_COMMAND_BUFFER_KHR** - the performance counter scope is a single complete command buffer.

- **VK_PERFORMANCE_COUNTER_SCOPE_RENDER_PASS_KHR** - the performance counter scope is zero or more complete render passes. The performance query containing the performance counter must begin and end outside a render pass instance.

- **VK_PERFORMANCE_COUNTER_SCOPE_COMMAND_KHR** - the performance counter scope is zero or more commands.

Performance counters have an associated storage. This storage describes the payload of a counter result.

The performance counter storage types which may be returned in `VkPerformanceCounterKHR::storage` are:

```c
// Provided by VK_KHR_performance_query
typedef enum VkPerformanceCounterStorageKHR {
   VK_PERFORMANCE_COUNTER_STORAGE_INT32_KHR = 0,
   VK_PERFORMANCE_COUNTER_STORAGE_INT64_KHR = 1,
   VK_PERFORMANCE_COUNTER_STORAGE_UINT32_KHR = 2,
   VK_PERFORMANCE_COUNTER_STORAGE_UINT64_KHR = 3,
   VK_PERFORMANCE_COUNTER_STORAGE_FLOAT32_KHR = 4,
   VK_PERFORMANCE_COUNTER_STORAGE_FLOAT64_KHR = 5,
} VkPerformanceCounterStorageKHR;
```

- **VK_PERFORMANCE_COUNTER_STORAGE_INT32_KHR** - the performance counter storage is a 32-bit signed integer.

- **VK_PERFORMANCE_COUNTER_STORAGE_INT64_KHR** - the performance counter storage is a 64-bit signed integer.

- **VK_PERFORMANCE_COUNTER_STORAGE_UINT32_KHR** - the performance counter storage is a 32-bit unsigned integer.

- **VK_PERFORMANCE_COUNTER_STORAGE_UINT64_KHR** - the performance counter storage is a 64-bit unsigned integer.

- **VK_PERFORMANCE_COUNTER_STORAGE_FLOAT32_KHR** - the performance counter storage is a 32-bit floating-point.

- **VK_PERFORMANCE_COUNTER_STORAGE_FLOAT64_KHR** - the performance counter storage is a 64-bit floating-point.

The `VkPerformanceCounterDescriptionKHR` structure is defined as:
```c
// Provided by VK_KHR_performance_query
typedef struct VkPerformanceCounterDescriptionKHR {
    VkStructureType sType;
    void* pNext;
    VkPerformanceCounterDescriptionFlagsKHR flags;
    char name[VK_MAX_DESCRIPTION_SIZE];
    char category[VK_MAX_DESCRIPTION_SIZE];
    char description[VK_MAX_DESCRIPTION_SIZE];
} VkPerformanceCounterDescriptionKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is a bitmask of `VkPerformanceCounterDescriptionFlagBitsKHR` indicating the usage behavior for the counter.
- **name** is an array of size `VK_MAX_DESCRIPTION_SIZE`, containing a null-terminated UTF-8 string specifying the name of the counter.
- **category** is an array of size `VK_MAX_DESCRIPTION_SIZE`, containing a null-terminated UTF-8 string specifying the category of the counter.
- **description** is an array of size `VK_MAX_DESCRIPTION_SIZE`, containing a null-terminated UTF-8 string specifying the description of the counter.

**Valid Usage (Implicit)**

- **VUID-VkPerformanceCounterDescriptionKHR-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PERFORMANCE_COUNTER_DESCRIPTION_KHR`
- **VUID-VkPerformanceCounterDescriptionKHR-pNext-pNext**
  - `pNext` must be `NULL`

Bits which can be set in `VkPerformanceCounterDescriptionKHR::flags`, specifying usage behavior of a performance counter, are:

```c
// Provided by VK_KHR_performance_query
typedef enum VkPerformanceCounterDescriptionFlagBitsKHR {
    VK_PERFORMANCE_COUNTER_DESCRIPTION_PERFORMANCE_IMPACTING_BIT_KHR = 0x00000001,
    VK_PERFORMANCE_COUNTER_DESCRIPTION_CONCURRENTLY_IMPACTED_BIT_KHR = 0x00000002,
    VK_PERFORMANCE_COUNTER_DESCRIPTION_PERFORMANCE_IMPACTING_KHR =
    VK_PERFORMANCE_COUNTER_DESCRIPTION_PERFORMANCE_IMPACTING_BIT_KHR,
    VK_PERFORMANCE_COUNTER_DESCRIPTION_CONCURRENTLY_IMPACTED_KHR =
    VK_PERFORMANCE_COUNTER_DESCRIPTION_CONCURRENTLY_IMPACTED_BIT_KHR,
} VkPerformanceCounterDescriptionFlagBitsKHR;
```

- **VK_PERFORMANCE_COUNTER_DESCRIPTION_PERFORMANCE_IMPACTING_BIT_KHR** specifies that recording the counter may have a noticeable performance impact.
- `VK_PERFORMANCE_COUNTER_DESCRIPTION_CONCURRENTLY_IMPACTED_BIT_KHR` specifies that concurrently recording the counter while other submitted command buffers are running may impact the accuracy of the recording.

```cpp
// Provided by VK_KHR_performance_query
typedef VkFlags VkPerformanceCounterDescriptionFlagsKHR;
```

`VkPerformanceCounterDescriptionFlagsKHR` is a bitmask type for setting a mask of zero or more `VkPerformanceCounterDescriptionFlagBitsKHR`.

### 5.2. Devices

Device objects represent logical connections to physical devices. Each device exposes a number of queue families each having one or more queues. All queues in a queue family support the same operations.

As described in Physical Devices, a Vulkan application will first query for all physical devices in a system. Each physical device can then be queried for its capabilities, including its queue and queue family properties. Once an acceptable physical device is identified, an application will create a corresponding logical device. The created logical device is then the primary interface to the physical device.

How to enumerate the physical devices in a system and query those physical devices for their queue family properties is described in the Physical Device Enumeration section above.

A single logical device can be created from multiple physical devices, if those physical devices belong to the same device group. A device group is a set of physical devices that support accessing each other’s memory and recording a single command buffer that can be executed on all the physical devices. Device groups are enumerated by calling `vkEnumeratePhysicalDeviceGroups`, and a logical device is created from a subset of the physical devices in a device group by passing the physical devices through `VkDeviceGroupDeviceCreateInfo`. For two physical devices to be in the same device group, they must support identical extensions, features, and properties.

**Note**

Physical devices in the same device group must be so similar because there are no rules for how different features/properties would interact. They must return the same values for nearly every invariant `vkGetPhysicalDevice*` feature, property, capability, etc., but could potentially differ for certain queries based on things like having a different display connected, or a different compositor. The specification does not attempt to enumerate which state is in each category, because such a list would quickly become out of date.

To retrieve a list of the device groups present in the system, call:

```cpp
// Provided by VK_VERSION_1_1
VkResult vkEnumeratePhysicalDeviceGroups(
    VkInstance instance,
```
or the equivalent command

```c
// Provided by VK_KHR_device_group_creation
VkResult vkEnumeratePhysicalDeviceGroupsKHR(
    VkInstance instance,
    uint32_t* pPhysicalDeviceGroupCount,
    VkPhysicalDeviceGroupProperties* pPhysicalDeviceGroupProperties);
```

- `instance` is a handle to a Vulkan instance previously created with `vkCreateInstance`.
- `pPhysicalDeviceGroupCount` is a pointer to an integer related to the number of device groups available or queried, as described below.
- `pPhysicalDeviceGroupProperties` is either `NULL` or a pointer to an array of `VkPhysicalDeviceGroupProperties` structures.

If `pPhysicalDeviceGroupProperties` is `NULL`, then the number of device groups available is returned in `pPhysicalDeviceGroupCount`. Otherwise, `pPhysicalDeviceGroupCount` must point to a variable set by the user to the number of elements in the `pPhysicalDeviceGroupProperties` array, and on return the variable is overwritten with the number of structures actually written to `pPhysicalDeviceGroupProperties`. If `pPhysicalDeviceGroupCount` is less than the number of device groups available, at most `pPhysicalDeviceGroupCount` structures will be written, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available device groups were returned.

Every physical device must be in exactly one device group.

### Valid Usage (Implicit)

- VUID-vkEnumeratePhysicalDeviceGroups-instance-parameter
  
  `instance` must be a valid `VkInstance` handle

- VUID-vkEnumeratePhysicalDeviceGroups-pPhysicalDeviceGroupCount-parameter
  
  `pPhysicalDeviceGroupCount` must be a valid pointer to a `uint32_t` value

- VUID-vkEnumeratePhysicalDeviceGroups-pPhysicalDeviceGroupProperties-parameter
  
  If the value referenced by `pPhysicalDeviceGroupCount` is not 0, and `pPhysicalDeviceGroupProperties` is not `NULL`, `pPhysicalDeviceGroupProperties` must be a valid pointer to an array of `pPhysicalDeviceGroupCount` `VkPhysicalDeviceGroupProperties` structures

### Return Codes

**Success**

- `VK_SUCCESS`
The `VkPhysicalDeviceGroupProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceGroupProperties {
    VkStructureType sType;
    void*pNext;
    uint32_t physicalDeviceCount;
    VkPhysicalDevice physicalDevices[VK_MAX_DEVICE_GROUP_SIZE];
    VkBool32 subsetAllocation;
} VkPhysicalDeviceGroupProperties;
```

or the equivalent

```c
// Provided by VK_KHR_device_group_creation
typedef VkPhysicalDeviceGroupProperties VkPhysicalDeviceGroupPropertiesKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **physicalDeviceCount** is the number of physical devices in the group.
- **physicalDevices** is an array of `VK_MAX_DEVICE_GROUP_SIZE` `VkPhysicalDevice` handles representing all physical devices in the group. The first `physicalDeviceCount` elements of the array will be valid.
- **subsetAllocation** specifies whether logical devices created from the group support allocating device memory on a subset of devices, via the `deviceMask` member of the `VkMemoryAllocateFlagsInfo`. If this is `VK_FALSE`, then all device memory allocations are made across all physical devices in the group. If `physicalDeviceCount` is 1, then `subsetAllocation` must be `VK_FALSE`.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceGroupProperties-sType-sType
  
  **sType** must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GROUP_PROPERTIES`

- VUID-VkPhysicalDeviceGroupProperties-pNext-pNext
  
  **pNext** must be `NULL`

`VK_MAX_DEVICE_GROUP_SIZE` is the length of an array containing `VkPhysicalDevice` handle values.
representing all physical devices in a group, as returned in `VkPhysicalDeviceGroupProperties::physicalDevices`.

```c
#define VK_MAX_DEVICE_GROUP_SIZE          32U
```
or the equivalent

```c
#define VK_MAX_DEVICE_GROUP_SIZE_KHR      VK_MAX_DEVICE_GROUP_SIZE
```

### 5.2.1. Device Creation

Logical devices are represented by `VkDevice` handles:

// Provided by VK_VERSION_1_0

```c
VK_DEFINE_HANDLE(VkDevice)
```

A logical device is created as a *connection* to a physical device. To create a logical device, call:

```
// Provided by VK_VERSION_1_0
VkResult vkCreateDevice(                  
    VkPhysicalDevice physicalDevice,     
    const VkDeviceCreateInfo* pCreateInfo, 
    const VkAllocationCallbacks* pAllocator, 
    VkDevice* pDevice);                   
```

- `physicalDevice` *must* be one of the device handles returned from a call to `vkEnumeratePhysicalDevices` (see Physical Device Enumeration).
- `pCreateInfo` is a pointer to a `VkDeviceCreateInfo` structure containing information about how to create the device.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pDevice` is a pointer to a handle in which the created `VkDevice` is returned.

`vkCreateDevice` verifies that extensions and features requested in the `ppEnabledExtensionNames` and `pEnabledFeatures` members of `pCreateInfo`, respectively, are supported by the implementation. If any requested extension is not supported, `vkCreateDevice` *must* return `VK_ERROR_EXTENSION_NOT_PRESENT`. If any requested feature is not supported, `vkCreateDevice` *must* return `VK_ERROR_FEATURE_NOT_PRESENT`. Support for extensions *can* be checked before creating a device by querying `vkEnumerateDeviceExtensionProperties`. Support for features *can* similarly be checked by querying `vkGetPhysicalDeviceFeatures`.

After verifying and enabling the extensions the `VkDevice` object is created and returned to the application.

Multiple logical devices *can* be created from the same physical device. Logical device creation *may*
fail due to lack of device-specific resources (in addition to other errors). If that occurs, `vkCreateDevice` will return `VK_ERROR_TOO_MANY_OBJECTS`.

### Valid Usage

- VUID-vkCreateDevice-ppEnabledExtensionNames-01387
  All required device extensions for each extension in the `VkDeviceCreateInfo ::ppEnabledExtensionNames` list must also be present in that list

### Valid Usage (Implicit)

- VUID-vkCreateDevice-physicalDevice-parameter
  `physicalDevice` must be a valid `VkPhysicalDevice` handle
- VUID-vkCreateDevice-pCreateInfo-parameter
  `pCreateInfo` must be a valid pointer to a valid `VkDeviceCreateInfo` structure
- VUID-vkCreateDevice-pAllocator-parameter
  If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure
- VUID-vkCreateDevice-pDevice-parameter
  `pDevice` must be a valid pointer to a `VkDevice` handle

### Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_INITIALIZATION_FAILED`
- `VK_ERROR_EXTENSION_NOT_PRESENT`
- `VK_ERROR_FEATURE_NOT_PRESENT`
- `VK_ERROR_TOO_MANY_OBJECTS`
- `VK_ERROR_DEVICE_LOST`

The `VkDeviceCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkDeviceCreateInfo {
    VkStructureType sType;
    const void*pNext;
} VkDeviceCreateInfo;
```
VkDeviceCreateInfo

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- flags is reserved for future use.
- queueCreateInfoCount is the unsigned integer size of the pQueueCreateInfos array. Refer to the Queue Creation section below for further details.
- pQueueCreateInfos is a pointer to an array of VkDeviceQueueCreateInfo structures describing the queues that are requested to be created along with the logical device. Refer to the Queue Creation section below for further details.
- enabledLayerCount is deprecated and ignored.
- ppEnabledLayerNames is deprecated and ignored. See Device Layer Deprecation.
- enabledExtensionCount is the number of device extensions to enable.
- ppEnabledExtensionNames is a pointer to an array of enabledExtensionCount null-terminated UTF-8 strings containing the names of extensions to enable for the created device. See the Extensions section for further details.
- pEnabledFeatures is NULL or a pointer to a VkPhysicalDeviceFeatures structure containing boolean indicators of all the features to be enabled. Refer to the Features section for further details.

Valid Usage

- VUID-VkDeviceCreateInfo-queueFamilyIndex-02802
  The queueFamilyIndex member of each element of pQueueCreateInfos must be unique within pQueueCreateInfos, except that two members can share the same queueFamilyIndex if one describes protected-capable queues and one describes queues that are not protected-capable.

- VUID-VkDeviceCreateInfo-pQueueCreateInfos-06755
  If multiple elements of pQueueCreateInfos share the same queueFamilyIndex, the sum of their queueCount members must be less than or equal to the queueCount member of the VkQueueFamilyProperties structure, as returned by vkGetPhysicalDeviceQueueFamilyProperties in the pQueueFamilyProperties[queueFamilyIndex].

- VUID-VkDeviceCreateInfo-pQueueCreateInfos-06654
  If multiple elements of pQueueCreateInfos share the same queueFamilyIndex, then all of
such elements must have the same global priority level, which can be specified explicitly by the including a VkDeviceQueueGlobalPriorityCreateInfoKHR structure in the pNext chain, or by the implicit default value

- VUID-VkDeviceCreateInfo-pNext-00373
  If the pNext chain includes a VkPhysicalDeviceFeatures2 structure, then pEnabledFeatures must be NULL

- VUID-VkDeviceCreateInfo-ppEnabledExtensionNames-01840
  If VkPhysicalDeviceProperties::apiVersion advertises Vulkan 1.1 or later, ppEnabledExtensionNames must not contain VK_AMD_negative_viewport_height

- VUID-VkDeviceCreateInfo-ppEnabledExtensionNames-00374
  ppEnabledExtensionNames must not contain both VK_KHR_maintenance1 and VK_AMD_negative_viewport_height

- VUID-VkDeviceCreateInfo-ppEnabledExtensionNames-03328
  ppEnabledExtensionNames must not contain both VK_KHR_buffer_device_address and VK_EXT_buffer_device_address

- VUID-VkDeviceCreateInfo-pNext-04748
  If the pNext chain includes a VkPhysicalDeviceVulkan12Features structure and VkPhysicalDeviceVulkan12Features::bufferDeviceAddress is VK_TRUE, ppEnabledExtensionNames must not contain VK_EXT_buffer_device_address

- VUID-VkDeviceCreateInfo-pNext-02829
  If the pNext chain includes a VkPhysicalDeviceVulkan11Features structure, then it must not include a VkPhysicalDevice16BitStorageFeatures, VkPhysicalDeviceMultiviewFeatures, VkPhysicalDeviceProtectedMemoryFeatures, VkPhysicalDeviceSamplerYcbcrConversionFeatures, or VkPhysicalDeviceShaderDrawParametersFeatures structure

- VUID-VkDeviceCreateInfo-pNext-02830
  If the pNext chain includes a VkPhysicalDeviceVulkan12Features structure, then it must not include a VkPhysicalDevice8BitStorageFeatures, VkPhysicalDeviceShader AtomicInt64Features, VkPhysicalDeviceShaderFloat16Int8Features, VkPhysicalDeviceDescriptorIndexingFeatures, VkPhysicalDeviceScalarBlockLayoutFeatures, VkPhysicalDeviceImagelessFramebufferFeatures, VkPhysicalDeviceUniformBufferStandardLayoutFeatures, VkPhysicalDeviceShaderSubgroupExtendedTypesFeatures, VkPhysicalDeviceSeparateDepthStencilLayoutsFeatures, VkPhysicalDeviceHostQueryResetFeatures, VkPhysicalDeviceTimelineSemaphoreFeatures, VkPhysicalDeviceBufferDeviceAddressFeatures, or VkPhysicalDeviceVulkanMemoryModelFeatures structure

- VUID-VkDeviceCreateInfo-ppEnabledExtensionNames-04476
  If ppEnabledExtensionNames contains "VK_KHR_shader_draw_parameters" and the pNext chain includes a VkPhysicalDeviceVulkan11Features structure, then VkPhysicalDeviceVulkan11Features::shaderDrawParameters must be VK_TRUE
If `ppEnabledExtensionNames` contains "VK_KHR_draw_indirect_count" and the `pNext` chain includes a `VkPhysicalDeviceVulkan12Features` structure, then `VkPhysicalDeviceVulkan12Features::drawIndirectCount` must be `VK_TRUE`.

If `ppEnabledExtensionNames` contains "VK_KHR_sampler_mirror_clamp_to_edge" and the `pNext` chain includes a `VkPhysicalDeviceVulkan12Features` structure, then `VkPhysicalDeviceVulkan12Features::samplerMirrorClampToEdge` must be `VK_TRUE`.

If `ppEnabledExtensionNames` contains "VK_EXT_descriptor_indexing" and the `pNext` chain includes a `VkPhysicalDeviceVulkan12Features` structure, then `VkPhysicalDeviceVulkan12Features::descriptorIndexing` must be `VK_TRUE`.

If `ppEnabledExtensionNames` contains "VK_EXT_sampler_filter_minmax" and the `pNext` chain includes a `VkPhysicalDeviceVulkan12Features` structure, then `VkPhysicalDeviceVulkan12Features::samplerFilterMinmax` must be `VK_TRUE`.

If `ppEnabledExtensionNames` contains "VK_EXT_shader_viewport_index_layer" and the `pNext` chain includes a `VkPhysicalDeviceVulkan12Features` structure, then `VkPhysicalDeviceVulkan12Features::shaderOutputViewportIndex` and `VkPhysicalDeviceVulkan12Features::shaderOutputLayer` must both be `VK_TRUE`.

If the `pNext` chain includes a `VkPhysicalDeviceVulkan13Features` structure, then it must not include a `VkPhysicalDeviceDynamicRenderingFeatures`, `VkPhysicalDeviceImageRobustnessFeatures`, `VkPhysicalDeviceInlineUniformBlockFeatures`, `VkPhysicalDeviceMaintenance4Features`, `VkPhysicalDevicePipelineCreationCacheControlFeatures`, `VkPhysicalDevicePrivateDataFeatures`, `VkPhysicalDeviceShaderDemoteToHelperInvocationFeatures`, `VkPhysicalDeviceShaderIntegerDotProductFeatures`, `VkPhysicalDeviceShaderTerminateInvocationFeatures`, `VkPhysicalDeviceSubgroupSizeControlFeatures`, `VkPhysicalDeviceSynchronization2Features`, `VkPhysicalDeviceTextureCompressionASTCHDRFeatures`, or `VkPhysicalDeviceZeroInitializeWorkgroupMemoryFeatures` structure.

If the `VK_KHR_portability_subset` extension is included in `pProperties` of `vkEnumerateDeviceExtensionProperties`, `ppEnabledExtensionNames` must include "VK_KHR_portability_subset".

If the `shadingRateImage` feature is enabled, the `pipelineFragmentShadingRate` feature must not be enabled.

If the `shadingRateImage` feature is enabled, the `primitiveFragmentShadingRate` feature must not be enabled.
• VUID-VkDeviceCreateInfo-shadingRateImage-04480
  If the shadingRateImage feature is enabled, the attachmentFragmentShadingRate feature must not be enabled

• VUID-VkDeviceCreateInfo-fragmentDensityMap-04481
  If the fragmentDensityMap feature is enabled, the pipelineFragmentShadingRate feature must not be enabled

• VUID-VkDeviceCreateInfo-fragmentDensityMap-04482
  If the fragmentDensityMap feature is enabled, the primitiveFragmentShadingRate feature must not be enabled

• VUID-VkDeviceCreateInfo-fragmentDensityMap-04483
  If the fragmentDensityMap feature is enabled, the attachmentFragmentShadingRate feature must not be enabled

• VUID-VkDeviceCreateInfo-None-04896
  If sparseImageInt64Atomics is enabled, shaderImageInt64Atomics must be enabled

• VUID-VkDeviceCreateInfo-None-04897
  If sparseImageFloat32Atomics is enabled, shaderImageFloat32Atomics must be enabled

• VUID-VkDeviceCreateInfo-None-04898
  If sparseImageFloat32AtomicAdd is enabled, shaderImageFloat32AtomicAdd must be enabled

• VUID-VkDeviceCreateInfo-sparseImageFloat32AtomicMinMax-04975
  If sparseImageFloat32AtomicMinMax is enabled, shaderImageFloat32AtomicMinMax must be enabled

• VUID-VkDeviceCreateInfo-None-08095
  If descriptorBuffer is enabled, ppEnabledExtensionNames must not contain VK_AMD_shader_fragment_mask

Valid Usage (Implicit)

• VUID-VkDeviceCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_DEVICE_CREATE_INFO

• VUID-VkDeviceCreateInfo-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkDeviceDeviceMemoryReportCreateInfoEXT,
  VkDeviceDiagnosticsConfigCreateInfoNV, VkDeviceGroupDeviceCreateInfo,
  VkDeviceMemoryOverallocationCreateInfoAMD, VkDevicePrivateDataCreateInfo,
  VkPhysicalDevice16BitStorageFeatures, VkPhysicalDevice4444FormatsFeaturesEXT,
  VkPhysicalDevice8BitStorageFeatures, VkPhysicalDeviceASTCDecodeFeaturesEXT,
  VkPhysicalDeviceAccelerationStructureFeaturesKHR,
  VkPhysicalDeviceAddressBindingReportFeaturesEXT,
  VkPhysicalDeviceAmigoProfilingFeaturesSEC,
  VkPhysicalDeviceAttachmentFeedbackLoopDynamicStateFeaturesEXT,
  VkPhysicalDeviceAttachmentFeedbackLoopLayoutFeaturesEXT,
  VkPhysicalDeviceBlendOperationAdvancedFeaturesEXT,
VkPhysicalDeviceBufferDeviceAddressFeatures,
VkPhysicalDeviceBufferDeviceAddressFeaturesEXT,
VkPhysicalDeviceClusterCullingShaderFeaturesHUAWEI,
VkPhysicalDeviceCoherentMemoryFeaturesAMD,
VkPhysicalDeviceColorWriteEnableFeaturesEXT,
VkPhysicalDeviceComputeShaderDerivativesFeaturesNV,
VkPhysicalDeviceConditionalRenderingFeaturesEXT,
VkPhysicalDeviceCooperativeMatrixFeaturesKHR,
VkPhysicalDeviceCooperativeMatrixFeaturesNV,
VkPhysicalDeviceCopyMemoryIndirectFeaturesNV,
VkPhysicalDeviceCornerSampledImageFeaturesNV,
VkPhysicalDeviceCoverageReductionModeFeaturesNV,
VkPhysicalDeviceCubicClampFeaturesQCOM,
VkPhysicalDeviceCubicWeightsFeaturesQCOM,
VkPhysicalDeviceCustomBorderColorFeaturesEXT,
VkPhysicalDeviceDedicatedAllocationImageAliasingFeaturesNV,
VkPhysicalDeviceDepthBiasControlFeaturesEXT,
VkPhysicalDeviceDepthClampZeroOneFeaturesEXT,
VkPhysicalDeviceDepthClipControlFeaturesEXT,
VkPhysicalDeviceDepthClipEnableFeaturesEXT,
VkPhysicalDeviceDescriptorBufferFeaturesEXT,
VkPhysicalDeviceDescriptorIndexingFeatures,
VkPhysicalDeviceDescriptorPoolOverallocationFeaturesNV,
VkPhysicalDeviceDescriptorSetHostMappingFeaturesVALVE,
VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV,
VkPhysicalDeviceDeviceGeneratedCommandsFeaturesNV,
VkPhysicalDeviceDeviceMemoryReportFeaturesEXT,
VkPhysicalDeviceDynamicState2FeaturesEXT,
VkPhysicalDeviceDynamicState3FeaturesEXT,
VkPhysicalDeviceDynamicStateFeaturesEXT,
VkPhysicalDeviceExclusiveScissorFeaturesNV,
VkPhysicalDeviceExtendedDynamicState2FeaturesEXT,
VkPhysicalDeviceExtendedDynamicState3FeaturesEXT,
VkPhysicalDeviceExtendedDynamicStateFeaturesEXT,
VkPhysicalDeviceExternalMemoryRDMAFeaturesNV,
VkPhysicalDeviceExternalMemoryScreenBufferFeaturesQNX,
VkPhysicalDeviceFaultFeaturesEXT,
VkPhysicalDeviceFragmentDensityMap2FeaturesEXT,
VkPhysicalDeviceFragmentDensityMapFeaturesEXT,
VkPhysicalDeviceFragmentDensityMapOffsetFeaturesQCOM,
VkPhysicalDeviceFragmentShaderBarycentricFeaturesKHR,
VkPhysicalDeviceFragmentShaderInterlockFeaturesEXT,
VkPhysicalDeviceFragmentShadingRate EnumsFeaturesNV,
VkPhysicalDeviceFragmentShadingRateFeaturesKHR,
VkPhysicalDeviceFrameBoundaryFeaturesEXT,
VkPhysicalDeviceGlobalPriorityQueryFeaturesKHR,
VkPhysicalDeviceGraphicsPipelineLibraryFeaturesEXT,
 VkPhysicalDeviceWorkgroupMemoryExplicitLayoutFeaturesKHR,  
 VkPhysicalDeviceYcbcr2Plane444FormatsFeaturesEXT,  
 VkPhysicalDeviceYcbcrDegammaFeaturesQCOM,  
 VkPhysicalDeviceYcbcrImageArraysFeaturesEXT,  
 or  
 VkPhysicalDeviceZeroInitializeWorkgroupMemoryFeatures  

• VUID-VkDeviceCreateInfo-sType-unique  
The sType value of each struct in the pNext chain must be unique, with the exception of structures of type VkDeviceDeviceMemoryReportCreateInfoEXT or VkDevicePrivateDataCreateInfo  

• VUID-VkDeviceCreateInfo-flags-zerobitmask  
flags must be 0  

• VUID-VkDeviceCreateInfo-pQueueCreateInfos-parameter  
pQueueCreateInfos must be a valid pointer to an array of queueCreateInfoCount valid VkDeviceQueueCreateInfo structures  

• VUID-VkDeviceCreateInfo-ppEnabledLayerNames-parameter  
If enabledLayerCount is not 0, ppEnabledLayerNames must be a valid pointer to an array of enabledLayerCount null-terminated UTF-8 strings  

• VUID-VkDeviceCreateInfo-ppEnabledExtensionNames-parameter  
If enabledExtensionCount is not 0, ppEnabledExtensionNames must be a valid pointer to an array of enabledExtensionCount null-terminated UTF-8 strings  

• VUID-VkDeviceCreateInfo-pEnabledFeatures-parameter  
If pEnabledFeatures is not NULL, pEnabledFeatures must be a valid pointer to a valid VkPhysicalDeviceFeatures structure  

• VUID-VkDeviceCreateInfo-queueCreateInfoCount-arraylength  
queueCreateInfoCount must be greater than 0  

// Provided by VK_VERSION_1_0  
typedef VkFlags VkDeviceCreateFlags;  

VkDeviceCreateFlags is a bitmask type for setting a mask, but is currently reserved for future use.  

A logical device can be created that connects to one or more physical devices by adding a VkDeviceGroupDeviceCreateInfo structure to the pNext chain of VkDeviceCreateInfo. The VkDeviceGroupDeviceCreateInfo structure is defined as:  

// Provided by VK_VERSION_1_1  
typedef struct VkDeviceGroupDeviceCreateInfo {  
    VkStructureType sType;  
    const void* pNext;  
    uint32_t physicalDeviceCount;  
    const VkPhysicalDevice* pPhysicalDevices;  
} VkDeviceGroupDeviceCreateInfo;
or the equivalent

```c
// Provided by VK_KHR_device_group_creation
typedef VkDeviceGroupDeviceCreateInfo VkDeviceGroupDeviceCreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `physicalDeviceCount` is the number of elements in the `pPhysicalDevices` array.
- `pPhysicalDevices` is a pointer to an array of physical device handles belonging to the same device group.

The elements of the `pPhysicalDevices` array are an ordered list of the physical devices that the logical device represents. These must be a subset of a single device group, and need not be in the same order as they were enumerated. The order of the physical devices in the `pPhysicalDevices` array determines the device index of each physical device, with element `i` being assigned a device index of `i`. Certain commands and structures refer to one or more physical devices by using device indices or device masks formed using device indices.

A logical device created without using `VkDeviceGroupDeviceCreateInfo`, or with `physicalDeviceCount` equal to zero, is equivalent to a `physicalDeviceCount` of one and `pPhysicalDevices` pointing to the `physicalDevice` parameter to `vkCreateDevice`. In particular, the device index of that physical device is zero.

### Valid Usage

- **VUID-VkDeviceGroupDeviceCreateInfo-pPhysicalDevices-00375**
  Each element of `pPhysicalDevices` must be unique

- **VUID-VkDeviceGroupDeviceCreateInfo-pPhysicalDevices-00376**
  All elements of `pPhysicalDevices` must be in the same device group as enumerated by `vkEnumeratePhysicalDeviceGroups`

- **VUID-VkDeviceGroupDeviceCreateInfo-physicalDeviceCount-00377**
  If `physicalDeviceCount` is not `0`, the `physicalDevice` parameter of `vkCreateDevice` must be an element of `pPhysicalDevices`

### Valid Usage (Implicit)

- **VUID-VkDeviceGroupDeviceCreateInfo-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_DEVICE_GROUP_DEVICE_CREATE_INFO`

- **VUID-VkDeviceGroupDeviceCreateInfo-pPhysicalDevices-parameter**
  If `physicalDeviceCount` is not `0`, `pPhysicalDevices` must be a valid pointer to an array of `physicalDeviceCount` valid `VkPhysicalDevice` handles

To specify whether device memory allocation is allowed beyond the size reported by
VkPhysicalDeviceMemoryProperties, add a VkDeviceMemoryOverallocationCreateInfoAMD structure to the pNext chain of the VkDeviceCreateInfo structure. If this structure is not specified, it is as if the VK_MEMORY_OVERALLOCATION_BEHAVIOR_DEFAULT_AMD value is used.

// Provided by VK_AMD_memory_overallocation_behavior
typedef struct VkDeviceMemoryOverallocationCreateInfoAMD {
    VkStructureType sType;
    const void* pNext;
    VkMemoryOverallocationBehaviorAMD overallocationBehavior;
} VkDeviceMemoryOverallocationCreateInfoAMD;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• overallocationBehavior is the desired overallocation behavior.

Valid Usage (Implicit)

• VUID-VkDeviceMemoryOverallocationCreateInfoAMD-sType-sType
  sType must be VK_STRUCTURE_TYPE_DEVICE_MEMORY_OVERALLOCATION_CREATE_INFO_AMD

• VUID-VkDeviceMemoryOverallocationCreateInfoAMD-overallocationBehavior-parameter
  overallocationBehavior must be a valid VkMemoryOverallocationBehaviorAMD value

Possible values for VkDeviceMemoryOverallocationCreateInfoAMD::overallocationBehavior include:

// Provided by VK_AMD_memory_overallocation_behavior
typedef enum VkMemoryOverallocationBehaviorAMD {
    VK_MEMORY_OVERALLOCATION_BEHAVIOR_DEFAULT_AMD = 0,
    VK_MEMORY_OVERALLOCATION_BEHAVIOR_ALLOWED_AMD = 1,
    VK_MEMORY_OVERALLOCATION_BEHAVIOR_DISALLOWED_AMD = 2,
} VkMemoryOverallocationBehaviorAMD;

• VK_MEMORY_OVERALLOCATION_BEHAVIOR_DEFAULT_AMD lets the implementation decide if overallocation is allowed.
• VK_MEMORY_OVERALLOCATION_BEHAVIOR_ALLOWED_AMD specifies overallocation is allowed if platform permits.
• VK_MEMORY_OVERALLOCATION_BEHAVIOR_DISALLOWED_AMD specifies the application is not allowed to allocate device memory beyond the heap sizes reported by VkPhysicalDeviceMemoryProperties. Allocations that are not explicitly made by the application within the scope of the Vulkan instance are not accounted for.

When using the Nsight™ Aftermath SDK, to configure how device crash dumps are created, add a VkDeviceDiagnosticsConfigCreateInfoNV structure to the pNext chain of the VkDeviceCreateInfo structure.
typedef struct VkDeviceDiagnosticsConfigCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkDeviceDiagnosticsConfigFlagsNV flags;
} VkDeviceDiagnosticsConfigCreateInfoNV;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is a bitmask of `VkDeviceDiagnosticsConfigFlagBitsNV` specifying additional parameters for configuring diagnostic tools.

### Valid Usage (Implicit)

- VUID-VkDeviceDiagnosticsConfigCreateInfoNV-sType-sType
  sType must be `VK_STRUCTURE_TYPE_DEVICE_DIAGNOSTICS_CONFIG_CREATE_INFO_NV`
- VUID-VkDeviceDiagnosticsConfigCreateInfoNV-flags-parameter
  flags must be a valid combination of `VkDeviceDiagnosticsConfigFlagBitsNV` values

Bits which can be set in `VkDeviceDiagnosticsConfigCreateInfoNV::flags` include:

typedef enum VkDeviceDiagnosticsConfigFlagBitsNV {
    VKDEVICE_DIAGNOSTICS_CONFIG_ENABLE_SHADER_DEBUG_INFO_BIT_NV = 0x00000001,
    VKDEVICE_DIAGNOSTICS_CONFIG_ENABLE_RESOURCE_TRACKING_BIT_NV = 0x00000002,
    VKDEVICE_DIAGNOSTICS_CONFIG_ENABLE_AUTOMATIC_CHECKPOINTS_BIT_NV = 0x00000004,
    VKDEVICE_DIAGNOSTICS_CONFIG_ENABLE_SHADER_ERROR_REPORTING_BIT_NV = 0x00000008,
} VkDeviceDiagnosticsConfigFlagBitsNV;

- **VKDEVICE_DIAGNOSTICS_CONFIG_ENABLE_SHADER_DEBUG_INFO_BIT_NV** enables the generation of debug information for shaders.
- **VKDEVICE_DIAGNOSTICS_CONFIG_ENABLE_RESOURCE_TRACKING_BIT_NV** enables driver side tracking of resources (images, buffers, etc.) used to augment the device fault information.
- **VKDEVICE_DIAGNOSTICS_CONFIG_ENABLE_AUTOMATIC_CHECKPOINTS_BIT_NV** enables automatic insertion of diagnostic checkpoints for draw calls, dispatches, trace rays, and copies. The CPU call stack at the time of the command will be associated as the marker data for the automatically inserted checkpoints.
- **VKDEVICE_DIAGNOSTICS_CONFIG_ENABLE_SHADER_ERROR_REPORTING_BIT_NV** enables shader error reporting.
\textbf{VkDeviceDiagnosticsConfigFlagsNV} is a bitmask type for setting a mask of zero or more \textbf{VkDeviceDiagnosticsConfigFlagBitsNV}.

To register callbacks for underlying device memory events of type \textbf{VkDeviceMemoryReportEventTypeEXT}, add one or multiple \textbf{VkDeviceDeviceMemoryReportCreateInfoEXT} structures to the \textit{pNext} chain of the \textbf{VkDeviceCreateInfo} structure.

```c
// Provided by VK_EXT_device_memory_report
typedef struct VkDeviceDeviceMemoryReportCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkDeviceMemoryReportFlagsEXT flags;
    PFN_vkDeviceMemoryReportCallbackEXT pfnUserCallback;
    void* pUserData;
} VkDeviceDeviceMemoryReportCreateInfoEXT;
```

- \textit{sType} is a \textbf{VkStructureType} value identifying this structure.
- \textit{pNext} is \texttt{NULL} or a pointer to a structure extending this structure.
- \textit{flags} is \texttt{0} and reserved for future use.
- \textit{pfnUserCallback} is the application callback function to call.
- \textit{pUserData} is user data to be passed to the callback.

The callback \textbf{may} be called from multiple threads simultaneously.

The callback \textbf{must} be called only once by the implementation when a \textbf{VkDeviceMemoryReportEventTypeEXT} event occurs.

\textbf{Valid Usage (Implicit)}

- VUID-VkDeviceDeviceMemoryReportCreateInfoEXT-sType-sType \textit{sType} must be \texttt{VK_STRUCTURE_TYPE_DEVICE_DEVICE_MEMORY_REPORT_CREATE_INFO_EXT}
- VUID-VkDeviceDeviceMemoryReportCreateInfoEXT-flags-zerobitmask \textit{flags} must be \texttt{0}
- VUID-VkDeviceDeviceMemoryReportCreateInfoEXT-pfnUserCallback-parameter \textit{pfnUserCallback} must be a valid \texttt{PFN_vkDeviceMemoryReportCallbackEXT} value
- VUID-VkDeviceDeviceMemoryReportCreateInfoEXT-pUserData-parameter \textit{pUserData} must be a pointer value

The prototype for the \textbf{VkDeviceDeviceMemoryReportCreateInfoEXT::pfnUserCallback} function
implemented by the application is:

```c
// Provided by VK_EXT_device_memory_report
typedef void (VKAPI_PTR *PFN_vkDeviceMemoryReportCallbackEXT)(
    const VkDeviceMemoryReportCallbackDataEXT* pCallbackData,
    void* pUserData);
```

- `pCallbackData` contains all the callback related data in the `VkDeviceMemoryReportCallbackDataEXT` structure.
- `pUserData` is the user data provided when the `VkDeviceDeviceMemoryReportCreateInfoEXT` was created.

The callback must not make calls to any Vulkan commands.

The definition of `VkDeviceMemoryReportCallbackDataEXT` is:

```c
// Provided by VK_EXT_device_memory_report
typedef struct VkDeviceMemoryReportCallbackDataEXT {
    VkStructureType sType;
    void* pNext;
    VkDeviceMemoryReportFlagsEXT flags;
    VkDeviceMemoryReportEventTypeEXT type;
    uint64_t memoryObjectId;
    VkDeviceSize size;
    VkObjectType objectType;
    uint64_t objectHandle;
    uint32_t heapIndex;
} VkDeviceMemoryReportCallbackDataEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is 0 and reserved for future use.
- `type` is a `VkDeviceMemoryReportEventTypeEXT` type specifying the type of event reported in this `VkDeviceMemoryReportCallbackDataEXT` structure.
- `memoryObjectId` is the unique id for the underlying memory object as described below.
- `size` is the size of the memory object in bytes. If `type` is `VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_ALLOCATE_EXT`, `VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_IMPORT_EXT` or `VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_ALLOCATION_FAILED_EXT`, `size` is a valid `VkDeviceSize` value. Otherwise, `size` is undefined.
- `objectType` is a `VkObjectType` value specifying the type of the object associated with this device memory report event. If `type` is `VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_ALLOCATE_EXT`, `VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_FREE_EXT`, `VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_IMPORT_EXT`, `VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_UNIMPORT_EXT` or `VKDEVICE_MEMORY_REPORT_EVENT_TYPE_ALLOCATION_FAILED_EXT`, `objectType` is a valid `VkObjectType`
enum. Otherwise, objectType is undefined.

- objectHandle is the object this device memory report event is attributed to. If type is
  
  - VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_ALLOCATE_EXT, VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_FREE_EXT,
  - VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_IMPORT_EXT
  or
  - VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_UNIMPORT_EXT, objectHandle is a valid Vulkan handle of the
    type associated with objectType as defined in the VkObjectType and Vulkan Handle Relationship
    table. Otherwise, objectHandle is undefined.

- heapIndex describes which memory heap this device memory allocation is made from. If type is
  
  - VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_ALLOCATE_EXT
  - VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_ALLOCATION_FAILED_EXT
  heapIndex corresponds to one of the valid heaps from the VkPhysicalDeviceMemoryProperties structure. Otherwise, heapIndex is
  undefined.

memoryObjectId is used to avoid double-counting on the same memory object.

If an internally-allocated device memory object or a VkDeviceMemory cannot be exported, memoryObjectId must be unique in the VkDevice.

If an internally-allocated device memory object or a VkDeviceMemory supports being exported, memoryObjectId must be unique system wide.

If an internal device memory object or a VkDeviceMemory is backed by an imported external memory object, memoryObjectId must be unique system wide.

---

**Implementor’s Note**

If the heap backing an internally-allocated device memory cannot be used to back VkDeviceMemory, implementations can advertise that heap with no types.

---

**Note**

This structure should only be considered valid during the lifetime of the triggered callback.

For

- VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_ALLOCATE_EXT
- VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_IMPORT_EXT

events, objectHandle usually will not yet exist when the application or tool receives the callback. objectHandle will only exist when the create or allocate call that triggered the event returns, and if the allocation or import ends up failing objectHandle will not ever exist.

---

**Valid Usage (Implicit)**

- VUID-VkDeviceMemoryReportCallbackDataEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_DEVICE_MEMORY_REPORT_CALLBACK_DATA_EXT
- VUID-VkDeviceMemoryReportCallbackDataEXT-pNext-pNext
  pNext must be NULL
typedef VkFlags VkDeviceMemoryReportFlagsEXT;

VkDeviceMemoryReportFlagsEXT is a bitmask type for setting a mask, but is currently reserved for future use.

Possible values of VkDeviceMemoryReportCallbackDataEXT::type, specifying event types which cause the device driver to call the callback, are:

- VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_ALLOCATE_EXT specifies this event corresponds to the allocation of an internal device memory object or a VkDeviceMemory.
- VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_FREE_EXT specifies this event corresponds to the deallocation of an internally-allocated device memory object or a VkDeviceMemory.
- VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_IMPORT_EXT specifies this event corresponds to the import of an external memory object.
- VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_UNIMPORT_EXT specifies this event is the release of an imported external memory object.
- VK_DEVICE_MEMORY_REPORT_EVENT_TYPE_ALLOCATION_FAILED_EXT specifies this event corresponds to the failed allocation of an internal device memory object or a VkDeviceMemory.

To reserve private data storage slots, add a VkDevicePrivateDataCreateInfo structure to the pNext chain of the VkDeviceCreateInfo structure. Reserving slots in this manner is not strictly necessary, but doing so may improve performance.

or the equivalent

typedef VkDevicePrivateDataCreateInfoEXT VkDevicePrivateDataCreateInfo;

or the equivalent

typedef VkDevicePrivateDataCreateInfo VkDevicePrivateDataCreateInfoEXT;
• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• privateDataSlotRequestCount is the amount of slots to reserve.

Valid Usage (Implicit)

- VUID-VkDevicePrivateDataCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_DEVICE_PRIVATE_DATA_CREATE_INFO

5.2.2. Device Use

The following is a high-level list of VkDevice uses along with references on where to find more information:

• Creation of queues. See the Queues section below for further details.
• Creation and tracking of various synchronization constructs. See Synchronization and Cache Control for further details.
• Allocating, freeing, and managing memory. See Memory Allocation and Resource Creation for further details.
• Creation and destruction of command buffers and command buffer pools. See Command Buffers for further details.
• Creation, destruction, and management of graphics state. See Pipelines and Resource Descriptors, among others, for further details.

5.2.3. Lost Device

A logical device may become lost for a number of implementation-specific reasons, indicating that pending and future command execution may fail and cause resources and backing memory to become undefined.

Note

Typical reasons for device loss will include things like execution timing out (to prevent denial of service), power management events, platform resource management, implementation errors.

Applications not adhering to valid usage may also result in device loss being reported, however this is not guaranteed. Even if device loss is reported, the system may be in an unrecoverable state, and further usage of the API is still considered invalid.

When this happens, certain commands will return VK_ERROR_DEVICE_LOST. After any such event, the logical device is considered lost. It is not possible to reset the logical device to a non-lost state, however the lost state is specific to a logical device (VkDevice), and the corresponding physical device (VkPhysicalDevice) may be otherwise unaffected.
In some cases, the physical device may also be lost, and attempting to create a new logical device will fail, returning `VK_ERROR_DEVICE_LOST`. This is usually indicative of a problem with the underlying implementation, or its connection to the host. If the physical device has not been lost, and a new logical device is successfully created from that physical device, it must be in the non-lost state.

**Note**

Whilst logical device loss may be recoverable, in the case of physical device loss, it is unlikely that an application will be able to recover unless additional, unaffected physical devices exist on the system. The error is largely informational and intended only to inform the user that a platform issue has occurred, and should be investigated further. For example, underlying hardware may have developed a fault or become physically disconnected from the rest of the system. In many cases, physical device loss may cause other more serious issues such as the operating system crashing; in which case it may not be reported via the Vulkan API.

When a device is lost, its child objects are not implicitly destroyed and their handles are still valid. Those objects must still be destroyed before their parents or the device can be destroyed (see the Object Lifetime section). The host address space corresponding to device memory mapped using `vkMapMemory` is still valid, and host memory accesses to these mapped regions are still valid, but the contents are undefined. It is still legal to call any API command on the device and child objects.

Once a device is lost, command execution may fail, and certain commands that return a `VkResult` may return `VK_ERROR_DEVICE_LOST`. These commands can be identified by the inclusion of `VK_ERROR_DEVICE_LOST` in the Return Codes section for each command. Commands that do not allow runtime errors must still operate correctly for valid usage and, if applicable, return valid data.

Commands that wait indefinitely for device execution (namely `vkDeviceWaitIdle`, `vkQueueWaitIdle`, `vkWaitForFences` or `vkAcquireNextImageKHR` with a maximum timeout, and `vkGetQueryPoolResults` with the `VK_QUERY_RESULT_WAIT_BIT` bit set in `flags`) must return in finite time even in the case of a lost device, and return either `VK_SUCCESS` or `VK_ERROR_DEVICE_LOST`. For any command that may return `VK_ERRORDEVICE_LOST`, for the purpose of determining whether a command buffer is in the pending state, or whether resources are considered in-use by the device, a return value of `VK_ERRORDEVICE_LOST` is equivalent to `VK_SUCCESS`.

If a device was created with the maintenance5 feature enabled, and any device command returns `VK_ERRORDEVICE_LOST`, then all device commands for which `VK_ERRORDEVICE_LOST` is a valid return value and which happen-after it on the same host thread must return `VK_ERRORDEVICE_LOST`.

Device commands executing on other threads must begin returning `VK_ERRORDEVICE_LOST` within finite time.

The content of any external memory objects that have been exported from or imported to a lost device become undefined. Objects on other logical devices or in other APIs which are associated with the same underlying memory resource as the external memory objects on the lost device are unaffected other than their content becoming undefined. The layout of subresources of images on other logical devices that are bound to `VkDeviceMemory` objects associated with the same underlying memory resources as external memory objects on the lost device becomes `VK_IMAGE_LAYOUT_UNDEFINED`. 

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The state of VkSemaphore objects on other logical devices created by importing a semaphore payload with temporary permanence which was exported from the lost device is undefined. The state of VkSemaphore objects on other logical devices that permanently share a semaphore payload with a VkSemaphore object on the lost device is undefined, and remains undefined following any subsequent signal operations. Implementations must ensure pending and subsequently submitted wait operations on such semaphores behave as defined in Semaphore State Requirements For Wait Operations for external semaphores not in a valid state for a wait operation.

5.2.4. Device Destruction

To destroy a device, call:

```c
// Provided by VK_VERSION_1_0
void vkDestroyDevice(
    VkDevice device,
    const VkAllocationCallbacks* pAllocator);
```

- `device` is the logical device to destroy.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

To ensure that no work is active on the device, `vkDeviceWaitIdle` can be used to gate the destruction of the device. Prior to destroying a device, an application is responsible for destroying/freeing any Vulkan objects that were created using that device as the first parameter of the corresponding `vkCreate*` or `vkAllocate*` command.

**Note**
The lifetime of each of these objects is bound by the lifetime of the `VkDevice` object. Therefore, to avoid resource leaks, it is critical that an application explicitly free all of these resources prior to calling `vkDestroyDevice`.

**Valid Usage**

- VUID-vkDestroyDevice-device-00378
  All child objects created on `device` must have been destroyed prior to destroying `device`

- VUID-vkDestroyDevice-device-00379
  If `VkAllocationCallbacks` were provided when `device` was created, a compatible set of callbacks must be provided here

- VUID-vkDestroyDevice-device-00380
  If no `VkAllocationCallbacks` were provided when `device` was created, `pAllocator` must be NULL

**Valid Usage (Implicit)**

- VUID-vkDestroyDevice-device-parameter
If `device` is not `NULL`, `device` must be a valid `VkDevice` handle

- VUID-vkDestroyDevice-pAllocator-parameter
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

### Host Synchronization

- Host access to `device` must be externally synchronized
- Host access to all `VkQueue` objects created from `device` must be externally synchronized

## 5.3. Queues

### 5.3.1. Queue Family Properties

As discussed in the Physical Device Enumeration section above, the `vkGetPhysicalDeviceQueueFamilyProperties` command is used to retrieve details about the queue families and queues supported by a device.

Each index in the `pQueueFamilyProperties` array returned by `vkGetPhysicalDeviceQueueFamilyProperties` describes a unique queue family on that physical device. These indices are used when creating queues, and they correspond directly with the `queueFamilyIndex` that is passed to the `vkCreateDevice` command via the `VkDeviceQueueCreateInfo` structure as described in the Queue Creation section below.

Grouping of queue families within a physical device is implementation-dependent.

**Note**

The general expectation is that a physical device groups all queues of matching capabilities into a single family. However, while implementations should do this, it is possible that a physical device may return two separate queue families with the same capabilities.

Once an application has identified a physical device with the queue(s) that it desires to use, it will create those queues in conjunction with a logical device. This is described in the following section.

### 5.3.2. Queue Creation

Creating a logical device also creates the queues associated with that device. The queues to create are described by a set of `VkDeviceQueueCreateInfo` structures that are passed to `vkCreateDevice` in `pQueueCreateInfos`.

Queues are represented by `VkQueue` handles:

```c
// Provided by VK_VERSION_1_0
```
The **VkDeviceQueueCreateInfo** structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkDeviceQueueCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkDeviceQueueCreateFlags flags;
    uint32_t queueFamilyIndex;
    uint32_t queueCount;
    const float* pQueuePriorities;
} VkDeviceQueueCreateInfo;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is a bitmask indicating behavior of the queues.
- **queueFamilyIndex** is an unsigned integer indicating the index of the queue family in which to create the queues on this device. This index corresponds to the index of an element of the **pQueueFamilyProperties** array that was returned by **vkGetPhysicalDeviceQueueFamilyProperties**.
- **queueCount** is an unsigned integer specifying the number of queues to create in the queue family indicated by **queueFamilyIndex**, and with the behavior specified by **flags**.
- **pQueuePriorities** is a pointer to an array of **queueCount** normalized floating point values, specifying priorities of work that will be submitted to each created queue. See **Queue Priority** for more information.

### Valid Usage

- **VUID-VkDeviceQueueCreateInfo-queueFamilyIndex-00381**
  queueFamilyIndex must be less than **pQueueFamilyPropertyCount** returned by **vkGetPhysicalDeviceQueueFamilyProperties**

- **VUID-VkDeviceQueueCreateInfo-queueCount-00382**
  queueCount must be less than or equal to the **queueCount** member of the **VkQueueFamilyProperties** structure, as returned by **vkGetPhysicalDeviceQueueFamilyProperties** in the **pQueueFamilyProperties[queueFamilyIndex]**

- **VUID-VkDeviceQueueCreateInfo-pQueuePriorities-00383**
  Each element of **pQueuePriorities** must be between 0.0 and 1.0 inclusive

- **VUID-VkDeviceQueueCreateInfo-flags-02861**
  If the protectedMemory feature is not enabled, the **VK_DEVICE_QUEUE_CREATE_PROTECTED_BIT** bit of **flags** must not be set

- **VUID-VkDeviceQueueCreateInfo-flags-06449**
  If **flags** includes **VK_DEVICE_QUEUE_CREATE_PROTECTED_BIT**, **queueFamilyIndex** must be the
Valid Usage (Implicit)

- **VUID-VkDeviceQueueCreateInfo-sType-sType**
  
  
  *sType* must be `VK_STRUCTURE_TYPE_DEVICE_QUEUE_CREATE_INFO`

- **VUID-VkDeviceQueueCreateInfo-pNext-pNext**
  
  *pNext* must be `NULL` or a pointer to a valid instance of `VkDeviceQueueGlobalPriorityCreateInfoKHR`

- **VUID-VkDeviceQueueCreateInfo-sType-unique**
  
  The *sType* value of each struct in the *pNext* chain must be unique

- **VUID-VkDeviceQueueCreateInfo-flags-parameter**
  
  *flags* must be a valid combination of `VkDeviceQueueCreateFlagBits` values

- **VUID-VkDeviceQueueCreateInfo-pQueuePriorities-parameter**
  
  *pQueuePriorities* must be a valid pointer to an array of `queueCount float` values

- **VUID-VkDeviceQueueCreateInfo-queueCount-arraylength**
  
  *queueCount* must be greater than 0

Bits which can be set in `VkDeviceQueueCreateInfo::flags`, specifying usage behavior of a queue, are:

```c
// Provided by VK_VERSION_1_1
typedef enum VkDeviceQueueCreateFlagBits {
    // Provided by VK_VERSION_1_1
    VK_DEVICE_QUEUE_CREATE_PROTECTED_BIT = 0x00000001,
} VkDeviceQueueCreateFlagBits;
```

- **VK_DEVICE_QUEUE_CREATE_PROTECTED_BIT** specifies that the device queue is a protected-capable queue.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkDeviceQueueCreateFlags;
```

`VkDeviceQueueCreateFlags` is a bitmask type for setting a mask of zero or more `VkDeviceQueueCreateFlagBits`.

Queues can be created with a system-wide priority by adding a `VkDeviceQueueGlobalPriorityCreateInfoKHR` structure to the *pNext* chain of `VkDeviceQueueCreateInfo`.

The `VkDeviceQueueGlobalPriorityCreateInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_global_priority
```
typedef struct VkDeviceQueueGlobalPriorityCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkQueueGlobalPriorityKHR globalPriority;
} VkDeviceQueueGlobalPriorityCreateInfoKHR;

or the equivalent

// Provided by VK_EXT_global_priority
typedef VkDeviceQueueGlobalPriorityCreateInfoKHR VkDeviceQueueGlobalPriorityCreateInfoEXT;

• `sType` is a `VkStructureType` value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.
• `globalPriority` is the system-wide priority associated to these queues as specified by `VkQueueGlobalPriorityEXT`

Queues created without specifying `VkDeviceQueueGlobalPriorityCreateInfoKHR` will default to `VK_QUEUE_GLOBAL_PRIORITY_MEDIUM_KHR`.

Valid Usage (Implicit)

• `VUID-VkDeviceQueueGlobalPriorityCreateInfoKHR-sType-sType` `sType` **must** be `VK_STRUCTURE_TYPE_DEVICE_QUEUE_GLOBAL_PRIORITY_CREATE_INFO_KHR`
• `VUID-VkDeviceQueueGlobalPriorityCreateInfoKHR-globalPriority-parameter` `globalPriority` **must** be a valid `VkQueueGlobalPriorityKHR` value

Possible values of `VkDeviceQueueGlobalPriorityCreateInfoKHR::globalPriority`, specifying a system-wide priority level are:

// Provided by VK_KHR_global_priority
typedef enum VkQueueGlobalPriorityKHR {
    VK_QUEUE_GLOBAL_PRIORITY_LOW_KHR = 128,
    VK_QUEUE_GLOBAL_PRIORITY_MEDIUM_KHR = 256,
    VK_QUEUE_GLOBAL_PRIORITY_HIGH_KHR = 512,
    VK_QUEUE_GLOBAL_PRIORITY_REALTIME_KHR = 1024,
    VK_QUEUE_GLOBAL_PRIORITY_LOW_EXT = VK_QUEUE_GLOBAL_PRIORITY_LOW_KHR,
    VK_QUEUE_GLOBAL_PRIORITY_MEDIUM_EXT = VK_QUEUE_GLOBAL_PRIORITY_MEDIUM_KHR,
    VK_QUEUE_GLOBAL_PRIORITY_HIGH_EXT = VK_QUEUE_GLOBAL_PRIORITY_HIGH_KHR,
    VK_QUEUE_GLOBAL_PRIORITY_REALTIME_EXT = VK_QUEUE_GLOBAL_PRIORITY_REALTIME_KHR,
} VkQueueGlobalPriorityKHR;

or the equivalent
Priority values are sorted in ascending order. A comparison operation on the enum values can be used to determine the priority order.

- `VK_QUEUE_GLOBAL_PRIORITY_LOW_KHR` is below the system default. Useful for non-interactive tasks.
- `VK_QUEUE_GLOBAL_PRIORITY_MEDIUM_KHR` is the system default priority.
- `VK_QUEUE_GLOBAL_PRIORITY_HIGH_KHR` is above the system default.
- `VK_QUEUE_GLOBAL_PRIORITY_REALTIME_KHR` is the highest priority. Useful for critical tasks.

Queues with higher system priority may be allotted more processing time than queues with lower priority. An implementation may allow a higher-priority queue to starve a lower-priority queue until the higher-priority queue has no further commands to execute.

Priorities imply no ordering or scheduling constraints.

No specific guarantees are made about higher priority queues receiving more processing time or better quality of service than lower priority queues.

The global priority level of a queue takes precedence over the per-process queue priority (`VkDeviceQueueCreateInfo::pQueuePriorities`).

Abuse of this feature may result in starving the rest of the system of implementation resources. Therefore, the driver implementation may deny requests to acquire a priority above the default priority (VK_QUEUE_GLOBAL_PRIORITY_MEDIUM_KHR) if the caller does not have sufficient privileges. In this scenario VK_ERROR_NOT_PERMITTED_KHR is returned.

The driver implementation may fail the queue allocation request if resources required to complete the operation have been exhausted (either by the same process or a different process). In this scenario VK_ERROR_INITIALIZATION_FAILED is returned.

If the `globalPriorityQuery` feature is enabled and the requested global priority is not reported via `VkQueueFamilyGlobalPriorityPropertiesKHR`, the driver implementation must fail the queue creation. In this scenario, VK_ERROR_INITIALIZATION_FAILED is returned.

To retrieve a handle to a `VkQueue` object, call:

```c
void vkGetDeviceQueue(
    VkDevice device,
    uint32_t queueFamilyIndex,
    uint32_t queueIndex,
    VkQueue* pQueue);
```

- `device` is the logical device that owns the queue.
- `queueFamilyIndex` is the index of the queue family to which the queue belongs.
• **queueIndex** is the index within this queue family of the queue to retrieve.

• **pQueue** is a pointer to a **VkQueue** object that will be filled with the handle for the requested queue.

**vkGetDeviceQueue** must only be used to get queues that were created with the **flags** parameter of **VkDeviceQueueCreateInfo** set to zero. To get queues that were created with a non-zero **flags** parameter use **vkGetDeviceQueue2**.

---

### Valid Usage

- **VUID-vkGetDeviceQueue-queueFamilyIndex-00384**  
  queueFamilyIndex **must** be one of the queue family indices specified when **device** was created, via the **VkDeviceQueueCreateInfo** structure

- **VUID-vkGetDeviceQueue-queueIndex-00385**  
  queueIndex **must** be less than the value of **VkDeviceQueueCreateInfo::queueCount** for the queue family indicated by queueFamilyIndex when **device** was created

- **VUID-vkGetDeviceQueue-flags-01841**  
  **VkDeviceQueueCreateInfo::flags** **must** have been set to zero when **device** was created

---

### Valid Usage (Implicit)

- **VUID-vkGetDeviceQueue-device-parameter**  
  **device** **must** be a valid **VkDevice** handle

- **VUID-vkGetDeviceQueue-pQueue-parameter**  
  **pQueue** **must** be a valid pointer to a **VkQueue** handle

To retrieve a handle to a **VkQueue** object with specific **VkDeviceQueueCreateFlags** creation flags, call:

```c
// Provided by VK_VERSION_1_1
void vkGetDeviceQueue2(
    VkDevice device,
    const VkDeviceQueueInfo2* pQueueInfo,
    VkQueue* pQueue);
```

• **device** is the logical device that owns the queue.

• **pQueueInfo** is a pointer to a **VkDeviceQueueInfo2** structure, describing parameters of the device queue to be retrieved.

• **pQueue** is a pointer to a **VkQueue** object that will be filled with the handle for the requested queue.
Valid Usage (Implicit)

- **VUID-vkGetDeviceQueue2-device-parameter**
  *device* must be a valid *VkDevice* handle

- **VUID-vkGetDeviceQueue2-pQueueInfo-parameter**
  *pQueueInfo* must be a valid pointer to a valid *VkDeviceQueueInfo2* structure

- **VUID-vkGetDeviceQueue2-pQueue-parameter**
  *pQueue* must be a valid pointer to a *VkQueue* handle

The *VkDeviceQueueInfo2* structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkDeviceQueueInfo2 {
    VkStructureType sType;
    const void* pNext;
    VkDeviceQueueCreateFlags flags;
    uint32_t queueFamilyIndex;
    uint32_t queueIndex;
} VkDeviceQueueInfo2;
```

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure. The **pNext** chain of *VkDeviceQueueInfo2* can be used to provide additional device queue parameters to *vkGetDeviceQueue2*.
- **flags** is a *VkDeviceQueueCreateFlags* value indicating the flags used to create the device queue.
- **queueFamilyIndex** is the index of the queue family to which the queue belongs.
- **queueIndex** is the index of the queue to retrieve from within the set of queues that share both the queue family and flags specified.

The queue returned by *vkGetDeviceQueue2* must have the same *flags* value from this structure as that used at device creation time in a *VkDeviceQueueCreateInfo* structure.

**Note**

Normally, if you create both protected-capable and non-protected-capable queues with the same family, they are treated as separate lists of queues and *queueIndex* is relative to the start of the list of queues specified by both *queueFamilyIndex* and *flags*. However, for historical reasons, some implementations may exhibit different behavior. These divergent implementations instead concatenate the lists of queues and treat *queueIndex* as relative to the start of the first list of queues with the given *queueFamilyIndex*. This only matters in cases where an application has created both protected-capable and non-protected-capable queues from the same queue family.

For such divergent implementations, the maximum value of *queueIndex* is equal to
the sum of `VkDeviceQueueCreateInfo::queueCount` minus one, for all `VkDeviceQueueCreateInfo` structures that share a common `queueFamilyIndex`.

Such implementations will return `NULL` for either the protected or unprotected queues when calling `vkGetDeviceQueue2` with `queueIndex` in the range zero to `VkDeviceQueueCreateInfo::queueCount` minus one. In cases where these implementations returned `NULL`, the corresponding queues are instead located in the extended range described in the preceding two paragraphs.

This behaviour will not be observed on any driver that has passed Vulkan conformance test suite version 1.3.3.0, or any subsequent version. This information can be found by querying `VkPhysicalDeviceDriverProperties::conformanceVersion`.

Valid Usage

- VUID-VkDeviceQueueInfo2-queueFamilyIndex-01842
  `queueFamilyIndex` must be one of the queue family indices specified when `device` was created, via the `VkDeviceQueueCreateInfo` structure

- VUID-VkDeviceQueueInfo2-flags-06225
  `flags` must be equal to `VkDeviceQueueCreateInfo::flags` for a `VkDeviceQueueCreateInfo` structure for the queue family indicated by `queueFamilyIndex` when `device` was created

- VUID-VkDeviceQueueInfo2-queueIndex-01843
  `queueIndex` must be less than `VkDeviceQueueCreateInfo::queueCount` for the corresponding queue family and flags indicated by `queueFamilyIndex` and `flags` when `device` was created

Valid Usage (Implicit)

- VUID-VkDeviceQueueInfo2-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_DEVICE_QUEUE_INFO_2`

- VUID-VkDeviceQueueInfo2-pNext-pNext
  `pNext` must be `NULL`

- VUID-VkDeviceQueueInfo2-flags-parameter
  `flags` must be a valid combination of `VkDeviceQueueCreateFlagBits` values

5.3.3. Queue Family Index

The queue family index is used in multiple places in Vulkan in order to tie operations to a specific family of queues.

When retrieving a handle to the queue via `vkGetDeviceQueue`, the queue family index is used to select which queue family to retrieve the `VkQueue` handle from as described in the previous section.

When creating a `VkCommandPool` object (see Command Pools), a queue family index is specified in the `VkCommandPoolCreateInfo` structure. Command buffers from this pool can only be submitted on
queues corresponding to this queue family.

When creating VkImage (see Images) and VkBuffer (see Buffers) resources, a set of queue families is included in the VkImageCreateInfo and VkBufferCreateInfo structures to specify the queue families that can access the resource.

When inserting a VkBufferMemoryBarrier or VkImageMemoryBarrier (see Pipeline Barriers), a source and destination queue family index is specified to allow the ownership of a buffer or image to be transferred from one queue family to another. See the Resource Sharing section for details.

5.3.4. Queue Priority

Each queue is assigned a priority, as set in the VkDeviceQueueCreateInfo structures when creating the device. The priority of each queue is a normalized floating point value between 0.0 and 1.0, which is then translated to a discrete priority level by the implementation. Higher values indicate a higher priority, with 0.0 being the lowest priority and 1.0 being the highest.

Within the same device, queues with higher priority may be allotted more processing time than queues with lower priority. The implementation makes no guarantees with regards to ordering or scheduling among queues with the same priority, other than the constraints defined by any explicit synchronization primitives. The implementation makes no guarantees with regards to queues across different devices.

An implementation may allow a higher-priority queue to starve a lower-priority queue on the same VkDevice until the higher-priority queue has no further commands to execute. The relationship of queue priorities must not cause queues on one VkDevice to starve queues on another VkDevice.

No specific guarantees are made about higher priority queues receiving more processing time or better quality of service than lower priority queues.

5.3.5. Queue Submission

Work is submitted to a queue via queue submission commands such as vkQueueSubmit2 or vkQueueSubmit. Queue submission commands define a set of queue operations to be executed by the underlying physical device, including synchronization with semaphores and fences.

Submission commands take as parameters a target queue, zero or more batches of work, and an optional fence to signal upon completion. Each batch consists of three distinct parts:

1. Zero or more semaphores to wait on before execution of the rest of the batch.
   - If present, these describe a semaphore wait operation.
2. Zero or more work items to execute.
   - If present, these describe a queue operation matching the work described.
3. Zero or more semaphores to signal upon completion of the work items.
   - If present, these describe a semaphore signal operation.

If a fence is present in a queue submission, it describes a fence signal operation.
All work described by a queue submission command **must** be submitted to the queue before the command returns.

**Sparse Memory Binding**

In Vulkan it is possible to sparsely bind memory to buffers and images as described in the *Sparse Resource* chapter. Sparse memory binding is a queue operation. A queue whose flags include the *VK_QUEUE_SPARSE_BINDING_BIT* **must** be able to support the mapping of a virtual address to a physical address on the device. This causes an update to the page table mappings on the device. This update **must** be synchronized on a queue to avoid corrupting page table mappings during execution of graphics commands. By binding the sparse memory resources on queues, all commands that are dependent on the updated bindings are synchronized to only execute after the binding is updated. See the *Synchronization and Cache Control* chapter for how this synchronization is accomplished.

**5.3.6. Queue Destruction**

Queues are created along with a logical device during **vkCreateDevice**. All queues associated with a logical device are destroyed when **vkDestroyDevice** is called on that device.
Chapter 6. Command Buffers

Command buffers are objects used to record commands which can be subsequently submitted to a device queue for execution. There are two levels of command buffers - primary command buffers, which can execute secondary command buffers, and which are submitted to queues, and secondary command buffers, which can be executed by primary command buffers, and which are not directly submitted to queues.

Command buffers are represented by VkCommandBuffer handles:

```c
// Provided by VK_VERSION_1_0
Vk_DEFINE_HANDLE(VkCommandBuffer)
```

Recorded commands include commands to bind pipelines and descriptor sets to the command buffer, commands to modify dynamic state, commands to draw (for graphics rendering), commands to dispatch (for compute), commands to execute secondary command buffers (for primary command buffers only), commands to copy buffers and images, and other commands.

Each command buffer manages state independently of other command buffers. There is no inheritance of state across primary and secondary command buffers, or between secondary command buffers. When a command buffer begins recording, all state in that command buffer is undefined. When secondary command buffer(s) are recorded to execute on a primary command buffer, the secondary command buffer inherits no state from the primary command buffer, and all state of the primary command buffer is undefined after an execute secondary command buffer command is recorded. There is one exception to this rule - if the primary command buffer is inside a render pass instance, then the render pass and subpass state is not disturbed by executing secondary command buffers. For state dependent commands (such as draws and dispatches), any state consumed by those commands must not be undefined.

VkCommandBufferInheritanceViewportScissorInfoNV defines an exception allowing limited inheritance of dynamic viewport and scissor state.

Unless otherwise specified, and without explicit synchronization, the various commands submitted to a queue via command buffers may execute in arbitrary order relative to each other, and/or concurrently. Also, the memory side effects of those commands may not be directly visible to other commands without explicit memory dependencies. This is true within a command buffer, and across command buffers submitted to a given queue. See the synchronization chapter for information on implicit and explicit synchronization between commands.

6.1. Command Buffer Lifecycle

Each command buffer is always in one of the following states:

**Initial**

When a command buffer is allocated, it is in the initial state. Some commands are able to reset a command buffer (or a set of command buffers) back to this state from any of the executable, recording or invalid state. Command buffers in the initial state can only be moved to the
recording state, or freed.

**Recording**

`vkBeginCommandBuffer` changes the state of a command buffer from the initial state to the *recording state*. Once a command buffer is in the recording state, `vkCmd*` commands can be used to record to the command buffer.

**Executable**

`vkEndCommandBuffer` ends the recording of a command buffer, and moves it from the recording state to the *executable state*. Executable command buffers can be submitted, reset, or recorded to another command buffer.

**Pending**

*Queue submission* of a command buffer changes the state of a command buffer from the executable state to the *pending state*. Whilst in the pending state, applications must not attempt to modify the command buffer in any way - as the device may be processing the commands recorded to it. Once execution of a command buffer completes, the command buffer either reverts back to the *executable state*, or if it was recorded with `VK_COMMAND_BUFFER_USAGE_ONE_TIME_SUBMIT_BIT`, it moves to the *invalid state*. A synchronization command should be used to detect when this occurs.

**Invalid**

Some operations, such as modifying or deleting a resource that was used in a command recorded to a command buffer, will transition the state of that command buffer into the *invalid state*. Command buffers in the invalid state can only be reset or freed.

![Figure 1. Lifecycle of a command buffer](image)

Any given command that operates on a command buffer has its own requirements on what state a command buffer must be in, which are detailed in the valid usage constraints for that command.

Resetting a command buffer is an operation that discards any previously recorded commands and puts a command buffer in the *initial state*. Resetting occurs as a result of `vkResetCommandBuffer` or `vkResetCommandPool`, or as part of `vkBeginCommandBuffer` (which additionally puts the command buffer in the *recording state*).
Secondary command buffers can be recorded to a primary command buffer via vkCmdExecuteCommands. This partially ties the lifecycle of the two command buffers together - if the primary is submitted to a queue, both the primary and any secondaries recorded to it move to the pending state. Once execution of the primary completes, so it does for any secondary recorded within it. After all executions of each command buffer complete, they each move to their appropriate completion state (either to the executable state or the invalid state, as specified above).

If a secondary moves to the invalid state or the initial state, then all primary buffers it is recorded in move to the invalid state. A primary moving to any other state does not affect the state of a secondary recorded in it.

Note
Resetting or freeing a primary command buffer removes the lifecycle linkage to all secondary command buffers that were recorded into it.

6.2. Command Pools

Command pools are opaque objects that command buffer memory is allocated from, and which allow the implementation to amortize the cost of resource creation across multiple command buffers. Command pools are externally synchronized, meaning that a command pool must not be used concurrently in multiple threads. That includes use via recording commands on any command buffers allocated from the pool, as well as operations that allocate, free, and reset command buffers or the pool itself.

Command pools are represented by VkCommandPool handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkCommandPool)
```

To create a command pool, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkCreateCommandPool(
    VkDevice device,
    const VkCommandPoolCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkCommandPool* pCommandPool);
```

- `device` is the logical device that creates the command pool.
- `pCreateInfo` is a pointer to a VkCommandPoolCreateInfo structure specifying the state of the command pool object.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pCommandPool` is a pointer to a VkCommandPool handle in which the created pool is returned.
Valid Usage

• VUID-vkCreateCommandPool-queueFamilyIndex-01937
  `pCreateInfo->queueFamilyIndex` must be the index of a queue family available in the logical device `device`

Valid Usage (Implicit)

• VUID-vkCreateCommandPool-device-parameter
  `device` must be a valid `VkDevice` handle

• VUID-vkCreateCommandPool-pCreateInfo-parameter
  `pCreateInfo` must be a valid pointer to a valid `VkCommandPoolCreateInfo` structure

• VUID-vkCreateCommandPool-pAllocator-parameter
  If `pAllocator` is not `NULL`, `Allocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

• VUID-vkCreateCommandPool-pCommandPool-parameter
  `pCommandPool` must be a valid pointer to a `VkCommandPool` handle

Return Codes

Success

• `VK_SUCCESS`

Failure

• `VK_ERROR_OUT_OF_HOST_MEMORY`

• `VK_ERROR_OUT_OF_DEVICE_MEMORY`

The `VkCommandPoolCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkCommandPoolCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkCommandPoolCreateFlags flags;
    uint32_t queueFamilyIndex;
} VkCommandPoolCreateInfo;
```

• `sType` is a `VkStructureType` value identifying this structure.

• `pNext` is `NULL` or a pointer to a structure extending this structure.

• `flags` is a bitmask of `VkCommandPoolCreateFlagBits` indicating usage behavior for the pool and command buffers allocated from it.
• **queueFamilyIndex** designates a queue family as described in section Queue Family Properties. All command buffers allocated from this command pool **must** be submitted on queues from the same queue family.

### Valid Usage

- **VUID-VkCommandPoolCreateInfo-flags-02860**
  If the protectedMemory feature is not enabled, the **VK_COMMAND_POOL_CREATE_PROTECTED_BIT** bit of **flags** **must** not be set.

### Valid Usage (Implicit)

- **VUID-VkCommandPoolCreateInfo-sType-sType**
  **sType** **must** be **VK_STRUCTURE_TYPE_COMMAND_POOL_CREATE_INFO**

- **VUID-VkCommandPoolCreateInfo-pNext-pNext**
  **pNext** **must** be **NULL**

- **VUID-VkCommandPoolCreateInfo-flags-parameter**
  **flags** **must** be a valid combination of **VkCommandPoolCreateFlagBits** values

Bits which **can** be set in **VkCommandPoolCreateInfo::flags**, specifying usage behavior for a command pool, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkCommandPoolCreateFlagBits {
  VK_COMMAND_POOL_CREATE_TRANSIENT_BIT = 0x00000001,
  VK_COMMAND_POOL_CREATE_RESET_COMMAND_BUFFER_BIT = 0x00000002,
// Provided by VK_VERSION_1_1
  VK_COMMAND_POOL_CREATE_PROTECTED_BIT = 0x00000004,
} VkCommandPoolCreateFlagBits;
```

- **VK_COMMAND_POOL_CREATE_TRANSIENT_BIT** specifies that command buffers allocated from the pool will be short-lived, meaning that they will be reset or freed in a relatively short timeframe. This flag **may** be used by the implementation to control memory allocation behavior within the pool.

- **VK_COMMAND_POOL_CREATE_RESET_COMMAND_BUFFER_BIT** allows any command buffer allocated from a pool to be individually reset to the **initial state**; either by calling **vkResetCommandBuffer**, or via the implicit reset when calling **vkBeginCommandBuffer**. If this flag is not set on a pool, then **vkResetCommandBuffer** **must** not be called for any command buffer allocated from that pool.

- **VK_COMMAND_POOL_CREATE_PROTECTED_BIT** specifies that command buffers allocated from the pool are protected command buffers.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkCommandPoolCreateFlags;
```
 VkCommandPoolCreateFlags is a bitmask type for setting a mask of zero or more VkCommandPoolCreateFlagBits.

To trim a command pool, call:

```c
// Provided by VK_VERSION_1_1
void vkTrimCommandPool(
    VkDevice device,
    VkCommandPool commandPool,
    VkCommandPoolTrimFlags flags);
```

or the equivalent command

```c
// Provided by VK_KHR_maintenance1
void vkTrimCommandPoolKHR(
    VkDevice device,
    VkCommandPool commandPool,
    VkCommandPoolTrimFlags flags);
```

- `device` is the logical device that owns the command pool.
- `commandPool` is the command pool to trim.
- `flags` is reserved for future use.

Trimming a command pool recycles unused memory from the command pool back to the system. Command buffers allocated from the pool are not affected by the command.

**Note**

This command provides applications with some control over the internal memory allocations used by command pools.

Unused memory normally arises from command buffers that have been recorded and later reset, such that they are no longer using the memory. On reset, a command buffer can return memory to its command pool, but the only way to release memory from a command pool to the system requires calling `vkResetCommandPool`, which cannot be executed while any command buffers from that pool are still in use. Subsequent recording operations into command buffers will reuse this memory but since total memory requirements fluctuate over time, unused memory can accumulate.

In this situation, trimming a command pool may be useful to return unused memory back to the system, returning the total outstanding memory allocated by the pool back to a more “average” value.

Implementations utilize many internal allocation strategies that make it impossible to guarantee that all unused memory is released back to the system. For instance, an implementation of a command pool may involve allocating memory in bulk from the system and sub-allocating from that memory. In such an
implementation any live command buffer that holds a reference to a bulk allocation would prevent that allocation from being freed, even if only a small proportion of the bulk allocation is in use.

In most cases trimming will result in a reduction in allocated but unused memory, but it does not guarantee the “ideal” behavior.

Trimming may be an expensive operation, and should not be called frequently. Trimming should be treated as a way to relieve memory pressure after application-known points when there exists enough unused memory that the cost of trimming is “worth” it.

---

Valid Usage (Implicit)

- VUID-vkTrimCommandPool-device-parameter
device must be a valid VkDevice handle
- VUID-vkTrimCommandPool-commandPool-parameter
commandPool must be a valid VkCommandPool handle
- VUID-vkTrimCommandPool-flags-zerobitmask
flags must be 0
- VUID-vkTrimCommandPool-commandPool-parent
commandPool must have been created, allocated, or retrieved from device

---

Host Synchronization

- Host access to commandPool must be externally synchronized

---

// Provided by VK_VERSION_1_1
typedef VkFlags VkCommandPoolTrimFlags;

or the equivalent

// Provided by VK_KHR_maintenance1
typedef VkCommandPoolTrimFlags VkCommandPoolTrimFlagsKHR;

VkCommandPoolTrimFlags is a bitmask type for setting a mask, but is currently reserved for future use.

To reset a command pool, call:

---

// Provided by VK_VERSION_1_0
VkResult vkResetCommandPool(
    VkDevice device,
    VkCommandPool commandPool,
    ...);

---
VkCommandPoolResetFlags flags);

- `device` is the logical device that owns the command pool.
- `commandPool` is the command pool to reset.
- `flags` is a bitmask of `VkCommandPoolResetFlagBits` controlling the reset operation.

Resetting a command pool recycles all of the resources from all of the command buffers allocated from the command pool back to the command pool. All command buffers that have been allocated from the command pool are put in the initial state.

Any primary command buffer allocated from another `VkCommandPool` that is in the recording or executable state and has a secondary command buffer allocated from `commandPool` recorded into it, becomes invalid.

**Valid Usage**

- VUID-vkResetCommandPool-commandPool-00040
  All `VkCommandBuffer` objects allocated from `commandPool` must not be in the pending state

**Valid Usage (Implicit)**

- VUID-vkResetCommandPool-device-parameter
  `device` must be a valid `VkDevice` handle
- VUID-vkResetCommandPool-commandPool-parameter
  `commandPool` must be a valid `VkCommandPool` handle
- VUID-vkResetCommandPool-flags-parameter
  `flags` must be a valid combination of `VkCommandPoolResetFlagBits` values
- VUID-vkResetCommandPool-commandPool-parent
  `commandPool` must have been created, allocated, or retrieved from `device`

**Host Synchronization**

- Host access to `commandPool` must be externally synchronized

**Return Codes**

- **Success**
  - `VK_SUCCESS`
- **Failure**
  - `VK_ERROR_OUT_OF_DEVICE_MEMORY`
Bits which **can** be set in `vkResetCommandPool::flags`, controlling the reset operation, are:

```cpp
// Provided by VK_VERSION_1_0
typedef enum VkCommandPoolResetFlagBits {
    VK_COMMAND_POOL_RESET_RELEASE_RESOURCES_BIT = 0x00000001,
} VkCommandPoolResetFlagBits;
```

- **VK_COMMAND_POOL_RESET_RELEASE_RESOURCES_BIT** specifies that resetting a command pool recycles all of the resources from the command pool back to the system.

```cpp
// Provided by VK_VERSION_1_0
typedef VkFlags VkCommandPoolResetFlags;
```

`VkCommandPoolResetFlags` is a bitmask type for setting a mask of zero or more `VkCommandPoolResetFlagBits`.

To destroy a command pool, call:

```cpp
// Provided by VK_VERSION_1_0
void vkDestroyCommandPool(
    VkDevice device,  // device is the logical device that destroys the command pool.
    VkCommandPool commandPool,  // commandPool is the handle of the command pool to destroy.
    const VkAllocationCallbacks* pAllocator);  // pAllocator controls host memory allocation as described in the Memory Allocation chapter.
```

When a pool is destroyed, all command buffers allocated from the pool are **freed**.

Any primary command buffer allocated from another `VkCommandPool` that is in the recording or executable state and has a secondary command buffer allocated from `commandPool` recorded into it, becomes **invalid**.

---

**Valid Usage**

- **VUID-vkDestroyCommandPool-commandPool-00041**
  All `VkCommandBuffer` objects allocated from `commandPool` **must** not be in the **pending state**

- **VUID-vkDestroyCommandPool-commandPool-00042**
  If `VkAllocationCallbacks` were provided when `commandPool` was created, a compatible set of callbacks **must** be provided here

- **VUID-vkDestroyCommandPool-commandPool-00043**
  If no `VkAllocationCallbacks` were provided when `commandPool` was created, `pAllocator` **must** be `NULL`
Valid Usage (Implicit)

- VUID-vkDestroyCommandPool-device-parameter
  - device must be a valid VkDevice handle

- VUID-vkDestroyCommandPool-commandPool-parameter
  - If commandPool is not VK_NULL_HANDLE, commandPool must be a valid VkCommandPool handle

- VUID-vkDestroyCommandPool-pAllocator-parameter
  - If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkDestroyCommandPool-commandPool-parent
  - If commandPool is a valid handle, it must have been created, allocated, or retrieved from device

Host Synchronization

- Host access to commandPool must be externally synchronized

6.3. Command Buffer Allocation and Management

To allocate command buffers, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkAllocateCommandBuffers(
    VkDevice device,
    const VkCommandBufferAllocateInfo* pAllocateInfo,
    VkCommandBuffer* pCommandBuffers);
```

- device is the logical device that owns the command pool.
- pAllocateInfo is a pointer to a VkCommandBufferAllocateInfo structure describing parameters of the allocation.
- pCommandBuffers is a pointer to an array of VkCommandBuffer handles in which the resulting command buffer objects are returned. The array must be at least the length specified by the commandBufferCount member of pAllocateInfo. Each allocated command buffer begins in the initial state.

vkAllocateCommandBuffers can be used to allocate multiple command buffers. If the allocation of any of those command buffers fails, the implementation must free all successfully allocated command buffer objects from this command, set all entries of the pCommandBuffers array to NULL and return the error.

Note
Filling `pCommandBuffers` with NULL values on failure is an exception to the default error behavior that output parameters will have undefined contents.

When command buffers are first allocated, they are in the initial state.

Valid Usage (Implicit)

- **VUID-vkAllocateCommandBuffers-device-parameter**
  
  `device` must be a valid `VkDevice` handle

- **VUID-vkAllocateCommandBuffers-pAllocateInfo-parameter**
  
  `pAllocateInfo` must be a valid pointer to a valid `VkCommandBufferAllocateInfo` structure

- **VUID-vkAllocateCommandBuffers-pCommandBuffers-parameter**
  
  `pCommandBuffers` must be a valid pointer to an array of `pAllocateInfo->commandBufferCount` `VkCommandBuffer` handles

- **VUID-vkAllocateCommandBuffers-pAllocateInfo::commandBufferCount-arraylength**
  
  `pAllocateInfo->commandBufferCount` must be greater than 0

Host Synchronization

- Host access to `pAllocateInfo->commandPool` must be externally synchronized

Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

The `VkCommandBufferAllocateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkCommandBufferAllocateInfo {
    VkStructureType sType;
    const void* pNext;
    VkCommandPool commandPool;
    VkCommandBufferLevel level;
    uint32_t commandBufferCount;
} VkCommandBufferAllocateInfo;
```

- `sType` is a `VkStructureType` value identifying this structure.
• `pNext` is NULL or a pointer to a structure extending this structure.
• `commandPool` is the command pool from which the command buffers are allocated.
• `level` is a `VkCommandBufferLevel` value specifying the command buffer level.
• `commandBufferCount` is the number of command buffers to allocate from the pool.

### Valid Usage (Implicit)

- VUID-VkCommandBufferAllocateInfo-sType-sType
  
  `sType` **must** be `VK_STRUCTURE_TYPE_COMMAND_BUFFER_ALLOCATE_INFO`

- VUID-VkCommandBufferAllocateInfo-pNext-pNext
  
  `pNext` **must** be `NULL`

- VUID-VkCommandBufferAllocateInfo-commandPool-parameter
  
  `commandPool` **must** be a valid `VkCommandPool` handle

- VUID-VkCommandBufferAllocateInfo-level-parameter
  
  `level` **must** be a valid `VkCommandBufferLevel` value

Possible values of `VkCommandBufferAllocateInfo::level`, specifying the command buffer level, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkCommandBufferLevel {
    VK_COMMAND_BUFFER_LEVEL_PRIMARY = 0,
    VK_COMMAND_BUFFER_LEVEL_SECONDARY = 1,
} VkCommandBufferLevel;
```

- `VK_COMMAND_BUFFER_LEVEL_PRIMARY` specifies a primary command buffer.
- `VK_COMMAND_BUFFER_LEVEL_SECONDARY` specifies a secondary command buffer.

To reset a command buffer, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkResetCommandBuffer(  
    VkCommandBuffer commandBuffer,  
    VkCommandBufferResetFlags flags);
```

- `commandBuffer` is the command buffer to reset. The command buffer **can** be in any state other than `pending`, and is moved into the initial state.
- `flags` is a bitmask of `VkCommandBufferResetFlagBits` controlling the reset operation.

Any primary command buffer that is in the recording or executable state and has `commandBuffer` recorded into it, becomes invalid.
Valid Usage

- VUID-vkResetCommandBuffer-commandBuffer-00045
  `commandBuffer` must not be in the **pending state**

- VUID-vkResetCommandBuffer-commandBuffer-00046
  `commandBuffer` must have been allocated from a pool that was created with the `VK_COMMAND_POOL_CREATE_RESET_COMMAND_BUFFER_BIT`

Valid Usage (Implicit)

- VUID-vkResetCommandBuffer-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkResetCommandBuffer-flags-parameter
  `flags` must be a valid combination of `VkCommandBufferResetFlagBits` values

Host Synchronization

- Host access to `commandBuffer` must be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

Bits which **can** be set in `vkResetCommandBuffer::flags`, controlling the reset operation, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkCommandBufferResetFlagBits {
    VK_COMMAND_BUFFER_RESET_RELEASE_RESOURCES_BIT = 0x00000001,
} VkCommandBufferResetFlagBits;
```

- `VK_COMMAND_BUFFER_RESET_RELEASE_RESOURCES_BIT` specifies that most or all memory resources currently owned by the command buffer **should** be returned to the parent command pool. If this flag is not set, then the command buffer **may** hold onto memory resources and reuse them when recording commands. `commandBuffer` is moved to the **initial state**.
typedef VkFlags VkCommandBufferResetFlags;

VkCommandBufferResetFlags is a bitmask type for setting a mask of zero or more VkCommandBufferResetFlagBits.

To free command buffers, call:

```c
void vkFreeCommandBuffers(
    VkDevice device,
    VkCommandPool commandPool,
    uint32_t commandBufferCount,
    const VkCommandBuffer* pCommandBuffers);
```

- `device` is the logical device that owns the command pool.
- `commandPool` is the command pool from which the command buffers were allocated.
- `commandBufferCount` is the length of the `pCommandBuffers` array.
- `pCommandBuffers` is a pointer to an array of handles of command buffers to free.

Any primary command buffer that is in the recording or executable state and has any element of `pCommandBuffers` recorded into it, becomes invalid.

### Valid Usage

- VUID-vkFreeCommandBuffers-pCommandBuffers-00047
  All elements of `pCommandBuffers` must not be in the pending state

- VUID-vkFreeCommandBuffers-pCommandBuffers-00048
  `pCommandBuffers` must be a valid pointer to an array of `commandBufferCount` VkCommandBuffer handles, each element of which must either be a valid handle or NULL

### Valid Usage (Implicit)

- VUID-vkFreeCommandBuffers-device-parameter
  `device` must be a valid `VkDevice` handle

- VUID-vkFreeCommandBuffers-commandPool-parameter
  `commandPool` must be a valid `VkCommandPool` handle

- VUID-vkFreeCommandBuffers-commandBufferCount-arraylength
  `commandBufferCount` must be greater than 0

- VUID-vkFreeCommandBuffers-commandPool-parent
  `commandPool` must have been created, allocated, or retrieved from `device`

- VUID-vkFreeCommandBuffers-pCommandBuffers-parent
Each element of \texttt{pCommandBuffers} that is a valid handle \textbf{must} have been created, allocated, or retrieved from \texttt{commandPool}

### Host Synchronization

- Host access to \texttt{commandPool} \textbf{must} be externally synchronized
- Host access to each member of \texttt{pCommandBuffers} \textbf{must} be externally synchronized

### 6.4. Command Buffer Recording

To begin recording a command buffer, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkBeginCommandBuffer(
    VkCommandBuffer commandBuffer,
    const VkCommandBufferBeginInfo* pBeginInfo);
```

- \texttt{commandBuffer} is the handle of the command buffer which is to be put in the recording state.
- \texttt{pBeginInfo} is a pointer to a \texttt{VkCommandBufferBeginInfo} structure defining additional information about how the command buffer begins recording.

### Valid Usage

- VUID-vkBeginCommandBuffer-commandBuffer-00049
  \texttt{commandBuffer} \textbf{must} not be in the \texttt{recording or pending state}

- VUID-vkBeginCommandBuffer-commandBuffer-00050
  If \texttt{commandBuffer} was allocated from a \texttt{VkCommandPool} which did not have the \texttt{VK_COMMAND_POOL_CREATE_RESET_COMMAND_BUFFER_BIT} flag set, \texttt{commandBuffer} \textbf{must} be in the \texttt{initial state}

- VUID-vkBeginCommandBuffer-commandBuffer-00051
  If \texttt{commandBuffer} is a secondary command buffer, the \texttt{pInheritanceInfo} member of \texttt{pBeginInfo} \textbf{must} be a valid \texttt{VkCommandBufferInheritanceInfo} structure

- VUID-vkBeginCommandBuffer-commandBuffer-00052
  If \texttt{commandBuffer} is a secondary command buffer and either the \texttt{occlusionQueryEnable} member of the \texttt{pInheritanceInfo} member of \texttt{pBeginInfo} is \texttt{VK_FALSE}, or the \texttt{occlusionQueryPrecise} feature is not enabled, then \texttt{pBeginInfo->pInheritanceInfo->queryFlags} \textbf{must} not contain \texttt{VK_QUERY_CONTROL_PRECISE_BIT}

- VUID-vkBeginCommandBuffer-commandBuffer-02840
  If \texttt{commandBuffer} is a primary command buffer, then \texttt{pBeginInfo->flags} \textbf{must} not set both the \texttt{VK_COMMAND_BUFFER_USAGE_ONE_TIME_SUBMIT_BIT} and the \texttt{VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT} flags
Valid Usage (Implicit)

- VUID-vkBeginCommandBuffer-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle
- VUID-vkBeginCommandBuffer-pBeginInfo-parameter
  pBeginInfo must be a valid pointer to a valid VkCommandBufferBeginInfo structure

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkCommandBufferBeginInfo structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkCommandBufferBeginInfo {
    VkStructureType sType;
    const void* pNext;
    VkCommandBufferUsageFlags flags;
    const VkCommandBufferInheritanceInfo* pInheritanceInfo;
} VkCommandBufferBeginInfo;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `flags` is a bitmask of VkCommandBufferUsageFlagBits specifying usage behavior for the command buffer.
- `pInheritanceInfo` is a pointer to a VkCommandBufferInheritanceInfo structure, used if commandBuffer is a secondary command buffer. If this is a primary command buffer, then this value is ignored.
Valid Usage

- VUID-VkCommandBufferBeginInfo-flags-09123
  If flags contains VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT, the VkCommandPool that commandBuffer was allocated from must support graphics operations.

- VUID-VkCommandBufferBeginInfo-flags-00055
  If flags contains VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT, the framebuffer member of pInheritanceInfo must be either VK_NULL_HANDLE, or a valid VkFramebuffer that is compatible with the renderPass member of pInheritanceInfo.

- VUID-VkCommandBufferBeginInfo-flags-09240
  If flags contains VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT and the dynamicRendering feature is not enabled, the renderPass member of pInheritanceInfo must not be VK_NULL_HANDLE.

- VUID-VkCommandBufferBeginInfo-flags-06002
  If flags contains VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT and the renderPass member of pInheritanceInfo is VK_NULL_HANDLE, the pNext chain of pInheritanceInfo must include a VkCommandBufferInheritanceRenderingInfo structure.

- VUID-VkCommandBufferBeginInfo-flags-06003
  If flags contains VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT, the renderPass member of pInheritanceInfo is VK_NULL_HANDLE, and the pNext chain of pInheritanceInfo includes a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, the colorAttachmentCount member of that structure must be equal to the value of VkCommandBufferInheritanceRenderingInfo::colorAttachmentCount.

- VUID-VkCommandBufferBeginInfo-flags-06000
  If flags contains VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT and the renderPass member of pInheritanceInfo is not VK_NULL_HANDLE, the renderPass member of pInheritanceInfo must be a valid VkRenderPass.

- VUID-VkCommandBufferBeginInfo-flags-06001
  If flags contains VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT and the renderPass member of pInheritanceInfo is not VK_NULL_HANDLE, the subpass member of pInheritanceInfo must be a valid subpass index within the renderPass member of pInheritanceInfo.

Valid Usage (Implicit)

- VUID-VkCommandBufferBeginInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_COMMAND_BUFFER_BEGIN_INFO.

- VUID-VkCommandBufferBeginInfo-pNext-pNext
  pNext must be NULL or a pointer to a valid instance of VkDeviceGroupCommandBufferBeginInfo.

- VUID-VkCommandBufferBeginInfo-sType-unique
  The sType value of each struct in the pNext chain must be unique.
Bits which **can** be set in `VkCommandBufferBeginInfo::flags`, specifying usage behavior for a command buffer, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkCommandBufferUsageFlagBits {
    VK_COMMAND_BUFFER_USAGE_ONE_TIME_SUBMIT_BIT = 0x00000001,
    VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT = 0x00000002,
    VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT = 0x00000004,
} VkCommandBufferUsageFlagBits;
```

- **VK_COMMAND_BUFFER_USAGE_ONE_TIME_SUBMIT_BIT** specifies that each recording of the command buffer will only be submitted once, and the command buffer will be reset and recorded again between each submission.

- **VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT** specifies that a secondary command buffer is considered to be entirely inside a render pass. If this is a primary command buffer, then this bit is ignored.

- **VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT** specifies that a command buffer **can** be resubmitted to a queue while it is in the *pending state*, and recorded into multiple primary command buffers.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkCommandBufferUsageFlags;
```

`VkCommandBufferUsageFlags` is a bitmask type for setting a mask of zero or more `VkCommandBufferUsageFlagBits`.

If the command buffer is a secondary command buffer, then the `VkCommandBufferInheritanceInfo` structure defines any state that will be inherited from the primary command buffer:

```c
// Provided by VK_VERSION_1_0
typedef struct VkCommandBufferInheritanceInfo {
    VkStructureType sType;
    const void* pNext;
    VkRenderPass renderPass;
    uint32_t subpass;
    VkFramebuffer framebuffer;
    VkBool32 occlusionQueryEnable;
    VkQueryControlFlags queryFlags;
    VkQueryPipelineStatisticFlags pipelineStatistics;
} VkCommandBufferInheritanceInfo;
```

- **sType** is a `VkStructureType` value identifying this structure.
• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **renderPass** is a **VkRenderPass** object defining which render passes the **VkCommandBuffer** will be compatible with and **can** be executed within.

• **subpass** is the index of the subpass within the render pass instance that the **VkCommandBuffer** will be executed within.

• **framebuffer** **can** refer to the **VkFramebuffer** object that the **VkCommandBuffer** will be rendering to if it is executed within a render pass instance. It **can** be **VK_NULL_HANDLE** if the framebuffer is not known.

Note

Specifying the exact framebuffer that the secondary command buffer will be executed with **may** result in better performance at command buffer execution time.

• **occlusionQueryEnable** specifies whether the command buffer **can** be executed while an occlusion query is active in the primary command buffer. If this is **VK_TRUE**, then this command buffer **can** be executed whether the primary command buffer has an occlusion query active or not. If this is **VK_FALSE**, then the primary command buffer **must** not have an occlusion query active.

• **queryFlags** specifies the query flags that **can** be used by an active occlusion query in the primary command buffer when this secondary command buffer is executed. If this value includes the **VK_QUERY_CONTROL_PRECISE_BIT** bit, then the active query **can** return boolean results or actual sample counts. If this bit is not set, then the active query **must** not use the **VK_QUERY_CONTROL_PRECISE_BIT** bit.

• **pipelineStatistics** is a bitmask of **VkQueryPipelineStatisticFlagBits** specifying the set of pipeline statistics that **can** be counted by an active query in the primary command buffer when this secondary command buffer is executed. If this value includes a given bit, then this command buffer **can** be executed whether the primary command buffer has a pipeline statistics query active that includes this bit or not. If this value excludes a given bit, then the active pipeline statistics query **must** not be from a query pool that counts that statistic.

If the **VkCommandBuffer** will not be executed within a render pass instance, or if the render pass instance was begun with **vkCmdBeginRendering**, **renderPass**, **subpass**, and **framebuffer** are ignored.

Valid Usage

• **VUID-VkCommandBufferInheritanceInfo-occlusionQueryEnable-00056**
  If the **inheritedQueries** feature is not enabled, **occlusionQueryEnable** **must** be **VK_FALSE**

• **VUID-VkCommandBufferInheritanceInfo-queryFlags-00057**
  If the **inheritedQueries** feature is enabled, **queryFlags** **must** be a valid combination of **VkQueryControlFlagBits** values

• **VUID-VkCommandBufferInheritanceInfo-queryFlags-02788**
  If the **inheritedQueries** feature is not enabled, **queryFlags** **must** be **0**

• **VUID-VkCommandBufferInheritanceInfo-pipelineStatistics-02789**
If the `pipelineStatisticsQuery` feature is enabled, `pipelineStatistics` must be a valid combination of `VkQueryPipelineStatisticFlagBits` values.

- VUID-VkCommandBufferInheritanceInfo-pipelineStatistics-00058

If the `pipelineStatisticsQuery` feature is not enabled, `pipelineStatistics` must be 0.

### Valid Usage (Implicit)

- VUID-VkCommandBufferInheritanceInfo-sType-sType
  
  The `sType` must be `VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_INFO`.

- VUID-VkCommandBufferInheritanceInfo-pNext-pNext
  
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkAttachmentSampleCountInfoAMD`, `VkCommandBufferInheritanceConditionalRenderingInfoEXT`, `VkCommandBufferInheritanceRenderPassTransformInfoQCOM`, `VkCommandBufferInheritanceRenderingInfo`, `VkCommandBufferInheritanceViewportScissorInfoNV`, or `VkMultiviewPerViewAttributesInfoNVX`.

- VUID-VkCommandBufferInheritanceInfo-sType-unique
  
  The `sType` value of each struct in the `pNext` chain must be unique.

- VUID-VkCommandBufferInheritanceInfo-commonparent
  
  Both of `framebuffer`, and `renderPass` that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same `VkDevice`.

---

<i>Note</i>

On some implementations, not using the `VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT` bit enables command buffers to be patched in-place if needed, rather than creating a copy of the command buffer.

If a command buffer is in the invalid, or executable state, and the command buffer was allocated from a command pool with the `VK_COMMAND_POOL_CREATE_RESET_COMMAND_BUFFER_BIT` flag set, then `vkBeginCommandBuffer` implicitly resets the command buffer, behaving as if `vkResetCommandBuffer` had been called with `VK_COMMAND_BUFFER_RESET_RELEASE_RESOURCES_BIT` not set. After the implicit reset, `commandBuffer` is moved to the recording state.

If the `pNext` chain of `VkCommandBufferInheritanceInfo` includes a `VkCommandBufferInheritanceConditionalRenderingInfoEXT` structure, then that structure controls whether a command buffer can be executed while conditional rendering is active in the primary command buffer.

The `VkCommandBufferInheritanceConditionalRenderingInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_conditional_rendering
typedef struct VkCommandBufferInheritanceConditionalRenderingInfoEXT {
    VkStructureType    sType;
}...
```
const void* pNext;
VkBool32 conditionalRenderingEnable;
} VkCommandBufferInheritanceConditionalRenderingInfoEXT;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **conditionalRenderingEnable** specifies whether the command buffer can be executed while conditional rendering is active in the primary command buffer. If this is VK_TRUE, then this command buffer can be executed whether the primary command buffer has active conditional rendering or not. If this is VK_FALSE, then the primary command buffer must not have conditional rendering active.

If this structure is not present, the behavior is as if `conditionalRenderingEnable` is VK_FALSE.

### Valid Usage

- **VUID-VkCommandBufferInheritanceConditionalRenderingInfoEXT-conditionalRenderingEnable-01977**
  
  If the inheritedConditionalRendering feature is not enabled, `conditionalRenderingEnable` must be VK_FALSE

### Valid Usage (Implicit)

- **VUID-VkCommandBufferInheritanceConditionalRenderingInfoEXT-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_CONDITIONAL_RENDERING_INFO_EXT`

To begin recording a secondary command buffer compatible with execution inside a render pass using render pass transform, add the `VkCommandBufferInheritanceRenderPassTransformInfoQCOM` to the `pNext` chain of `VkCommandBufferInheritanceInfo` structure passed to the `vkBeginCommandBuffer` command specifying the parameters for transformed rasterization.

The `VkCommandBufferInheritanceRenderPassTransformInfoQCOM` structure is defined as:

```c
// Provided by VK_QCOM_render_pass_transform
typedef struct VkCommandBufferInheritanceRenderPassTransformInfoQCOM {
    VkStructureType sType;
    void* pNext;
    VkSurfaceTransformFlagBitsKHR transform;
    VkRect2D renderArea;
} VkCommandBufferInheritanceRenderPassTransformInfoQCOM;
```

- **sType** is a `VkStructureType` value identifying this structure.
• `pNext` is NULL or a pointer to a structure extending this structure.

• `transform` is a `VkSurfaceTransformFlagBitsKHR` value describing the transform to be applied to the render pass.

• `renderArea` is the render area that is affected by the command buffer.

When the secondary is recorded to execute within a render pass instance using `vkCmdExecuteCommands`, the render pass transform parameters of the secondary command buffer must be consistent with the render pass transform parameters specified for the render pass instance. In particular, the `transform` and `renderArea` for command buffer must be identical to the `transform` and `renderArea` of the render pass instance.

### Valid Usage

- VUID-VkCommandBufferInheritanceRenderPassTransformInfoQCOM-transform-02864

  `transform` must be `VK_SURFACE_TRANSFORM_IDENTITY_BIT_KHR`, `VK_SURFACE_TRANSFORM_ROTATE_90_BIT_KHR`, `VK_SURFACE_TRANSFORM_ROTATE_180_BIT_KHR`, or `VK_SURFACE_TRANSFORM_ROTATE_270_BIT_KHR`.

### Valid Usage (Implicit)

- VUID-VkCommandBufferInheritanceRenderPassTransformInfoQCOM-sType-sType

  `sType` must be `VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_RENDER_PASS_TRANSFORM_INFO_QCOM`.

The `VkCommandBufferInheritanceViewportScissorInfoNV` structure is defined as:

```c
// Provided by VK_NV_inherited_viewport_scissor
typedef struct VkCommandBufferInheritanceViewportScissorInfoNV {
  VkStructureType   sType;
  const void*       pNext;
  VkBool32          viewportScissor2D;
  uint32_t          viewportDepthCount;
  const VkViewport* pViewportDepths;
} VkCommandBufferInheritanceViewportScissorInfoNV;
```

• `sType` is a `VkStructureType` value identifying this structure.

• `pNext` is NULL or a pointer to a structure extending this structure.

• `viewportScissor2D` specifies whether the listed dynamic state is inherited.

• `viewportDepthCount` specifies the maximum number of viewports to inherit. When `viewportScissor2D` is `VK_FALSE`, the behavior is as if this value is zero.

• `pViewportDepths` is a pointer to a `VkViewport` structure specifying the expected depth range for each inherited viewport.
If the `pNext` chain of `VkCommandBufferInheritanceInfo` includes a `VkCommandBufferInheritanceViewportScissorInfoNV` structure, then that structure controls whether a command buffer can inherit the following state from other command buffers:

- `VK_DYNAMIC_STATE_SCISSOR`
- `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT`
- `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT`
- `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT`
- `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT`

as well as the following state, with restrictions on inherited depth values and viewport count:

- `VK_DYNAMIC_STATE_VIEWPORT`
- `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT`

If `viewportScissor2D` is `VK_FALSE`, then the command buffer does not inherit the listed dynamic state, and should set this state itself. If this structure is not present, the behavior is as if `viewportScissor2D` is `VK_FALSE`.

If `viewportScissor2D` is `VK_TRUE`, then the listed dynamic state is inherited, and the command buffer must not set this state, except that the viewport and scissor count may be set by binding a graphics pipeline that does not specify this state as dynamic.

**Note**
Due to this restriction, applications should ensure either all or none of the graphics pipelines bound in this secondary command buffer use dynamic viewport/scissor counts.

When the command buffer is executed as part of a the execution of a `vkCmdExecuteCommands` command, the inherited state (if enabled) is determined by the following procedure, performed separately for each dynamic state, and separately for each value for dynamic state that consists of multiple values (e.g. multiple viewports).

- With `i` being the index of the executed command buffer in the `pCommandBuffers` array of `vkCmdExecuteCommands`, if `i > 0` and any secondary command buffer from index 0 to `i-1` modifies the state, the inherited state is provisionally set to the final value set by the last such secondary command buffer. Binding a graphics pipeline defining the state statically is equivalent to setting the state to an undefined value.

- Otherwise, the tentatative inherited state is that of the primary command buffer at the point the `vkCmdExecuteCommands` command was recorded; if the state is undefined, then so is the provisional inherited state.

- If the provisional inherited state is an undefined value, then the state is not inherited.

- If the provisional inherited state is a viewport, with `n` being its viewport index, then if `n ≥ viewportDepthCount`, or if either `VkViewport::minDepth` or `VkViewport::maxDepth` are not equal to the respective values of the `n`th element of `pViewportDepths`, then the state is not inherited.
• If the provisional inherited state passes both checks, then it becomes the actual inherited state.

Note
There is no support for inheriting dynamic state from a secondary command buffer executed as part of a different `vkCmdExecuteCommands` command.

Valid Usage

• VUID-VkCommandBufferInheritanceViewportScissorInfoNV-viewportScissor2D-04782
  If the `inheritedViewportScissor2D` feature is not enabled, `viewportScissor2D` must be `VK_FALSE`

• VUID-VkCommandBufferInheritanceViewportScissorInfoNV-viewportScissor2D-04783
  If the `multiViewport` feature is not enabled and `viewportScissor2D` is `VK_TRUE`, then `viewportDepthCount` must be 1

• VUID-VkCommandBufferInheritanceViewportScissorInfoNV-viewportScissor2D-04784
  If `viewportScissor2D` is `VK_TRUE`, then `viewportDepthCount` must be greater than 0

• VUID-VkCommandBufferInheritanceViewportScissorInfoNV-viewportScissor2D-04785
  If `viewportScissor2D` is `VK_TRUE`, then `pViewportDepths` must be a valid pointer to an array of `viewportDepthCount` valid `VkViewport` structures, except any requirements on `x`, `y`, `width`, and `height` do not apply

• VUID-VkCommandBufferInheritanceViewportScissorInfoNV-viewportScissor2D-04786
  If `viewportScissor2D` is `VK_TRUE`, then the command buffer must be recorded with the `VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT`

Valid Usage ( Implicit )

• VUID-VkCommandBufferInheritanceViewportScissorInfoNV-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_VIEWPORT_SCISSOR_INFO_NV`

The `VkCommandBufferInheritanceRenderingInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkCommandBufferInheritanceRenderingInfo {
    VkStructureType sType;
    const void* pNext;
    VkRenderingFlags flags;
    uint32_t viewMask;
    uint32_t colorAttachmentCount;
    const VkFormat* pColorAttachmentFormats;
    VkFormat depthAttachmentFormat;
    VkFormat stencilAttachmentFormat;
    VkSampleCountFlagBits rasterizationSamples;
} VkCommandBufferInheritanceRenderingInfo;
```
or the equivalent

```c
// Provided by VK_KHR_dynamic_rendering
typedef VkCommandBufferInheritanceRenderingInfo
    VkCommandBufferInheritanceRenderingInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkRenderingFlagBits` used by the render pass instance.
- `viewMask` is the view mask used for rendering.
- `colorAttachmentCount` is the number of color attachments specified in the render pass instance.
- `pColorAttachmentFormats` is a pointer to an array of `VkFormat` values defining the format of color attachments.
- `depthAttachmentFormat` is a `VkFormat` value defining the format of the depth attachment.
- `stencilAttachmentFormat` is a `VkFormat` value defining the format of the stencil attachment.
- `rasterizationSamples` is a `VkSampleCountFlagBits` specifying the number of samples used in rasterization.

If the `pNext` chain of `VkCommandBufferInheritanceInfo` includes a `VkCommandBufferInheritanceRenderingInfo` structure, then that structure controls parameters of dynamic render pass instances that the `VkCommandBuffer` can be executed within. If `VkCommandBufferInheritanceInfo::renderPass` is not `VK_NULL_HANDLE`, or `VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT` is not specified in `VkCommandBufferBeginInfo::flags`, parameters of this structure are ignored.

If `colorAttachmentCount` is `0` and the `variableMultisampleRate` feature is enabled, `rasterizationSamples` is ignored.

If `depthAttachmentFormat`, `stencilAttachmentFormat`, or any element of `pColorAttachmentFormats` is `VK_FORMAT_UNDEFINED`, it indicates that the corresponding attachment is unused within the render pass and writes to those attachments are discarded.

### Valid Usage

- **VUID-VkCommandBufferInheritanceRenderingInfo-colorAttachmentCount-06004**
  
  If `colorAttachmentCount` is not `0`, `rasterizationSamples` must be a valid `VkSampleCountFlagBits` value.

- **VUID-VkCommandBufferInheritanceRenderingInfo-variableMultisampleRate-06005**
  
  If the `variableMultisampleRate` feature is not enabled, `rasterizationSamples` must be a valid `VkSampleCountFlagBits` value.

- **VUID-VkCommandBufferInheritanceRenderingInfo-depthAttachmentFormat-06540**
  
  If `depthAttachmentFormat` is not `VK_FORMAT_UNDEFINED`, it must be a format that includes a depth component.
• VUID-VkCommandBufferInheritanceRenderingInfo-depthAttachmentFormat-06007
  If depthAttachmentFormat is not VK_FORMAT_UNDEFINED, it must be a format with potential format features that include VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT.

• VUID-VkCommandBufferInheritanceRenderingInfo-pColorAttachmentFormats-06492
  If any element of pColorAttachmentFormats is not VK_FORMAT_UNDEFINED, it must be a format with potential format features that include VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT, or VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV if the linearColorAttachment feature is enabled.

• VUID-VkCommandBufferInheritanceRenderingInfo-stencilAttachmentFormat-06541
  If stencilAttachmentFormat is not VK_FORMAT_UNDEFINED, it must be a format that includes a stencil aspect.

• VUID-VkCommandBufferInheritanceRenderingInfo-stencilAttachmentFormat-06199
  If stencilAttachmentFormat is not VK_FORMAT_UNDEFINED, it must be a format with potential format features that include VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT.

• VUID-VkCommandBufferInheritanceRenderingInfo-depthAttachmentFormat-06200
  If depthAttachmentFormat is not VK_FORMAT_UNDEFINED and stencilAttachmentFormat is not VK_FORMAT_UNDEFINED, depthAttachmentFormat must equal stencilAttachmentFormat.

• VUID-VkCommandBufferInheritanceRenderingInfo-multiview-06008
  If the multiview feature is not enabled, viewMask must be 0.

• VUID-VkCommandBufferInheritanceRenderingInfo-viewMask-06009
  The index of the most significant bit in viewMask must be less than maxMultiviewViewCount.

Valid Usage (Implicit)

• VUID-VkCommandBufferInheritanceRenderingInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_RENDERING_INFO.

• VUID-VkCommandBufferInheritanceRenderingInfo-flags-parameter
  flags must be a valid combination of VkRenderingFlagBits values.

• VUID-VkCommandBufferInheritanceRenderingInfo-pColorAttachmentFormats-parameter
  If colorAttachmentCount is not 0, pColorAttachmentFormats must be a valid pointer to an array of colorAttachmentCount valid VkFormat values.

• VUID-VkCommandBufferInheritanceRenderingInfo-depthAttachmentFormat-parameter
  depthAttachmentFormat must be a valid VkFormat value.

• VUID-VkCommandBufferInheritanceRenderingInfo-stencilAttachmentFormat-parameter
  stencilAttachmentFormat must be a valid VkFormat value.

• VUID-VkCommandBufferInheritanceRenderingInfo-rasterizationSamples-parameter
  If rasterizationSamples is not 0, rasterizationSamples must be a valid VkSampleCountFlagBits value.

The VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure is defined as:
// Provided by VK_KHR_dynamic_rendering with VK_AMD_mixed_attachment_samples

typedef struct VkAttachmentSampleCountInfoAMD {
    VkStructureType sType;
    const void* pNext;
    uint32_t colorAttachmentCount;
    const VkSampleCountFlagBits* pColorAttachmentSamples;
    VkSampleCountFlagBits depthStencilAttachmentSamples;
} VkAttachmentSampleCountInfoAMD;

or the equivalent

// Provided by VK_KHR_dynamic_rendering with VK_NV_framebuffer_mixed_samples

typedef VkAttachmentSampleCountInfoAMD VkAttachmentSampleCountInfoNV;

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **colorAttachmentCount** is the number of color attachments specified in a render pass instance.
- **pColorAttachmentSamples** is a pointer to an array of *VkSampleCountFlagBits* values defining the sample count of color attachments.
- **depthStencilAttachmentSamples** is a *VkSampleCountFlagBits* value defining the sample count of a depth/stencil attachment.

If *VkCommandBufferInheritanceInfo::renderPass* is VK_NULL_HANDLE, *VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT* is specified in *VkCommandBufferBeginInfo::flags*, and the **pNext** chain of *VkCommandBufferInheritanceInfo* includes *VkAttachmentSampleCountInfoAMD*, then this structure defines the sample counts of each attachment within the render pass instance. If *VkAttachmentSampleCountInfoAMD* is not included, the value of *VkAttachmentSampleCountInfoAMD* is used as the sample count for each attachment. If *VkCommandBufferInheritanceInfo::renderPass* is not VK_NULL_HANDLE, or *VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT* is not specified in *VkCommandBufferBeginInfo::flags*, parameters of this structure are ignored.

*VkAttachmentSampleCountInfoAMD* can also be included in the **pNext** chain of *VkGraphicsPipelineCreateInfo*. When a graphics pipeline is created without a *VkRenderPass*, if this structure is included in the **pNext** chain of *VkGraphicsPipelineCreateInfo*, it specifies the sample count of attachments used for rendering. If this structure is not specified, and the pipeline does not include a *VkRenderPass*, the value of *VkPipelineMultisampleStateCreateInfo::rasterizationSamples* is used as the sample count for each attachment. If a graphics pipeline is created with a valid *VkRenderPass*, parameters of this structure are ignored.

### Valid Usage (Implicit)

- **VUID-VkAttachmentSampleCountInfoAMD-sType-sType**
  
  *sType* must be *VK_STRUCTURE_TYPE_ATTACHMENT_SAMPLE_COUNT_INFO_AMD*
Once recording starts, an application records a sequence of commands (vkCmd*) to set state in the command buffer, draw, dispatch, and other commands.

Several commands can also be recorded indirectly from VkBuffer content, see Device-Generated Commands.

To complete recording of a command buffer, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkEndCommandBuffer(
    VkCommandBuffer commandBuffer);
```

- `commandBuffer` is the command buffer to complete recording.

The command buffer must have been in the recording state, and, if successful, is moved to the executable state.

If there was an error during recording, the application will be notified by an unsuccessful return code returned by `vkEndCommandBuffer`, and the command buffer will be moved to the invalid state.

In case the application recorded one or more video encode operations into the command buffer, implementations may return the VK_ERROR_INVALID_VIDEO_STD_PARAMETERS_KHR error if any of the specified Video Std parameters do not adhere to the syntactic or semantic requirements of the used video compression standard, or if values derived from parameters according to the rules defined by the used video compression standard do not adhere to the capabilities of the video compression standard or the implementation.

**Note**

Applications should not rely on the VK_ERROR_INVALID_VIDEO_STD_PARAMETERS_KHR error being returned by any command as a means to verify Video Std parameters, as implementations are not required to report the error in any specific set of cases.

**Valid Usage**

- VUID-vkEndCommandBuffer-commandBuffer-00059
  commandBuffer must be in the recording state
- VUID-vkEndCommandBuffer-commandBuffer-00060
  If commandBuffer is a primary command buffer, there must not be an active render pass instance
- VUID-vkEndCommandBuffer-commandBuffer-00061
  All queries made active during the recording of commandBuffer must have been made inactive
- VUID-vkEndCommandBuffer-None-01978
  Conditional rendering must not be active
- VUID-vkEndCommandBuffer-None-06991
  There must be no video session object bound
If `commandBuffer` is a secondary command buffer, there **must** not be an outstanding `vkCmdBeginDebugUtilsLabelEXT` command recorded to `commandBuffer` that has not previously been ended by a call to `vkCmdEndDebugUtilsLabelEXT`.

If `commandBuffer` is a secondary command buffer, there **must** not be an outstanding `vkCmdDebugMarkerBeginEXT` command recorded to `commandBuffer` that has not previously been ended by a call to `vkCmdDebugMarkerEndEXT`.

**Valid Usage (Implicit)**

- VUID-vkEndCommandBuffer-commandBuffer-parameter
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

**Host Synchronization**

- Host access to `commandBuffer` **must** be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized

**Return Codes**

**Success**

- VK_SUCCESS

**Failure**

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_INVALID_VIDEO_STD_PARAMETERS_KHR

When a command buffer is in the executable state, it **can** be submitted to a queue for execution.

### 6.5. Command Buffer Submission

**Note**

Submission can be a high overhead operation, and applications **should** attempt to batch work together into as few calls to `vkQueueSubmit` or `vkQueueSubmit2` as possible.

To submit command buffers to a queue, call:
// Provided by VK_VERSION_1_3
VkResult vkQueueSubmit2(
    VkQueue queue, uint32_t submitCount, const VkSubmitInfo2* pSubmits,
    VkFence fence);

or the equivalent command

// Provided by VK_KHR_synchronization2
VkResult vkQueueSubmit2KHR(
    VkQueue queue, uint32_t submitCount, const VkSubmitInfo2* pSubmits,
    VkFence fence);

- `queue` is the queue that the command buffers will be submitted to.
- `submitCount` is the number of elements in the `pSubmits` array.
- `pSubmits` is a pointer to an array of `VkSubmitInfo2` structures, each specifying a command buffer submission batch.
- `fence` is an optional handle to a fence to be signaled once all submitted command buffers have completed execution. If `fence` is not `VK_NULL_HANDLE`, it defines a fence signal operation.

`vkQueueSubmit2` is a queue submission command, with each batch defined by an element of `pSubmits`.

Semaphore operations submitted with `vkQueueSubmit2` have additional ordering constraints compared to other submission commands, with dependencies involving previous and subsequent queue operations. Information about these additional constraints can be found in the semaphore section of the synchronization chapter.

If any command buffer submitted to this queue is in the executable state, it is moved to the pending state. Once execution of all submissions of a command buffer complete, it moves from the pending state, back to the executable state. If a command buffer was recorded with the `VK_COMMAND_BUFFER_USAGE_ONE_TIME_SUBMIT_BIT` flag, it instead moves back to the invalid state.

If `vkQueueSubmit2` fails, it may return `VK_ERROR_OUT_OF_HOST_MEMORY` or `VK_ERROR_OUT_OF_DEVICE_MEMORY`. If it does, the implementation must ensure that the state and contents of any resources or synchronization primitives referenced by the submitted command buffers and any semaphores referenced by `pSubmits` is unaffected by the call or its failure. If `vkQueueSubmit2` fails in such a way that the implementation is unable to make that guarantee, the implementation must return `VK_ERROR_DEVICE_LOST`. See Lost Device.

**Valid Usage**

- VUID-vkQueueSubmit2-fence-04894
  If `fence` is not `VK_NULL_HANDLE`, `fence` must be unsigned

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• VUID-vkQueueSubmit2-fence-04895
  If `fence` is not `VK_NULL_HANDLE`, `fence` must not be associated with any other queue command that has not yet completed execution on that queue.

• VUID-vkQueueSubmit2-synchronization2-03866
  The `synchronization2` feature must be enabled.

• VUID-vkQueueSubmit2-commandBuffer-03867
  If a command recorded into the `commandBuffer` member of any element of the `pCommandBufferInfos` member of any element of `pSubmits` referenced an `VkEvent`, that event must not be referenced by a command that has been submitted to another queue and is still in the `pending state`.

• VUID-vkQueueSubmit2-semaphore-03868
  The `semaphore` member of any binary semaphore element of the `pSignalSemaphoreInfos` member of any element of `pSubmits` must be unsignaled when the semaphore signal operation it defines is executed on the device.

• VUID-vkQueueSubmit2-stageMask-03869
  The `stageMask` member of any element of the `pSignalSemaphoreInfos` member of any element of `pSubmits` must only include pipeline stages that are supported by the queue family which `queue` belongs to.

• VUID-vkQueueSubmit2-stageMask-03870
  The `stageMask` member of any element of the `pWaitSemaphoreInfos` member of any element of `pSubmits` must only include pipeline stages that are supported by the queue family which `queue` belongs to.

• VUID-vkQueueSubmit2-semaphore-03871
  When a semaphore wait operation for a binary semaphore is executed, as defined by the `semaphore` member of any element of the `pWaitSemaphoreInfos` member of any element of `pSubmits`, there must be no other queues waiting on the same semaphore.

• VUID-vkQueueSubmit2-semaphore-03873
  The `semaphore` member of any element of the `pWaitSemaphoreInfos` member of any element of `pSubmits` that was created with a `VkSemaphoreTypeKHR` of `VK_SEMAPHORE_TYPE_BINARY_KHR` must reference a semaphore signal operation that has been submitted for execution and any semaphore signal operations on which it depends must have also been submitted for execution.

• VUID-vkQueueSubmit2-commandBuffer-03874
  The `commandBuffer` member of any element of the `pCommandBufferInfos` member of any element of `pSubmits` must be in the `pending or executable state`.

• VUID-vkQueueSubmit2-commandBuffer-03875
  If a command recorded into the `commandBuffer` member of any element of the `pCommandBufferInfos` member of any element of `pSubmits` was not recorded with the `VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT`, it must not be in the `pending state`.

• VUID-vkQueueSubmit2-commandBuffer-03876
  Any secondary command buffers recorded into the `commandBuffer` member of any element of the `pCommandBufferInfos` member of any element of `pSubmits` must be in the `pending or executable state`.
If any secondary command buffers recorded into the commandBuffer member of any element of the pCommandBufferInfos member of any element of pSubmits was not recorded with the VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT, it must not be in the pending state.

The commandBuffer member of any element of the pCommandBufferInfos member of any element of pSubmits must have been allocated from a VkCommandPool that was created for the same queue family queue belongs to.

If a command recorded into the commandBuffer member of any element of the pCommandBufferInfos member of any element of pSubmits includes a Queue Family Transfer Acquire Operation, there must exist a previously submitted Queue Family Transfer Release Operation on a queue in the queue family identified by the acquire operation, with parameters matching the acquire operation as defined in the definition of such acquire operations, and which happens before the acquire operation.

If a command recorded into the commandBuffer member of any element of the pCommandBufferInfos member of any element of pSubmits was a vkCmdBeginQuery whose queryPool was created with a queryType of VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR, the profiling lock must have been held continuously on the VkDevice that queue was retrieved from, throughout recording of those command buffers.

If queue was not created with VKDEVICE_QUEUE_CREATE_PROTECTED_BIT, the flags member of any element of pSubmits must not include VK_SUBMIT_PROTECTED_BIT_KHR.

Valid Usage (Implicit)

- VUID-vkQueueSubmit2-queue-parameter
  queue must be a valid VkQueue handle

- VUID-vkQueueSubmit2-pSubmits-parameter
  If submitCount is not 0, pSubmits must be a valid pointer to an array of submitCount valid VkSubmitInfo2 structures

- VUID-vkQueueSubmit2-fence-parameter
  If fence is not VK_NULL_HANDLE, fence must be a valid VkFence handle

- VUID-vkQueueSubmit2-commonparent
  Both of fence, and queue that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

- Host access to queue must be externally synchronized

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Host access to fence must be externally synchronized

## Command Properties

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## Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_DEVICE_LOST

The VkSubmitInfo2 structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkSubmitInfo2 {
    VkStructureType           sType;
    const void*               pNext;
    VkSubmitFlags             flags;
    uint32_t                  waitSemaphoreInfoCount;
    const VkSemaphoreSubmitInfo* pWaitSemaphoreInfos;
    uint32_t                  commandBufferInfoCount;
    const VkCommandBufferSubmitInfo* pCommandBufferInfos;
    uint32_t                  signalSemaphoreInfoCount;
    const VkSemaphoreSubmitInfo* pSignalSemaphoreInfos;
} VkSubmitInfo2;
```

or the equivalent

```c
// Provided by VK_KHR_synchronization2
typedef VkSubmitInfo2 VkSubmitInfo2KHR;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `flags` is a bitmask of VkSubmitFlagBits.
- `waitSemaphoreInfoCount` is the number of elements in `pWaitSemaphoreInfos`.
• `pWaitSemaphoreInfos` is a pointer to an array of `VkSemaphoreSubmitInfo` structures defining semaphore wait operations.

• `commandBufferInfoCount` is the number of elements in `pCommandBufferInfos` and the number of command buffers to execute in the batch.

• `pCommandBufferInfos` is a pointer to an array of `VkCommandBufferSubmitInfo` structures describing command buffers to execute in the batch.

• `signalSemaphoreInfoCount` is the number of elements in `pSignalSemaphoreInfos`.

• `pSignalSemaphoreInfos` is a pointer to an array of `VkSemaphoreSubmitInfo` describing semaphore signal operations.

**Valid Usage**

• VUID-VkSubmitInfo2-semaphore-03881
  If the same semaphore is used as the `semaphore` member of both an element of `pSignalSemaphoreInfos` and `pWaitSemaphoreInfos`, and that semaphore is a timeline semaphore, the value member of the `pSignalSemaphoreInfos` element must be greater than the value member of the `pWaitSemaphoreInfos` element

• VUID-VkSubmitInfo2-semaphore-03882
  If the `semaphore` member of any element of `pSignalSemaphoreInfos` is a timeline semaphore, the value member of that element must have a value greater than the current value of the semaphore when the semaphore signal operation is executed

• VUID-VkSubmitInfo2-semaphore-03883
  If the `semaphore` member of any element of `pSignalSemaphoreInfos` is a timeline semaphore, the value member of that element must have a value which does not differ from the current value of the semaphore or the value of any outstanding semaphore wait or signal operation on that semaphore by more than `maxTimelineSemaphoreValueDifference`

• VUID-VkSubmitInfo2-semaphore-03884
  If the `semaphore` member of any element of `pWaitSemaphoreInfos` is a timeline semaphore, the value member of that element must have a value which does not differ from the current value of the semaphore or the value of any outstanding semaphore wait or signal operation on that semaphore by more than `maxTimelineSemaphoreValueDifference`

• VUID-VkSubmitInfo2-flags-03886
  If `flags` includes `VK_SUBMIT_PROTECTED_BIT`, all elements of `pCommandBuffers` must be protected command buffers

• VUID-VkSubmitInfo2-flags-03887
  If `flags` does not include `VK_SUBMIT_PROTECTED_BIT`, each element of `pCommandBuffers` must not be a protected command buffer

• VUID-VkSubmitInfo2KHR-commandBuffer-06192
  If any `commandBuffer` member of an element of `pCommandBufferInfos` contains any resumed render pass instances, they must be suspended by a render pass instance earlier in submission order within `pCommandBufferInfos`

• VUID-VkSubmitInfo2KHR-commandBuffer-06010
  If any `commandBuffer` member of an element of `pCommandBufferInfos` contains any
suspended render pass instances, they must be resumed by a render pass instance later in submission order within pCommandBufferInfos

- VUID-VkSubmitInfo2KHR-commandBuffer-06011
  If any commandBuffer member of an element of pCommandBufferInfos contains any suspended render pass instances, there must be no action or synchronization commands between that render pass instance and the render pass instance that resumes it

- VUID-VkSubmitInfo2KHR-commandBuffer-06012
  If any commandBuffer member of an element of pCommandBufferInfos contains any suspended render pass instances, there must be no render pass instances between that render pass instance and the render pass instance that resumes it

- VUID-VkSubmitInfo2KHR-variableSampleLocations-06013
  If the variableSampleLocations limit is not supported, and any commandBuffer member of an element of pCommandBufferInfos contains any suspended render pass instances, where a graphics pipeline has been bound, any pipelines bound in the render pass instance that resumes it, or any subsequent render pass instances that resume from that one and so on, must use the same sample locations

Valid Usage (Implicit)

- VUID-VkSubmitInfo2-sType-sType
  sType must be VK_STRUCTURE_TYPE_SUBMIT_INFO_2

- VUID-VkSubmitInfo2-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkFrameBoundaryEXT, VkPerformanceQuerySubmitInfoKHR, VkWin32KeyedMutexAcquireReleaseInfoKHR, or VkWin32KeyedMutexAcquireReleaseInfoNV

- VUID-VkSubmitInfo2-sType-unique
  The sType value of each struct in the pNext chain must be unique

- VUID-VkSubmitInfo2-flags-parameter
  flags must be a valid combination of VkSubmitFlagBits values

- VUID-VkSubmitInfo2-pWaitSemaphoreInfos-parameter
  If waitSemaphoreInfoCount is not 0, pWaitSemaphoreInfos must be a valid pointer to an array of waitSemaphoreInfoCount valid VkSemaphoreSubmitInfo structures

- VUID-VkSubmitInfo2-pCommandBufferInfos-parameter
  If commandBufferInfoCount is not 0, pCommandBufferInfos must be a valid pointer to an array of commandBufferInfoCount valid VkCommandBufferSubmitInfo structures

- VUID-VkSubmitInfo2-pSignalSemaphoreInfos-parameter
  If signalSemaphoreInfoCount is not 0, pSignalSemaphoreInfos must be a valid pointer to an array of signalSemaphoreInfoCount valid VkSemaphoreSubmitInfo structures

Bits which can be set in VkSubmitInfo2::flags, specifying submission behavior, are:
// Provided by VK_VERSION_1_3
typedef enum VkSubmitFlagBits {
    VK_SUBMIT_PROTECTED_BIT = 0x00000001,
    VK_SUBMIT_PROTECTED_BIT_KHR = VK_SUBMIT_PROTECTED_BIT,
} VkSubmitFlagBits;

or the equivalent

// Provided by VK_KHR_synchronization2
typedef VkSubmitFlagBits VkSubmitFlagBitsKHR;

• **VK_SUBMIT_PROTECTED_BIT** specifies that this batch is a protected submission.

// Provided by VK_VERSION_1_3
typedef VkFlags VkSubmitFlags;

or the equivalent

// Provided by VK_KHR_synchronization2
typedef VkSubmitFlags VkSubmitFlagsKHR;

VkSubmitFlags is a bitmask type for setting a mask of zero or more VkSubmitFlagBits.

The VkSemaphoreSubmitInfo structure is defined as:

// Provided by VK_VERSION_1_3
typedef struct VkSemaphoreSubmitInfo {
    VkStructureType sType;
    const void* pNext;
    VkSemaphore semaphore;
    uint64_t value;
    VkPipelineStageFlags2 stageMask;
    uint32_t deviceIndex;
} VkSemaphoreSubmitInfo;

or the equivalent

// Provided by VK_KHR_synchronization2
typedef VkSemaphoreSubmitInfo VkSemaphoreSubmitInfoKHR;

• **sType** is a VkStructureType value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.
• **semaphore** is aVkSemaphore affected by this operation.
• value is either the value used to signal semaphore or the value waited on by semaphore, if semaphore is a timeline semaphore. Otherwise it is ignored.

• stageMask is a VkPipelineStageFlags2 mask of pipeline stages which limit the first synchronization scope of a semaphore signal operation, or second synchronization scope of a semaphore wait operation as described in the semaphore wait operation and semaphore signal operation sections of the synchronization chapter.

• deviceIndex is the index of the device within a device group that executes the semaphore wait or signal operation.

Whether this structure defines a semaphore wait or signal operation is defined by how it is used.

Valid Usage

• VUID-VkSemaphoreSubmitInfo-stageMask-03929
If the geometryShader feature is not enabled, stageMask must not contain VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT

• VUID-VkSemaphoreSubmitInfo-stageMask-03930
If the tessellationShader feature is not enabled, stageMask must not contain VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT or VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT

• VUID-VkSemaphoreSubmitInfo-stageMask-03931
If the conditionalRendering feature is not enabled, stageMask must not contain VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT

• VUID-VkSemaphoreSubmitInfo-stageMask-03932
If the fragmentDensityMap feature is not enabled, stageMask must not contain VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT

• VUID-VkSemaphoreSubmitInfo-stageMask-03933
If the transformFeedback feature is not enabled, stageMask must not contain VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT

• VUID-VkSemaphoreSubmitInfo-stageMask-03934
If the meshShader feature is not enabled, stageMask must not contain VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT

• VUID-VkSemaphoreSubmitInfo-stageMask-03935
If the taskShader feature is not enabled, stageMask must not contain VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT

• VUID-VkSemaphoreSubmitInfo-stageMask-07316
If neither the shadingRateImage or attachmentFragmentShadingRate are enabled, stageMask must not contain VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

• VUID-VkSemaphoreSubmitInfo-stageMask-04957
If the subpassShading feature is not enabled, stageMask must not contain VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI

• VUID-VkSemaphoreSubmitInfo-stageMask-04995
If the invocationMask feature is not enabled, stageMask must not contain
If neither the \texttt{VK_NV_ray_tracing} extension or \texttt{rayTracingPipeline} feature are enabled, \texttt{stageMask} must not contain \texttt{VK_PIPELINE_STAGE_2RAY_TRACING_SHADER_BIT_KHR}.

If the \texttt{device} that \texttt{semaphore} was created on is not a device group, \texttt{deviceIndex} must be 0.

If the \texttt{device} that \texttt{semaphore} was created on is a device group, \texttt{deviceIndex} must be a valid device index.

### Valid Usage (Implicit)

- \texttt{VUID-VkSemaphoreSubmitInfo-sType-sType} \\
  \texttt{sType} must be \texttt{VK_STRUCTURE_TYPE_SEMAPHORE_SUBMIT_INFO}

- \texttt{VUID-VkSemaphoreSubmitInfo-pNext-pNext} \\
  \texttt{pNext} must be \texttt{NULL}

- \texttt{VUID-VkSemaphoreSubmitInfo-semaphore-parameter} \\
  \texttt{semaphore} must be a valid \texttt{VkSemaphore} handle

- \texttt{VUID-VkSemaphoreSubmitInfo-stageMask-parameter} \\
  \texttt{stageMask} must be a valid combination of \texttt{VkPipelineStageFlagBits2} values

The \texttt{VkCommandBufferSubmitInfo} structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkCommandBufferSubmitInfo {
    VkStructureType sType;
    const void* pNext;
    VkCommandBuffer commandBuffer;
    uint32_t deviceMask;
} VkCommandBufferSubmitInfo;
```

or the equivalent

```c
// Provided by VK_KHR_synchronization2
typedef VkCommandBufferSubmitInfo VkCommandBufferSubmitInfoKHR;
```

- \texttt{sType} is a \texttt{VkStructureType} value identifying this structure.
- \texttt{pNext} is \texttt{NULL} or a pointer to a structure extending this structure.
- \texttt{commandBuffer} is a \texttt{VkCommandBuffer} to be submitted for execution.
- \texttt{deviceMask} is a bitmask indicating which devices in a device group execute the command buffer. A \texttt{deviceMask} of 0 is equivalent to setting all bits corresponding to valid devices in the group to 1.
Valid Usage

- VUID-VkCommandBufferSubmitInfo-commandBuffer-03890
  `commandBuffer` must not have been allocated with `VK_COMMAND_BUFFER_LEVEL_SECONDARY`

- VUID-VkCommandBufferSubmitInfo-deviceMask-03891
  If `deviceMask` is not 0, it must be a valid device mask

Valid Usage (Implicit)

- VUID-VkCommandBufferSubmitInfo-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_COMMAND_BUFFER_SUBMIT_INFO`

- VUID-VkCommandBufferSubmitInfo-pNext-pNext
  `pNext` must be NULL

- VUID-VkCommandBufferSubmitInfo-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

To submit command buffers to a queue, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkQueueSubmit(
    VkQueue queue,
    uint32_t submitCount,
    const VkSubmitInfo* pSubmits,
    VkFence fence);
```

- `queue` is the queue that the command buffers will be submitted to.
- `submitCount` is the number of elements in the `pSubmits` array.
- `pSubmits` is a pointer to an array of `VkSubmitInfo` structures, each specifying a command buffer submission batch.
- `fence` is an optional handle to a fence to be signaled once all submitted command buffers have completed execution. If `fence` is not `VK_NULL_HANDLE`, it defines a fence signal operation.

`vkQueueSubmit` is a queue submission command, with each batch defined by an element of `pSubmits`. Batches begin execution in the order they appear in `pSubmits`, but may complete out of order.

Fence and semaphore operations submitted with `vkQueueSubmit` have additional ordering constraints compared to other submission commands, with dependencies involving previous and subsequent queue operations. Information about these additional constraints can be found in the semaphore and fence sections of the synchronization chapter.

Details on the interaction of `pWaitDstStageMask` with synchronization are described in the semaphore wait operation section of the synchronization chapter.

The order that batches appear in `pSubmits` is used to determine submission order, and thus all the
There are implicit ordering guarantees that respect it. Other than these implicit ordering guarantees and any explicit synchronization primitives, these batches may overlap or otherwise execute out of order.

If any command buffer submitted to this queue is in the executable state, it is moved to the pending state. Once execution of all submissions of a command buffer complete, it moves from the pending state, back to the executable state. If a command buffer was recorded with the VK_COMMAND_BUFFER_USAGE_ONE_TIME_SUBMIT_BIT flag, it instead moves to the invalid state.

If vkQueueSubmit fails, it may return VK_ERROR_OUT_OF_HOST_MEMORY or VK_ERROR_OUT_OF_DEVICE_MEMORY. If it does, the implementation must ensure that the state and contents of any resources or synchronization primitives referenced by the submitted command buffers and any semaphores referenced by pSubmits is unaffected by the call or its failure. If vkQueueSubmit fails in such a way that the implementation is unable to make that guarantee, the implementation must return VK_ERROR_DEVICE_LOST. See Lost Device.

Valid Usage

- VUID-vkQueueSubmit-fence-00063
  If fence is not VK_NULL_HANDLE, fence must be unsignaled

- VUID-vkQueueSubmit-fence-00064
  If fence is not VK_NULL_HANDLE, fence must not be associated with any other queue command that has not yet completed execution on that queue

- VUID-vkQueueSubmit-pCommandBuffers-00065
  Any calls to vkCmdSetEvent, vkCmdResetEvent or vkCmdWaitEvents that have been recorded into any of the command buffer elements of the pCommandBuffers member of any element of pSubmits, must not reference any VkEvent that is referenced by any of those commands in a command buffer that has been submitted to another queue and is still in the pending state

- VUID-vkQueueSubmit-pWaitDstStageMask-00066
  Any stage flag included in any element of the pWaitDstStageMask member of any element of pSubmits must be a pipeline stage supported by one of the capabilities of queue, as specified in the table of supported pipeline stages

- VUID-vkQueueSubmit-pSignalSemaphores-00067
  Each binary semaphore element of the pSignalSemaphores member of any element of pSubmits must be unsignaled when the semaphore signal operation it defines is executed on the device

- VUID-vkQueueSubmit-pWaitSemaphores-00068
  When a semaphore wait operation referring to a binary semaphore defined by any element of the pWaitSemaphores member of any element of pSubmits executes on queue, there must be no other queues waiting on the same semaphore

- VUID-vkQueueSubmit-pWaitSemaphores-03238
  All elements of the pWaitSemaphores member of all elements of pSubmits created with a VkSemaphoreType of VK_SEMAPHORE_TYPE_BINARY must reference a semaphore signal operation that has been submitted for execution and any semaphore signal operations on which it depends must have also been submitted for execution
Each element of the `pCommandBuffers` member of each element of `pSubmits` must be in the pending or executable state.

If any element of the `pCommandBuffers` member of any element of `pSubmits` was not recorded with the `VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT`, it must not be in the pending state.

Any secondary command buffers recorded into any element of the `pCommandBuffers` member of any element of `pSubmits` must be in the pending or executable state.

If any secondary command buffers recorded into any element of `pCommandBuffers` was not recorded with the `VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT`, it must not be in the pending state.

Each element of the `pCommandBuffers` member of each element of `pSubmits` must have been allocated from a `VkCommandPool` that was created for the same queue family `queue` belongs to.

If any element of `pSubmits->pCommandBuffers` includes a Queue Family Transfer Acquire Operation, there must exist a previously submitted Queue Family Transfer Release Operation on a queue in the queue family identified by the acquire operation, with parameters matching the acquire operation as defined in the definition of such acquire operations, and which happens-before the acquire operation.

If a command recorded into any element of `pCommandBuffers` was a `vkCmdBeginQuery` whose `queryPool` was created with a `queryType` of `VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR`, the profiling lock must have been held continuously on the `VkDevice` that `queue` was retrieved from, throughout recording of those command buffers.

Any resource created with `VK_SHARING_MODE_EXCLUSIVE` that is read by an operation specified by `pSubmits` must not be owned by any queue family other than the one which `queue` belongs to, at the time it is executed.

Any resource created with `VK_SHARING_MODE_CONCURRENT` that is accessed by an operation specified by `pSubmits` must have included the queue family of `queue` at resource creation time.

If `queue` was not created with `VK_DEVICE_QUEUE_CREATE_PROTECTED_BIT`, there must be no element of `pSubmits` that includes an `VkProtectedSubmitInfo` structure in its `pNext` chain with `protectedSubmit` equal to `VK_TRUE`. 
Valid Usage (Implicit)

- VUID-vkQueueSubmit-queue-parameter
  queue must be a valid VkQueue handle

- VUID-vkQueueSubmit-pSubmits-parameter
  If submitCount is not 0, pSubmits must be a valid pointer to an array of submitCount valid VkSubmitInfo structures

- VUID-vkQueueSubmit-fence-parameter
  If fence is not VK_NULL_HANDLE, fence must be a valid VkFence handle

- VUID-vkQueueSubmit-commonparent
  Both of fence, and queue that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

- Host access to queue must be externally synchronized
- Host access to fence must be externally synchronized

Command Properties

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Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_DEVICE_LOST

The VkSubmitInfo structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkSubmitInfo {
    VkStructureType sType;
    const void* pNext;
} VkSubmitInfo;
```
uint32_t waitSemaphoreCount;
const VkSemaphore* pWaitSemaphores;
const VkPipelineStageFlags* pWaitDstStageMask;
uint32_t commandBufferCount;
const VkCommandBuffer* pCommandBuffers;
uint32_t signalSemaphoreCount;
const VkSemaphore* pSignalSemaphores;
}
VkSubmitInfo;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• waitSemaphoreCount is the number of semaphores upon which to wait before executing the command buffers for the batch.
• pWaitSemaphores is a pointer to an array of VkSemaphore handles upon which to wait before the command buffers for this batch begin execution. If semaphores to wait on are provided, they define a semaphore wait operation.
• pWaitDstStageMask is a pointer to an array of pipeline stages at which each corresponding semaphore wait will occur.
• commandBufferCount is the number of command buffers to execute in the batch.
• pCommandBuffers is a pointer to an array of VkCommandBuffer handles to execute in the batch.
• signalSemaphoreCount is the number of semaphores to be signaled once the commands specified in pCommandBuffers have completed execution.
• pSignalSemaphores is a pointer to an array of VkSemaphore handles which will be signaled when the command buffers for this batch have completed execution. If semaphores to be signaled are provided, they define a semaphore signal operation.

The order that command buffers appear in pCommandBuffers is used to determine submission order, and thus all the implicit ordering guarantees that respect it. Other than these implicit ordering guarantees and any explicit synchronization primitives, these command buffers may overlap or otherwise execute out of order.

Valid Usage

• VUID-VkSubmitInfo-pWaitDstStageMask-04090
  If the geometryShader feature is not enabled, pWaitDstStageMask must not contain VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT

• VUID-VkSubmitInfo-pWaitDstStageMask-04091
  If the tessellationShader feature is not enabled, pWaitDstStageMask must not contain VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT or VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT

• VUID-VkSubmitInfo-pWaitDstStageMask-04092
  If the conditionalRendering feature is not enabled, pWaitDstStageMask must not contain VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT
• VUID-VkSubmitInfo-pWaitDstStageMask-04093
  If the fragmentDensityMap feature is not enabled, pWaitDstStageMask must not contain VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT

• VUID-VkSubmitInfo-pWaitDstStageMask-04094
  If the transformFeedback feature is not enabled, pWaitDstStageMask must not contain VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT

• VUID-VkSubmitInfo-pWaitDstStageMask-04095
  If the meshShader feature is not enabled, pWaitDstStageMask must not contain VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT

• VUID-VkSubmitInfo-pWaitDstStageMask-04096
  If the taskShader feature is not enabled, pWaitDstStageMask must not contain VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT

• VUID-VkSubmitInfo-pWaitDstStageMask-07318
  If neither the shadingRateImage or attachmentFragmentShadingRate are enabled, pWaitDstStageMask must not contain VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

• VUID-VkSubmitInfo-pWaitDstStageMask-03937
  If the synchronization2 feature is not enabled, pWaitDstStageMask must not be 0

• VUID-VkSubmitInfo-pWaitDstStageMask-07949
  If neither the VK_NV_ray_tracing extension or rayTracingPipeline feature are enabled, pWaitDstStageMask must not contain VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR

• VUID-VkSubmitInfo-pCommandBuffers-00075
  Each element of pCommandBuffers must not have been allocated with VK_COMMAND_BUFFER_LEVEL_SECONDARY

• VUID-VkSubmitInfo-pWaitDstStageMask-00078
  Each element of pWaitDstStageMask must not include VK_PIPELINE_STAGE_HOST_BIT

• VUID-VkSubmitInfo-pWaitSemaphores-03239
  If any element of pWaitSemaphores or pSignalSemaphores was created with a VkSemaphoreType of VK_SEMAPHORE_TYPE_TIMELINE, then the pNext chain must include a VkTimelineSemaphoreSubmitInfo structure

• VUID-VkSubmitInfo-pNext-03240
  If the pNext chain of this structure includes a VkTimelineSemaphoreSubmitInfo structure and any element of pWaitSemaphores was created with a VkSemaphoreType of VK_SEMAPHORE_TYPE_TIMELINE, then its waitSemaphoreValueCount member must equal waitSemaphoreCount

• VUID-VkSubmitInfo-pNext-03241
  If the pNext chain of this structure includes a VkTimelineSemaphoreSubmitInfo structure and any element of pSignalSemaphores was created with a VkSemaphoreType of VK_SEMAPHORE_TYPE_TIMELINE, then its signalSemaphoreValueCount member must equal signalSemaphoreCount

• VUID-VkSubmitInfo-pSignalSemaphores-03242
  For each element of pSignalSemaphores created with a VkSemaphoreType of VK_SEMAPHORE_TYPE_TIMELINE the corresponding element of
VkTimelineSemaphoreSubmitInfo::pSignalSemaphoreValues must have a value greater than the current value of the semaphore when the semaphore signal operation is executed

- VUID-VkSubmitInfo-pWaitSemaphores-03243
  For each element of pWaitSemaphores created with a VkSemaphoreType of VK_SEMAPHORE_TYPE_TIMELINE the corresponding element of VkTimelineSemaphoreSubmitInfo::pWaitSemaphoreValues must have a value which does not differ from the current value of the semaphore or the value of any outstanding semaphore wait or signal operation on that semaphore by more than maxTimelineSemaphoreValueDifference

- VUID-VkSubmitInfo-pSignalSemaphores-03244
  For each element of pSignalSemaphores created with a VkSemaphoreType of VK_SEMAPHORE_TYPE_TIMELINE the corresponding element of VkTimelineSemaphoreSubmitInfo::pSignalSemaphoreValues must have a value which does not differ from the current value of the semaphore or the value of any outstanding semaphore wait or signal operation on that semaphore by more than maxTimelineSemaphoreValueDifference

- VUID-VkSubmitInfo-pNext-04120
  If the pNext chain of this structure does not include a VkProtectedSubmitInfo structure with protectedSubmit set to VK_TRUE, then each element of the pCommandBuffers array must be an unprotected command buffer

- VUID-VkSubmitInfo-pNext-04148
  If the pNext chain of this structure includes a VkProtectedSubmitInfo structure with protectedSubmit set to VK_TRUE, then each element of the pCommandBuffers array must be a protected command buffer

- VUID-VkSubmitInfo-pCommandBuffers-06193
  If pCommandBuffers contains any resumed render pass instances, they must be suspended by a render pass instance earlier in submission order within pCommandBuffers

- VUID-VkSubmitInfo-pCommandBuffers-06014
  If pCommandBuffers contains any suspended render pass instances, they must be resumed by a render pass instance later in submission order within pCommandBuffers

- VUID-VkSubmitInfo-pCommandBuffers-06015
  If pCommandBuffers contains any suspended render pass instances, there must be no action or synchronization commands executed in a primary or secondary command buffer between that render pass instance and the render pass instance that resumes it

- VUID-VkSubmitInfo-pCommandBuffers-06016
  If pCommandBuffers contains any suspended render pass instances, there must be no render pass instances between that render pass instance and the render pass instance that resumes it

- VUID-VkSubmitInfo-variableSampleLocations-06017
  If the variableSampleLocations limit is not supported, and any element of pCommandBuffers contains any suspended render pass instances, where a graphics pipeline has been bound, any pipelines bound in the render pass instance that resumes it, or any subsequent render pass instances that resume from that one and so on, must use the same sample
Valid Usage (Implicit)

- **VUID-VkSubmitInfo-sType-sType**
  - The `sType` must be `VK_STRUCTURE_TYPE_SUBMIT_INFO`

- **VUID-VkSubmitInfo-pNext-pNext**
  - Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkAmigoProfilingSubmitInfoSEC`, `VkD3D12FenceSubmitInfoKHR`, `VkDeviceGroupSubmitInfo`, `VkFrameBoundaryEXT`, `VkPerformanceQuerySubmitInfoKHR`, `VkTimelineSemaphoreSubmitInfo`, `VkWin32KeyedMutexAcquireReleaseInfoKHR`, or `VkWin32KeyedMutexAcquireReleaseInfoNV`

- **VUID-VkSubmitInfo-sType-unique**
  - The `sType` value of each struct in the `pNext` chain must be unique

- **VUID-VkSubmitInfo-pWaitSemaphores-parameter**
  - If `waitSemaphoreCount` is not 0, `pWaitSemaphores` must be a valid pointer to an array of `waitSemaphoreCount` valid `VkSemaphore` handles

- **VUID-VkSubmitInfo-pWaitDstStageMask-parameter**
  - If `waitSemaphoreCount` is not 0, `pWaitDstStageMask` must be a valid pointer to an array of `waitSemaphoreCount` valid combinations of `VkPipelineStageFlagBits` values

- **VUID-VkSubmitInfo-pCommandBuffers-parameter**
  - If `commandBufferCount` is not 0, `pCommandBuffers` must be a valid pointer to an array of `commandBufferCount` valid `VkCommandBuffer` handles

- **VUID-VkSubmitInfo-pSignalSemaphores-parameter**
  - If `signalSemaphoreCount` is not 0, `pSignalSemaphores` must be a valid pointer to an array of `signalSemaphoreCount` valid `VkSemaphore` handles

- **VUID-VkSubmitInfo-commonparent**
  - Each of the elements of `pCommandBuffers`, the elements of `pSignalSemaphores`, and the elements of `pWaitSemaphores` that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same `VkDevice`

To specify the values to use when waiting for and signaling semaphores created with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_TIMELINE`, add a `VkTimelineSemaphoreSubmitInfo` structure to the `pNext` chain of the `VkSubmitInfo` structure when using `vkQueueSubmit` or the `VkBindSparseInfo` structure when using `vkQueueBindSparse`. The `VkTimelineSemaphoreSubmitInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkTimelineSemaphoreSubmitInfo {
    VkStructureType sType;
    const void* pNext;
    uint32_t waitSemaphoreValueCount;
} VkTimelineSemaphoreSubmitInfo;
```
const uint64_t* pWaitSemaphoreValues;
uint32_t signalSemaphoreValueCount;
const uint64_t* pSignalSemaphoreValues;
} VkTimelineSemaphoreSubmitInfo;

or the equivalent

// Provided by VK_KHR_timeline_semaphore
typedef VkTimelineSemaphoreSubmitInfo VkTimelineSemaphoreSubmitInfoKHR;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• waitSemaphoreValueCount is the number of semaphore wait values specified in pWaitSemaphoreValues.
• pWaitSemaphoreValues is a pointer to an array of waitSemaphoreValueCount values for the corresponding semaphores in VkSubmitInfo::pWaitSemaphores to wait for.
• signalSemaphoreValueCount is the number of semaphore signal values specified in pSignalSemaphoreValues.
• pSignalSemaphoreValues is a pointer to an array signalSemaphoreValueCount values for the corresponding semaphores in VkSubmitInfo::pSignalSemaphores to set when signaled.

If the semaphore in VkSubmitInfo::pWaitSemaphores or VkSubmitInfo::pSignalSemaphores corresponding to an entry in pWaitSemaphoreValues or pSignalSemaphoreValues respectively was not created with a VkSemaphoreType of VK_SEMAPHORE_TYPE_TIMELINE, the implementation must ignore the value in the pWaitSemaphoreValues or pSignalSemaphoreValues entry.

Valid Usage (Implicit)

- VUID-VkTimelineSemaphoreSubmitInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_TIMELINE_SEMAPHORE_SUBMIT_INFO
- VUID-VkTimelineSemaphoreSubmitInfo-pWaitSemaphoreValues-parameter
  If waitSemaphoreValueCount is not 0, and pWaitSemaphoreValues is not NULL, pWaitSemaphoreValues must be a valid pointer to an array of waitSemaphoreValueCount uint64_t values
- VUID-VkTimelineSemaphoreSubmitInfo-pSignalSemaphoreValues-parameter
  If signalSemaphoreValueCount is not 0, and pSignalSemaphoreValues is not NULL, pSignalSemaphoreValues must be a valid pointer to an array of signalSemaphoreValueCount uint64_t values

To specify the values to use when waiting for and signaling semaphores whose current payload refers to a Direct3D 12 fence, add a VkD3D12FenceSubmitInfoKHR structure to the pNext chain of the VkSubmitInfo structure. The VkD3D12FenceSubmitInfoKHR structure is defined as:
typedef struct VkD3D12FenceSubmitInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t waitSemaphoreValuesCount;
    const uint64_t* pWaitSemaphoreValues;
    uint32_t signalSemaphoreValuesCount;
    const uint64_t* pSignalSemaphoreValues;
} VkD3D12FenceSubmitInfoKHR;

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **waitSemaphoreValuesCount** is the number of semaphore wait values specified in **pWaitSemaphoreValues**.
- **pWaitSemaphoreValues** is a pointer to an array of **waitSemaphoreValuesCount** values for the corresponding semaphores in *VkSubmitInfo::pWaitSemaphores* to wait for.
- **signalSemaphoreValuesCount** is the number of semaphore signal values specified in **pSignalSemaphoreValues**.
- **pSignalSemaphoreValues** is a pointer to an array of **signalSemaphoreValuesCount** values for the corresponding semaphores in *VkSubmitInfo::pSignalSemaphores* to set when signaled.

If the semaphore in *VkSubmitInfo::pWaitSemaphores* or *VkSubmitInfo::pSignalSemaphores* corresponding to an entry in **pWaitSemaphoreValues** or **pSignalSemaphoreValues** respectively does not currently have a payload referring to a Direct3D 12 fence, the implementation must ignore the value in the **pWaitSemaphoreValues** or **pSignalSemaphoreValues** entry.

**Note**

As the introduction of the external semaphore handle type `VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_D3D12_FENCE_BIT` predates that of timeline semaphores, support for importing semaphore payloads from external handles of that type into semaphores created (implicitly or explicitly) with a *VkSemaphoreType* of `VK_SEMAPHORE_TYPE_BINARY` is preserved for backwards compatibility. However, applications should prefer importing such handle types into semaphores created with a *VkSemaphoreType* of `VK_SEMAPHORE_TYPE_TIMELINE`, and use the *VkTimelineSemaphoreSubmitInfo* structure instead of the *VkD3D12FenceSubmitInfoKHR* structure to specify the values to use when waiting for and signaling such semaphores.

**Valid Usage**

- `VUID-VkD3D12FenceSubmitInfoKHR-waitSemaphoreValuesCount-00079`
  
  **waitSemaphoreValuesCount** must be the same value as *VkSubmitInfo::waitSemaphoreCount*, where this structure is in the **pNext** chain of a *VkSubmitInfo* structure

- `VUID-VkD3D12FenceSubmitInfoKHR-signalSemaphoreValuesCount-00080`
signalSemaphoreValuesCount must be the same value as VkSubmitInfo::signalSemaphoreCount, where this structure is in the pNext chain of a VkSubmitInfo structure.

**Valid Usage (Implicit)**

- VUID-VkD3D12FenceSubmitInfoKHR-sType-sType
  
  sType must be VK_STRUCTURE_TYPE_D3D12_FENCE_SUBMIT_INFO_KHR

- VUID-VkD3D12FenceSubmitInfoKHR-pWaitSemaphoreValues-parameter
  
  If waitSemaphoreValuesCount is not 0, and pWaitSemaphoreValues is not NULL, pWaitSemaphoreValues must be a valid pointer to an array of waitSemaphoreValuesCount uint64_t values.

- VUID-VkD3D12FenceSubmitInfoKHR-pSignalSemaphoreValues-parameter
  
  If signalSemaphoreValuesCount is not 0, and pSignalSemaphoreValues is not NULL, pSignalSemaphoreValues must be a valid pointer to an array of signalSemaphoreValuesCount uint64_t values.

When submitting work that operates on memory imported from a Direct3D 11 resource to a queue, the keyed mutex mechanism may be used in addition to Vulkan semaphores to synchronize the work. Keyed mutexes are a property of a properly created shareable Direct3D 11 resource. They can only be used if the imported resource was created with the D3D11_RESOURCE_MISC_SHARED_KEYED_MUTEX flag.

To acquire keyed mutexes before submitted work and/or release them after, add a VkWin32KeyedMutexAcquireReleaseInfoKHR structure to the pNext chain of the VkSubmitInfo structure.

The VkWin32KeyedMutexAcquireReleaseInfoKHR structure is defined as:

```c
// Provided by VK_KHR_win32_keyed_mutex
typedef struct VkWin32KeyedMutexAcquireReleaseInfoKHR {
    VkStructureType    sType;
    const void*        pNext;
    uint32_t           acquireCount;
    const VkDeviceMemory* pAcquireSyncs;
    const uint64_t*    pAcquireKeys;
    const uint32_t*    pAcquireTimeouts;
    uint32_t           releaseCount;
    const VkDeviceMemory* pReleaseSyncs;
    const uint64_t*    pReleaseKeys;
} VkWin32KeyedMutexAcquireReleaseInfoKHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- acquireCount is the number of entries in the pAcquireSyncs, pAcquireKeys, and pAcquireTimeouts arrays.
• **pAcquireSyncs** is a pointer to an array of **VkDeviceMemory** objects which were imported from Direct3D 11 resources.

• **pAcquireKeys** is a pointer to an array of mutex key values to wait for prior to beginning the submitted work. Entries refer to the keyed mutex associated with the corresponding entries in **pAcquireSyncs**.

• **pAcquireTimeouts** is a pointer to an array of timeout values, in millisecond units, for each acquire specified in **pAcquireKeys**.

• **releaseCount** is the number of entries in the **pReleaseSyncs** and **pReleaseKeys** arrays.

• **pReleaseSyncs** is a pointer to an array of **VkDeviceMemory** objects which were imported from Direct3D 11 resources.

• **pReleaseKeys** is a pointer to an array of mutex key values to set when the submitted work has completed. Entries refer to the keyed mutex associated with the corresponding entries in **pReleaseSyncs**.

---

**Valid Usage**

• VUID-VkWin32KeyedMutexAcquireReleaseInfoKHR-pAcquireSyncs-00081
  Each member of **pAcquireSyncs** and **pReleaseSyncs** must be a device memory object imported by setting **VkImportMemoryWin32HandleInfoKHR::handleType** to **VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_BIT** or **VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_KMT_BIT**

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**Valid Usage (Implicit)**

• VUID-VkWin32KeyedMutexAcquireReleaseInfoKHR-sType-sType
  **sType** must be **VK_STRUCTURE_TYPE_WIN32_KEYED_MUTEX_ACQUIRE_RELEASE_INFO_KHR**

• VUID-VkWin32KeyedMutexAcquireReleaseInfoKHR-pAcquireSyncs-parameter
  If **acquireCount** is not 0, **pAcquireSyncs** must be a valid pointer to an array of **acquireCount** valid **VkDeviceMemory** handles

• VUID-VkWin32KeyedMutexAcquireReleaseInfoKHR-pAcquireKeys-parameter
  If **acquireCount** is not 0, **pAcquireKeys** must be a valid pointer to an array of **acquireCount** uint64_t values

• VUID-VkWin32KeyedMutexAcquireReleaseInfoKHR-pAcquireTimeouts-parameter
  If **acquireCount** is not 0, **pAcquireTimeouts** must be a valid pointer to an array of **acquireCount** uint32_t values

• VUID-VkWin32KeyedMutexAcquireReleaseInfoKHR-pReleaseSyncs-parameter
  If **releaseCount** is not 0, **pReleaseSyncs** must be a valid pointer to an array of **releaseCount** valid **VkDeviceMemory** handles

• VUID-VkWin32KeyedMutexAcquireReleaseInfoKHR-pReleaseKeys-parameter
  If **releaseCount** is not 0, **pReleaseKeys** must be a valid pointer to an array of **releaseCount** uint64_t values

• VUID-VkWin32KeyedMutexAcquireReleaseInfoKHR-commonparent
Both of the elements of `pAcquireSyncs`, and the elements of `pReleaseSyncs` that are valid handles of non-ignored parameters **must** have been created, allocated, or retrieved from the same `VkDevice`.

When submitting work that operates on memory imported from a Direct3D 11 resource to a queue, the keyed mutex mechanism **may** be used in addition to Vulkan semaphores to synchronize the work. Keyed mutexes are a property of a properly created shareable Direct3D 11 resource. They **can** only be used if the imported resource was created with the `D3D11_RESOURCE_MISC_SHARED_KEYEDMUTEX` flag.

To acquire keyed mutexes before submitted work and/or release them after, add a `VkWin32KeyedMutexAcquireReleaseInfoNV` structure to the `pNext` chain of the `VkSubmitInfo` structure.

The `VkWin32KeyedMutexAcquireReleaseInfoNV` structure is defined as:

```c
// Provided by VK_NV_win32_keyed_mutex
typedef struct VkWin32KeyedMutexAcquireReleaseInfoNV {
    VkStructureType sType;
    const void* pNext;
    uint32_t acquireCount;
    const VkDeviceMemory* pAcquireSyncs;
    const uint64_t* pAcquireKeys;
    const uint32_t* pAcquireTimeoutMilliseconds;
    uint32_t releaseCount;
    const VkDeviceMemory* pReleaseSyncs;
    const uint64_t* pReleaseKeys;
} VkWin32KeyedMutexAcquireReleaseInfoNV;
```

- `acquireCount` is the number of entries in the `pAcquireSyncs`, `pAcquireKeys`, and `pAcquireTimeoutMilliseconds` arrays.
- `pAcquireSyncs` is a pointer to an array of `VkDeviceMemory` objects which were imported from Direct3D 11 resources.
- `pAcquireKeys` is a pointer to an array of mutex key values to wait for prior to beginning the submitted work. Entries refer to the keyed mutex associated with the corresponding entries in `pAcquireSyncs`.
- `pAcquireTimeoutMilliseconds` is a pointer to an array of timeout values, in millisecond units, for each acquire specified in `pAcquireKeys`.
- `releaseCount` is the number of entries in the `pReleaseSyncs` and `pReleaseKeys` arrays.
- `pReleaseSyncs` is a pointer to an array of `VkDeviceMemory` objects which were imported from Direct3D 11 resources.
- `pReleaseKeys` is a pointer to an array of mutex key values to set when the submitted work has completed. Entries refer to the keyed mutex associated with the corresponding entries in `pReleaseSyncs`. 
Valid Usage (Implicit)

- **VUID-VkWin32KeyedMutexAcquireReleaseInfoNV-sType-sType**
  
  *sType* must be `VK_STRUCTURE_TYPE_WIN32_KEYED_MUTEX_ACQUIRE_RELEASE_INFO_NV`

- **VUID-VkWin32KeyedMutexAcquireReleaseInfoNV-pAcquireSyncs-parameter**
  
  If `acquireCount` is not 0, `pAcquireSyncs` must be a valid pointer to an array of `acquireCount` valid `VkDeviceMemory` handles

- **VUID-VkWin32KeyedMutexAcquireReleaseInfoNV-pAcquireKeys-parameter**
  
  If `acquireCount` is not 0, `pAcquireKeys` must be a valid pointer to an array of `acquireCount` `uint64_t` values

- **VUID-VkWin32KeyedMutexAcquireReleaseInfoNV-pAcquireTimeoutMilliseconds-parameter**
  
  If `acquireCount` is not 0, `pAcquireTimeoutMilliseconds` must be a valid pointer to an array of `acquireCount` `uint32_t` values

- **VUID-VkWin32KeyedMutexAcquireReleaseInfoNV-pReleaseSyncs-parameter**
  
  If `releaseCount` is not 0, `pReleaseSyncs` must be a valid pointer to an array of `releaseCount` valid `VkDeviceMemory` handles

- **VUID-VkWin32KeyedMutexAcquireReleaseInfoNV-pReleaseKeys-parameter**
  
  If `releaseCount` is not 0, `pReleaseKeys` must be a valid pointer to an array of `releaseCount` `uint64_t` values

- **VUID-VkWin32KeyedMutexAcquireReleaseInfoNV-commonparent**
  
  Both of the elements of `pAcquireSyncs`, and the elements of `pReleaseSyncs` that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same `VkDevice`

If the `pNext` chain of `VkSubmitInfo` includes a `VkProtectedSubmitInfo` structure, then the structure indicates whether the batch is protected. The `VkProtectedSubmitInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkProtectedSubmitInfo {  
  VkStructureType sType;  
  const void* pNext;  
  VkBool32 protectedSubmit; 
} VkProtectedSubmitInfo;
```

- `protectedSubmit` specifies whether the batch is protected. If `protectedSubmit` is `VK_TRUE`, the batch is protected. If `protectedSubmit` is `VK_FALSE`, the batch is unprotected. If the `VkSubmitInfo::pNext` chain does not include this structure, the batch is unprotected.

Valid Usage (Implicit)

- **VUID-VkProtectedSubmitInfo-sType-sType**
  
  *sType* must be `VK_STRUCTURE_TYPE_PROTECTED_SUBMIT_INFO`
If the `pNext` chain of `VkSubmitInfo` includes a `VkDeviceGroupSubmitInfo` structure, then that structure includes device indices and masks specifying which physical devices execute semaphore operations and command buffers.

The `VkDeviceGroupSubmitInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkDeviceGroupSubmitInfo {
    VkStructureType sType;
    const void* pNext;
    uint32_t waitSemaphoreCount;
    const uint32_t* pWaitSemaphoreDeviceIndices;
    uint32_t commandBufferCount;
    const uint32_t* pCommandBufferDeviceMasks;
    uint32_t signalSemaphoreCount;
    const uint32_t* pSignalSemaphoreDeviceIndices;
} VkDeviceGroupSubmitInfo;
```

or the equivalent

```c
// Provided by VK_KHR_device_group
typedef VkDeviceGroupSubmitInfo VkDeviceGroupSubmitInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `waitSemaphoreCount` is the number of elements in the `pWaitSemaphoreDeviceIndices` array.
- `pWaitSemaphoreDeviceIndices` is a pointer to an array of `waitSemaphoreCount` device indices indicating which physical device executes the semaphore wait operation in the corresponding element of `VkSubmitInfo::pWaitSemaphores`.
- `commandBufferCount` is the number of elements in the `pCommandBufferDeviceMasks` array.
- `pCommandBufferDeviceMasks` is a pointer to an array of `commandBufferCount` device masks indicating which physical devices execute the command buffer in the corresponding element of `VkSubmitInfo::pCommandBuffers`. A physical device executes the command buffer if the corresponding bit is set in the mask.
- `signalSemaphoreCount` is the number of elements in the `pSignalSemaphoreDeviceIndices` array.
- `pSignalSemaphoreDeviceIndices` is a pointer to an array of `signalSemaphoreCount` device indices indicating which physical device executes the semaphore signal operation in the corresponding element of `VkSubmitInfo::pSignalSemaphores`.

If this structure is not present, semaphore operations and command buffers execute on device index zero.
Valid Usage

- VUID-VkDeviceGroupSubmitInfo-waitSemaphoreCount-00082
  waitSemaphoreCount must equal VkSubmitInfo::waitSemaphoreCount

- VUID-VkDeviceGroupSubmitInfo-commandBufferCount-00083
  commandBufferCount must equal VkSubmitInfo::commandBufferCount

- VUID-VkDeviceGroupSubmitInfo-signalSemaphoreCount-00084
  signalSemaphoreCount must equal VkSubmitInfo::signalSemaphoreCount

- VUID-VkDeviceGroupSubmitInfo-pWaitSemaphoreDeviceIndices-00085
  All elements of pWaitSemaphoreDeviceIndices and pSignalSemaphoreDeviceIndices must be valid device indices

- VUID-VkDeviceGroupSubmitInfo-pCommandBufferDeviceMasks-00086
  All elements of pCommandBufferDeviceMasks must be valid device masks

Valid Usage (Implicit)

- VUID-VkDeviceGroupSubmitInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_DEVICE_GROUP_SUBMIT_INFO

- VUID-VkDeviceGroupSubmitInfo-pWaitSemaphoreDeviceIndices-parameter
  If waitSemaphoreCount is not 0, pWaitSemaphoreDeviceIndices must be a valid pointer to an array of waitSemaphoreCount uint32_t values

- VUID-VkDeviceGroupSubmitInfo-pCommandBufferDeviceMasks-parameter
  If commandBufferCount is not 0, pCommandBufferDeviceMasks must be a valid pointer to an array of commandBufferCount uint32_t values

- VUID-VkDeviceGroupSubmitInfo-pSignalSemaphoreDeviceIndices-parameter
  If signalSemaphoreCount is not 0, pSignalSemaphoreDeviceIndices must be a valid pointer to an array of signalSemaphoreCount uint32_t values

If the pNext chain of VkSubmitInfo includes a VkPerformanceQuerySubmitInfoKHR structure, then the structure indicates which counter pass is active for the batch in that submit.

The VkPerformanceQuerySubmitInfoKHR structure is defined as:

```c
// Provided by VK_KHR_performance_query
typedef struct VkPerformanceQuerySubmitInfoKHR {
    VkStructureType      sType;
    const void*           pNext;
    uint32_t              counterPassIndex;
} VkPerformanceQuerySubmitInfoKHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
• **counterPassIndex** specifies which counter pass index is active.

If the **VkSubmitInfo::pNext** chain does not include this structure, the batch defaults to use counter pass index 0.

**Valid Usage**

- VUID-VkPerformanceQuerySubmitInfoKHR-counterPassIndex-03221
  - **counterPassIndex must** be less than the number of counter passes required by any queries within the batch. The required number of counter passes for a performance query is obtained by calling `vkGetPhysicalDeviceQueueFamilyPerformanceQueryPassesKHR`

**Valid Usage (Implicit)**

- VUID-VkPerformanceQuerySubmitInfoKHR-sType-sType
  - **sType must** be `VK_STRUCTURE_TYPE_PERFORMANCE_QUERY_SUBMIT_INFO_KHR`

### 6.6. Queue Forward Progress

When using binary semaphores, the application **must** ensure that command buffer submissions will be able to complete without any subsequent operations by the application on any queue. After any call to `vkQueueSubmit` (or other queue operation), for every queued wait on a semaphore created with a **VkSemaphoreType** of **VK_SEMAPHORE_TYPE_BINARY** there **must** be a prior signal of that semaphore that will not be consumed by a different wait on the semaphore.

When using timeline semaphores, wait-before-signal behavior is well-defined and applications **can** submit work via `vkQueueSubmit` defining a timeline semaphore wait operation before submitting a corresponding semaphore signal operation. For each timeline semaphore wait operation defined by a call to `vkQueueSubmit`, the application **must** ensure that a corresponding semaphore signal operation is executed before forward progress can be made.

If a command buffer submission waits for any events to be signaled, the application **must** ensure that command buffer submissions will be able to complete without any subsequent operations by the application. Events signaled by the host **must** be signaled before the command buffer waits on those events.

**Note**

The ability for commands to wait on the host to set an events was originally added to allow low-latency updates to resources between host and device. However, to ensure quality of service, implementations would necessarily detect extended stalls in execution and timeout after a short period. As this period is not defined in the Vulkan specification, it is impossible to correctly validate any application with any wait period. Since the original users of this functionality were highly limited and platform-specific, this functionality is now considered defunct and should not be used.
6.7. Secondary Command Buffer Execution

A secondary command buffer must not be directly submitted to a queue. Instead, secondary command buffers are recorded to execute as part of a primary command buffer with the command:

```c
// Provided by VK_VERSION_1_0
void vkCmdExecuteCommands(
    VkCommandBuffer commandBuffer,
    uint32_t commandBufferCount,
    const VkCommandBuffer* pCommandBuffers);
```

- `commandBuffer` is a handle to a primary command buffer that the secondary command buffers are executed in.
- `commandBufferCount` is the length of the `pCommandBuffers` array.
- `pCommandBuffers` is a pointer to an array of `commandBufferCount` secondary command buffer handles, which are recorded to execute in the primary command buffer in the order they are listed in the array.

If any element of `pCommandBuffers` was not recorded with the `VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT` flag, and it was recorded into any other primary command buffer which is currently in the executable or recording state, that primary command buffer becomes invalid.

Valid Usage

- VUID-vkCmdExecuteCommands-pCommandBuffers-00088
  Each element of `pCommandBuffers` must have been allocated with a level of `VK_COMMAND_BUFFER_LEVEL_SECONDARY`

- VUID-vkCmdExecuteCommands-pCommandBuffers-00089
  Each element of `pCommandBuffers` must be in the pending or executable state

- VUID-vkCmdExecuteCommands-pCommandBuffers-00091
  If any element of `pCommandBuffers` was not recorded with the `VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT` flag, it must not be in the pending state

- VUID-vkCmdExecuteCommands-pCommandBuffers-00092
  If any element of `pCommandBuffers` was not recorded with the `VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT` flag, it must not have already been recorded to `commandBuffer`

- VUID-vkCmdExecuteCommands-pCommandBuffers-00093
  If any element of `pCommandBuffers` was not recorded with the `VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT` flag, it must not appear more than once in `pCommandBuffers`

- VUID-vkCmdExecuteCommands-pCommandBuffers-00094
  Each element of `pCommandBuffers` must have been allocated from a `VkCommandPool` that was
• VUID-vkCmdExecuteCommands-pCommandBuffers-00096
  If \( \text{vkCmdExecuteCommands} \) is being called within a render pass instance, each element of \( p\text{CommandBuffers} \) must have been recorded with the VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT

• VUID-vkCmdExecuteCommands-pCommandBuffers-00099
  If \( \text{vkCmdExecuteCommands} \) is being called within a render pass instance, and any element of \( p\text{CommandBuffers} \) was recorded with \( \text{VkCommandBufferInheritanceInfo}::\text{framebuffer} \) not equal to VK_NULL_HANDLE, that \( \text{VkFramebuffer} \) must match the \( \text{VkFramebuffer} \) used in the current render pass instance

• VUID-vkCmdExecuteCommands-contents-06018
  If \( \text{vkCmdExecuteCommands} \) is being called within a render pass instance begun with \( \text{vkCmdBeginRenderPass} \), its \textit{contents} parameter must have been set to VK_SUBPASS_CONTENTS_SECONDARY_COMMAND_BUFFERS

• VUID-vkCmdExecuteCommands-pCommandBuffers-06019
  If \( \text{vkCmdExecuteCommands} \) is being called within a render pass instance begun with \( \text{vkCmdBeginRenderPass} \), each element of \( p\text{CommandBuffers} \) must have been recorded with \( \text{VkCommandBufferInheritanceInfo}::\text{subpass} \) set to the index of the subpass which the given command buffer will be executed in

• VUID-vkCmdExecuteCommands-pBeginInfo-06020
  If \( \text{vkCmdExecuteCommands} \) is being called within a render pass instance begun with \( \text{vkCmdBeginRenderPass} \), the render passes specified in the \( p\text{BeginInfo->pInheritanceInfo->renderPass} \) members of the \( \text{vkBeginCommandBuffer} \) commands used to begin recording each element of \( p\text{CommandBuffers} \) must be compatible with the current render pass

• VUID-vkCmdExecuteCommands-pNext-02865
  If \( \text{vkCmdExecuteCommands} \) is being called within a render pass instance that included \( \text{VkRenderPassTransformBeginInfoQCOM} \) in the \( p\text{Next} \) chain of \( \text{VkRenderPassBeginInfo} \), then each element of \( p\text{CommandBuffers} \) must have been recorded with \( \text{VkCommandBufferInheritanceRenderPassTransformInfoQCOM} \) in the \( p\text{Next} \) chain of \( \text{VkCommandBufferBeginInfo} \)

• VUID-vkCmdExecuteCommands-pNext-02866
  If \( \text{vkCmdExecuteCommands} \) is being called within a render pass instance that included \( \text{VkRenderPassTransformBeginInfoQCOM} \) in the \( p\text{Next} \) chain of \( \text{VkRenderPassBeginInfo} \), then each element of \( p\text{CommandBuffers} \) must have been recorded with \( \text{VkCommandBufferInheritanceRenderPassTransformInfoQCOM}::\text{transform} \) identical to \( \text{VkRenderPassTransformBeginInfoQCOM}::\text{transform} \)

• VUID-vkCmdExecuteCommands-pNext-02867
  If \( \text{vkCmdExecuteCommands} \) is being called within a render pass instance that included \( \text{VkRenderPassTransformBeginInfoQCOM} \) in the \( p\text{Next} \) chain of \( \text{VkRenderPassBeginInfo} \), then each element of \( p\text{CommandBuffers} \) must have been recorded with \( \text{VkCommandBufferInheritanceRenderPassTransformInfoQCOM}::\text{renderArea} \) identical to \( \text{VkRenderPassBeginInfo}::\text{renderArea} \)

• VUID-vkCmdExecuteCommands-pCommandBuffers-00100
If `vkCmdExecuteCommands` is not being called within a render pass instance, each element of `pCommandBuffers` must not have been recorded with the `VK_COMMAND_BUFFER_USAGE_RENDER_PASS_CONTINUE_BIT`

- VUID-vkCmdExecuteCommands-commandBuffer-00101
  If the `inheritedQueries` feature is not enabled, `commandBuffer` must not have any queries active

- VUID-vkCmdExecuteCommands-commandBuffer-00102
  If `commandBuffer` has a `VK_QUERY_TYPE_OCCLUSION` query active, then each element of `pCommandBuffers` must have been recorded with `VkCommandBufferInheritanceInfo::occlusionQueryEnable` set to `VK_TRUE`

- VUID-vkCmdExecuteCommands-commandBuffer-00103
  If `commandBuffer` has a `VK_QUERY_TYPE_OCCLUSION` query active, then each element of `pCommandBuffers` must have been recorded with `VkCommandBufferInheritanceInfo::queryFlags` having all bits set that are set for the query

- VUID-vkCmdExecuteCommands-commandBuffer-00104
  If `commandBuffer` has a `VK_QUERY_TYPE_PIPELINE_STATISTICS` query active, then each element of `pCommandBuffers` must have been recorded with `VkCommandBufferInheritanceInfo::pipelineStatistics` having all bits set that are set in the `VkQueryPool` the query uses

- VUID-vkCmdExecuteCommands-pCommandBuffers-00105
  Each element of `pCommandBuffers` must not begin any query types that are active in `commandBuffer`

- VUID-vkCmdExecuteCommands-commandBuffer-07594
  `commandBuffer` must not have any queries other than `VK_QUERY_TYPE_OCCLUSION` and `VK_QUERY_TYPE_PIPELINE_STATISTICS` active

- VUID-vkCmdExecuteCommands-commandBuffer-01820
  If `commandBuffer` is a protected command buffer and protectedNoFault is not supported, each element of `pCommandBuffers` must be a protected command buffer

- VUID-vkCmdExecuteCommands-commandBuffer-01821
  If `commandBuffer` is an unprotected command buffer and protectedNoFault is not supported, each element of `pCommandBuffers` must be an unprotected command buffer

- VUID-vkCmdExecuteCommands-None-02286
  This command must not be recorded when transform feedback is active

- VUID-vkCmdExecuteCommands-commandBuffer-06533
  If `vkCmdExecuteCommands` is being called within a render pass instance and any recorded command in `commandBuffer` in the current subpass will write to an image subresource as an attachment, commands recorded in elements of `pCommandBuffers` must not read from the memory backing that image subresource in any other way

- VUID-vkCmdExecuteCommands-commandBuffer-06534
  If `vkCmdExecuteCommands` is being called within a render pass instance and any recorded command in `commandBuffer` in the current subpass will read from an image subresource used as an attachment in any way other than as an attachment, commands recorded in elements of `pCommandBuffers` must not write to that image subresource as an attachment

- VUID-vkCmdExecuteCommands-pCommandBuffers-06535
If `vkCmdExecuteCommands` is being called within a render pass instance and any recorded command in a given element of `pCommandBuffers` will write to an image subresource as an attachment, commands recorded in elements of `pCommandBuffers` at a higher index must not read from the memory backing that image subresource in any other way.

- VUID-vkCmdExecuteCommands-pCommandBuffers-06536
  If `vkCmdExecuteCommands` is being called within a render pass instance and any recorded command in a given element of `pCommandBuffers` will read from an image subresource used as an attachment in any way other than as an attachment, commands recorded in elements of `pCommandBuffers` at a higher index must not write to that image subresource as an attachment.

- VUID-vkCmdExecuteCommands-pCommandBuffers-06021
  If `pCommandBuffers` contains any suspended render pass instances, there must be no action or synchronization commands between that render pass instance and any render pass instance that resumes it.

- VUID-vkCmdExecuteCommands-pCommandBuffers-06022
  If `pCommandBuffers` contains any suspended render pass instances, there must be no render pass instances between that render pass instance and any render pass instance that resumes it.

- VUID-vkCmdExecuteCommands-variableSampleLocations-06023
  If the `variableSampleLocations` limit is not supported, and any element of `pCommandBuffers` contains any suspended render pass instances, where a graphics pipeline has been bound, any pipelines bound in the render pass instance that resumes it, or any subsequent render pass instances that resume from that one and so on, must use the same sample locations.

- VUID-vkCmdExecuteCommands-flags-06024
  If `vkCmdExecuteCommands` is being called within a render pass instance begun with `vkCmdBeginRendering`, its `VkRenderingInfo::flags` parameter must have included `VK_RENDERING_CONTENTS_SECONDARY_COMMAND_BUFFERS_BIT`.

- VUID-vkCmdExecuteCommands-pBeginInfo-06025
  If `vkCmdExecuteCommands` is being called within a render pass instance begun with `vkCmdBeginRendering`, the render passes specified in the `pBeginInfo->pInheritanceInfo->renderPass` members of the `vkBeginCommandBuffer` commands used to begin recording each element of `pCommandBuffers` must be `VK_NULL_HANDLE`.

- VUID-vkCmdExecuteCommands-flags-06026
  If `vkCmdExecuteCommands` is being called within a render pass instance begun with `vkCmdBeginRendering`, the `flags` member of the `VkCommandBufferInheritanceRenderingInfo` structure included in the `pNext` chain of `VkCommandBufferBeginInfo::pInheritanceInfo` used to begin recording each element of `pCommandBuffers` must be equal to the `VkRenderingInfo::flags` parameter to `vkCmdBeginRendering`, excluding `VK_RENDERING_CONTENTS_SECONDARY_COMMAND_BUFFERS_BIT`.

- VUID-vkCmdExecuteCommands-colorAttachmentCount-06027
  If `vkCmdExecuteCommands` is being called within a render pass instance begun with `vkCmdBeginRendering`, the `colorAttachmentCount` member of the `VkCommandBufferInheritanceRenderingInfo` structure included in the `pNext` chain of `VkCommandBufferBeginInfo::pInheritanceInfo` used to begin recording each element of
**pCommandBuffers must** be equal to the **VkRenderingInfo::colorAttachmentCount** parameter to **vkCmdBeginRendering**

- **VUID-vkCmdExecuteCommands-imageView-06028**  
  If **vkCmdExecuteCommands** is being called within a render pass instance begun with **vkCmdBeginRendering**, if the **imageView** member of an element of the **VkRenderingInfo::pColorAttachments** parameter to **vkCmdBeginRendering** is not **VK_NULL_HANDLE**, the corresponding element of the **pColorAttachmentFormats** member of the **VkCommandBufferInheritanceRenderingInfo** structure included in the **pNext** chain of **VkCommandBufferBeginInfo::pInheritanceInfo** used to begin recording each element of **pCommandBuffers** must be equal to the format used to create that image view.

- **VUID-vkCmdExecuteCommands-imageView-07606**  
  If **vkCmdExecuteCommands** is being called within a render pass instance begun with **vkCmdBeginRendering**, if the **imageView** member of an element of the **VkRenderingInfo::pColorAttachments** parameter to **vkCmdBeginRendering** is **VK_NULL_HANDLE**, the corresponding element of the **pColorAttachmentFormats** member of the **VkCommandBufferInheritanceRenderingInfo** structure included in the **pNext** chain of **VkCommandBufferBeginInfo::pInheritanceInfo** used to begin recording each element of **pCommandBuffers** must be **VK_FORMAT_UNDEFINED**.

- **VUID-vkCmdExecuteCommands-pDepthAttachment-06029**  
  If **vkCmdExecuteCommands** is being called within a render pass instance begun with **vkCmdBeginRendering**, if the **VkRenderingInfo::pDepthAttachment->imageView** parameter to **vkCmdBeginRendering** is not **VK_NULL_HANDLE**, the value of the **depthAttachmentFormat** member of the **VkCommandBufferInheritanceRenderingInfo** structure included in the **pNext** chain of **VkCommandBufferBeginInfo::pInheritanceInfo** used to begin recording each element of **pCommandBuffers** must be equal to the format used to create that image view.

- **VUID-vkCmdExecuteCommands-pStencilAttachment-06030**  
  If **vkCmdExecuteCommands** is being called within a render pass instance begun with **vkCmdBeginRendering**, if the **VkRenderingInfo::pStencilAttachment->imageView** parameter to **vkCmdBeginRendering** is **VK_NULL_HANDLE**, the value of the **stencilAttachmentFormat** member of the **VkCommandBufferInheritanceRenderingInfo** structure included in the **pNext** chain of **VkCommandBufferBeginInfo::pInheritanceInfo** used to begin recording each element of **pCommandBuffers** must be **VK_FORMAT_UNDEFINED**.

- **VUID-vkCmdExecuteCommands-pDepthAttachment-06774**  
  If **vkCmdExecuteCommands** is being called within a render pass instance begun with **vkCmdBeginRendering** and the **VkRenderingInfo::pDepthAttachment->imageView** parameter to **vkCmdBeginRendering** was **VK_NULL_HANDLE**, the value of the **depthAttachmentFormat** member of the **VkCommandBufferInheritanceRenderingInfo** structure included in the **pNext** chain of **VkCommandBufferBeginInfo::pInheritanceInfo** used to begin recording each element of **pCommandBuffers** must be **VK_FORMAT_UNDEFINED**.

- **VUID-vkCmdExecuteCommands-pStencilAttachment-06775**  
  If **vkCmdExecuteCommands** is being called within a render pass instance begun with **vkCmdBeginRendering** and the **VkRenderingInfo::pStencilAttachment->imageView** parameter to **vkCmdBeginRendering** was **VK_NULL_HANDLE**, the value of the
stencilAttachmentFormat member of the VkCommandBufferInheritanceRenderingInfo structure included in the pNext chain of VkCommandBufferBeginInfo::pInheritanceInfo used to begin recording each element of pCommandBuffers must be VK_FORMAT_UNDEFINED

• VUID-vkCmdExecuteCommands-viewMask-06031
  If vkCmdExecuteCommands is being called within a render pass instance begun with vkCmdBeginRendering, the viewMask member of the VkCommandBufferInheritanceRenderingInfo structure included in the pNext chain of VkCommandBufferBeginInfo::pInheritanceInfo used to begin recording each element of pCommandBuffers must be equal to the VkRenderingInfo::viewMask parameter to vkCmdBeginRendering

• VUID-vkCmdExecuteCommands-pNext-06032
  If vkCmdExecuteCommands is being called within a render pass instance begun with vkCmdBeginRendering and the pNext chain of VkCommandBufferInheritanceInfo includes a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, if the imageView member of an element of the VkRenderingInfo::pColorAttachments parameter to vkCmdBeginRendering is not VK_NULL_HANDLE, the corresponding element of the pColorAttachmentSamples member of the VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure included in the pNext chain of VkCommandBufferBeginInfo::pInheritanceInfo used to begin recording each element of pCommandBuffers must be equal to the sample count used to create that image view

• VUID-vkCmdExecuteCommands-pNext-06033
  If vkCmdExecuteCommands is being called within a render pass instance begun with vkCmdBeginRendering and the pNext chain of VkCommandBufferInheritanceInfo includes a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, if the VkRenderingInfo::pDepthAttachment->imageView parameter to vkCmdBeginRendering is not VK_NULL_HANDLE, the value of the depthStencilAttachment Samples member of the VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure included in the pNext chain of VkCommandBufferBeginInfo::pInheritanceInfo used to begin recording each element of pCommandBuffers must be equal to the sample count used to create that image view

• VUID-vkCmdExecuteCommands-pNext-06034
  If vkCmdExecuteCommands is being called within a render pass instance begun with vkCmdBeginRendering and the pNext chain of VkCommandBufferInheritanceInfo includes a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, if the VkRenderingInfo::pStencilAttachment->imageView parameter to vkCmdBeginRendering is not VK_NULL_HANDLE, the value of the depthStencilAttachment Samples member of the VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure included in the pNext chain of VkCommandBufferBeginInfo::pInheritanceInfo used to begin recording each element of pCommandBuffers must be equal to the sample count used to create that image view

• VUID-vkCmdExecuteCommands-pNext-06035
  If vkCmdExecuteCommands is being called within a render pass instance begun with vkCmdBeginRendering and the pNext chain of VkCommandBufferInheritanceInfo does not include a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, if the imageView member of an element of the VkRenderingInfo
::pColorAttachments parameter to vkCmdBeginRendering is not VK_NULL_HANDLE, the value of VkCommandBufferInheritanceRenderingInfo::rasterizationSamples must be equal to the sample count used to create that image view

- VUID-vkCmdExecuteCommands-pNext-06036
  If vkCmdExecuteCommands is being called within a render pass instance begun with vkCmdBeginRendering and the pNext chain of VkCommandBufferInheritanceInfo does not include a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, if the VkRenderingInfo::pDepthAttachment->imageView parameter to vkCmdBeginRendering is not VK_NULL_HANDLE, the value of VkCommandBufferInheritanceRenderingInfo::rasterizationSamples must be equal to the sample count used to create that image view

- VUID-vkCmdExecuteCommands-pNext-06037
  If vkCmdExecuteCommands is being called within a render pass instance begun with vkCmdBeginRendering and the pNext chain of VkCommandBufferInheritanceInfo does not include a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, if the VkRenderingInfo::pStencilAttachment->imageView parameter to vkCmdBeginRendering is not VK_NULL_HANDLE, the value of VkCommandBufferInheritanceRenderingInfo::rasterizationSamples must be equal to the sample count used to create that image view

Valid Usage (Implicit)

- VUID-vkCmdExecuteCommands-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdExecuteCommands-pCommandBuffers-parameter
  pCommandBuffers must be a valid pointer to an array of commandBufferCount valid VkCommandBuffer handles

- VUID-vkCmdExecuteCommands-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdExecuteCommands-commandBuffer-cmdpool
  TheVkCommandPoolthat commandBuffer was allocated from must support transfer, graphics, or compute operations

- VUID-vkCmdExecuteCommands-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdExecuteCommands-bufferlevel
  commandBuffer must be a primary VkCommandBuffer

- VUID-vkCmdExecuteCommands-commandBufferCount-arraylength
  commandBufferCount must be greater than 0

- VUID-vkCmdExecuteCommands-commonparent
  Both of commandBuffer, and the elements of pCommandBuffers must have been created, allocated, or retrieved from the same VkDevice
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

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<tr>
<th>Command Buffer Levels</th>
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</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Both</td>
<td>Outside</td>
<td>Transfer Graphics Compute</td>
<td>Indirection</td>
</tr>
</tbody>
</table>

6.8. Command Buffer Device Mask

Each command buffer has a piece of state storing the current device mask of the command buffer. This mask controls which physical devices within the logical device all subsequent commands will execute on, including state-setting commands, action commands, and synchronization commands.

Scissor, exclusive scissor, and viewport state (excluding the count of each) can be set to different values on each physical device (only when set as dynamic state), and each physical device will render using its local copy of the state. Other state is shared between physical devices, such that all physical devices use the most recently set values for the state. However, when recording an action command that uses a piece of state, the most recent command that set that state must have included all physical devices that execute the action command in its current device mask.

The command buffer's device mask is orthogonal to the `pCommandBufferDeviceMasks` member of `VkDeviceGroupSubmitInfo`. Commands only execute on a physical device if the device index is set in both device masks.

If the `pNext` chain of `VkCommandBufferBeginInfo` includes a `VkDeviceGroupCommandBufferBeginInfo` structure, then that structure includes an initial device mask for the command buffer.

The `VkDeviceGroupCommandBufferBeginInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkDeviceGroupCommandBufferBeginInfo {
    VkStructureType sType;
    const void* pNext;
    uint32_t deviceMask;
} VkDeviceGroupCommandBufferBeginInfo;
```

or the equivalent
typedef VkDeviceGroupCommandBufferBeginInfo VkDeviceGroupCommandBufferBeginInfoKHR;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **deviceMask** is the initial value of the command buffer’s device mask.

The initial device mask also acts as an upper bound on the set of devices that can ever be in the device mask in the command buffer.

If this structure is not present, the initial value of a command buffer’s device mask is set to include all physical devices in the logical device when the command buffer begins recording.

**Valid Usage**

- VUID-VkDeviceGroupCommandBufferBeginInfo-deviceMask-00106
  
  deviceMask must be a valid device mask value

- VUID-VkDeviceGroupCommandBufferBeginInfo-deviceMask-00107
  
  deviceMask must not be zero

**Valid Usage (Implicit)**

- VUID-VkDeviceGroupCommandBufferBeginInfo-sType-sType
  
  sType must be `VK_STRUCTURE_TYPE_DEVICE_GROUP_COMMAND_BUFFER_BEGIN_INFO`

To update the current device mask of a command buffer, call:

```c
// Provided by VK_VERSION_1_1
void vkCmdSetDeviceMask(
    VkCommandBuffer commandBuffer,
    uint32_t deviceMask);

or the equivalent command

// Provided by VK_KHR_device_group
void vkCmdSetDeviceMaskKHR(
    VkCommandBuffer commandBuffer,
    uint32_t deviceMask);
```

- **commandBuffer** is command buffer whose current device mask is modified.
- **deviceMask** is the new value of the current device mask.

deviceMask is used to filter out subsequent commands from executing on all physical devices whose
bit indices are not set in the mask, except commands beginning a render pass instance, commands transitioning to the next subpass in the render pass instance, and commands ending a render pass instance, which always execute on the set of physical devices whose bit indices are included in the `deviceMask` member of the `VkDeviceGroupRenderPassBeginInfo` structure passed to the command beginning the corresponding render pass instance.

**Valid Usage**

- VUID-vkCmdSetDeviceMask-deviceMask-00108
  `deviceMask` must be a valid device mask value

- VUID-vkCmdSetDeviceMask-deviceMask-00109
  `deviceMask` must not be zero

- VUID-vkCmdSetDeviceMask-deviceMask-00110
  `deviceMask` must not include any set bits that were not in the `VkDeviceGroupCommandBufferBeginInfo::deviceMask` value when the command buffer began recording

- VUID-vkCmdSetDeviceMask-deviceMask-00111
  If `vkCmdSetDeviceMask` is called inside a render pass instance, `deviceMask` must not include any set bits that were not in the `VkDeviceGroupRenderPassBeginInfo::deviceMask` value when the render pass instance began recording

**Valid Usage (Implicit)**

- VUID-vkCmdSetDeviceMask-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdSetDeviceMask-commandBuffer-recording
  `commandBuffer` must be in the recording state

- VUID-vkCmdSetDeviceMask-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, compute, or transfer operations

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized
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<td>Both</td>
<td>Graphics</td>
<td>State</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compute</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
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</table>
Chapter 7. Synchronization and Cache Control

Synchronization of access to resources is primarily the responsibility of the application in Vulkan. The order of execution of commands with respect to the host and other commands on the device has few implicit guarantees, and needs to be explicitly specified. Memory caches and other optimizations are also explicitly managed, requiring that the flow of data through the system is largely under application control.

Whilst some implicit guarantees exist between commands, five explicit synchronization mechanisms are exposed by Vulkan:

**Fences**
Fences can be used to communicate to the host that execution of some task on the device has completed, controlling resource access between host and device.

**Semaphores**
Semaphores can be used to control resource access across multiple queues.

**Events**
Events provide a fine-grained synchronization primitive which can be signaled either within a command buffer or by the host, and can be waited upon within a command buffer or queried on the host. Events can be used to control resource access within a single queue.

**Pipeline Barriers**
Pipeline barriers also provide synchronization control within a command buffer, but at a single point, rather than with separate signal and wait operations. Pipeline barriers can be used to control resource access within a single queue.

**Render Passes**
Render passes provide a useful synchronization framework for most rendering tasks, built upon the concepts in this chapter. Many cases that would otherwise need an application to use other synchronization primitives can be expressed more efficiently as part of a render pass. Render pass objects can be used to control resource access within a single queue.

7.1. Execution and Memory Dependencies

An operation is an arbitrary amount of work to be executed on the host, a device, or an external entity such as a presentation engine. Synchronization commands introduce explicit execution dependencies, and memory dependencies between two sets of operations defined by the command’s two synchronization scopes.

The synchronization scopes define which other operations a synchronization command is able to create execution dependencies with. Any type of operation that is not in a synchronization command’s synchronization scopes will not be included in the resulting dependency. For example, for many synchronization commands, the synchronization scopes can be limited to just operations executing in specific pipeline stages, which allows other pipeline stages to be excluded from a
dependency. Other scoping options are possible, depending on the particular command.

An execution dependency is a guarantee that for two sets of operations, the first set must happen-before the second set. If an operation happens-before another operation, then the first operation must complete before the second operation is initiated. More precisely:

- Let \(\text{Ops}_1\) and \(\text{Ops}_2\) be separate sets of operations.
- Let \(\text{Sync}\) be a synchronization command.
- Let \(\text{Scope}_{\text{1st}}\) and \(\text{Scope}_{\text{2nd}}\) be the synchronization scopes of \(\text{Sync}\).
- Let \(\text{ScopedOps}_1\) be the intersection of sets \(\text{Ops}_1\) and \(\text{Scope}_{\text{1st}}\).
- Let \(\text{ScopedOps}_2\) be the intersection of sets \(\text{Ops}_2\) and \(\text{Scope}_{\text{2nd}}\).
- Submitting \(\text{Ops}_1\), \(\text{Sync}\) and \(\text{Ops}_2\) for execution, in that order, will result in execution dependency \(\text{ExeDep}\) between \(\text{ScopedOps}_1\) and \(\text{ScopedOps}_2\).
- Execution dependency \(\text{ExeDep}\) guarantees that \(\text{ScopedOps}_1\) happen-before \(\text{ScopedOps}_2\).

An execution dependency chain is a sequence of execution dependencies that form a happens-before relation between the first dependency’s \(\text{ScopedOps}_1\) and the final dependency’s \(\text{ScopedOps}_2\). For each consecutive pair of execution dependencies, a chain exists if the intersection of \(\text{Scope}_{\text{2nd}}\) in the first dependency and \(\text{Scope}_{\text{1st}}\) in the second dependency is not an empty set. The formation of a single execution dependency from an execution dependency chain can be described by substituting the following in the description of execution dependencies:

- Let \(\text{Sync}\) be a set of synchronization commands that generate an execution dependency chain.
- Let \(\text{Scope}_{\text{1st}}\) be the first synchronization scope of the first command in \(\text{Sync}\).
- Let \(\text{Scope}_{\text{2nd}}\) be the second synchronization scope of the last command in \(\text{Sync}\).

Execution dependencies alone are not sufficient to guarantee that values resulting from writes in one set of operations can be read from another set of operations.

Three additional types of operations are used to control memory access. Availability operations cause the values generated by specified memory write accesses to become available to a memory domain for future access. Any available value remains available until a subsequent write to the same memory location occurs (whether it is made available or not) or the memory is freed. Memory domain operations cause writes that are available to a source memory domain to become available to a destination memory domain (an example of this is making writes available to the host domain available to the device domain). Visibility operations cause values available to a memory domain to become visible to specified memory accesses.

Availability, visibility, memory domains, and memory domain operations are formally defined in the Availability and Visibility section of the Memory Model chapter. Which API operations perform each of these operations is defined in Availability, Visibility, and Domain Operations.

A memory dependency is an execution dependency which includes availability and visibility operations such that:

- The first set of operations happens-before the availability operation.
• The availability operation happens-before the visibility operation.
• The visibility operation happens-before the second set of operations.

Once written values are made visible to a particular type of memory access, they can be read or written by that type of memory access. Most synchronization commands in Vulkan define a memory dependency.

The specific memory accesses that are made available and visible are defined by the access scopes of a memory dependency. Any type of access that is in a memory dependency’s first access scope and occurs in \texttt{ScopedOps}_1 is made available. Any type of access that is in a memory dependency’s second access scope and occurs in \texttt{ScopedOps}_2 has any available writes made visible to it. Any type of operation that is not in a synchronization command’s access scopes will not be included in the resulting dependency.

A memory dependency enforces availability and visibility of memory accesses and execution order between two sets of operations. Adding to the description of execution dependency chains:

• Let \texttt{MemOps}_1 be the set of memory accesses performed by \texttt{ScopedOps}_1.
• Let \texttt{MemOps}_2 be the set of memory accesses performed by \texttt{ScopedOps}_2.
• Let \texttt{AccessScope}_{1st} be the first access scope of the first command in the \texttt{Sync} chain.
• Let \texttt{AccessScope}_{2nd} be the second access scope of the last command in the \texttt{Sync} chain.
• Let \texttt{ScopedMemOps}_1 be the intersection of sets \texttt{MemOps}_1 and \texttt{AccessScope}_{1st}.
• Let \texttt{ScopedMemOps}_2 be the intersection of sets \texttt{MemOps}_2 and \texttt{AccessScope}_{2nd}.
• Submitting \texttt{Ops}_1, \texttt{Sync}, and \texttt{Ops}_2 for execution, in that order, will result in a memory dependency \texttt{MemDep} between \texttt{ScopedOps}_1 and \texttt{ScopedOps}_2.
• Memory dependency \texttt{MemDep} guarantees that:
  ◦ Memory writes in \texttt{ScopedMemOps}_1 are made available.
  ◦ Available memory writes, including those from \texttt{ScopedMemOps}_1, are made visible to \texttt{ScopedMemOps}_2.

\textbf{Note}

Execution and memory dependencies are used to solve data hazards, i.e. to ensure that read and write operations occur in a well-defined order. Write-after-read hazards can be solved with just an execution dependency, but read-after-write and write-after-write hazards need appropriate memory dependencies to be included between them. If an application does not include dependencies to solve these hazards, the results and execution orders of memory accesses are undefined.

\subsection*{7.1.1. Image Layout Transitions}

Image subresources can be transitioned from one layout to another as part of a memory dependency (e.g. by using an image memory barrier). When a layout transition is specified in a memory dependency, it happens-after the availability operations in the memory dependency, and happens-before the visibility operations. Image layout transitions may perform read and write
accesses on all memory bound to the image subresource range, so applications must ensure that all memory writes have been made available before a layout transition is executed. Available memory is automatically made visible to a layout transition, and writes performed by a layout transition are automatically made available.

Layout transitions always apply to a particular image subresource range, and specify both an old layout and new layout. The old layout must either be VK_IMAGE_LAYOUT_UNDEFINED, or match the current layout of the image subresource range. If the old layout matches the current layout of the image subresource range, the transition preserves the contents of that range. If the old layout is VK_IMAGE_LAYOUT_UNDEFINED, the contents of that range may be discarded.

Note
Image layout transitions with VK_IMAGE_LAYOUT_UNDEFINED allow the implementation to discard the image subresource range, which can provide performance or power benefits. Tile-based architectures may be able to avoid flushing tile data to memory, and immediate style renderers may be able to achieve fast metadata clears to reinitialize frame buffer compression state, or similar.

If the contents of an attachment are not needed after a render pass completes, then applications should use VK_ATTACHMENT_STORE_OP_DONT_CARE.

As image layout transitions may perform read and write accesses on the memory bound to the image, if the image subresource affected by the layout transition is bound to peer memory for any device in the current device mask then the memory heap the bound memory comes from must support the VK_PEER_MEMORY_FEATURE_GENERIC_SRC_BIT and VK_PEER_MEMORY_FEATURE_GENERIC_DST_BIT capabilities as returned by vkGetDeviceGroupPeerMemoryFeatures.

Note
Applications must ensure that layout transitions happen-after all operations accessing the image with the old layout, and happen-before any operations that will access the image with the new layout. Layout transitions are potentially read/write operations, so not defining appropriate memory dependencies to guarantee this will result in a data race.

Image layout transitions interact with memory aliasing.

Layout transitions that are performed via image memory barriers execute in their entirety in submission order, relative to other image layout transitions submitted to the same queue, including those performed by render passes. In effect there is an implicit execution dependency from each such layout transition to all layout transitions previously submitted to the same queue.

The image layout of each image subresource of a depth/stencil image created with VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT is dependent on the last sample locations used to render to the image subresource as a depth/stencil attachment, thus when the image member of an image memory barrier is an image created with this flag the application can chain a VkSampleLocationsInfoEXT structure to the pNext chain of VkImageMemoryBarrier2 or VkImageMemoryBarrier to specify the sample locations to use during any image layout transition.
If the VkSampleLocationsInfoEXT structure does not match the sample location state last used to render to the image subresource range specified by subresourceRange, or if no VkSampleLocationsInfoEXT structure is present, then the contents of the given image subresource range becomes undefined as if oldLayout would equal VK_IMAGE_LAYOUT_UNDEFINED.

7.1.2. Pipeline Stages

The work performed by an action command consists of multiple operations, which are performed as a sequence of logically independent steps known as pipeline stages. The exact pipeline stages executed depend on the particular command that is used, and current command buffer state when the command was recorded.

Operations performed by synchronization commands (e.g. availability and visibility operations) are not executed by a defined pipeline stage. However other commands can still synchronize with them by using the synchronization scopes to create a dependency chain.

Execution of operations across pipeline stages must adhere to implicit ordering guarantees, particularly including pipeline stage order. Otherwise, execution across pipeline stages may overlap or execute out of order with regards to other stages, unless otherwise enforced by an execution dependency.

Several of the synchronization commands include pipeline stage parameters, restricting the synchronization scopes for that command to just those stages. This allows fine grained control over the exact execution dependencies and accesses performed by action commands. Implementations should use these pipeline stages to avoid unnecessary stalls or cache flushing.

Bits which can be set in a VkPipelineStageFlags2 mask, specifying stages of execution, are:

```
// Provided by VK_VERSION_1_3
// Flag bits forVkPipelineStageFlagBits2
typedef VkFlags64 VkPipelineStageFlagBits2;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_NONE = 0ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_NONE_KHR = 0ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_TOP_OF_PIPE_BIT = 0x00000001ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_TOP_OF_PIPE_BIT_KHR = 0x00000001ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT = 0x00000002ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT_KHR = 0x00000002ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_VERTEX_INPUT_BIT = 0x00000004ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_VERTEX_INPUT_BIT_KHR = 0x00000004ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT = 0x00000008ULL;
```
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT_KHR = 0x00000008ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT = 0x00000010ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT_KHR = 0x00000010ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT = 0x00000020ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT_KHR = 0x00000020ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT = 0x00000040ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT_KHR = 0x00000040ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT = 0x00000080ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT_KHR = 0x00000080ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT = 0x00000100ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT_KHR = 0x00000100ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT = 0x00000200ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT_KHR = 0x00000200ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT = 0x00000400ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT_KHR = 0x00000400ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT = 0x00000800ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT_KHR = 0x00000800ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT = 0x00001000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT_KHR = 0x00001000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_TRANSFER_BIT = 0x00001000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_TRANSFER_BIT_KHR = 0x00001000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_BOTTOM_OF_PIPE_BIT = 0x00002000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_BOTTOM_OF_PIPE_BIT_KHR = 0x00002000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_HOST_BIT = 0x00004000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_HOST_BIT_KHR = 0x00004000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT = 0x00008000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT_KHR = 0x00008000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT = 0x00010000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT_KHR = 0x00010000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_COPY_BIT = 0x100000000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_COPY_BIT_KHR = 0x100000000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_RESOLVE_BIT = 0x200000000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_RESOLVE_BIT_KHR = 0x200000000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_BLIT_BIT = 0x400000000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_BLIT_BIT_KHR = 0x400000000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_CLEAR_BIT = 0x800000000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_CLEAR_BIT_KHR = 0x800000000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_INDEX_INPUT_BIT = 0x1000000000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_INDEX_INPUT_BIT_KHR = 0x1000000000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_VERTEX_ATTRIBUTE_INPUT_BIT = 0x2000000000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_VERTEX_ATTRIBUTE_INPUT_BIT_KHR = 0x2000000000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_PRE_RASTERIZATION_SHADERS_BIT = 0x4000000000ULL;
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_PRE_RASTERIZATION_SHADERS_BIT_KHR = 0x4000000000ULL;
// Provided by VK_KHR_video_decode_queue
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR = 0x04000000ULL;
#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_video_encode_queue
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR = 0x08000000ULL;
#endif
// Provided by VK_KHR_synchronization2 with VK_EXT_transform_feedback
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT = 0x01000000ULL;
// Provided by VK_KHR_synchronization2 with VK_EXT_conditional_rendering
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT = 0x00040000ULL;
// Provided by VK_KHR_synchronization2 with VK_NV_device_generated_commands
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV = 0x00020000ULL;
// Provided by VK_KHR_fragment_shading_rate with VK_KHR_synchronization2
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR = 0x00400000ULL;
// Provided by VK_KHR_synchronization2 with VK_NV_shading_rate_image
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_SHADING_RATE_IMAGE_BIT_NV = 0x00400000ULL;
// Provided by VK_KHR_acceleration_structure with VK_KHR_synchronization2
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR = 0x02000000ULL;
// Provided by VK_KHR_ray_tracing_pipeline with VK_KHR_synchronization2
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR = 0x00200000ULL;
// Provided by VK_KHR_synchronization2 with VK_NV_ray_tracing
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_NV = 0x00200000ULL;
// Provided by VK_KHR_synchronization2 with VK_NV_ray_tracing
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_NV = 0x02000000ULL;
// Provided by VK_KHR_synchronization2 with VK_EXT_fragment_density_map
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT = 0x00800000ULL;
// Provided by VK_KHR_synchronization2 with VK_NV_mesh_shader
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_NV = 0x00080000ULL;
// Provided by VK_KHR_synchronization2 with VK_NV_mesh_shader
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_NV = 0x00100000ULL;
// Provided by VK_KHR_synchronization2 with VK_EXT_mesh_shader
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT = 0x00080000ULL;
// Provided by VK_KHR_synchronization2 with VK_EXT_mesh_shader
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT = 0x00100000ULL;
// Provided by VK_HUAWEI_subpass_shading
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI = 0x8000000000ULL;
// Provided by VK_HUAWEI_subpass_shading
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_SUBPASS_SHADING_BIT_HUAWEI = 0x8000000000ULL;
// Provided by VK_HUAWEI_invocation_mask
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI = 0x10000000000ULL;
// Provided by VK_KHR_ray_tracing_maintenance1 with VK_KHR_synchronization2
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR = 0x10000000ULL;
// Provided by VK_EXT_opacity_micromap
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT = 0x40000000ULL;
// Provided by VK_HUAWEI_cluster_culling_shader
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_CLUSTER_CULLING_SHADER_BIT_HUAWEI = 0x20000000000ULL;
// Provided by VK_NV_optical_flow
static const VkPipelineStageFlagBits2 VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV = 272
or the equivalent

```c
// Provided by VK_KHR_synchronization2
typedef VkPipelineStageFlagBits2 VkPipelineStageFlagBits2KHR;
```

- **VK_PIPELINE_STAGE_2_NONE** specifies no stages of execution.
- **VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT** specifies the stage of the pipeline where indirect command parameters are consumed. This stage also includes reading commands written by `vkCmdPreprocessGeneratedCommandsNV`.
- **VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT** specifies the task shader stage.
- **VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT** specifies the mesh shader stage.
- **VK_PIPELINE_STAGE_2_INDEX_INPUT_BIT** specifies the stage of the pipeline where index buffers are consumed.
- **VK_PIPELINE_STAGE_2_VERTEX_ATTRIBUTE_INPUT_BIT** specifies the stage of the pipeline where vertex buffers are consumed.
- **VK_PIPELINE_STAGE_2_VERTEX_INPUT_BIT** is equivalent to the logical OR of:
  - **VK_PIPELINE_STAGE_2_INDEX_INPUT_BIT**
  - **VK_PIPELINE_STAGE_2_VERTEX_ATTRIBUTE_INPUT_BIT**
- **VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT** specifies the vertex shader stage.
- **VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT** specifies the tessellation control shader stage.
- **VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT** specifies the tessellation evaluation shader stage.
- **VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT** specifies the geometry shader stage.
- **VK_PIPELINE_STAGE_2_PRE_RASTERIZATION_SHADERS_BIT** is equivalent to specifying all supported pre-rasterization shader stages:
  - **VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT**
  - **VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT**
  - **VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT**
  - **VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT**
  - **VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT**
  - **VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT**
  - **VK_PIPELINE_STAGE_2_CLUSTER_CULLING_SHADER_BIT_HUAWEI**
- **VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT** specifies the fragment shader stage.
- **VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT** specifies the stage of the pipeline where early fragment tests (depth and stencil tests before fragment shading) are performed. This stage also
includes render pass load operations for framebuffer attachments with a depth/stencil format.

- VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT specifies the stage of the pipeline where late fragment tests (depth and stencil tests after fragment shading) are performed. This stage also includes render pass store operations for framebuffer attachments with a depth/stencil format.

- VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT specifies the stage of the pipeline where final color values are output from the pipeline. This stage includes blending, logic operations, render pass load and store operations for color attachments, render pass multisample resolve operations, and vkCmdClearAttachments.

- VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT specifies the compute shader stage.

- VK_PIPELINE_STAGE_2_HOST_BIT specifies a pseudo-stage indicating execution on the host of reads/writes of device memory. This stage is not invoked by any commands recorded in a command buffer.

- VK_PIPELINE_STAGE_2_COPY_BIT specifies the execution of all copy commands, including vkCmdCopyQueryPoolResults.

- VK_PIPELINE_STAGE_2_BLIT_BIT specifies the execution of vkCmdBlitImage.

- VK_PIPELINE_STAGE_2_RESOLVE_BIT specifies the execution of vkCmdResolveImage.

- VK_PIPELINE_STAGE_2_CLEAR_BIT specifies the execution of clear commands, with the exception of vkCmdClearAttachments.

- VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT is equivalent to specifying all of:
  - VK_PIPELINE_STAGE_2_COPY_BIT
  - VK_PIPELINE_STAGE_2_BLIT_BIT
  - VK_PIPELINE_STAGE_2_RESOLVE_BIT
  - VK_PIPELINE_STAGE_2_CLEAR_BIT
  - VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR

- VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR specifies the execution of the ray tracing shader stages.

- VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR specifies the execution of acceleration structure commands or acceleration structure copy commands.

- VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR specifies the execution of acceleration structure copy commands.

- VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT specifies the execution of all graphics pipeline stages, and is equivalent to the logical OR of:
  - VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT
  - VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT
  - VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT
  - VK_PIPELINE_STAGE_2_VERTEX_INPUT_BIT
  - VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT
  - VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT

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• **VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT**
  - Specifies all operations performed by all commands supported on the queue it is used with.

• **VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT**
  - Specifies the stage of the pipeline where the predicate of conditional rendering is consumed.

• **VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT**
  - Specifies the stage of the pipeline where vertex attribute output values are written to the transform feedback buffers.

• **VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT**
  - Specifies the stage of the pipeline where device-side generation of commands via `vkCmdPreprocessGeneratedCommandsNV` is handled.

• **VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR**
  - Specifies the stage of the pipeline where the fragment shading rate attachment or shading rate image is read to determine the fragment shading rate for portions of a rasterized primitive.

• **VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT**
  - Specifies the stage of the pipeline where the fragment density map is read to generate the fragment areas.

• **VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI**
  - Specifies the stage of the pipeline where the invocation mask image is read by the implementation to optimize the ray dispatch.

• **VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR**
  - Specifies the execution of video decode operations.

• **VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR**
  - Specifies the execution of video encode operations.

• **VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV**
  - Specifies the stage of the pipeline where optical flow operation are performed.

• **VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI**
  - Specifies the subpass shading shader stage.

• **VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT**
  - Specifies the execution of micromap commands.

• **VK_PIPELINE_STAGE_2_CLUSTER_CULLING_SHADER_BIT_HUAWEI**
  - Specifies the cluster culling shader stage.

• **VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT** is equivalent to **VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT** with **VkAccessFlags2** set to 0 when specified in the second synchronization scope, but equivalent to
VK_PIPELINE_STAGE_2_NONE in the first scope.

- VK_PIPELINE_STAGE_2_BOTTOM_OF_PIPE_BIT is equivalent to VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT with VkAccessFlags2 set to 0 when specified in the first synchronization scope, but equivalent to VK_PIPELINE_STAGE_2_NONE in the second scope.

Note
The TOP and BOTTOM pipeline stages are deprecated, and applications should prefer VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT and VK_PIPELINE_STAGE_2_NONE.

Note
The VkPipelineStageFlags2 bitmask goes beyond the 31 individual bit flags allowable within a C99 enum, which is how VkPipelineStageFlagBits is defined. The first 31 values are common to both, and are interchangeable.

VkPipelineStageFlags2 is a bitmask type for setting a mask of zero or more VkPipelineStageFlagBits2 flags:

```c
typedef VkFlags64 VkPipelineStageFlags2;
```

or the equivalent

```c
// Provided by VK_KHR_synchronization2
typedef VkPipelineStageFlags2 VkPipelineStageFlags2KHR;
```

Bits which can be set in a VkPipelineStageFlags mask, specifying stages of execution, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkPipelineStageFlagBits {
    VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT = 0x00000001,
    VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT = 0x00000002,
    VK_PIPELINE_STAGE_VERTEX_INPUT_BIT = 0x00000004,
    VK_PIPELINE_STAGE_VERTEX_SHADER_BIT = 0x00000008,
    VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT = 0x00000010,
    VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT = 0x00000020,
    VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT = 0x00000040,
    VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT = 0x00000080,
    VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT = 0x00000100,
    VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT = 0x00000200,
    VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT = 0x00000400,
    VK_PIPELINE_STAGE_COMPUTE_SHADER_BIT = 0x00000800,
    VK_PIPELINE_STAGE_TRANSFER_BIT = 0x00001000,
    VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT = 0x00002000,
    VK_PIPELINE_STAGE_HOST_BIT = 0x00004000,
    VK_PIPELINE_STAGE_ALL_GRAPHICS_BIT = 0x00008000,
    VK_PIPELINE_STAGE_ALL_COMMANDS_BIT = 0x00010000,
} VkPipelineStageFlagBits;
```
These values all have the same meaning as the equivalently named values for \texttt{VkPipelineStageFlags2}.

- \texttt{VK_PIPELINE_STAGE_NONE} specifies no stages of execution.
- \texttt{VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT} specifies the stage of the pipeline where \texttt{VkDrawIndirect* / VkDispatchIndirect* / VkTraceRaysIndirect*} data structures are consumed. This stage also includes reading commands written by \texttt{vkCmdExecuteGeneratedCommandsNV}.
- \texttt{VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT} specifies the task shader stage.
- \texttt{VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT} specifies the mesh shader stage.
- \texttt{VK_PIPELINE_STAGE_VERTEX_INPUT_BIT} specifies the stage of the pipeline where vertex and index buffers are consumed.
• **VK_PIPELINE_STAGE_VERTEX_SHADER_BIT** specifies the vertex shader stage.

• **VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT** specifies the tessellation control shader stage.

• **VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT** specifies the tessellation evaluation shader stage.

• **VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT** specifies the geometry shader stage.

• **VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT** specifies the fragment shader stage.

• **VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT** specifies the stage of the pipeline where early fragment tests (depth and stencil tests before fragment shading) are performed. This stage also includes render pass load operations for framebuffer attachments with a depth/stencil format.

• **VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT** specifies the stage of the pipeline where late fragment tests (depth and stencil tests after fragment shading) are performed. This stage also includes render pass store operations for framebuffer attachments with a depth/stencil format.

• **VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT** specifies the stage of the pipeline after blending where the final color values are output from the pipeline. This stage includes blending, logic operations, render pass load and store operations for color attachments, render pass multisample resolve operations, and vkCmdClearAttachments.

• **VK_PIPELINE_STAGE_COMPUTE_SHADER_BIT** specifies the execution of a compute shader.

• **VK_PIPELINE_STAGE_TRANSFER_BIT** specifies the following commands:
  - All copy commands, including vkCmdCopyQueryPoolResults
  - vkCmdBlitImage2 and vkCmdBlitImage
  - vkCmdResolveImage2 and vkCmdResolveImage
  - All clear commands, with the exception of vkCmdClearAttachments

• **VK_PIPELINE_STAGE_HOST_BIT** specifies a pseudo-stage indicating execution on the host of reads/writes of device memory. This stage is not invoked by any commands recorded in a command buffer.

• **VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR** specifies the execution of vkCmdBuildAccelerationStructureNV, vkCmdWriteAccelerationStructuresPropertiesNV, vkCmdBuildAccelerationStructuresIndirectKHR, vkCmdCopyAccelerationStructureToMemoryKHR, vkCmdCopyMemoryToAccelerationStructureKHR, and vkCmdWriteAccelerationStructuresPropertiesKHR.

• **VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR** specifies the execution of the ray tracing shader stages, via vkCmdTraceRaysNV, vkCmdTraceRaysKHR, or vkCmdTraceRaysIndirectKHR.

• **VK_PIPELINE_STAGE_ALL_GRAPHICS_BIT** specifies the execution of all graphics pipeline stages, and is equivalent to the logical OR of:
  - **VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT**
  - **VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT**
  - **VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT**
VK_PIPELINE_STAGE_VERTEX_INPUT_BIT
VK_PIPELINE_STAGE_VERTEX_SHADER_BIT
VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT
VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT
VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT
VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT
VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT
VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT
VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT
VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT
VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT
VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR
VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT

VK_PIPELINE_STAGE_ALL_COMMANDS_BIT specifies all operations performed by all commands supported on the queue it is used with.

VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT specifies the stage of the pipeline where the predicate of conditional rendering is consumed.

VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT specifies the stage of the pipeline where vertex attribute output values are written to the transform feedback buffers.

VK_PIPELINE_STAGE_COMMAND_PREPROCESS_BIT_NV specifies the stage of the pipeline where device-side preprocessing for generated commands via vkCmdPreprocessGeneratedCommandsNV is handled.

VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR specifies the stage of the pipeline where the fragment shading rate attachment or shading rate image is read to determine the fragment shading rate for portions of a rasterized primitive.

VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT specifies the stage of the pipeline where the fragment density map is read to generate the fragment areas.

VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT is equivalent to VK_PIPELINE_STAGE_ALL_COMMANDS_BIT with VkAccessFlags set to 0 when specified in the second synchronization scope, but specifies no stage of execution when specified in the first scope.

VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT is equivalent to VK_PIPELINE_STAGE_ALL_COMMANDS_BIT with VkAccessFlags set to 0 when specified in the first synchronization scope, but specifies no stage of execution when specified in the second scope.

// Provided by VK_VERSION_1_0
typedef VkFlags VkPipelineStageFlags;

VkPipelineStageFlags is a bitmask type for setting a mask of zero or more VkPipelineStageFlagBits.
If a synchronization command includes a source stage mask, its first synchronization scope only includes execution of the pipeline stages specified in that mask and any logically earlier stages. Its first access scope only includes memory accesses performed by pipeline stages explicitly specified in the source stage mask.

If a synchronization command includes a destination stage mask, its second synchronization scope only includes execution of the pipeline stages specified in that mask and any logically later stages. Its second access scope only includes memory accesses performed by pipeline stages explicitly specified in the destination stage mask.

**Note**

Note that access scopes do not interact with the logically earlier or later stages for either scope - only the stages the app specifies are considered part of each access scope.

Certain pipeline stages are only available on queues that support a particular set of operations. The following table lists, for each pipeline stage flag, which queue capability flag must be supported by the queue. When multiple flags are enumerated in the second column of the table, it means that the pipeline stage is supported on the queue if it supports any of the listed capability flags. For further details on queue capabilities see Physical Device Enumeration and Queues.

**Table 3. Supported pipeline stage flags**

<table>
<thead>
<tr>
<th>Pipeline stage flag</th>
<th>Required queue capability flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_PIPELINE_STAGE_2_NONE</td>
<td>None required</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_TOP_OF_PIPE_BIT</td>
<td>None required</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT or VK_QUEUE_COMPUTE_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_VERTEX_INPUT_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT</td>
<td>VK_QUEUE_COMPUTE_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT or VK_QUEUE_COMPUTE_BIT or VK_QUEUE_TRANSFER_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_BOTTOM_OF_PIPE_BIT</td>
<td>None required</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_HOST_BIT</td>
<td>None required</td>
</tr>
<tr>
<td>Pipeline stage flag</td>
<td>Required queue capability flag</td>
</tr>
<tr>
<td>---------------------------------------------------------</td>
<td>--------------------------------------------------------------------</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT</td>
<td>None required</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_COPY_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT or VK_QUEUE_COMPUTE_BIT or VK_QUEUE_TRANSFER_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_RESOLVE_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT or VK_QUEUE_COMPUTE_BIT or VK_QUEUE_TRANSFER_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_BLIT_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT or VK_QUEUE_COMPUTE_BIT or VK_QUEUE_TRANSFER_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_CLEAR_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT or VK_QUEUE_COMPUTE_BIT or VK_QUEUE_TRANSFER_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_INDEX_INPUT_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_VERTEX_ATTRIBUTE_INPUT_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_PRE_RASTERIZATION_SHADER_BIT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR</td>
<td>VK_QUEUE_VIDEO_DECODE_BIT_KHR</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR</td>
<td>VK_QUEUE_VIDEO_ENCODE_BIT_KHR</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT</td>
<td>VK_QUEUE_GRAPHICS_BIT or VK_QUEUE_COMPUTE_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV</td>
<td>VK_QUEUE_GRAPHICS_BIT or VK_QUEUE_COMPUTE_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR</td>
<td>VK_QUEUE_COMPUTE_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR</td>
<td>VK_QUEUE_COMPUTE_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR</td>
<td>VK_QUEUE_GRAPHICS_BIT or VK_QUEUE_COMPUTE_BIT or VK_QUEUE_TRANSFER_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT</td>
<td>VK_QUEUE_COMPUTE_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_CLUSTER_CULLING_SHADER_BIT_HUAWEI</td>
<td>VK_QUEUE_GRAPHICS_BIT</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV</td>
<td>VK_QUEUE_OPTICAL_FLOW_BIT_NV</td>
</tr>
</tbody>
</table>
Pipeline stages that execute as a result of a command logically complete execution in a specific order, such that completion of a logically later pipeline stage must not happen-before completion of a logically earlier stage. This means that including any stage in the source stage mask for a particular synchronization command also implies that any logically earlier stages are included in Scope\textsubscript{1st} for that command.

Similarly, initiation of a logically earlier pipeline stage must not happen-after initiation of a logically later pipeline stage. Including any given stage in the destination stage mask for a particular synchronization command also implies that any logically later stages are included in Scope\textsubscript{2nd} for that command.

**Note**

Implementations may not support synchronization at every pipeline stage for every synchronization operation. If a pipeline stage that an implementation does not support synchronization for appears in a source stage mask, it may substitute any logically later stage in its place for the first synchronization scope. If a pipeline stage that an implementation does not support synchronization for appears in a destination stage mask, it may substitute any logically earlier stage in its place for the second synchronization scope.

For example, if an implementation is unable to signal an event immediately after vertex shader execution is complete, it may instead signal the event after color attachment output has completed.

If an implementation makes such a substitution, it must not affect the semantics of execution or memory dependencies or image and buffer memory barriers.

Graphics pipelines are executable on queues supporting VK\_QUEUE\_GRAPHICS\_BIT. Stages executed by graphics pipelines can only be specified in commands recorded for queues supporting VK\_QUEUE\_GRAPHICS\_BIT.

The graphics primitive pipeline executes the following stages, with the logical ordering of the stages matching the order specified here:

- VK\_PIPELINE\_STAGE\_2\_DRAW\_INDIRECT\_BIT
- VK\_PIPELINE\_STAGE\_2\_INDEX\_INPUT\_BIT
- VK\_PIPELINE\_STAGE\_2\_VERTEX\_ATTRIBUTE\_INPUT\_BIT
- VK\_PIPELINE\_STAGE\_2\_VERTEX\_SHADER\_BIT
- VK\_PIPELINE\_STAGE\_2\_TESSELLATION\_CONTROL\_SHADER\_BIT
- VK\_PIPELINE\_STAGE\_2\_TESSELLATION\_EVALUATION\_SHADER\_BIT
- VK\_PIPELINE\_STAGE\_2\_GEOMETRY\_SHADER\_BIT
- VK\_PIPELINE\_STAGE\_2\_TRANSFORM\_FEEDBACK\_BIT\_EXT
- VK\_PIPELINE\_STAGE\_2\_FRAGMENT\_SHADING\_RATE\_ATTACHMENT\_BIT\_KHR
- VK\_PIPELINE\_STAGE\_2\_EARLY\_FRAGMENT\_TESTS\_BIT
- VK\_PIPELINE\_STAGE\_2\_FRAGMENT\_SHADER\_BIT
• VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT
• VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT

The graphics mesh pipeline executes the following stages, with the logical ordering of the stages matching the order specified here:

• VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT
• VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT
• VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT
• VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR
• VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT
• VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT
• VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT
• VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT

For the compute pipeline, the following stages occur in this order:

• VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT
• VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT

For the subpass shading pipeline, the following stages occur in this order:

• VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI

For graphics pipeline commands executing in a render pass with a fragment density map attachment, the following pipeline stage where the fragment density map read happens has no particular order relative to the other stages, except that it is logically earlier than VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT:

• VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT
• VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT

The conditional rendering stage is formally part of both the graphics, and the compute pipeline. The pipeline stage where the predicate read happens has unspecified order relative to other stages of these pipelines:

• VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT

For the transfer pipeline, the following stages occur in this order:

• VK_PIPELINE_STAGE_2_TRANSFER_BIT

For host operations, only one pipeline stage occurs, so no order is guaranteed:

• VK_PIPELINE_STAGE_2_HOST_BIT

For the command preprocessing pipeline, the following stages occur in this order:
• VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV

For acceleration structure build operations, only one pipeline stage occurs, so no order is guaranteed:

• VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR

For acceleration structure copy operations, only one pipeline stage occurs, so no order is guaranteed:

• VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR

For opacity micromap build operations, only one pipeline stage occurs, so no order is guaranteed:

• VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT

For the ray tracing pipeline, the following stages occur in this order:

• VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT
• VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR

For the video decode pipeline, the following stages occur in this order:

• VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR

For the video encode pipeline, the following stages occur in this order:

• VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR

7.1.3. Access Types

Memory in Vulkan can be accessed from within shader invocations and via some fixed-function stages of the pipeline. The access type is a function of the descriptor type used, or how a fixed-function stage accesses memory.

Some synchronization commands take sets of access types as parameters to define the access scopes of a memory dependency. If a synchronization command includes a source access mask, its first access scope only includes accesses via the access types specified in that mask. Similarly, if a synchronization command includes a destination access mask, its second access scope only includes accesses via the access types specified in that mask.

Bits which can be set in the srcAccessMask and dstAccessMask members of VkMemoryBarrier2KHR, VkImageMemoryBarrier2KHR, and VkBufferMemoryBarrier2KHR, specifying access behavior, are:

```c
// Provided by VK_VERSION_1_3
// Flag bits for VkAccessFlagBits2
typedef VkFlags64 VkAccessFlagBits2;
static const VkAccessFlagBits2 VK_ACCESS_2_NONE = 0ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_NONE_KHR = 0ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_INDIRECT_COMMAND_READ_BIT = 0x00000001ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_INDIRECT_COMMAND_READ_BIT_KHR =
```
0x00000001ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_INDEX_READ_BIT = 0x00000002ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_INDEX_READ_BIT_KHR = 0x00000002ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_VERTEX_ATTRIBUTE_READ_BIT = 0x00000004ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_VERTEX_ATTRIBUTE_READ_BIT_KHR = 0x00000004ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_UNIFORM_READ_BIT = 0x00000008ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_UNIFORM_READ_BIT_KHR = 0x00000008ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_INPUT_ATTACHMENT_READ_BIT = 0x00000010ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_INPUT_ATTACHMENT_READ_BIT_KHR = 0x00000010ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_SHADER_READ_BIT = 0x00000020ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_SHADER_READ_BIT_KHR = 0x00000020ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_SHADER_WRITE_BIT = 0x00000040ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_SHADER_WRITE_BIT_KHR = 0x00000040ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_COLOR_ATTACHMENT_READ_BIT = 0x00000080ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_COLOR_ATTACHMENT_READ_BIT_KHR = 0x00000080ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_COLOR_ATTACHMENT_WRITE_BIT = 0x00000100ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_COLOR_ATTACHMENT_WRITE_BIT_KHR = 0x00000100ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_READ_BIT = 0x00000200ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_READ_BIT_KHR = 0x00000200ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT = 0x00000400ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT_KHR = 0x00000400ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_TRANSFER_READ_BIT = 0x00000800ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_TRANSFER_READ_BIT_KHR = 0x00000800ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_TRANSFER_WRITE_BIT = 0x00001000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_TRANSFER_WRITE_BIT_KHR = 0x00001000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_HOST_READ_BIT = 0x00002000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_HOST_READ_BIT_KHR = 0x00002000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_HOST_WRITE_BIT = 0x00004000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_HOST_WRITE_BIT_KHR = 0x00004000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_MEMORY_READ_BIT = 0x00008000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_MEMORY_READ_BIT_KHR = 0x00008000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_MEMORY_WRITE_BIT = 0x00010000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_MEMORY_WRITE_BIT_KHR = 0x00010000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_SHADER_SAMPLED_READ_BIT = 0x100000000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_SHADER_SAMPLED_READ_BIT_KHR = 0x100000000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_SHADER_STORAGE_READ_BIT = 0x200000000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_SHADER_STORAGE_READ_BIT_KHR = 0x200000000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_SHADER_STORAGE_WRITE_BIT = 0x400000000ULL;
static const VkAccessFlagBits2 VK_ACCESS_2_SHADER_STORAGE_WRITE_BIT_KHR = 0x400000000ULL;

// Provided by VK_KHR_video_decode_queue
static const VkAccessFlagBits2 VK_ACCESS_2_VIDEO_DECODE_READ_BIT_KHR = 0x800000000ULL;
// Provided by VK_KHR_video_decode_queue
static const VkAccessFlagBits2 VK_ACCESS_2_VIDEO_DECODE_WRITE_BIT_KHR = 0x1000000000ULL;

#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_video_encode_queue
static const VkAccessFlagBits2 VK_ACCESS_2_VIDEO_ENCODE_READ_BIT_KHR = 0x2000000000ULL;
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_video_encode_queue
static const VkAccessFlagBits2 VK_ACCESS_2_VIDEO_ENCODE_WRITE_BIT_KHR = 0x4000000000ULL;
#endif

// Provided by VK_KHR_synchronization2 with VK_EXT_transform_feedback
static const VkAccessFlagBits2 VK_ACCESS_2_TRANSFORM_FEEDBACK_WRITE_BIT_EXT = 0x02000000ULL;
// Provided by VK_KHR_synchronization2 with VK_EXT_transform_feedback
static const VkAccessFlagBits2 VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT = 0x04000000ULL;
// Provided by VK_KHR_synchronization2 with VK_EXT_transform_feedback
static const VkAccessFlagBits2 VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_WRITE_BIT_EXT = 0x08000000ULL;
// Provided by VK_KHR_synchronization2 with VK_KHR_acceleration_structure
static const VkAccessFlagBits2 VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR = 0x00200000ULL;
// Provided by VK_KHR_synchronization2 with VK_KHR_acceleration_structure
static const VkAccessFlagBits2 VK_ACCESS_2_ACCELERATION_STRUCTURE_WRITE_BIT_KHR = 0x00400000ULL;
// Provided by VK_KHR_synchronization2 with VK_NV_ray_tracing
static const VkAccessFlagBits2 VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_NV = 0x00200000ULL;
// Provided by VK_KHR_synchronization2 with VK_NV_ray_tracing
static const VkAccessFlagBits2 VK_ACCESS_2_ACCELERATION_STRUCTURE_WRITE_BIT_NV = 0x00400000ULL;
// Provided by VK_KHR_synchronization2 with VK_EXT_fragment_density_map
static const VkAccessFlagBits2 VK_ACCESS_2_FRAGMENT_SHADING_RATE_ATTACHMENT_READ_BIT_KHR = 0x00800000ULL;
// Provided by VK_KHR_synchronization2 with VK_KHR_acceleration_structure
static const VkAccessFlagBits2 VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR = 0x00200000ULL;
// Provided by VK_KHR_synchronization2 with VK_KHR_acceleration_structure
static const VkAccessFlagBits2 VK_ACCESS_2_ACCELERATION_STRUCTURE_WRITE_BIT_KHR = 0x00400000ULL;
// Provided by VK_KHR_synchronization2 with VK_KHR_acceleration_structure
static const VkAccessFlagBits2 VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_NV = 0x00200000ULL;
// Provided by VK_KHR_synchronization2 with VK_KHR_acceleration_structure
static const VkAccessFlagBits2 VK_ACCESS_2_ACCELERATION_STRUCTURE_WRITE_BIT_NV = 0x00400000ULL;
// Provided by VK_KHR_synchronization2 with VK_KHR_synchronization2
static const VkAccessFlagBits2 VK_ACCESS_2_COMMAND_PREPROCESS_READ_BIT_NV = 0x00020000ULL;
// Provided by VK_KHR_synchronization2 with VK_KHR_synchronization2
static const VkAccessFlagBits2 VK_ACCESS_2_COMMAND_PREPROCESS_WRITE_BIT_NV = 0x00040000ULL;
// Provided by VK_KHR_synchronization2 with VK_KHR_fragment_shading_rate
static const VkAccessFlagBits2 VK_ACCESS_2_FRAGMENT_SHADING_RATE_ATTACHMENT_READ_BIT_KHR = 0x00800000ULL;
// Provided by VK_KHR_synchronization2 with VK_KHR_synchronization2
static const VkAccessFlagBits2 VK_ACCESS_2_FRAGMENT_SHADING_RATE_IMAGE_READ_BIT_NV = 0x00800000ULL;
// Provided by VK_KHR_synchronization2 with VK_KHR_synchronization2
static const VkAccessFlagBits2 VK_ACCESS_2_SHADER_IMAGE_READ_BIT_NV = 0x00800000ULL;
// Provided by VK_KHR_synchronization2 with VK_KHR_synchronization2
or the equivalent

```c
// Provided by VK_KHR_synchronization2
typedef VkAccessFlagBits2 VkAccessFlagBits2KHR;
```

- `VK_ACCESS_2_NONE` specifies no accesses.
- `VK_ACCESS_2_MEMORY_READ_BIT` specifies all read accesses. It is always valid in any access mask, and is treated as equivalent to setting all `READ` access flags that are valid where it is used.
- `VK_ACCESS_2_MEMORY_WRITE_BIT` specifies all write accesses. It is always valid in any access mask, and is treated as equivalent to setting all `WRITE` access flags that are valid where it is used.
- `VK_ACCESS_2_INDIRECT_COMMAND_READ_BIT` specifies read access to command data read from indirect buffers as part of an indirect build, trace, drawing or dispatch command. Such access occurs in the `VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT` pipeline stage.
- `VK_ACCESS_2_INDEX_READ_BIT` specifies read access to an index buffer as part of an indexed drawing command, bound by `vkCmdBindIndexBuffer2KHR` and `vkCmdBindIndexBuffer`. Such access occurs in the `VK_PIPELINE_STAGE_2_INDEX_INPUT_BIT` pipeline stage.
- `VK_ACCESS_2_VERTEX_ATTRIBUTE_READ_BIT` specifies read access to a vertex buffer as part of a drawing command, bound by `vkCmdBindVertexBuffers`. Such access occurs in the `VK_PIPELINE_STAGE_2_VERTEX_ATTRIBUTE_INPUT_BIT` pipeline stage.
- `VK_ACCESS_2_UNIFORM_READ_BIT` specifies read access to a uniform buffer in any shader pipeline
• **VK_ACCESS_2_INPUT_ATTACHMENT_READ_BIT** specifies read access to an input attachment within a render pass during subpass shading or fragment shading. Such access occurs in the `VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI` or `VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT` pipeline stage.

• **VK_ACCESS_2_SHADER_SAMPLED_READ_BIT** specifies read access to a uniform texel buffer or sampled image in any shader pipeline stage.

• **VK_ACCESS_2_SHADER_STORAGE_READ_BIT** specifies read access to a storage buffer, physical storage buffer, storage texel buffer, or storage image in any shader pipeline stage.

• **VK_ACCESS_2_SHADER_BINDING_TABLE_READ_BIT_KHR** specifies read access to a shader binding table in any shader pipeline stage.

• **VK_ACCESS_2_SHADER_READ_BIT** is equivalent to the logical OR of:
  - **VK_ACCESS_2_SHADER_SAMPLED_READ_BIT**
  - **VK_ACCESS_2_SHADER_STORAGE_READ_BIT**
  - **VK_ACCESS_2_SHADER_BINDING_TABLE_READ_BIT_KHR**

• **VK_ACCESS_2_SHADER_WRITE_BIT** is equivalent to **VK_ACCESS_2_SHADER_STORAGE_WRITE_BIT**.

• **VK_ACCESS_2_COLOR_ATTACHMENT_READ_BIT** specifies read access to a color attachment, such as via blending (other than advanced blend operations), logic operations or certain render pass load operations in the `VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT` pipeline stage or via fragment shader tile image reads in the `VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT` pipeline stage.

• **VK_ACCESS_2_COLOR_ATTACHMENT_WRITE_BIT** specifies write access to a color attachment during a render pass or via certain render pass load, store, and multisample resolve operations. Such access occurs in the `VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT` pipeline stage.

• **VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_READ_BIT** specifies read access to a depth/stencil attachment, via depth or stencil operations or certain render pass load operations in the `VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT` or `VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT` pipeline stages or via fragment shader tile image reads in the `VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT` pipeline stage.

• **VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT** specifies write access to a depth/stencil attachment, via depth or stencil operations or certain render pass load and store operations. Such access occurs in the `VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT` or `VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT` pipeline stages.

• **VK_ACCESS_2_TRANSFER_READ_BIT** specifies read access to an image or buffer in a copy operation. Such access occurs in the `VK_PIPELINE_STAGE_2_COPY_BIT`, `VK_PIPELINE_STAGE_2_BLIT_BIT`, or `VK_PIPELINE_STAGE_2_RESOLVE_BIT` pipeline stages.

• **VK_ACCESS_2_TRANSFER_WRITE_BIT** specifies write access to an image or buffer in a clear or copy operation. Such access occurs in the `VK_PIPELINE_STAGE_2_COPY_BIT`, `VK_PIPELINE_STAGE_2_BLIT_BIT`, or `VK_PIPELINE_STAGE_2_RESOLVE_BIT` pipeline stages.
VK_ACCESS_2_HOST_READ_BIT specifies read access by a host operation. Accesses of this type are not performed through a resource, but directly on memory. Such access occurs in the VK_PIPELINE_STAGE_2_HOST_BIT pipeline stage.

VK_ACCESS_2_HOST_WRITE_BIT specifies write access by a host operation. Accesses of this type are not performed through a resource, but directly on memory. Such access occurs in the VK_PIPELINE_STAGE_2_HOST_BIT pipeline stage.

VK_ACCESS_2_CONDITIONAL_RENDERING_READ_BIT_EXT specifies read access to a predicate as part of conditional rendering. Such access occurs in the VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT pipeline stage.

VK_ACCESS_2_TRANSFORM_FEEDBACK_WRITE_BIT_EXT specifies write access to a transform feedback buffer made when transform feedback is active. Such access occurs in the VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT pipeline stage.

VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT specifies read access to a transform feedback counter buffer which is read when vkCmdBeginTransformFeedbackEXT executes. Such access occurs in the VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT pipeline stage.

VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_WRITE_BIT_EXT specifies write access to a transform feedback counter buffer which is written when vkCmdEndTransformFeedbackEXT executes. Such access occurs in the VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT pipeline stage.

VK_ACCESS_2_COMMAND_PREPROCESS_READ_BIT_NV specifies reads from buffer inputs to vkCmdPreprocessGeneratedCommandsNV. Such access occurs in the VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV pipeline stage.

VK_ACCESS_2_COMMAND_PREPROCESS_WRITE_BIT_NV specifies writes to the target command buffer preprocess outputs. Such access occurs in the VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV pipeline stage.

VK_ACCESS_2_COLOR_ATTACHMENT_READ_NONCOHERENT_BIT_EXT specifies read access to color attachments, including advanced blend operations. Such access occurs in the VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT pipeline stage.

VK_ACCESS_2_INVOCATION_MASK_READ_BIT_HUAWEI specifies read access to a invocation mask image in the VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI pipeline stage.

VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR specifies read access to an acceleration structure as part of a trace, build, or copy command, or to an acceleration structure scratch buffer as part of a build command. Such access occurs in the VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR or VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR pipeline stage.

VK_ACCESS_2_ACCELERATION_STRUCTURE_WRITE_BIT_KHR specifies write access to an acceleration structure or acceleration structure scratch buffer as part of a build or copy command. Such access occurs in the VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR pipeline stage.

VK_ACCESS_2_FRAGMENT_DENSITY_MAP_READ_BIT_EXT specifies read access to a fragment density map attachment during dynamic fragment density map operations. Such access occurs in the VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT pipeline stage.

VK_ACCESS_2_FRAGMENT_SHADING_RATE_ATTACHMENT_READ_BIT_KHR specifies read access to a fragment shading rate attachment during rasterization. Such access occurs in the VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR pipeline stage.
• **VK_ACCESS_2_SHADING_RATE_IMAGE_READ_BIT_NV** specifies read access to a shading rate image during rasterization. Such access occurs in the **VK_PIPELINE_STAGE_2_SHADING_RATE_IMAGE_BIT_NV** pipeline stage. It is equivalent to **VK_ACCESS_2_FRAGMENT_SHADING_RATE_ATTACHMENT_READ_BIT_KHR**.

• **VK_ACCESS_2_VIDEO_DECODE_READ_BIT_KHR** specifies read access to an image or buffer resource in a **video decode operation**. Such access occurs in the **VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR** pipeline stage.

• **VK_ACCESS_2_VIDEO_DECODE_WRITE_BIT_KHR** specifies write access to an image or buffer resource in a **video decode operation**. Such access occurs in the **VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR** pipeline stage.

• **VK_ACCESS_2_VIDEO_ENCODE_READ_BIT_KHR** specifies read access to an image or buffer resource in a **video encode operation**. Such access occurs in the **VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR** pipeline stage.

• **VK_ACCESS_2_VIDEO_ENCODE_WRITE_BIT_KHR** specifies write access to an image or buffer resource in a **video encode operation**. Such access occurs in the **VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR** pipeline stage.

• **VK_ACCESS_2_DESCRIPTOR_BUFFER_READ_BIT_EXT** specifies read access to a **descriptor buffer** in any shader pipeline stage.

• **VK_ACCESS_2_OPTICAL_FLOW_READ_BIT_NV** specifies read access to an image or buffer resource as part of a **optical flow operation**. Such access occurs in the **VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV** pipeline stage.

• **VK_ACCESS_2_OPTICAL_FLOW_WRITE_BIT_NV** specifies write access to an image or buffer resource as part of a **optical flow operation**. Such access occurs in the **VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV** pipeline stage.

• **VK_ACCESS_2_MICROMAP_WRITE_BIT_EXT** specifies write access to a micromap object. Such access occurs in the **VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT** pipeline stage.

• **VK_ACCESS_2_MICROMAP_READ_BIT_EXT** specifies read access to a micromap object. Such access occurs in the **VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT** and **VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR** pipeline stages.

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**Note**
In situations where an application wishes to select all access types for a given set of pipeline stages, **VK_ACCESS_2_MEMORY_READ_BIT** or **VK_ACCESS_2_MEMORY_WRITE_BIT** can be used. This is particularly useful when specifying stages that only have a single access type.

**Note**
The **VkAccessFlags2** bitmask goes beyond the 31 individual bit flags allowable within a C99 enum, which is how **VkAccessFlagBits** is defined. The first 31 values are common to both, and are interchangeable.

**VkAccessFlags2** is a bitmask type for setting a mask of zero or more **VkAccessFlagBits2**:

```cpp
// Provided by VK_VERSION_1_3
```
typedef VkFlags64 VkAccessFlags2;

or the equivalent

// Provided by VK_KHR_synchronization2
typedef VkAccessFlags2 VkAccessFlags2KHR;

Bits which \textbf{can} be set in the \texttt{srcAccessMask} and \texttt{dstAccessMask} members of \texttt{VkSubpassDependency}, \texttt{VkSubpassDependency2}, \texttt{VkMemoryBarrier}, \texttt{VkBufferMemoryBarrier}, and \texttt{VkImageMemoryBarrier}, specifying access behavior, are:

// Provided by VK_VERSION_1_0
typedef enum VkAccessFlagBits {
    VK_ACCESS_INDIRECT_COMMAND_READ_BIT = 0x00000001,
    VK_ACCESS_INDEX_READ_BIT = 0x00000002,
    VK_ACCESS_VERTEX_ATTRIBUTE_READ_BIT = 0x00000004,
    VK_ACCESS_UNIFORM_READ_BIT = 0x00000008,
    VK_ACCESS_INPUT_ATTACHMENT_READ_BIT = 0x00000010,
    VK_ACCESS_SHADER_READ_BIT = 0x00000020,
    VK_ACCESS_SHADER_WRITE_BIT = 0x00000040,
    VK_ACCESS_COLOR_ATTACHMENT_READ_BIT = 0x00000080,
    VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT = 0x00000100,
    VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_READ_BIT = 0x00000200,
    VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT = 0x00000400,
    VK_ACCESS_TRANSFER_READ_BIT = 0x00000800,
    VK_ACCESS_TRANSFER_WRITE_BIT = 0x00001000,
    VK_ACCESS_HOST_READ_BIT = 0x00002000,
    VK_ACCESS_HOST_WRITE_BIT = 0x00004000,
    VK_ACCESS_MEMORY_READ_BIT = 0x00008000,
    VK_ACCESS_MEMORY_WRITE_BIT = 0x00010000,
    // Provided by VK_VERSION_1_3
    VK_ACCESS_NONE = 0,
    // Provided by VK_EXT_transform_feedback
    VK_ACCESS_TRANSFORM_FEEDBACK_WRITE_BIT_EXT = 0x02000000,
    // Provided by VK_KHR_acceleration_structure
    VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR = 0x00200000,
    VK_ACCESS_ACCELERATION_STRUCTURE_WRITE_BIT_KHR = 0x00400000,
    // Provided by VK_EXT_fragment_density_map
    VK_ACCESS_FRAGMENT_DENSITY_MAP_READ_BIT_EXT = 0x01000000,
} VkAccessFlagBits;

// Provided by VK_KHR.acceleration_structure
VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR = 0x00200000,
// Provided by VK_KHR.acceleration_structure
VK_ACCESS_ACCELERATION_STRUCTURE_WRITE_BIT_KHR = 0x00400000,
// Provided by VK_EXT.fragment_density_map
VK_ACCESS_FRAGMENT_DENSITY_MAP_READ_BIT_EXT = 0x01000000,
These values all have the same meaning as the equivalently named values for `VkAccessFlags2`.

- **VK_ACCESS_NONE** specifies no accesses.
- **VK_ACCESS_MEMORY_READ_BIT** specifies all read accesses. It is always valid in any access mask, and is treated as equivalent to setting all `READ` access flags that are valid where it is used.
- **VK_ACCESS_MEMORY_WRITE_BIT** specifies all write accesses. It is always valid in any access mask, and is treated as equivalent to setting all `WRITE` access flags that are valid where it is used.
- **VK_ACCESS_INDIRECT_COMMAND_READ_BIT** specifies read access to indirect command data read as part of an indirect build, trace, drawing or dispatching command. Such access occurs in the `VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT` pipeline stage.
- **VK_ACCESS_INDEX_READ_BIT** specifies read access to an index buffer as part of an indexed drawing command, bound by `vkCmdBindIndexBuffer2KHR` and `vkCmdBindIndexBuffer`. Such access occurs in the `VK_PIPELINE_STAGE_VERTEX_INPUT_BIT` pipeline stage.
- **VK_ACCESS_VERTEX_ATTRIBUTE_READ_BIT** specifies read access to a vertex buffer as part of a drawing command, bound by `vkCmdBindVertexBuffer`. Such access occurs in the `VK_PIPELINE_STAGE_VERTEX_INPUT_BIT` pipeline stage.
- **VK_ACCESS_UNIFORM_READ_BIT** specifies read access to a uniform buffer in any shader pipeline stage.
- **VK_ACCESS_INPUT_ATTACHMENT_READ_BIT** specifies read access to an input attachment within a render pass during subpass shading or fragment shading. Such access occurs in the `VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI` or `VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT` pipeline stage.
- **VK_ACCESS_SHADER_READ_BIT** specifies read access to a uniform texel buffer, sampled image, storage buffer, physical storage buffer, shader binding table, storage texel buffer, or storage image in any shader pipeline stage.
- **VK_ACCESS_SHADER_WRITE_BIT** specifies write access to a storage buffer, physical storage buffer,
storage texel buffer, or storage image in any shader pipeline stage.

- **VK_ACCESS_COLOR_ATTACHMENT_READ_BIT** specifies read access to a color attachment, such as via blending (other than advanced blend operations), logic operations or certain render pass load operations in the **VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT** pipeline stage or via fragment shader tile image reads in the **VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT** pipeline stage.

- **VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT** specifies write access to a color, resolve, or depth/stencil resolve attachment during a render pass or via certain render pass load and store operations. Such access occurs in the **VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT** pipeline stage.

- **VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_READ_BIT** specifies read access to a depth/stencil attachment, via depth or stencil operations or certain render pass load operations in the **VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT** or **VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT** pipeline stages or via fragment shader tile image reads in the **VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT** pipeline stage.

- **VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT** specifies write access to a depth/stencil attachment, via depth or stencil operations or certain render pass load and store operations. Such access occurs in the **VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT** or **VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT** pipeline stages.

- **VK_ACCESS_TRANSFER_READ_BIT** specifies read access to an image or buffer in a copy operation. Such access occurs in the **VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT** pipeline stage.

- **VK_ACCESS_TRANSFER_WRITE_BIT** specifies write access to an image or buffer in a clear or copy operation. Such access occurs in the **VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT** pipeline stage.

- **VK_ACCESS_HOST_READ_BIT** specifies read access by a host operation. Accesses of this type are not performed through a resource, but directly on memory. Such access occurs in the **VK_PIPELINE_STAGE_HOST_BIT** pipeline stage.

- **VK_ACCESS_HOST_WRITE_BIT** specifies write access by a host operation. Accesses of this type are not performed through a resource, but directly on memory. Such access occurs in the **VK_PIPELINE_STAGE_HOST_BIT** pipeline stage.

- **VK_ACCESS_CONDITIONAL_RENDERING_READ_BIT_EXT** specifies read access to a predicate as part of conditional rendering. Such access occurs in the **VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT** pipeline stage.

- **VK_ACCESS_TRANSFORM_FEEDBACK_WRITE_BIT_EXT** specifies write access to a transform feedback buffer made when transform feedback is active. Such access occurs in the **VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT** pipeline stage.

- **VK_ACCESS_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT** specifies read access to a transform feedback counter buffer which is read when **vkCmdBeginTransformFeedbackEXT** executes. Such access occurs in the **VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT** pipeline stage.

- **VK_ACCESS_TRANSFORM_FEEDBACK_COUNTER_WRITE_BIT_EXT** specifies write access to a transform feedback counter buffer which is written when **vkCmdEndTransformFeedbackEXT** executes. Such access occurs in the **VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT** pipeline stage.

- **VK_ACCESS_COMMAND_PREPROCESS_READ_BIT_NV** specifies reads from buffer inputs to **vkCmdPreprocessGeneratedCommandsNV**. Such access occurs in the **VK_PIPELINE_STAGE_COMMAND_PREPROCESS_BIT_NV** pipeline stage.
• **VK_ACCESS_COMMAND_PREPROCESS_WRITE_BIT_NV** specifies writes to the target command buffer preprocess outputs in `vkCmdPreprocessGeneratedCommandsNV`. Such access occurs in the `VK_PIPELINE_STAGE_COMMAND_PREPROCESS_BIT_NV` pipeline stage.

• **VK_ACCESS_COLOR_ATTACHMENT_READ_NONCOHERENT_BIT_EXT** specifies read access to color attachments, including advanced blend operations. Such access occurs in the `VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT` pipeline stage.

• **VK_ACCESS_2_INVOCATION_MASK_READ_BIT_HUAWEI** specifies read access to a invocation mask image in the `VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI` pipeline stage.

• **VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR** specifies read access to an acceleration structure as part of a trace, build, or copy command, or to an acceleration structure scratch buffer as part of a build command. Such access occurs in the `VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR` pipeline stage or `VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR` pipeline stage.

• **VK_ACCESS_ACCELERATION_STRUCTURE_WRITE_BIT_KHR** specifies write access to an acceleration structure or acceleration structure scratch buffer as part of a build or copy command. Such access occurs in the `VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR` pipeline stage.

• **VK_ACCESS_FRAGMENT_DENSITY_MAP_READ_BIT_EXT** specifies read access to a fragment density map attachment during dynamic fragment density map operations. Such access occurs in the `VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT` pipeline stage.

• **VK_ACCESS_FRAGMENT_SHADING_RATE_ATTACHMENT_READ_BIT_KHR** specifies read access to a fragment shading rate attachment during rasterization. Such access occurs in the `VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR` pipeline stage.

• **VK_ACCESS_SHADING_RATE_IMAGE_READ_BIT_NV** specifies read access to a shading rate image during rasterization. Such access occurs in the `VK_PIPELINE_STAGE_SHADING_RATE_IMAGE_BIT_NV` pipeline stage. It is equivalent to `VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`.

Certain access types are only performed by a subset of pipeline stages. Any synchronization command that takes both stage masks and access masks uses both to define the access scopes - only the specified access types performed by the specified stages are included in the access scope. An application **must** not specify an access flag in a synchronization command if it does not include a pipeline stage in the corresponding stage mask that is able to perform accesses of that type. The following table lists, for each access flag, which pipeline stages can perform that type of access.

**Table 4. Supported access types**

<table>
<thead>
<tr>
<th>Access flag</th>
<th>Supported pipeline stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_ACCESS_2_NONE</td>
<td>Any</td>
</tr>
<tr>
<td>VK_ACCESS_2 INDIRECT_COMMAND_READ_BIT</td>
<td>VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR</td>
</tr>
<tr>
<td>VK_ACCESS_2_INDEX_READ_BIT</td>
<td>VK_PIPELINE_STAGE_2_VERTEX_INPUT_BIT, VK_PIPELINE_STAGE_2_INDEX_INPUT_BIT</td>
</tr>
<tr>
<td>VK_ACCESS_2_VERTEX_ATTRIBUTE_READ_BIT</td>
<td>VK_PIPELINE_STAGE_2_VERTEX_INPUT_BIT, VK_PIPELINE_STAGE_2_VERTEX_ATTRIBUTE_INPUT_BIT</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Access flag</th>
<th>Supported pipeline stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_ACCESS_2_UNIFORM_READ_BIT</td>
<td>VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT, VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT, VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT, VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT, VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR, VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI, VK_PIPELINE_STAGE_2_CLUSTER_CULLING_SHADER_BIT_HUAWEI</td>
</tr>
<tr>
<td>VK_ACCESS_2_INPUT_ATTACHMENT_READ_BIT</td>
<td>VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT, VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI</td>
</tr>
<tr>
<td>VK_ACCESS_2_SHADER_READ_BIT</td>
<td>VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR, VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT, VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT, VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT, VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT, VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT, VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR, VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI, VK_PIPELINE_STAGE_2_CLUSTER_CULLING_SHADER_BIT_HUAWEI</td>
</tr>
<tr>
<td>VK_ACCESS_2_SHADER_WRITE_BIT</td>
<td>VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT, VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT, VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT, VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT, VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR, VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI, VK_PIPELINE_STAGE_2_CLUSTER_CULLING_SHADER_BIT_HUAWEI</td>
</tr>
<tr>
<td>Access flag</td>
<td>Supported pipeline stages</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>VK_ACCESS_2_COLOR_ATTACHMENT_READ_BIT</td>
<td>VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT, VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT</td>
</tr>
<tr>
<td>VK_ACCESS_2_COLOR_ATTACHMENT_WRITE_BIT</td>
<td>VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT</td>
</tr>
<tr>
<td>VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_READ_BIT</td>
<td>VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT, VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT,</td>
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<tr>
<td></td>
<td>VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT</td>
</tr>
<tr>
<td>VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT</td>
<td>VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT, VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT</td>
</tr>
<tr>
<td>VK_ACCESS_2_TRANSFER_READ_BIT</td>
<td>VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT, VK_PIPELINE_STAGE_2_COPY_BIT, VK_PIPELINE_STAGE_2_RGB_ATTRIBUTE_BIT_KHR, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR, VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT</td>
</tr>
<tr>
<td>VK_ACCESS_2_TRANSFER_WRITE_BIT</td>
<td>VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT, VK_PIPELINE_STAGE_2_COPY_BIT, VK_PIPELINE_STAGE_2_RGB_ATTRIBUTE_BIT_KHR, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR, VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT</td>
</tr>
<tr>
<td>VK_ACCESS_2_HOST_READ_BIT</td>
<td>VK_PIPELINE_STAGE_2_HOST_BIT</td>
</tr>
<tr>
<td>VK_ACCESS_2_HOST_WRITE_BIT</td>
<td>VK_PIPELINE_STAGE_2_HOST_BIT</td>
</tr>
<tr>
<td>VK_ACCESS_2_MEMORY_READ_BIT</td>
<td>Any</td>
</tr>
<tr>
<td>VK_ACCESS_2_MEMORY_WRITE_BIT</td>
<td>Any</td>
</tr>
<tr>
<td>Access flag</td>
<td>Supported pipeline stages</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>VK_ACCESS_2_SHADER_SAMPLED_READ_BIT</td>
<td>VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT, VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT, VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT, VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT, VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR, VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI, VK_PIPELINE_STAGE_2_CLUSTER_CULLING_SHADER_BIT_HUAWEI</td>
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<tr>
<td>VK_ACCESS_2_SHADER_STORAGE_READ_BIT</td>
<td>VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT, VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT, VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT, VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT, VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR, VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI, VK_PIPELINE_STAGE_2_CLUSTER_CULLING_SHADER_BIT_HUAWEI</td>
</tr>
<tr>
<td>VK_ACCESS_2_SHADER_STORAGE_WRITE_BIT</td>
<td>VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT, VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT, VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT, VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT, VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR, VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI, VK_PIPELINE_STAGE_2_CLUSTER_CULLING_SHADER_BIT_HUAWEI</td>
</tr>
<tr>
<td>VK_ACCESS_2_VIDEO_DECODE_READ_BIT_KHR</td>
<td>VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR</td>
</tr>
<tr>
<td>VK_ACCESS_2_VIDEO_DECODE_WRITE_BIT_KHR</td>
<td>VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR</td>
</tr>
<tr>
<td>VK_ACCESS_2_VIDEO_ENCODE_READ_BIT_KHR</td>
<td>VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR</td>
</tr>
<tr>
<td>VK_ACCESS_2_VIDEO_ENCODE_WRITE_BIT_KHR</td>
<td>VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR</td>
</tr>
<tr>
<td>Access flag</td>
<td>Supported pipeline stages</td>
</tr>
<tr>
<td>---------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>VK_ACCESS_2_TRANSFORM_FEEDBACK_WRITE_BIT_EXT</td>
<td>VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT</td>
</tr>
<tr>
<td>VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT</td>
<td>VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT, VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT</td>
</tr>
<tr>
<td>VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_WRITE_BIT_EXT</td>
<td>VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT</td>
</tr>
<tr>
<td>VK_ACCESS_2CONDITIONAL_RENDERING_READ_BIT_EXT</td>
<td>VK_PIPELINE_STAGE_2CONDITIONAL_RENDERING_BIT_EXT</td>
</tr>
<tr>
<td>VK_ACCESS_2_COMMAND_PREPROCESS_READ_BIT_NV</td>
<td>VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV</td>
</tr>
<tr>
<td>VK_ACCESS_2_COMMAND_PREPROCESS_WRITE_BIT_NV</td>
<td>VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV</td>
</tr>
<tr>
<td>VK_ACCESS_2_FRAGMENT_SHADING_RATE_ATTACHMENT_READ_BIT_KHR</td>
<td>VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_READ_BIT_KHR</td>
</tr>
<tr>
<td>VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR</td>
<td>VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSellation_CONTROL_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSellation_EVALUATION_SHADER_BIT, VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT, VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT, VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT, VK_PIPELINE_STAGE_2RAY_TRACING_SHADER_BIT_KHR, VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_CLUSTER_Culling_SHADER_BIT_HUAWEI, VK_PIPELINE_STAGE_2ACCELERATION_STRUCTURE_BUILD_BIT_KHR, VK_PIPELINE_STAGE_2ACCELERATION_STRUCTURE_COPY_BIT_KHR, VK_PIPELINE_STAGE_2SUBPASS_SHADER_BIT_HUAWEI</td>
</tr>
<tr>
<td>VK_ACCESS_2 ACCELERATION_STRUCTURE_WRITE_BIT_KHR</td>
<td>VK_PIPELINE_STAGE_2 ACCELERATION_STRUCTURE_BUILD_BIT_KHR</td>
</tr>
<tr>
<td>VK_ACCESS_2_FRAGMENT_DENSITY_MAP_READ_BIT_EXT</td>
<td>VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT</td>
</tr>
<tr>
<td>VK_ACCESS_2_COLOR_ATTACHMENT_READ_NONCOHERENT_BIT_EXT</td>
<td>VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT_EXT</td>
</tr>
<tr>
<td>Access flag</td>
<td>Supported pipeline stages</td>
</tr>
<tr>
<td>------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>VK_ACCESS_2_DESCRIPTOR_BUFFER_READ_BIT_EXT</td>
<td>VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT, VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT, VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT, VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT, VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR, VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI, VK_PIPELINE_STAGE_2_CLUSTER_CULLING_SHADER_BIT_HUAWEI</td>
</tr>
<tr>
<td>VK_ACCESS_2_INVOCATION_MASK_READ_BIT_HUAWEI</td>
<td>VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI</td>
</tr>
<tr>
<td>VK_ACCESS_2_SHADER_BINDING_TABLE_READ_BIT_KHR</td>
<td>VK_PIPELINE_STAGE_2_VERTEX_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT, VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT, VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT, VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT, VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT, VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR, VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT, VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI, VK_PIPELINE_STAGE_2_CLUSTER_CULLING_SHADER_BIT_HUAWEI</td>
</tr>
<tr>
<td>VK_ACCESS_2_MICROMAP_READ_BIT_EXT</td>
<td>VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR</td>
</tr>
<tr>
<td>VK_ACCESS_2_MICROMAP_WRITE_BIT_EXT</td>
<td>VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT</td>
</tr>
<tr>
<td>VK_ACCESS_2_OPTICAL_FLOW_READ_BIT_NV</td>
<td>VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV</td>
</tr>
<tr>
<td>VK_ACCESS_2_OPTICAL_FLOW_WRITE_BIT_NV</td>
<td>VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV</td>
</tr>
</tbody>
</table>

// Provided by VK_VERSION_1_0
typedef VkFlags VkAccessFlags;

**VkAccessFlags** is a bitmask type for setting a mask of zero or more **VkAccessFlagBits**.

If a memory object does not have the **VK_MEMORY_PROPERTY_HOST_COHERENT_BIT** property, then **vkFlushMappedMemoryRanges** must be called in order to guarantee that writes to the memory object from the host are made available to the host domain, where they can be further made available to the device domain via a domain operation. Similarly, **vkInvalidateMappedMemoryRanges** must be called to guarantee that writes which are available to
the host domain are made visible to host operations.

If the memory object does have the `VK_MEMORY_PROPERTY_HOST_COHERENT_BIT` property flag, writes to
the memory object from the host are automatically made available to the host domain. Similarly,
writes made available to the host domain are automatically made visible to the host.

```
Note
Queue submission commands automatically perform a domain operation from
host to device for all writes performed before the command executes, so in most
cases an explicit memory barrier is not needed for this case. In the few
circumstances where a submit does not occur between the host write and the
device read access, writes can be made available by using an explicit memory
barrier.
```

### 7.1.4. Framebuffer Region Dependencies

**Pipeline stages** that operate on, or with respect to, the framebuffer are collectively the `framebuffer-space` pipeline stages. These stages are:

- `VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT`
- `VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT`
- `VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT`
- `VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT`

For these pipeline stages, an execution or memory dependency from the first set of operations to
the second set can either be a single `framebuffer-global` dependency, or split into multiple
`framebuffer-local` dependencies. A dependency with non-framebuffer-space pipeline stages is
neither framebuffer-global nor framebuffer-local.

A **framebuffer region** is a subset of the entire framebuffer, and can either be:

- A **sample region**, which is set of sample (x, y, layer, sample) coordinates that is a subset of the
  entire framebuffer, or
- A **fragment region**, which is a set of fragment (x, y, layer) coordinates that is a subset of the
  entire framebuffer.

Both **synchronization scopes** of a framebuffer-local dependency include only the operations
performed within corresponding framebuffer regions (as defined below). No ordering guarantees
are made between different framebuffer regions for a framebuffer-local dependency.

Both **synchronization scopes** of a framebuffer-global dependency include operations on all
framebuffer-regions.

If the first synchronization scope includes operations on pixels/fragments with N samples and the
second synchronization scope includes operations on pixels/fragments with M samples, where N
does not equal M, then a framebuffer region containing all samples at a given (x, y, layer)
coordinate in the first synchronization scope corresponds to a region containing all samples at the
same coordinate in the second synchronization scope. In other words, the framebuffer region is a
fragment region and it is a pixel granularity dependency. If N equals M, and if the `VkSubpassDescription::flags` does not specify the `VK_SUBPASS_DESCRIPTION_FRAGMENT_REGION_BIT_QCOM` flag, then a framebuffer region containing a single (x, y, layer, sample) coordinate in the first synchronization scope corresponds to a region containing the same sample at the same coordinate in the second synchronization scope. In other words, the framebuffer region is a sample region and it is a sample granularity dependency.

If the pipeline performing the operation was created with `VK_PIPELINE_COLOR_BLEND_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_BIT_EXT`, `VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT`, or `VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT`, the framebuffer region is a fragment region and it is a pixel granularity dependency.

**Note**

Since fragment shader invocations are not specified to run in any particular groupings, the size of a framebuffer region is implementation-dependent, not known to the application, and **must** be assumed to be no larger than specified above.

**Note**

Practically, the pixel vs. sample granularity dependency means that if an input attachment has a different number of samples than the pipeline's `rasterizationSamples`, then a fragment **can** access any sample in the input attachment's pixel even if it only uses framebuffer-local dependencies. If the input attachment has the same number of samples, then the fragment **can** only access the covered samples in its input `SampleMask` (i.e. the fragment operations happen-after a framebuffer-local dependency for each sample the fragment covers). To access samples that are not covered, either the `VkSubpassDescription::flags` `VK_SUBPASS_DESCRIPTION_FRAGMENT_REGION_BIT_QCOM` flag is required, or a framebuffer-global dependency is required.

If a synchronization command includes a `dependencyFlags` parameter, and specifies the `VK_DEPENDENCY_BY_REGION_BIT` flag, then it defines framebuffer-local dependencies for the framebuffer-space pipeline stages in that synchronization command, for all framebuffer regions. If no `dependencyFlags` parameter is included, or the `VK_DEPENDENCY_BY_REGION_BIT` flag is not specified, then a framebuffer-global dependency is specified for those stages. The `VK_DEPENDENCY_BY_REGION_BIT` flag does not affect the dependencies between non-framebuffer-space pipeline stages, nor does it affect the dependencies between framebuffer-space and non-framebuffer-space pipeline stages.

**Note**

Framebuffer-local dependencies are more efficient for most architectures; particularly tile-based architectures - which can keep framebuffer-regions entirely in on-chip registers and thus avoid external bandwidth across such a dependency. Including a framebuffer-global dependency in your rendering will usually force all implementations to flush data to memory, or to a higher level cache, breaking any potential locality optimizations.
7.1.5. View-Local Dependencies

In a render pass instance that has multiview enabled, dependencies can be either view-local or view-global.

A view-local dependency only includes operations from a single source view from the source subpass in the first synchronization scope, and only includes operations from a single destination view from the destination subpass in the second synchronization scope. A view-global dependency includes all views in the view mask of the source and destination subpasses in the corresponding synchronization scopes.

If a synchronization command includes a dependencyFlags parameter and specifies the VK_DEPENDENCY_VIEW_LOCAL_BIT flag, then it defines view-local dependencies for that synchronization command, for all views. If no dependencyFlags parameter is included or the VK_DEPENDENCY_VIEW_LOCAL_BIT flag is not specified, then a view-global dependency is specified.

7.1.6. Device-Local Dependencies

Dependencies can be either device-local or non-device-local. A device-local dependency acts as multiple separate dependencies, one for each physical device that executes the synchronization command, where each dependency only includes operations from that physical device in both synchronization scopes. A non-device-local dependency is a single dependency where both synchronization scopes include operations from all physical devices that participate in the synchronization command. For subpass dependencies, all physical devices in the VkDeviceGroupRenderPassBeginInfo::deviceMask participate in the dependency, and for pipeline barriers all physical devices that are set in the command buffer's current device mask participate in the dependency.

If a synchronization command includes a dependencyFlags parameter and specifies the VK_DEPENDENCY_DEVICE_GROUP_BIT flag, then it defines a non-device-local dependency for that synchronization command. If no dependencyFlags parameter is included or the VK_DEPENDENCY_DEVICE_GROUP_BIT flag is not specified, then it defines device-local dependencies for that synchronization command, for all participating physical devices.

Semaphore and event dependencies are device-local and only execute on the one physical device that performs the dependency.

7.2. Implicit Synchronization Guarantees

A small number of implicit ordering guarantees are provided by Vulkan, ensuring that the order in which commands are submitted is meaningful, and avoiding unnecessary complexity in common operations.

Submission order is a fundamental ordering in Vulkan, giving meaning to the order in which action and synchronization commands are recorded and submitted to a single queue. Explicit and implicit ordering guarantees between commands in Vulkan all work on the premise that this ordering is meaningful. This order does not itself define any execution or memory dependencies; synchronization commands and other orderings within the API use this ordering to define their scopes.
Submission order for any given set of commands is based on the order in which they were recorded to command buffers and then submitted. This order is determined as follows:

1. The initial order is determined by the order in which `vkQueueSubmit` and `vkQueueSubmit2` commands are executed on the host, for a single queue, from first to last.

2. The order in which `VkSubmitInfo` structures are specified in the `pSubmits` parameter of `vkQueueSubmit`, or in which `VkSubmitInfo2` structures are specified in the `pSubmits` parameter of `vkQueueSubmit2`, from lowest index to highest.

3. The order in which command buffers are specified in the `pCommandBuffers` member of `VkSubmitInfo` or `VkSubmitInfo2` from lowest index to highest.

4. The order in which commands were recorded to a command buffer on the host, from first to last:
   - For commands recorded outside a render pass, this includes all other commands recorded outside a render pass, including `vkCmdBeginRenderPass` and `vkCmdEndRenderPass` commands; it does not directly include commands inside a render pass.
   - For commands recorded inside a render pass, this includes all other commands recorded inside the same subpass, including the `vkCmdBeginRenderPass` and `vkCmdEndRenderPass` commands that delimit the same render pass instance; it does not include commands recorded to other subpasses. **State commands** do not execute any operations on the device, instead they set the state of the command buffer when they execute on the host, in the order that they are recorded. **Action commands** consume the current state of the command buffer when they are recorded, and will execute state changes on the device as required to match the recorded state.

The order of primitives passing through the graphics pipeline and image layout transitions as part of an image memory barrier provide additional guarantees based on submission order.

Execution of **pipeline stages** within a given command also has a loose ordering, dependent only on a single command.

**Signal operation order** is a fundamental ordering in Vulkan, giving meaning to the order in which semaphore and fence signal operations occur when submitted to a single queue. The signal operation order for queue operations is determined as follows:

1. The initial order is determined by the order in which `vkQueueSubmit` and `vkQueueSubmit2` commands are executed on the host, for a single queue, from first to last.

2. The order in which `VkSubmitInfo` structures are specified in the `pSubmits` parameter of `vkQueueSubmit`, or in which `VkSubmitInfo2` structures are specified in the `pSubmits` parameter of `vkQueueSubmit2`, from lowest index to highest.

3. The fence signal operation defined by the `fence` parameter of a `vkQueueSubmit` or `vkQueueSubmit2` or `vkQueueBindSparse` command is ordered after all semaphore signal operations defined by that command.

Semaphore signal operations defined by a single `VkSubmitInfo` or `VkSubmitInfo2` or `VkBindSparseInfo` structure are unordered with respect to other semaphore signal operations defined within the same structure.
The `vkSignalSemaphore` command does not execute on a queue but instead performs the signal operation from the host. The semaphore signal operation defined by executing a `vkSignalSemaphore` command happens-after the `vkSignalSemaphore` command is invoked and happens-before the command returns.

**Note**

When signaling timeline semaphores, it is the responsibility of the application to ensure that they are ordered such that the semaphore value is strictly increasing. Because the first synchronization scope for a semaphore signal operation contains all semaphore signal operations which occur earlier in submission order, all semaphore signal operations contained in any given batch are guaranteed to happen-after all semaphore signal operations contained in any previous batches. However, no ordering guarantee is provided between the semaphore signal operations defined within a single batch. This, combined with the requirement that timeline semaphore values strictly increase, means that it is invalid to signal the same timeline semaphore twice within a single batch.

If an application wishes to ensure that some semaphore signal operation happens-after some other semaphore signal operation, it can submit a separate batch containing only semaphore signal operations, which will happen-after the semaphore signal operations in any earlier batches.

When signaling a semaphore from the host, the only ordering guarantee is that the signal operation happens-after when `vkSignalSemaphore` is called and happens-before it returns. Therefore, it is invalid to call `vkSignalSemaphore` while there are any outstanding signal operations on that semaphore from any queue submissions unless those queue submissions have some dependency which ensures that they happen-after the host signal operation. One example of this would be if the pending signal operation is, itself, waiting on the same semaphore at a lower value and the call to `vkSignalSemaphore` signals that lower value. Furthermore, if there are two or more processes or threads signaling the same timeline semaphore from the host, the application must ensure that the `vkSignalSemaphore` with the lower semaphore value returns before `vkSignalSemaphore` is called with the higher value.

### 7.3. Fences

Fences are a synchronization primitive that can be used to insert a dependency from a queue to the host. Fences have two states - signaled and unsignaled. A fence can be signaled as part of the execution of a queue submission command. Fences can be unsignaled on the host with `vkResetFences`. Fences can be waited on by the host with the `vkWaitForFences` command, and the current state can be queried with `vkGetFenceStatus`.

The internal data of a fence may include a reference to any resources and pending work associated with signal or unsignal operations performed on that fence object, collectively referred to as the fence’s *payload*. Mechanisms to import and export that internal data to and from fences are provided below. These mechanisms indirectly enable applications to share fence state between two or more fences and other synchronization primitives across process and API boundaries.
Fences are represented by `VkFence` handles:

```
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkFence)
```

To create a fence, call:

```
// Provided by VK_VERSION_1_0
VkResult vkCreateFence(
    VkDevice device,
    const VkFenceCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkFence* pFence);
```

- `device` is the logical device that creates the fence.
- `pCreateInfo` is a pointer to a `VkFenceCreateInfo` structure containing information about how the fence is to be created.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pFence` is a pointer to a handle in which the resulting fence object is returned.

### Valid Usage (Implicit)

- VUID-vkCreateFence-device-parameter
  device must be a valid `VkDevice` handle
- VUID-vkCreateFence-pCreateInfo-parameter
  `pCreateInfo` must be a valid pointer to a valid `VkFenceCreateInfo` structure
- VUID-vkCreateFence-pAllocator-parameter
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure
- VUID-vkCreateFence-pFence-parameter
  `pFence` must be a valid pointer to a `VkFence` handle

### Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

The `VkFenceCreateInfo` structure is defined as:
typedef struct VkFenceCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkFenceCreateFlags flags;
} VkFenceCreateInfo;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• flags is a bitmask of VkFenceCreateFlagBits specifying the initial state and behavior of the fence.

Valid Usage (Implicit)

• VUID-VkFenceCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_FENCE_CREATE_INFO

• VUID-VkFenceCreateInfo-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkExportFenceCreateInfo or VkExportFenceWin32HandleInfoKHR

• VUID-VkFenceCreateInfo-sType-unique
  The sType value of each struct in the pNext chain must be unique

• VUID-VkFenceCreateInfo-flags-parameter
  flags must be a valid combination of VkFenceCreateFlagBits values

typedef enum VkFenceCreateFlagBits {
    VK_FENCE_CREATE_SIGNALED_BIT = 0x00000001,
} VkFenceCreateFlagBits;

• VK_FENCE_CREATE_SIGNALED_BIT specifies that the fence object is created in the signaled state. Otherwise, it is created in the unsignaled state.

typedef VkFlags VkFenceCreateFlags;

VkFenceCreateFlags is a bitmask type for setting a mask of zero or more VkFenceCreateFlagBits.

To create a fence whose payload can be exported to external handles, add a VkExportFenceCreateInfo structure to the pNext chain of the VkFenceCreateInfo structure. The VkExportFenceCreateInfo structure is defined as:
typedef struct VkExportFenceCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkExternalFenceHandleTypeFlags handleTypes;
} VkExportFenceCreateInfo;

or the equivalent

typedef VkExportFenceCreateInfo VkExportFenceCreateInfoKHR;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• handleTypes is a bitmask of VkExternalFenceHandleTypeFlagBits specifying one or more fence handle types the application can export from the resulting fence. The application can request multiple handle types for the same fence.

Valid Usage

• VUID-VkExportFenceCreateInfo-handleTypes-01446
  The bits in handleTypes must be supported and compatible, as reported by VkExternalFenceProperties

Valid Usage (Implicit)

• VUID-VkExportFenceCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_EXPORT_FENCE_CREATE_INFO
• VUID-VkExportFenceCreateInfo-handleTypes-parameter
  handleTypes must be a valid combination of VkExternalFenceHandleTypeFlagBits values

To specify additional attributes of NT handles exported from a fence, add a VkExportFenceWin32HandleInfoKHR structure to the pNext chain of the VkFenceCreateInfo structure. The VkExportFenceWin32HandleInfoKHR structure is defined as:

typedef struct VkExportFenceWin32HandleInfoKHR {
    VkStructureType sType;
    const void* pNext;
    const SECURITY_ATTRIBUTES* pAttributes;
    DWORD dwAccess;
    LPCWSTR name;
} VkExportFenceWin32HandleInfoKHR;
• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **pAttributes** is a pointer to a Windows `SECURITY_ATTRIBUTES` structure specifying security attributes of the handle.

• **dwAccess** is a `DWORD` specifying access rights of the handle.

• **name** is a null-terminated UTF-16 string to associate with the underlying synchronization primitive referenced by NT handles exported from the created fence.

If `VkExportFenceCreateInfo` is not included in the same **pNext** chain, this structure is ignored.

If `VkExportFenceCreateInfo` is included in the **pNext** chain of `VkFenceCreateInfo` with a Windows `handleType`, but either `VkExportFenceWin32HandleInfoKHR` is not included in the **pNext** chain, or it is included but **pAttributes** is set to `NULL`, default security descriptor values will be used, and child processes created by the application will not inherit the handle, as described in the MSDN documentation for “Synchronization Object Security and Access Rights”. Further, if the structure is not present, the access rights will be

`DXGI_SHARED_RESOURCE_READ | DXGI_SHARED_RESOURCE_WRITE`

for handles of the following types:

`VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_BIT`

1


---

**Valid Usage**

• **VUID-VkExportFenceWin32HandleInfoKHR-handleTypes-01447**

  If `VkExportFenceCreateInfo::handleTypes` does not include `VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_BIT`, a `VkExportFenceWin32HandleInfoKHR` structure **must** not be included in the **pNext** chain of `VkFenceCreateInfo`.

---

**Valid Usage (Implicit)**

• **VUID-VkExportFenceWin32HandleInfoKHR-sType-sType**

  **sType** **must** be `VK_STRUCTURE_TYPE_EXPORT_FENCE_WIN32_HANDLE_INFO_KHR`.

• **VUID-VkExportFenceWin32HandleInfoKHR-pAttributes-parameter**

  If **pAttributes** is not `NULL`, **pAttributes** **must** be a valid pointer to a valid `SECURITY_ATTRIBUTES` value.

---

To export a Windows handle representing the state of a fence, call:
// Provided by VK_KHR_external_fence_win32
VkResult vkGetFenceWin32HandleKHR(
    VkDevice device,
    const VkFenceGetWin32HandleInfoKHR* pGetWin32HandleInfo,
    HANDLE* pHandle);

• device is the logical device that created the fence being exported.
• pGetWin32HandleInfo is a pointer to a VkFenceGetWin32HandleInfoKHR structure containing parameters of the export operation.
• pHandle will return the Windows handle representing the fence state.

For handle types defined as NT handles, the handles returned by vkGetFenceWin32HandleKHR are owned by the application. To avoid leaking resources, the application must release ownership of them using the CloseHandle system call when they are no longer needed.

Exporting a Windows handle from a fence may have side effects depending on the transference of the specified handle type, as described in Importing Fence Payloads.

Valid Usage (Implicit)

• VUID-vkGetFenceWin32HandleKHR-device-parameter
device must be a valid VkDevice handle
• VUID-vkGetFenceWin32HandleKHR-pGetWin32HandleInfo-parameter
pGetWin32HandleInfo must be a valid pointer to a valid VkFenceGetWin32HandleInfoKHR structure
• VUID-vkGetFenceWin32HandleKHR-pHandle-parameter
pHandle must be a valid pointer to a HANDLE value

Return Codes

Success
• VK_SUCCESS

Failure
• VK_ERROR_TOO_MANY_OBJECTS
• VK_ERROR_OUT_OF_HOST_MEMORY

The VkFenceGetWin32HandleInfoKHR structure is defined as:

// Provided by VK_KHR_external_fence_win32
typedef struct VkFenceGetWin32HandleInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkFence fence;
}
VkExternalFenceHandleTypeFlagBits handleType;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `fence` is the fence from which state will be exported.
- `handleType` is a `VkExternalFenceHandleTypeFlagBits` value specifying the type of handle requested.

The properties of the handle returned depend on the value of `handleType`. See `VkExternalFenceHandleTypeFlagBits` for a description of the properties of the defined external fence handle types.

**Valid Usage**

- VUID-VkFenceGetWin32HandleInfoKHR-handleType-01448
  `handleType` must have been included in `VkExportFenceCreateInfo::handleTypes` when the fence's current payload was created.

- VUID-VkFenceGetWin32HandleInfoKHR-handleType-01449
  If `handleType` is defined as an NT handle, `vkGetFenceWin32HandleKHR` must be called no more than once for each valid unique combination of `fence` and `handleType`.

- VUID-VkFenceGetWin32HandleInfoKHR-fence-01450
  `fence` must not currently have its payload replaced by an imported payload as described below in Importing Fence Payloads unless that imported payload's handle type was included in `VkExternalFenceProperties::exportFromImportedHandleTypes` for `handleType`.

- VUID-VkFenceGetWin32HandleInfoKHR-handleType-01451
  If `handleType` refers to a handle type with copy payload transference semantics, `fence` must be signaled, or have an associated `fence signal operation` pending execution.

- VUID-VkFenceGetWin32HandleInfoKHR-handleType-01452
  `handleType` must be defined as an NT handle or a global share handle.

**Valid Usage (Implicit)**

- VUID-VkFenceGetWin32HandleInfoKHR-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_FENCE_GET_WIN32_HANDLE_INFO_KHR`.

- VUID-VkFenceGetWin32HandleInfoKHR-pNext-pNext
  `pNext` must be `NULL`.

- VUID-VkFenceGetWin32HandleInfoKHR-fence-parameter
  `fence` must be a valid `VkFence` handle.

- VUID-VkFenceGetWin32HandleInfoKHR-handleType-parameter
  `handleType` must be a valid `VkExternalFenceHandleTypeFlagBits` value.
To export a POSIX file descriptor representing the payload of a fence, call:

```c
// Provided by VK_KHR_external_fence_fd
VkResult vkGetFenceFdKHR(
    VkDevice device,
    const VkFenceGetFdInfoKHR* pGetFdInfo,
    int* pFd);
```

- `device` is the logical device that created the fence being exported.
- `pGetFdInfo` is a pointer to a `VkFenceGetFdInfoKHR` structure containing parameters of the export operation.
- `pFd` will return the file descriptor representing the fence payload.

Each call to `vkGetFenceFdKHR` must create a new file descriptor and transfer ownership of it to the application. To avoid leaking resources, the application must release ownership of the file descriptor when it is no longer needed.

**Note**
Ownership can be released in many ways. For example, the application can call `close()` on the file descriptor, or transfer ownership back to Vulkan by using the file descriptor to import a fence payload.

If `pGetFdInfo->handleType` is `VK_EXTERNAL_FENCE_HANDLE_TYPE_SYNC_FD_BIT` and the fence is signaled at the time `vkGetFenceFdKHR` is called, `pFd` may return the value `-1` instead of a valid file descriptor.

Where supported by the operating system, the implementation must set the file descriptor to be closed automatically when an `execve` system call is made.

Exporting a file descriptor from a fence may have side effects depending on the transference of the specified handle type, as described in Importing Fence State.

**Valid Usage (Implicit)**

- VUID-vkGetFenceFdKHR-device-parameter `device` must be a valid `VkDevice` handle
- VUID-vkGetFenceFdKHR-pGetFdInfo-parameter `pGetFdInfo` must be a valid pointer to a valid `VkFenceGetFdInfoKHR` structure
- VUID-vkGetFenceFdKHR-pFd-parameter `pFd` must be a valid pointer to an `int` value

**Return Codes**

**Success**

- `VK_SUCCESS`
The `VkFenceGetFdInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_external_fence_fd
typedef struct VkFenceGetFdInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkFence fence;
    VkExternalFenceHandleTypeFlagBits handleType;
} VkFenceGetFdInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `fence` is the fence from which state will be exported.
- `handleType` is a `VkExternalFenceHandleTypeFlagBits` value specifying the type of handle requested.

The properties of the file descriptor returned depend on the value of `handleType`. See `VkExternalFenceHandleTypeFlagBits` for a description of the properties of the defined external fence handle types.

**Valid Usage**

- **VUID-VkFenceGetFdInfoKHR-handleType-01453**
  
  `handleType` must have been included in `VkExportFenceCreateInfo::handleTypes` when `fence`'s current payload was created

- **VUID-VkFenceGetFdInfoKHR-handleType-01454**
  
  If `handleType` refers to a handle type with copy payload transference semantics, `fence` must be signaled, or have an associated `fence signal operation` pending execution

- **VUID-VkFenceGetFdInfoKHR-fence-01455**
  
  `fence` must not currently have its payload replaced by an imported payload as described below in Importing Fence Payloads unless that imported payload's handle type was included in `VkExternalFenceProperties::exportFromImportedHandleTypes` for `handleType`

- **VUID-VkFenceGetFdInfoKHR-handleType-01456**
  
  `handleType` must be defined as a POSIX file descriptor handle

**Valid Usage (Implicit)**

- **VUID-VkFenceGetFdInfoKHR-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_FENCE_GET_FD_INFO_KHR`
To destroy a fence, call:

```c
// Provided by VK_VERSION_1_0
define vkDestroyFence
    device, fence, pAllocator);
```

- `device` is the logical device that destroys the fence.
- `fence` is the handle of the fence to destroy.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

### Valid Usage

- **VUID-vkDestroyFence-fence-01120**
  All queue submission commands that refer to `fence` must have completed execution.

- **VUID-vkDestroyFence-fence-01121**
  If `VkAllocationCallbacks` were provided when `fence` was created, a compatible set of callbacks must be provided here.

- **VUID-vkDestroyFence-fence-01122**
  If no `VkAllocationCallbacks` were provided when `fence` was created, `pAllocator` must be `NULL`.

### Valid Usage (Implicit)

- **VUID-vkDestroyFence-device-parameter**
  `device` must be a valid `VkDevice` handle.

- **VUID-vkDestroyFence-fence-parameter**
  If `fence` is not `VK_NULL_HANDLE`, `fence` must be a valid `VkFence` handle.

- **VUID-vkDestroyFence-pAllocator-parameter**
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure.

- **VUID-vkDestroyFence-fence-parent**
  If `fence` is a valid handle, it must have been created, allocated, or retrieved from `device`. 
Host Synchronization

- Host access to fence must be externally synchronized

To query the status of a fence from the host, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkGetFenceStatus(
    VkDevice device,
    VkFence fence);
```

- `device` is the logical device that owns the fence.
- `fence` is the handle of the fence to query.

Upon success, `vkGetFenceStatus` returns the status of the fence object, with the following return codes:

### Table 5. Fence Object Status Codes

<table>
<thead>
<tr>
<th>Status</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_SUCCESS</td>
<td>The fence specified by <code>fence</code> is signaled.</td>
</tr>
<tr>
<td>VK_NOT_READY</td>
<td>The fence specified by <code>fence</code> is unsignaled.</td>
</tr>
<tr>
<td>VK_ERROR_DEVICE_LOST</td>
<td>The device has been lost. See Lost Device.</td>
</tr>
</tbody>
</table>

If a queue submission command is pending execution, then the value returned by this command may immediately be out of date.

If the device has been lost (see Lost Device), `vkGetFenceStatus` may return any of the above status codes. If the device has been lost and `vkGetFenceStatus` is called repeatedly, it will eventually return either VK_SUCCESS or VK_ERROR_DEVICE_LOST.

### Valid Usage (Implicit)

- VUID-vkGetFenceStatus-device-parameter
  - `device` must be a valid `VkDevice` handle
- VUID-vkGetFenceStatus-fence-parameter
  - `fence` must be a valid `VkFence` handle
- VUID-vkGetFenceStatus-fence-parent
  - `fence` must have been created, allocated, or retrieved from `device`
Return Codes

**Success**

- VK_SUCCESS
- VK_NOT_READY

**Failure**

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_DEVICE_LOST

To set the state of fences to unsignaled from the host, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkResetFences(
    VkDevice device,
    uint32_t fenceCount,
    const VkFence* pFences);
```

- `device` is the logical device that owns the fences.
- `fenceCount` is the number of fences to reset.
- `pFences` is a pointer to an array of fence handles to reset.

If any member of `pFences` currently has its payload imported with temporary permanence, that fence’s prior permanent payload is first restored. The remaining operations described therefore operate on the restored payload.

When `vkResetFences` is executed on the host, it defines a fence unsignal operation for each fence, which resets the fence to the unsignaled state.

If any member of `pFences` is already in the unsignaled state when `vkResetFences` is executed, then `vkResetFences` has no effect on that fence.

**Valid Usage**

- VUID-vkResetFences-pFences-01123
  Each element of `pFences` must not be currently associated with any queue command that has not yet completed execution on that queue

**Valid Usage (Implicit)**

- VUID-vkResetFences-device-parameter
  `device` must be a valid `VkDevice` handle
• **VUID-vkResetFences-pFences-parameter**
  *pFences must* be a valid pointer to an array of *fenceCount* valid *VkFence* handles

• **VUID-vkResetFences-fenceCount-arraylength**
  *fenceCount must* be greater than 0

• **VUID-vkResetFences-pFences-parent**
  Each element of *pFences must* have been created, allocated, or retrieved from *device*

---

**Host Synchronization**

• Host access to each member of *pFences must* be externally synchronized

---

**Return Codes**

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_DEVICE_MEMORY

---

When a fence is submitted to a queue as part of a *queue submission* command, it defines a memory dependency on the batches that were submitted as part of that command, and defines a *fence signal operation* which sets the fence to the signaled state.

The first *synchronization scope* includes every batch submitted in the same *queue submission* command. Fence signal operations that are defined by *vkQueueSubmit* or *vkQueueSubmit2* additionally include in the first synchronization scope all commands that occur earlier in *submission order*. Fence signal operations that are defined by *vkQueueSubmit* or *vkQueueSubmit2* or *vkQueueBindSparse* additionally include in the first synchronization scope any semaphore and fence signal operations that occur earlier in *signal operation order*.

The second *synchronization scope* only includes the fence signal operation.

The first *access scope* includes all memory access performed by the device.

The second *access scope* is empty.

To wait for one or more fences to enter the signaled state on the host, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkWaitForFences(
    VkDevice device,
    uint32_t fenceCount,
    const VkFence* pFences,
    VkBool32 waitAll,
    uint64_t timeout);
```
• **device** is the logical device that owns the fences.

• **fenceCount** is the number of fences to wait on.

• **pFences** is a pointer to an array of **fenceCount** fence handles.

• **waitAll** is the condition that **must** be satisfied to successfully unblock the wait. If **waitAll** is **VK_TRUE**, then the condition is that all fences in **pFences** are signaled. Otherwise, the condition is that at least one fence in **pFences** is signaled.

• **timeout** is the timeout period in units of nanoseconds. **timeout** is adjusted to the closest value allowed by the implementation-dependent timeout accuracy, which **may** be substantially longer than one nanosecond, and **may** be longer than the requested period.

If the condition is satisfied when **vkWaitForFences** is called, then **vkWaitForFences** returns immediately. If the condition is not satisfied at the time **vkWaitForFences** is called, then **vkWaitForFences** will block and wait until the condition is satisfied or the **timeout** has expired, whichever is sooner.

If **timeout** is zero, then **vkWaitForFences** does not wait, but simply returns the current state of the fences. **VK_TIMEOUT** will be returned in this case if the condition is not satisfied, even though no actual wait was performed.

If the condition is satisfied before the **timeout** has expired, **vkWaitForFences** returns **VK_SUCCESS**. Otherwise, **vkWaitForFences** returns **VK_TIMEOUT** after the **timeout** has expired.

If device loss occurs (see Lost Device) before the timeout has expired, **vkWaitForFences** must return in finite time with either **VK_SUCCESS** or **VK_ERROR_DEVICE_LOST**.

**Note**

While we guarantee that **vkWaitForFences** **must** return in finite time, no guarantees are made that it returns immediately upon device loss. However, the client can reasonably expect that the delay will be on the order of seconds and that calling **vkWaitForFences** will not result in a permanently (or seemingly permanently) dead process.

**Valid Usage (Implicit)**

- **VUID-vkWaitForFences-device-parameter**
  
  **device** **must** be a valid **VkDevice** handle

- **VUID-vkWaitForFences-pFences-parameter**
  
  **pFences** **must** be a valid pointer to an array of **fenceCount** valid **VkFence** handles

- **VUID-vkWaitForFences-fenceCount-arraylength**
  
  **fenceCount** **must** be greater than 0

- **VUID-vkWaitForFences-pFences-parent**
  
  Each element of **pFences** **must** have been created, allocated, or retrieved from **device**
Return Codes

Success
• VK_SUCCESS
• VK_TIMEOUT

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY
• VK_ERROR_DEVICE_LOST

An execution dependency is defined by waiting for a fence to become signaled, either via `vkWaitForFences` or by polling on `vkGetFenceStatus`.

The first synchronization scope includes only the fence signal operation.

The second synchronization scope includes the host operations of `vkWaitForFences` or `vkGetFenceStatus` indicating that the fence has become signaled.

Note
Signaling a fence and waiting on the host does not guarantee that the results of memory accesses will be visible to the host, as the access scope of a memory dependency defined by a fence only includes device access. A memory barrier or other memory dependency must be used to guarantee this. See the description of host access types for more information.

7.3.1. Alternate Methods to Signal Fences

Besides submitting a fence to a queue as part of a queue submission command, a fence may also be signaled when a particular event occurs on a device or display.

To create a fence that will be signaled when an event occurs on a device, call:

```c
// Provided by VK_EXT_display_control
VkResult vkRegisterDeviceEventEXT(
    VkDevice device,
    const VkDeviceEventInfoEXT* pDeviceEventInfo,
    const VkAllocationCallbacks* pAllocator,
    VkFence* pFence);
```

- `device` is a logical device on which the event may occur.
- `pDeviceEventInfo` is a pointer to a `VkDeviceEventInfoEXT` structure describing the event of interest to the application.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
• `pFence` is a pointer to a handle in which the resulting fence object is returned.

Valid Usage (Implicit)

• VUID-vkRegisterDeviceEventEXT-device-parameter
  
  `device` must be a valid `VkDevice` handle

• VUID-vkRegisterDeviceEventEXT-pDeviceEventInfo-parameter
  
  `pDeviceEventInfo` must be a valid pointer to a valid `VkDeviceEventInfoEXT` structure

• VUID-vkRegisterDeviceEventEXT-pAllocator-parameter
  
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

• VUID-vkRegisterDeviceEventEXT-pFence-parameter
  
  `pFence` must be a valid pointer to a `VkFence` handle

Return Codes

Success

• `VK_SUCCESS`

Failure

• `VK_ERROR_OUT_OF_HOST_MEMORY`

The `VkDeviceEventInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_display_control
typedef struct VkDeviceEventInfoEXT {
    VkStructureType sType;
    const void*pNext;
    VkDeviceEventTypeEXT deviceEvent;
} VkDeviceEventInfoEXT;
```

• `sType` is a `VkStructureType` value identifying this structure.

• `pNext` is `NULL` or a pointer to a structure extending this structure.

• `device` is a `VkDeviceEventTypeEXT` value specifying when the fence will be signaled.

Valid Usage (Implicit)

• VUID-VkDeviceEventInfoEXT-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_DEVICE_EVENT_INFO_EXT`

• VUID-VkDeviceEventInfoEXT-pNext-pNext
  
  `pNext` must be `NULL`

• VUID-VkDeviceEventInfoEXT-deviceEvent-parameter
deviceEvent must be a valid VkDeviceEventTypeEXT value

Possible values of VkDeviceEventInfoEXT::device, specifying when a fence will be signaled, are:

```c
// Provided by VK_EXT_display_control
typedef enumVkDeviceEventTypeEXT {
    VKDEVICEEVENTTYPE_DISPLAYHOTPLUG_EXT = 0,
} VkDeviceEventTypeEXT;
```

• VK_DEVICE_EVENT_TYPE_DISPLAY_HOTPLUG_EXT specifies that the fence is signaled when a display is plugged into or unplugged from the specified device. Applications can use this notification to determine when they need to re-enumerate the available displays on a device.

To create a fence that will be signaled when an event occurs on a VkDisplayKHR object, call:

```c
// Provided by VK_EXT_display_control
VkResult vkRegisterDisplayEventEXT(
    VkDevice device,                  // device
    VkDisplayKHR display,             // display
    const VkDisplayEventInfoEXT* pDisplayEventInfo, // pDisplayEventInfo
    const VkAllocationCallbacks* pAllocator, // pAllocator
    VkFence* pFence); // pFence
```

• device is a logical device associated with display
• display is the display on which the event may occur.
• pDisplayEventInfo is a pointer to a VkDisplayEventInfoEXT structure describing the event of interest to the application.
• pAllocator controls host memory allocation as described in the Memory Allocation chapter.
• pFence is a pointer to a handle in which the resulting fence object is returned.

Valid Usage (Implicit)

• VUID-vkRegisterDisplayEventEXT-device-parameter
device must be a valid VkDevice handle
• VUID-vkRegisterDisplayEventEXT-display-parameter
display must be a valid VkDisplayKHR handle
• VUID-vkRegisterDisplayEventEXT-pDisplayEventInfo-parameter
pDisplayEventInfo must be a valid pointer to a valid VkDisplayEventInfoEXT structure
• VUID-vkRegisterDisplayEventEXT-pAllocator-parameter
If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure
• VUID-vkRegisterDisplayEventEXT-pFence-parameter
pFence must be a valid pointer to a VkFence handle
Both of device, and display must have been created, allocated, or retrieved from the same VkPhysicalDevice.

### Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY

The `VkDisplayEventInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_display_control
typedef struct VkDisplayEventInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkDisplayEventTypeEXT displayEvent;
} VkDisplayEventInfoEXT;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `displayEvent` is a VkDisplayEventTypeEXT specifying when the fence will be signaled.

### Valid Usage (Implicit)

- VUID-VkDisplayEventInfoEXT-sType-sType
  `sType` must be VK_STRUCTURE_TYPE_DISPLAY_EVENT_INFO_EXT

- VUID-VkDisplayEventInfoEXT-pNext-pNext
  `pNext` must be NULL

- VUID-VkDisplayEventInfoEXT-displayEvent-parameter
  `displayEvent` must be a valid VkDisplayEventTypeEXT value

Possible values of `VkDisplayEventInfoEXT::displayEvent`, specifying when a fence will be signaled, are:

```c
// Provided by VK_EXT_display_control
typedef enum VkDisplayEventTypeEXT {
    VK_DISPLAY_EVENT_TYPE_FIRST_PIXEL_OUT_EXT = 0,
} VkDisplayEventTypeEXT;
```

- `VK_DISPLAY_EVENT_TYPE_FIRST_PIXEL_OUT_EXT` specifies that the fence is signaled when the first
Applications can import a fence payload into an existing fence using an external fence handle. The effects of the import operation will be either temporary or permanent, as specified by the application. If the import is temporary, the fence will be restored to its permanent state the next time that fence is passed to `vkResetFences`.

Performing a subsequent temporary import on a fence before resetting it has no effect on this requirement; the next unsignal of the fence must still restore its last permanent state. A permanent payload import behaves as if the target fence was destroyed, and a new fence was created with the same handle but the imported payload. Because importing a fence payload temporarily or permanently detaches the existing payload from a fence, similar usage restrictions to those applied to `vkDestroyFence` are applied to any command that imports a fence payload. Which of these import types is used is referred to as the import operation’s permanence. Each handle type supports either one or both types of permanence.

The implementation must perform the import operation by either referencing or copying the payload referred to by the specified external fence handle, depending on the handle’s type. The import method used is referred to as the handle type’s transference. When using handle types with reference transference, importing a payload to a fence adds the fence to the set of all fences sharing that payload. This set includes the fence from which the payload was exported. Fence signaling, waiting, and resetting operations performed on any fence in the set must behave as if the set were a single fence. Importing a payload using handle types with copy transference creates a duplicate copy of the payload at the time of import, but makes no further reference to it. Fence signaling, waiting, and resetting operations performed on the target of copy imports must not affect any other fence or payload.

Export operations have the same transference as the specified handle type’s import operations. Additionally, exporting a fence payload to a handle with copy transference has the same side effects on the source fence’s payload as executing a fence reset operation. If the fence was using a temporarily imported payload, the fence’s prior permanent payload will be restored.

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External synchronization allows implementations to modify an object’s internal state, i.e. payload, without internal synchronization. However, for fences sharing a payload across processes, satisfying the external synchronization requirements of `VkFence` parameters as if all fences in the set were the same object is sometimes infeasible. Satisfying valid usage constraints on the state of a fence would similarly require impractical coordination or levels of trust between processes.
Therefore, these constraints only apply to a specific fence handle, not to its payload. For distinct fence objects which share a payload:

- If multiple commands which queue a signal operation, or which unsignal a fence, are called concurrently, behavior will be as if the commands were called in an arbitrary sequential order.
- If a queue submission command is called with a fence that is sharing a payload, and the payload is already associated with another queue command that has not yet completed execution, either one or both of the commands will cause the fence to become signaled when they complete execution.
- If a fence payload is reset while it is associated with a queue command that has not yet completed execution, the payload will become unsignaled, but may become signaled again when the command completes execution.
- In the preceding cases, any of the devices associated with the fences sharing the payload may be lost, or any of the queue submission or fence reset commands may return VK_ERROR_INITIALIZATION_FAILED.

Other than these non-deterministic results, behavior is well defined. In particular:

- The implementation must not crash or enter an internally inconsistent state where future valid Vulkan commands might cause undefined results,
- Timeouts on future wait commands on fences sharing the payload must be effective.

**Note**

These rules allow processes to synchronize access to shared memory without trusting each other. However, such processes must still be cautious not to use the shared fence for more than synchronizing access to the shared memory. For example, a process should not use a fence with shared payload to tell when commands it submitted to a queue have completed and objects used by those commands may be destroyed, since the other process can accidentally or maliciously cause the fence to signal before the commands actually complete.

When a fence is using an imported payload, its `VkExportFenceCreateInfo::handleTypes` value is specified when creating the fence from which the payload was exported, rather than specified when creating the fence. Additionally, `VkExternalFenceProperties::exportFromImportedHandleTypes` restricts which handle types can be exported from such a fence based on the specific handle type used to import the current payload. Passing a fence to `vkAcquireNextImageKHR` is equivalent to temporarily importing a fence payload to that fence.

**Note**

Because the exportable handle types of an imported fence correspond to its current imported payload, and `vkAcquireNextImageKHR` behaves the same as a temporary import operation for which the source fence is opaque to the application, applications have no way of determining whether any external handle types can be exported from a fence in this state. Therefore, applications must not attempt to export handles from fences using a temporarily imported payload from `vkAcquireNextImageKHR`. 


When importing a fence payload, it is the responsibility of the application to ensure the external handles meet all valid usage requirements. However, implementations must perform sufficient validation of external handles to ensure that the operation results in a valid fence which will not cause program termination, device loss, queue stalls, host thread stalls, or corruption of other resources when used as allowed according to its import parameters. If the external handle provided does not meet these requirements, the implementation must fail the fence payload import operation with the error code VK_ERROR_INVALID_EXTERNAL_HANDLE.

To import a fence payload from a Windows handle, call:

```c
// Provided by VK_KHR_external_fence_win32
VkResult vkImportFenceWin32HandleKHR(
    VkDevice device,
    const VkImportFenceWin32HandleInfoKHR* pImportFenceWin32HandleInfo);
```

- `device` is the logical device that created the fence.
- `pImportFenceWin32HandleInfo` is a pointer to a `VkImportFenceWin32HandleInfoKHR` structure specifying the fence and import parameters.

Importing a fence payload from Windows handles does not transfer ownership of the handle to the Vulkan implementation. For handle types defined as NT handles, the application must release ownership using the `CloseHandle` system call when the handle is no longer needed.

Applications can import the same fence payload into multiple instances of Vulkan, into the same instance from which it was exported, and multiple times into a given Vulkan instance.

### Valid Usage

- VUID-vkImportFenceWin32HandleKHR-fence-04448
  fence must not be associated with any queue command that has not yet completed execution on that queue

### Valid Usage (Implicit)

- VUID-vkImportFenceWin32HandleKHR-device-parameter
  `device must` be a valid `VkDevice` handle
- VUID-vkImportFenceWin32HandleKHR-pImportFenceWin32HandleInfo-parameter
  `pImportFenceWin32HandleInfo must` be a valid pointer to a valid `VkImportFenceWin32HandleInfoKHR` structure

### Return Codes

**Success**

- `VK_SUCCESS`
Failure

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_INVALID_EXTERNAL_HANDLE

The **VkImportFenceWin32HandleInfoKHR** structure is defined as:

```c
// Provided by VK_KHR_external_fence_win32
typedef struct VkImportFenceWin32HandleInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkFence fence;
    VkFenceImportFlags flags;
    VkExternalFenceHandleTypeFlagBits handleType;
    HANDLE handle;
    LPCWSTR name;
} VkImportFenceWin32HandleInfoKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **fence** is the fence into which the state will be imported.
- **flags** is a bitmask of `VkFenceImportFlagBits` specifying additional parameters for the fence payload import operation.
- **handleType** is a `VkExternalFenceHandleTypeFlagBits` value specifying the type of `handle`.
- **handle** is `NULL` or the external handle to import.
- **name** is `NULL` or a null-terminated UTF-16 string naming the underlying synchronization primitive to import.

The handle types supported by **handleType** are:

**Table 6. Handle Types Supported by VkImportFenceWin32HandleInfoKHR**

<table>
<thead>
<tr>
<th>Handle Type</th>
<th>Transference</th>
<th>Permanence Supported</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_BIT</td>
<td>Reference</td>
<td>Temporary,Permanent</td>
</tr>
<tr>
<td>VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_KMT_B</td>
<td>Reference</td>
<td>Temporary,Permanent</td>
</tr>
</tbody>
</table>

**Valid Usage**

- VUID-VkImportFenceWin32HandleInfoKHR-handleType-01457
  **handleType** must be a value included in the **Handle Types Supported by VkImportFenceWin32HandleInfoKHR** table
- VUID-VkImportFenceWin32HandleInfoKHR-handleType-01459
If `handleType` is not `VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_BIT`, name must be NULL

- VUID-VkImportFenceWin32HandleInfoKHR-handleType-01460
  If `handle` is NULL, name must name a valid synchronization primitive of the type specified by `handleType`

- VUID-VkImportFenceWin32HandleInfoKHR-handleType-01461
  If name is NULL, handle must be a valid handle of the type specified by `handleType`

- VUID-VkImportFenceWin32HandleInfoKHR-handleType-01462
  If `handle` is not NULL, name must be NULL

- VUID-VkImportFenceWin32HandleInfoKHR-handle-01463
  If name is NULL, handle must obey any requirements listed for `handleType` in external fence handle types compatibility

- VUID-VkImportFenceWin32HandleInfoKHR-name-01464
  If name is not NULL, it must obey any requirements listed for `handleType` in external fence handle types compatibility

**Valid Usage (Implicit)**

- VUID-VkImportFenceWin32HandleInfoKHR-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_IMPORT_FENCE_WIN32_HANDLE_INFO_KHR`

- VUID-VkImportFenceWin32HandleInfoKHR-pNext-pNext
  `pNext` must be NULL

- VUID-VkImportFenceWin32HandleInfoKHR-fence-parameter
  `fence` must be a valid `VkFence` handle

- VUID-VkImportFenceWin32HandleInfoKHR-flags-parameter
  `flags` must be a valid combination of `VkFenceImportFlagBits` values

**Host Synchronization**

- Host access to `fence` must be externally synchronized

To import a fence payload from a POSIX file descriptor, call:

```c
// Provided by VK_KHR_external_fence_fd
VkResult vkImportFenceFdKHR(
    VkDevice device,
    const VkImportFenceFdInfoKHR* pImportFenceFdInfo);
```

- `device` is the logical device that created the fence.
- `pImportFenceFdInfo` is a pointer to a `VkImportFenceFdInfoKHR` structure specifying the fence and import parameters.
Importing a fence payload from a file descriptor transfers ownership of the file descriptor from the application to the Vulkan implementation. The application **must** not perform any operations on the file descriptor after a successful import.

Applications **can** import the same fence payload into multiple instances of Vulkan, into the same instance from which it was exported, and multiple times into a given Vulkan instance.

### Valid Usage

- **VUID-vkImportFenceFdKHR-fence-01463**
  - *fence must not be associated with any queue command that has not yet completed execution on that queue*

### Valid Usage (Implicit)

- **VUID-vkImportFenceFdKHR-device-parameter**
  - *device must be a valid *VkDevice* handle*

- **VUID-vkImportFenceFdKHR-pImportFenceFdInfo-parameter**
  - *pImportFenceFdInfo must be a valid pointer to a valid *VkImportFenceFdInfoKHR* structure*

### Return Codes

**Success**

- **VK_SUCCESS**

**Failure**

- **VK_ERROR_OUT_OF_HOST_MEMORY**
- **VK_ERROR_INVALID_EXTERNAL_HANDLE**

The *VkImportFenceFdInfoKHR* structure is defined as:

```c
// Provided by VK_KHR_external_fence_fd
typedef struct VkImportFenceFdInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkFence fence;
    VkFenceImportFlags flags;
    VkExternalFenceHandleTypeFlagBits handleType;
    int fd;
} VkImportFenceFdInfoKHR;
```

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
• **fence** is the fence into which the payload will be imported.
• **flags** is a bitmask of VkFenceImportFlagBits specifying additional parameters for the fence payload import operation.
• **handleType** is a VkExternalFenceHandleTypeFlagBits value specifying the type of **fd**.
• **fd** is the external handle to import.

The handle types supported by **handleType** are:

<table>
<thead>
<tr>
<th>Handle Type</th>
<th>Transference</th>
<th>Permanence Supported</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_FD_BIT</td>
<td>Reference</td>
<td>Temporary, Permanent</td>
</tr>
<tr>
<td>VK_EXTERNAL_FENCE_HANDLE_TYPE_SYNC_FD_BIT</td>
<td>Copy</td>
<td>Temporary</td>
</tr>
</tbody>
</table>

**Valid Usage**

- **VUID-VkImportFenceFdInfoKHR-handleType-01464**
  - **handleType** must be a value included in the Handle Types Supported by VkImportFenceFdInfoKHR table
- **VUID-VkImportFenceFdInfoKHR-fd-01541**
  - **fd** must obey any requirements listed for **handleType** in external fence handle types compatibility
- **VUID-VkImportFenceFdInfoKHR-handleType-07306**
  - If **handleType** refers to a handle type with copy payload transference semantics, **flags** must contain VK_FENCE_IMPORT_TEMPORARY_BIT

If **handleType** is VK_EXTERNAL_FENCE_HANDLE_TYPE_SYNC_FD_BIT, the special value -1 for **fd** is treated like a valid sync file descriptor referring to an object that has already signaled. The import operation will succeed and the **VkFence** will have a temporarily imported payload as if a valid file descriptor had been provided.

**Note**

This special behavior for importing an invalid sync file descriptor allows easier interoperability with other system APIs which use the convention that an invalid sync file descriptor represents work that has already completed and does not need to be waited for. It is consistent with the option for implementations to return a -1 file descriptor when exporting a VK_EXTERNAL_FENCE_HANDLE_TYPE_SYNC_FD_BIT from a **VkFence** which is signaled.

**Valid Usage (Implicit)**

- **VUID-VkImportFenceFdInfoKHR-sType-sType**
  - **sType** must be VK_STRUCTURE_TYPE_IMPORT_FENCE_FD_INFO_KHR
• VUID-VkImportFenceFdInfoKHR-pNext-pNext
  pNext must be NULL

• VUID-VkImportFenceFdInfoKHR-fence-parameter
  fence must be a valid VkFence handle

• VUID-VkImportFenceFdInfoKHR-flags-parameter
  flags must be a valid combination of VkFenceImportFlagBits values

• VUID-VkImportFenceFdInfoKHR-handleType-parameter
  handleType must be a valid VkExternalFenceHandleTypeFlagBits value

---

**Host Synchronization**

- Host access to fence must be externally synchronized

---

Bits which can be set in

- VkImportFenceWin32HandleInfoKHR::flags
- VkImportFenceFdInfoKHR::flags

specifying additional parameters of a fence import operation are:

```c
// Provided by VK_VERSION_1_1
typedef enum VkFenceImportFlagBits {
  VK_FENCE_IMPORT_TEMPORARY_BIT = 0x00000001,
// Provided by VK_KHR_external_fence
  VK_FENCE_IMPORT_TEMPORARY_BIT_KHR = VK_FENCE_IMPORT_TEMPORARY_BIT,
} VkFenceImportFlagBits;
```

or the equivalent

```c
// Provided by VK_KHR_external_fence
typedef VkFenceImportFlagBits VkFenceImportFlagBitsKHR;
```

- **VK_FENCE_IMPORT_TEMPORARY_BIT** specifies that the fence payload will be imported only temporarily, as described in Importing Fence Payloads, regardless of the permanence of handleType.

```c
// Provided by VK_VERSION_1_1
typedef VkFlags VkFenceImportFlags;
```

or the equivalent

```c
// Provided by VK_KHR_external_fence
```
typedef VkFenceImportFlags VkFenceImportFlagsKHR;

VkFenceImportFlags is a bitmask type for setting a mask of zero or more VkFenceImportFlagBits.

### 7.4. Semaphores

Semaphores are a synchronization primitive that can be used to insert a dependency between queue operations or between a queue operation and the host. Binary semaphores have two states—signaled and unsignaled. Timeline semaphores have a strictly increasing 64-bit unsigned integer payload and are signaled with respect to a particular reference value. A semaphore can be signaled after execution of a queue operation is completed, and a queue operation can wait for a semaphore to become signaled before it begins execution. A timeline semaphore can additionally be signaled from the host with the vkSignalSemaphore command and waited on from the host with the vkWaitSemaphores command.

The internal data of a semaphore may include a reference to any resources and pending work associated with signal or unsignal operations performed on that semaphore object, collectively referred to as the semaphore's payload. Mechanisms to import and export that internal data to and from semaphores are provided below. These mechanisms indirectly enable applications to share semaphore state between two or more semaphores and other synchronization primitives across process and API boundaries.

Semaphores are represented by VkSemaphore handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkSemaphore)
```

To create a semaphore, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkCreateSemaphore(
    VkDevice                device,
    const VkSemaphoreCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkSemaphore*            pSemaphore);
```

- **device** is the logical device that creates the semaphore.
- **pCreateInfo** is a pointer to a VkSemaphoreCreateInfo structure containing information about how the semaphore is to be created.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
- **pSemaphore** is a pointer to a handle in which the resulting semaphore object is returned.

Valid Usage (Implicit)

- VUID-vkCreateSemaphore-device-parameter
device must be a valid VkDevice handle

- VUID-vkCreateSemaphore-pCreateInfo-parameter
  pCreateInfo must be a valid pointer to a valid VkSemaphoreCreateInfo structure

- VUID-vkCreateSemaphore-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkCreateSemaphore-pSemaphore-parameter
  pSemaphore must be a valid pointer to a VkSemaphore handle

---

**Return Codes**

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkSemaphoreCreateInfo structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkSemaphoreCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkSemaphoreCreateFlags flags;
} VkSemaphoreCreateInfo;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- flags is reserved for future use.

---

**Valid Usage**

- VUID-VkSemaphoreCreateInfo-pNext-06789
  If the pNext chain includes a VkExportMetalObjectCreateInfoEXT structure, its exportObjectType member must be VK_EXPORT_METAL_OBJECT_TYPE_METAL_SHARED_EVENT_BIT_EXT

---

**Valid Usage (Implicit)**

- VUID-VkSemaphoreCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_SEMAPHORE_CREATE_INFO
Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkExportMetalObjectCreateInfoEXT`, `VkExportSemaphoreCreateInfo`, `VkImportMetalSharedEventInfoEXT`, `VkQueryLowLatencySupportNV`, or `VkSemaphoreTypeCreateInfo`.

The `sType` value of each struct in the `pNext` chain must be unique, with the exception of structures of type `VkExportMetalObjectCreateInfoEXT`.

Flags must be 0.

```
typedef VkFlags VkSemaphoreCreateFlags;
```

`VkSemaphoreCreateFlags` is a bitmask type for setting a mask, but is currently reserved for future use.

The `VkSemaphoreTypeCreateInfo` structure is defined as:

```
// Provided by VK_VERSION_1_0
typedef struct VkSemaphoreTypeCreateInfo {
    VkStructureType sType;
    const void*pNext;
    VkSemaphoreType semaphoreType;
    uint64_t initialValue;
} VkSemaphoreTypeCreateInfo;
```

or the equivalent

```
// Provided by VK_KHR_timeline_semaphore
typedef VkSemaphoreTypeCreateInfo VkSemaphoreTypeCreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `semaphoreType` is a `VkSemaphoreType` value specifying the type of the semaphore.
- `initialValue` is the initial payload value if `semaphoreType` is `VK_SEMAPHORE_TYPE_TIMELINE`.

To create a semaphore of a specific type, add a `VkSemaphoreTypeCreateInfo` structure to the `pNext` chain of `VkSemaphoreCreateInfo`.

If no `VkSemaphoreTypeCreateInfo` structure is included in the `pNext` chain of `VkSemaphoreCreateInfo`, then the created semaphore will have a default `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_BINARY`. 
Valid Usage

- VUID-VkSemaphoreTypeCreateInfo-timelineSemaphore-03252
  If the `timelineSemaphore` feature is not enabled, `semaphoreType` must not equal `VK_SEMAPHORE_TYPE_TIMELINE`

- VUID-VkSemaphoreTypeCreateInfo-semaphoreType-03279
  If `semaphoreType` is `VK_SEMAPHORE_TYPE_BINARY`, `initialValue` must be zero

Valid Usage (Implicit)

- VUID-VkSemaphoreTypeCreateInfo-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_SEMAPHORE_TYPE_CREATE_INFO`

- VUID-VkSemaphoreTypeCreateInfo-semaphoreType-parameter
  `semaphoreType` must be a valid `VkSemaphoreType` value

Possible values of `VkSemaphoreTypeCreateInfo::semaphoreType`, specifying the type of a semaphore, are:

```c
// Provided by VK_VERSION_1_2
typedef enum VkSemaphoreType {
    VK_SEMAPHORE_TYPE_BINARY = 0,
    VK_SEMAPHORE_TYPE_TIMELINE = 1,
    // Provided by VK_KHR_timeline_semaphore
    VK_SEMAPHORE_TYPE_BINARY_KHR = VK_SEMAPHORE_TYPE_BINARY,
    // Provided by VK_KHR_timeline_semaphore
    VK_SEMAPHORE_TYPE_TIMELINE_KHR = VK_SEMAPHORE_TYPE_TIMELINE,
} VkSemaphoreType;
```

or the equivalent

```c
// Provided by VK_KHR_timeline_semaphore
typedef VkSemaphoreType VkSemaphoreTypeKHR;
```

- `VK_SEMAPHORE_TYPE_BINARY` specifies a `binary semaphore` type that has a boolean payload indicating whether the semaphore is currently signaled or unsignaled. When created, the semaphore is in the unsignaled state.

- `VK_SEMAPHORE_TYPE_TIMELINE` specifies a `timeline semaphore` type that has a strictly increasing 64-bit unsigned integer payload indicating whether the semaphore is signaled with respect to a particular reference value. When created, the semaphore payload has the value given by the `initialValue` field of `VkSemaphoreTypeCreateInfo`.

To create a semaphore whose payload can be exported to external handles, add a `VkExportSemaphoreCreateInfo` structure to the `pNext` chain of the `VkSemaphoreCreateInfo`.
structure. The \texttt{VkExportSemaphoreCreateInfo} structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkExportSemaphoreCreateInfo {
    VkStructureType sType;
    const \textbf{void}* pNext;
    VkExternalSemaphoreHandleTypeFlags handleTypes;
} VkExportSemaphoreCreateInfo;
```

or the equivalent

```c
// Provided by VK_KHR_external_semaphore
typedef VkExportSemaphoreCreateInfo VkExportSemaphoreCreateInfoKHR;
```

- \texttt{sType} is a \texttt{VkStructureType} value identifying this structure.
- \texttt{pNext} is \texttt{NULL} or a pointer to a structure extending this structure.
- \texttt{handleTypes} is a bitmask of \texttt{VkExternalSemaphoreHandleTypeFlagBits} specifying one or more semaphore handle types the application \textbf{can} export from the resulting semaphore. The application \textbf{can} request multiple handle types for the same semaphore.

### Valid Usage

- VUID-VkExportSemaphoreCreateInfo-handleTypes-01124
  The bits in \texttt{handleTypes} \textbf{must} be supported and compatible, as reported by \texttt{VkExternalSemaphoreProperties}.

### Valid Usage (Implicit)

- VUID-VkExportSemaphoreCreateInfo-sType-sType
  \texttt{sType} \textbf{must} be \texttt{VK_STRUCTURE_TYPE_EXPORT_SEMAPHORE_CREATE_INFO}.

- VUID-VkExportSemaphoreCreateInfo-handleTypes-parameter
  \texttt{handleTypes} \textbf{must} be a valid combination of \texttt{VkExternalSemaphoreHandleTypeFlagBits} values.

To specify additional attributes of NT handles exported from a semaphore, add a \texttt{VkExportSemaphoreWin32HandleInfoKHR} structure to the \texttt{pNext} chain of the \texttt{VkSemaphoreCreateInfo} structure. The \texttt{VkExportSemaphoreWin32HandleInfoKHR} structure is defined as:

```c
// Provided by VK_KHR_external_semaphore_win32
typedef struct VkExportSemaphoreWin32HandleInfoKHR {
    VkStructureType sType;
    const \textbf{void}* pNext;
    const SECURITY_ATTRIBUTES* pAttributes;
} VkExportSemaphoreWin32HandleInfoKHR;
```
DWORD dwAccess;
LPCWSTR name;
}

VkExportSemaphoreWin32HandleInfoKHR

• **sType** is a **VkStructureType** value identifying this structure.
• **pNext** is **NULL** or a pointer to a structure extending this structure.
• **pAttributes** is a pointer to a Windows **SECURITY_ATTRIBUTES** structure specifying security attributes of the handle.
• **dwAccess** is a **DWORD** specifying access rights of the handle.
• **name** is a null-terminated UTF-16 string to associate with the underlying synchronization primitive referenced by NT handles exported from the created semaphore.

If **VkExportSemaphoreCreateInfo** is not included in the same **pNext** chain, this structure is ignored.

If **VkExportSemaphoreCreateInfo** is included in the **pNext** chain of **VkSemaphoreCreateInfo** with a Windows **handleType**, but either **VkExportSemaphoreWin32HandleInfoKHR** is not included in the **pNext** chain, or it is included but **pAttributes** is set to **NULL**, default security descriptor values will be used, and child processes created by the application will not inherit the handle, as described in the MSDN documentation for “Synchronization Object Security and Access Rights”¹. Further, if the structure is not present, the access rights used depend on the handle type.

For handles of the following types:

**VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_BIT**

The implementation **must** ensure the access rights allow both signal and wait operations on the semaphore.

For handles of the following types:

**VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_D3D12_FENCE_BIT**

The access rights **must** be:

**GENERIC_ALL**


---

**Valid Usage**

- **VUID-VkExportSemaphoreWin32HandleInfoKHR-handleTypes-01125**
  If **VkExportSemaphoreCreateInfo::handleTypes** does not include **VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_BIT** or **VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_D3D12_FENCE_BIT**, **VkExportSemaphoreWin32HandleInfoKHR** **must** not be included in the **pNext** chain of **VkSemaphoreCreateInfo**
To export a Windows handle representing the payload of a semaphore, call:

```c
// Provided by VK_KHR_external_semaphore_win32
VkResult vkGetSemaphoreWin32HandleKHR(
    VkDevice device,
    const VkSemaphoreGetWin32HandleInfoKHR* pGetWin32HandleInfo,
    HANDLE* pHandle);
```

- `device` is the logical device that created the semaphore being exported.
- `pGetWin32HandleInfo` is a pointer to a `VkSemaphoreGetWin32HandleInfoKHR` structure containing parameters of the export operation.
- `pHandle` will return the Windows handle representing the semaphore state.

For handle types defined as NT handles, the handles returned by `vkGetSemaphoreWin32HandleKHR` are owned by the application. To avoid leaking resources, the application must release ownership of them using the `CloseHandle` system call when they are no longer needed.

Exporting a Windows handle from a semaphore may have side effects depending on the transference of the specified handle type, as described in Importing Semaphore Payloads.

### Valid Usage (Implicit)

- **VUID-vkGetSemaphoreWin32HandleKHR-device-parameter** `device` must be a valid `VkDevice` handle
- **VUID-vkGetSemaphoreWin32HandleKHR-pGetWin32HandleInfo-parameter** `pGetWin32HandleInfo` must be a valid pointer to a valid `VkSemaphoreGetWin32HandleInfoKHR` structure
- **VUID-vkGetSemaphoreWin32HandleKHR-pHandle-parameter** `pHandle` must be a valid pointer to a `HANDLE` value

### Return Codes

**Success**

- **VK_SUCCESS**
Failure

- VK_ERROR_TOO_MANY_OBJECTS
- VK_ERROR_OUT_OF_HOST_MEMORY

The VkSemaphoreGetWin32HandleInfoKHR structure is defined as:

```c
// Provided by VK_KHR_external_semaphore_win32
typedef struct VkSemaphoreGetWin32HandleInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkSemaphore semaphore;
    VkExternalSemaphoreHandleTypeFlagBits handleType;
} VkSemaphoreGetWin32HandleInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `semaphore` is the semaphore from which state will be exported.
- `handleType` is a `VkExternalSemaphoreHandleTypeFlagBits` value specifying the type of handle requested.

The properties of the handle returned depend on the value of `handleType`. See `VkExternalSemaphoreHandleTypeFlagBits` for a description of the properties of the defined external semaphore handle types.

Valid Usage

- VUID-VkSemaphoreGetWin32HandleInfoKHR-handleType-01126
  `handleType` must have been included in `VkExportSemaphoreCreateInfo::handleTypes` when the `semaphore`'s current payload was created

- VUID-VkSemaphoreGetWin32HandleInfoKHR-handleType-01127
  If `handleType` is defined as an NT handle, `vkGetSemaphoreWin32HandleKHR` must be called no more than once for each valid unique combination of `semaphore` and `handleType`

- VUID-VkSemaphoreGetWin32HandleInfoKHR-semaphore-01128
  `semaphore` must not currently have its payload replaced by an imported payload as described below in Importing Semaphore Payloads unless that imported payload’s handle type was included in `VkExternalSemaphoreProperties::exportFromImportedHandleTypes` for `handleType`

- VUID-VkSemaphoreGetWin32HandleInfoKHR-handleType-01129
  If `handleType` refers to a handle type with copy payload transference semantics, as defined below in Importing Semaphore Payloads, there must be no queue waiting on `semaphore`

- VUID-VkSemaphoreGetWin32HandleInfoKHR-handleType-01130
  If `handleType` refers to a handle type with copy payload transference semantics, `semaphore` must be signaled, or have an associated `semaphore signal operation` pending execution
**Valid Usage (Implicit)**

- VUID-VkSemaphoreGetWin32HandleInfoKHR-handleType-01131
  
  `handleType` must be defined as an NT handle or a global share handle

- VUID-VkSemaphoreGetWin32HandleInfoKHR-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_SEMAPHORE_GET_WIN32_HANDLE_INFO_KHR`

- VUID-VkSemaphoreGetWin32HandleInfoKHR-pNext-pNext
  
  `pNext` must be `NULL`

- VUID-VkSemaphoreGetWin32HandleInfoKHR-semaphore-parameter
  
  `semaphore` must be a valid `VkSemaphore` handle

- VUID-VkSemaphoreGetWin32HandleInfoKHR-handleType-parameter
  
  `handleType` must be a valid `VkExternalSemaphoreHandleTypeFlagBits` value

The `VkQueryLowLatencySupportNV` structure is defined as:

```c
// Provided by VK_NV_low_latency
typedef struct VkQueryLowLatencySupportNV {
    VkStructureType sType;
    const void* pNext;
    void* pQueriedLowLatencyData;
} VkQueryLowLatencySupportNV;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `pQueriedLowLatencyData` is used for NVIDIA Reflex Support.

**Valid Usage (Implicit)**

- VUID-VkQueryLowLatencySupportNV-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_QUERY_LOW_LATENCY_SUPPORT_NV`

- VUID-VkQueryLowLatencySupportNV-pQueriedLowLatencyData-parameter
  
  `pQueriedLowLatencyData` must be a pointer value

To export a POSIX file descriptor representing the payload of a semaphore, call:

```c
// Provided by VK_KHR_external_semaphore_fd
VkResult vkGetSemaphoreFdKHR(
    VkDevice device,
    const VkSemaphoreGetFdInfoKHR* pGetFdInfo,
    VkSemaphoreFdKHR* pSemaphoreFd);```
Each call to `vkGetSemaphoreFdKHR` must create a new file descriptor and transfer ownership of it to the application. To avoid leaking resources, the application must release ownership of the file descriptor when it is no longer needed.

**Note**
Ownership can be released in many ways. For example, the application can call `close()` on the file descriptor, or transfer ownership back to Vulkan by using the file descriptor to import a semaphore payload.

Where supported by the operating system, the implementation must set the file descriptor to be closed automatically when an `execve` system call is made.

Exporting a file descriptor from a semaphore may have side effects depending on the transference of the specified handle type, as described in Importing Semaphore State.

### Valid Usage (Implicit)

- VUID-vkGetSemaphoreFdKHR-device-parameter
  - `device` must be a valid `VkDevice` handle
- VUID-vkGetSemaphoreFdKHR-pGetFdInfo-parameter
  - `pGetFdInfo` must be a valid pointer to a valid `VkSemaphoreGetFdInfoKHR` structure
- VUID-vkGetSemaphoreFdKHR-pFd-parameter
  - `pFd` must be a valid pointer to an `int` value

### Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_TOO_MANY_OBJECTS`
- `VK_ERROR_OUT_OF_HOST_MEMORY`

The `VkSemaphoreGetFdInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_external_semaphore_fd
typedef struct VkSemaphoreGetFdInfoKHR {
```
VkStructureType
const void* sType;
pNext;
VkSemaphore semaphore;
VkExternalSemaphoreHandleTypeFlagBits handleType;
}

VkSemaphoreGetFdInfoKHR

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **semaphore** is the semaphore from which state will be exported.
- **handleType** is a *VkExternalSemaphoreHandleTypeFlagBits* value specifying the type of handle requested.

The properties of the file descriptor returned depend on the value of **handleType**. See *VkExternalSemaphoreHandleTypeFlagBits* for a description of the properties of the defined external semaphore handle types.

---

**Valid Usage**

- **VUID-VkSemaphoreGetFdInfoKHR-handleType-01132**
  
  **handleType must** have been included in *VkExportSemaphoreCreateInfo::handleTypes* when **semaphore**’s current payload was created.

- **VUID-VkSemaphoreGetFdInfoKHR-semaphore-01133**
  
  **semaphore must** not currently have its payload replaced by an imported payload as described below in Importing Semaphore Payloads unless that imported payload’s handle type was included in *VkExternalSemaphoreProperties::exportFromImportedHandleTypes* for **handleType**.

- **VUID-VkSemaphoreGetFdInfoKHR-handleType-01134**
  
  If **handleType** refers to a handle type with copy payload transference semantics, as defined below in Importing Semaphore Payloads, there **must** be no queue waiting on **semaphore**.

- **VUID-VkSemaphoreGetFdInfoKHR-handleType-01135**
  
  If **handleType** refers to a handle type with copy payload transference semantics, **semaphore** **must** be signalled, or have an associated **semaphore signal operation** pending execution.

- **VUID-VkSemaphoreGetFdInfoKHR-handleType-01136**
  
  **handleType must** be defined as a POSIX file descriptor handle.

- **VUID-VkSemaphoreGetFdInfoKHR-handleType-03253**
  
  If **handleType** refers to a handle type with copy payload transference semantics, **semaphore** **must** have been created with a **VkSemaphoreType** of VK_SEMAPHORE_TYPE_BINARY.

- **VUID-VkSemaphoreGetFdInfoKHR-handleType-03254**
  
  If **handleType** refers to a handle type with copy payload transference semantics, **semaphore** **must** have an associated semaphore signal operation that has been submitted for execution and any semaphore signal operations on which it depends (if any) **must** have also been submitted for execution.
To export a Zircon event handle representing the payload of a semaphore, call:

```c
// Provided by VK_FUCHSIA_external_semaphore
VkResult vkGetSemaphoreZirconHandleFUCHSIA(
    VkDevice device,
    const VkSemaphoreGetZirconHandleInfoFUCHSIA* pGetZirconHandleInfo,
    zx_handle_t* pZirconHandle);
```

- `device` is the logical device that created the semaphore being exported.
- `pGetZirconHandleInfo` is a pointer to a `VkSemaphoreGetZirconHandleInfoFUCHSIA` structure containing parameters of the export operation.
- `pZirconHandle` will return the Zircon event handle representing the semaphore payload.

Each call to `vkGetSemaphoreZirconHandleFUCHSIA` must create a Zircon event handle and transfer ownership of it to the application. To avoid leaking resources, the application must release ownership of the Zircon event handle when it is no longer needed.

**Note**
Ownership can be released in many ways. For example, the application can call `zx_handle_close()` on the file descriptor, or transfer ownership back to Vulkan by using the file descriptor to import a semaphore payload.

Exporting a Zircon event handle from a semaphore may have side effects depending on the transference of the specified handle type, as described in Importing Semaphore State.
Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_TOO_MANY_OBJECTS
- VK_ERROR_OUT_OF_HOST_MEMORY

The VkSemaphoreGetZirconHandleInfoFUCHSIA structure is defined as:

```c
// Provided by VK_FUCHSIA_external_semaphore
typedef struct VkSemaphoreGetZirconHandleInfoFUCHSIA {
    VkStructureType sType;
    const void* pNext;
    VkSemaphore semaphore;
    VkExternalSemaphoreHandleTypeFlagBits handleType;
} VkSemaphoreGetZirconHandleInfoFUCHSIA;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `semaphore` is the semaphore from which state will be exported.
- `handleType` is a VkExternalSemaphoreHandleTypeFlagBits value specifying the type of handle requested.

The properties of the Zircon event handle returned depend on the value of `handleType`. See VkExternalSemaphoreHandleTypeFlagBits for a description of the properties of the defined external semaphore handle types.

Valid Usage

- VUID-VkSemaphoreGetZirconHandleInfoFUCHSIA-handleType-04758
  `handleType` must have been included in VkExportSemaphoreCreateInfo::handleTypes when `semaphore`’s current payload was created

- VUID-VkSemaphoreGetZirconHandleInfoFUCHSIA-semaphore-04759
  `semaphore` must not currently have its payload replaced by an imported payload as described below in Importing Semaphore Payloads unless that imported payload’s handle type was included in VkExternalSemaphoreProperties::exportFromImportedHandleTypes for `handleType`

- VUID-VkSemaphoreGetZirconHandleInfoFUCHSIA-handleType-04760
If `handleType` refers to a handle type with copy payload transference semantics, as defined below in Importing Semaphore Payloads, there **must** be no queue waiting on `semaphore`

- VUID-VkSemaphoreGetZirconHandleInfoFUCHSIA-handleType-04761
  If `handleType` refers to a handle type with copy payload transference semantics, `semaphore must` be signaled, or have an associated `semaphore signal operation` pending execution

- VUID-VkSemaphoreGetZirconHandleInfoFUCHSIA-handleType-04762
  `handleType must` be defined as a Zircon event handle

- VUID-VkSemaphoreGetZirconHandleInfoFUCHSIA-semaphore-04763
  `semaphore must` have been created with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_BINARY`

**Valid Usage (Implicit)**

- VUID-VkSemaphoreGetZirconHandleInfoFUCHSIA-sType-sType
  `sType must` be `VK_STRUCTURE_TYPE_SEMAPHORE_GET_ZIRCON_HANDLE_INFO_FUCHSIA`

- VUID-VkSemaphoreGetZirconHandleInfoFUCHSIA-pNext-pNext
  `pNext must` be NULL

- VUID-VkSemaphoreGetZirconHandleInfoFUCHSIA-semaphore-parameter
  `semaphore must` be a valid `VkSemaphore` handle

- VUID-VkSemaphoreGetZirconHandleInfoFUCHSIA-handleType-parameter
  `handleType must` be a valid `VkExternalSemaphoreHandleTypeFlagBits` value

To destroy a semaphore, call:

```c
// Provided by VK_VERSION_1_0
void vkDestroySemaphore(
    VkDevice device,
    VkSemaphore semaphore,
    const VkAllocationCallbacks* pAllocator);
```

- `device` is the logical device that destroys the semaphore.
- `semaphore` is the handle of the semaphore to destroy.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

**Valid Usage**

- VUID-vkDestroySemaphore-semaphore-01137
  All submitted batches that refer to `semaphore must` have completed execution

- VUID-vkDestroySemaphore-semaphore-01138
  If `VkAllocationCallbacks` were provided when `semaphore` was created, a compatible set of callbacks **must** be provided here

- VUID-vkDestroySemaphore-semaphore-01139
If no `VkAllocationCallbacks` were provided when `semaphore` was created, `pAllocator` must be `NULL`.

## Valid Usage (Implicit)

- **VUID-vkDestroySemaphore-device-parameter**  
  `device` must be a valid `VkDevice` handle.

- **VUID-vkDestroySemaphore-semaphore-parameter**  
  If `semaphore` is not `VK_NULL_HANDLE`, `semaphore` must be a valid `VkSemaphore` handle.

- **VUID-vkDestroySemaphore-pAllocator-parameter**  
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure.

- **VUID-vkDestroySemaphore-semaphore-parent**  
  If `semaphore` is a valid handle, it must have been created, allocated, or retrieved from `device`.

## Host Synchronization

- Host access to `semaphore` must be externally synchronized.

### 7.4.1. Semaphore Signaling

When a batch is submitted to a queue via a `queue submission`, and it includes semaphores to be signaled, it defines a memory dependency on the batch, and defines `semaphore signal operations` which set the semaphores to the signaled state.

In case of semaphores created with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_TIMELINE` the semaphore is considered signaled with respect to the counter value set to be signaled as specified in `VkTimelineSemaphoreSubmitInfo` or `VkSemaphoreSignalInfo`.

The first synchronization scope includes every command submitted in the same batch. In the case of `vkQueueSubmit2`, the first synchronization scope is limited to the pipeline stage specified by `VkSemaphoreSubmitInfo::stageMask`. Semaphore signal operations that are defined by `vkQueueSubmit` or `vkQueueSubmit2` additionally include all commands that occur earlier in submission order. Semaphore signal operations that are defined by `vkQueueSubmit` or `vkQueueSubmit2` or `vkQueueBindSparse` additionally include in the first synchronization scope any semaphore and fence signal operations that occur earlier in signal operation order.

The second synchronization scope includes only the semaphore signal operation.

The first access scope includes all memory access performed by the device.

The second access scope is empty.
7.4.2. Semaphore Waiting

When a batch is submitted to a queue via a queue submission, and it includes semaphores to be waited on, it defines a memory dependency between prior semaphore signal operations and the batch, and defines semaphore wait operations.

Such semaphore wait operations set the semaphores created with a VkSemaphoreType of VK_SEMAPHORE_TYPE_BINARY to the unsignaled state. In case of semaphores created with a VkSemaphoreType of VK_SEMAPHORE_TYPE_TIMELINE a prior semaphore signal operation defines a memory dependency with a semaphore wait operation if the value the semaphore is signaled with is greater than or equal to the value the semaphore is waited with, thus the semaphore will continue to be considered signaled with respect to the counter value waited on as specified in VkTimelineSemaphoreSubmitInfo.

The first synchronization scope includes all semaphore signal operations that operate on semaphores waited on in the same batch, and that happen-before the wait completes.

The second synchronization scope includes every command submitted in the same batch. In the case of vkQueueSubmit, the second synchronization scope is limited to operations on the pipeline stages determined by the destination stage mask specified by the corresponding element of pWaitDstStageMask. In the case of vkQueueSubmit2, the second synchronization scope is limited to the pipeline stage specified by VkSemaphoreSubmitInfo::stageMask. Also, in the case of either vkQueueSubmit2 or vkQueueSubmit, the second synchronization scope additionally includes all commands that occur later in submission order.

The first access scope is empty.

The second access scope includes all memory access performed by the device.

The semaphore wait operation happens-after the first set of operations in the execution dependency, and happens-before the second set of operations in the execution dependency.

Note

Unlike timeline semaphores, fences or events, the act of waiting for a binary semaphore also unsignals that semaphore. Applications must ensure that between two such wait operations, the semaphore is signaled again, with execution dependencies used to ensure these occur in order. Binary semaphore waits and signals should thus occur in discrete 1:1 pairs.

Note

A common scenario for using pWaitDstStageMask with values other than VK_PIPELINE_STAGE_ALL_COMMANDS_BIT is when synchronizing a window system presentation operation against subsequent command buffers which render the next frame. In this case, a presentation image must not be overwritten until the presentation operation completes, but other pipeline stages can execute without waiting. A mask of VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT prevents subsequent color attachment writes from executing until the semaphore signals. Some implementations may be able to execute transfer operations and/or prerasterization work before the semaphore is signaled.
If an image layout transition needs to be performed on a presentable image before it is used in a framebuffer, that can be performed as the first operation submitted to the queue after acquiring the image, and should not prevent other work from overlapping with the presentation operation. For example, a `VkImageMemoryBarrier` could use:

- `srcStageMask = VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT`
- `srcAccessMask = 0`
- `dstStageMask = VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT`
- `dstAccessMask = VK_ACCESS_COLOR_ATTACHMENT_READ_BIT | VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT`.
- `oldLayout = VK_IMAGE_LAYOUT_PRESENT_SRC_KHR`
- `newLayout = VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL`

Alternatively, `oldLayout` can be `VK_IMAGE_LAYOUT_UNDEFINED`, if the image’s contents need not be preserved.

This barrier accomplishes a dependency chain between previous presentation operations and subsequent color attachment output operations, with the layout transition performed in between, and does not introduce a dependency between previous work and any pre-rasterization shader stages. More precisely, the semaphore signals after the presentation operation completes, the semaphore wait stalls the `VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT` stage, and there is a dependency from that same stage to itself with the layout transition performed in between.

### 7.4.3. Semaphore State Requirements For Wait Operations

Before waiting on a semaphore, the application must ensure the semaphore is in a valid state for a wait operation. Specifically, when a semaphore wait operation is submitted to a queue:

- A binary semaphore must be signaled, or have an associated semaphore signal operation that is pending execution.
- Any semaphore signal operations on which the pending binary semaphore signal operation depends must also be completed or pending execution.
- There must be no other queue waiting on the same binary semaphore when the operation executes.

### 7.4.4. Host Operations on Semaphores

In addition to semaphore signal operations and semaphore wait operations submitted to device queues, timeline semaphores support the following host operations:

- Query the current counter value of the semaphore using the `vkGetSemaphoreCounterValue` command.
- Wait for a set of semaphores to reach particular counter values using the `vkWaitSemaphores`
• Signal the semaphore with a particular counter value from the host using the `vkSignalSemaphore` command.

To query the current counter value of a semaphore created with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_TIMELINE` from the host, call:

```c
// Provided by VK_VERSION_1_2
VkResult vkGetSemaphoreCounterValue(
    VkDevice device,
    VkSemaphore semaphore,
    uint64_t* pValue);
```
or the equivalent command

```c
// Provided by VK_KHR_timeline_semaphore
VkResult vkGetSemaphoreCounterValueKHR(
    VkDevice device,
    VkSemaphore semaphore,
    uint64_t* pValue);
```

• `device` is the logical device that owns the semaphore.

• `semaphore` is the handle of the semaphore to query.

• `pValue` is a pointer to a 64-bit integer value in which the current counter value of the semaphore is returned.

**Note**

If a queue submission command is pending execution, then the value returned by this command may immediately be out of date.

**Valid Usage**

- VUID-vkGetSemaphoreCounterValue-semaphore-03255 `semaphore` must have been created with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_TIMELINE`

**Valid Usage (Implicit)**

- VUID-vkGetSemaphoreCounterValue-device-parameter `device` must be a valid `VkDevice` handle

- VUID-vkGetSemaphoreCounterValue-semaphore-parameter `semaphore` must be a valid `VkSemaphore` handle

- VUID-vkGetSemaphoreCounterValue-pValue-parameter
pValue must be a valid pointer to a uint64_t value

- VUID-vkGetSemaphoreCounterValue-semaphore-parent
  semaphore must have been created, allocated, or retrieved from device

Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERRORDEVICE_LOST

To wait for a set of semaphores created with a VkSemaphoreType of VK_SEMAPHORE_TYPE_TIMELINE to reach particular counter values on the host, call:

```c
// Provided by VK_VERSION_1_2
VkResult vkWaitSemaphores(
    VkDevice device,
    const VkSemaphoreWaitInfo* pWaitInfo,
    uint64_t timeout);
```

or the equivalent command

```c
// Provided by VK_KHR_timeline_semaphore
VkResult vkWaitSemaphoresKHR(
    VkDevice device,
    const VkSemaphoreWaitInfo* pWaitInfo,
    uint64_t timeout);
```

- device is the logical device that owns the semaphores.
- pWaitInfo is a pointer to a VkSemaphoreWaitInfo structure containing information about the wait condition.
- timeout is the timeout period in units of nanoseconds. timeout is adjusted to the closest value allowed by the implementation-dependent timeout accuracy, which may be substantially longer than one nanosecond, and may be longer than the requested period.

If the condition is satisfied when vkWaitSemaphores is called, then vkWaitSemaphores returns immediately. If the condition is not satisfied at the time vkWaitSemaphores is called, then vkWaitSemaphores will block and wait until the condition is satisfied or the timeout has expired, whichever is sooner.

If timeout is zero, then vkWaitSemaphores does not wait, but simply returns information about the
current state of the semaphores. \texttt{VK\_TIMEOUT} will be returned in this case if the condition is not satisfied, even though no actual wait was performed.

If the condition is satisfied before the \texttt{timeout} has expired, \texttt{vkWaitSemaphores} returns \texttt{VK\_SUCCESS}. Otherwise, \texttt{vkWaitSemaphores} returns \texttt{VK\_TIMEOUT} after the \texttt{timeout} has expired.

If device loss occurs (see \texttt{Lost Device}) before the timeout has expired, \texttt{vkWaitSemaphores} \textbf{must} return in finite time with either \texttt{VK\_SUCCESS} or \texttt{VK\_ERROR\_DEVICE\_LOST}.

### Valid Usage (Implicit)
- VUID-vkWaitSemaphores-device-parameter
  \texttt{device} \textbf{must} be a valid \texttt{VkDevice} handle
- VUID-vkWaitSemaphores-pWaitInfo-parameter
  \texttt{pWaitInfo} \textbf{must} be a valid pointer to a valid \texttt{VkSemaphoreWaitInfo} structure

### Return Codes

#### Success
- \texttt{VK\_SUCCESS}
- \texttt{VK\_TIMEOUT}

#### Failure
- \texttt{VK\_ERROR\_OUT\_OF\_HOST\_MEMORY}
- \texttt{VK\_ERROR\_OUT\_OF\_DEVICE\_MEMORY}
- \texttt{VK\_ERROR\_DEVICE\_LOST}

The \texttt{VkSemaphoreWaitInfo} structure is defined as:

```c
// Provided by VK\_VERSION\_1\_2
typedef struct VkSemaphoreWaitInfo {
    VkStructureType sType;
    const void* pNext;
    VkSemaphoreWaitFlags flags;
    uint32_t semaphoreCount;
    const VkSemaphore* pSemaphores;
    const uint64_t* pValues;
} VkSemaphoreWaitInfo;
```

or the equivalent

```c
// Provided by VK\_KHR\_timeline\_semaphore
typedef VkSemaphoreWaitInfo VkSemaphoreWaitInfoKHR;
```
• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **flags** is a bitmask of `VkSemaphoreWaitFlagBits` specifying additional parameters for the semaphore wait operation.

• **semaphoreCount** is the number of semaphores to wait on.

• **pSemaphores** is a pointer to an array of `semaphoreCount` semaphore handles to wait on.

• **pValues** is a pointer to an array of `semaphoreCount` timeline semaphore values.

### Valid Usage

- VUID-VkSemaphoreWaitInfo-pSemaphores-03256
  All of the elements of **pSemaphores** must reference a semaphore that was created with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_TIMELINE`

### Valid Usage (Implicit)

- VUID-VkSemaphoreWaitInfo-sType-sType
  **sType** must be `VK_STRUCTURE_TYPE_SEMAPHORE_WAIT_INFO`

- VUID-VkSemaphoreWaitInfo-pNext-pNext
  **pNext** must be NULL

- VUID-VkSemaphoreWaitInfo-flags-parameter
  **flags** must be a valid combination of `VkSemaphoreWaitFlagBits` values

- VUID-VkSemaphoreWaitInfo-pSemaphores-parameter
  **pSemaphores** must be a valid pointer to an array of `semaphoreCount` valid `VkSemaphore` handles

- VUID-VkSemaphoreWaitInfo-pValues-parameter
  **pValues** must be a valid pointer to an array of `semaphoreCount uint64_t` values

- VUID-VkSemaphoreWaitInfo-semaphoreCount-arraylength
  `semaphoreCount` must be greater than 0

Bits which can be set in **VkSemaphoreWaitInfo::flags**, specifying additional parameters of a semaphore wait operation, are:

```c
// Provided by VK_VERSION_1_2
typedef enum VkSemaphoreWaitFlagBits {
    VK_SEMAPHORE_WAIT_ANY_BIT = 0x00000001,
    // Provided by VK_KHR_timeline_semaphore
    VK_SEMAPHORE_WAIT_ANY_BIT_KHR = VK_SEMAPHORE_WAIT_ANY_BIT,
} VkSemaphoreWaitFlagBits;
```

or the equivalent
// Provided by VK_KHR_timeline_semaphore
typedef VkSemaphoreWaitFlagBits VkSemaphoreWaitFlagBitsKHR;

- **VK_SEMAPHORE_WAIT_ANY_BIT** specifies that the semaphore wait condition is that at least one of the semaphores in `VkSemaphoreWaitInfo::pSemaphores` has reached the value specified by the corresponding element of `VkSemaphoreWaitInfo::pValues`. If **VK_SEMAPHORE_WAIT_ANY_BIT** is not set, the semaphore wait condition is that all of the semaphores in `VkSemaphoreWaitInfo::pSemaphores` have reached the value specified by the corresponding element of `VkSemaphoreWaitInfo::pValues`.

// Provided by VK_VERSION_1_2
typedef VkFlags VkSemaphoreWaitFlags;

or the equivalent

// Provided by VK_KHR_timeline_semaphore
typedef VkSemaphoreWaitFlags VkSemaphoreWaitFlagsKHR;

VkSemaphoreWaitFlags is a bitmask type for setting a mask of zero or more `VkSemaphoreWaitFlagBits`.

To signal a semaphore created with a `VkSemaphoreType` of **VK_SEMAPHORE_TYPE_TIMELINE** with a particular counter value, on the host, call:

// Provided by VK_VERSION_1_2
VkResult vkSignalSemaphore(
    VkDevice device,
    const VkSemaphoreSignalInfo* pSignalInfo);

or the equivalent command

// Provided by VK_KHR_timeline_semaphore
VkResult vkSignalSemaphoreKHR(
    VkDevice device,
    const VkSemaphoreSignalInfo* pSignalInfo);

- `device` is the logical device that owns the semaphore.
- `pSignalInfo` is a pointer to a `VkSemaphoreSignalInfo` structure containing information about the signal operation.

When `vkSignalSemaphore` is executed on the host, it defines and immediately executes a *semaphore signal operation* which sets the timeline semaphore to the given value.

The first synchronization scope is defined by the host execution model, but includes execution of `vkSignalSemaphore` on the host and anything that happened-before it.
The second synchronization scope is empty.

### Valid Usage (Implicit)

- VUID-vkSignalSemaphore-device-parameter
  `- device` must be a valid `VkDevice` handle
- VUID-vkSignalSemaphore-pSignalInfo-parameter
  `- pSignalInfo` must be a valid pointer to a valid `VkSemaphoreSignalInfo` structure

### Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

The `VkSemaphoreSignalInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkSemaphoreSignalInfo {
    VkStructureType sType;
    const void* pNext;
    VkSemaphore semaphore;
    uint64_t value;
} VkSemaphoreSignalInfo;
```

or the equivalent

```c
// Provided by VK_KHR_timeline_semaphore
typedef VkSemaphoreSignalInfo VkSemaphoreSignalInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `semaphore` is the handle of the semaphore to signal.
- `value` is the value to signal.

### Valid Usage

- VUID-VkSemaphoreSignalInfo-semaphore-03257
  `- semaphore` must have been created with `VkSemaphoreType` of

```c
semaphore
```
7.4.5. Importing Semaphore Payloads

Applications can import a semaphore payload into an existing semaphore using an external semaphore handle. The effects of the import operation will be either temporary or permanent, as specified by the application. If the import is temporary, the implementation must restore the semaphore to its prior permanent state after submitting the next semaphore wait operation. Performing a subsequent temporary import on a semaphore before performing a semaphore wait has no effect on this requirement; the next wait submitted on the semaphore must still restore its last permanent state. A permanent payload import behaves as if the target semaphore was destroyed, and a new semaphore was created with the same handle but the imported payload. Because importing a semaphore payload temporarily or permanently detaches the existing payload from a semaphore, similar usage restrictions to those applied to vkDestroySemaphore are applied to any command that imports a semaphore payload. Which of these import types is used is referred to as the import operation's permanence. Each handle type supports either one or both types of permanence.

The implementation must perform the import operation by either referencing or copying the payload referred to by the specified external semaphore handle, depending on the handle's type. The import method used is referred to as the handle type's transference. When using handle types with reference transference, importing a payload to a semaphore adds the semaphore to the set of all semaphores sharing that payload. This set includes the semaphore from which the payload was exported. Semaphore signaling and waiting operations performed on any semaphore in the set must behave as if the set were a single semaphore. Importing a payload using handle types with copy transference creates a duplicate copy of the payload at the time of import, but makes no further reference to it. Semaphore signaling and waiting operations performed on the target of
copy imports **must** not affect any other semaphore or payload.

Export operations have the same transference as the specified handle type's import operations. Additionally, exporting a semaphore payload to a handle with copy transference has the same side effects on the source semaphore's payload as executing a semaphore wait operation. If the semaphore was using a temporarily imported payload, the semaphore's prior permanent payload will be restored.

**Note**
The permanence and transference of handle types can be found in:

- Handle Types Supported by `VkImportSemaphoreWin32HandleInfoKHR`
- Handle Types Supported by `VkImportSemaphoreFdInfoKHR`
- Handle Types Supported by `VkImportSemaphoreZirconHandleInfoFUCHSIA`

**External synchronization** allows implementations to modify an object's internal state, i.e. payload, without internal synchronization. However, for semaphores sharing a payload across processes, satisfying the external synchronization requirements of `VkSemaphore` parameters as if all semaphores in the set were the same object is sometimes infeasible. Satisfying the **wait operation state requirements** would similarly require impractical coordination or levels of trust between processes. Therefore, these constraints only apply to a specific semaphore handle, not to its payload. For distinct semaphore objects which share a payload, if the semaphores are passed to separate queue submission commands concurrently, behavior will be as if the commands were called in an arbitrary sequential order. If the **wait operation state requirements** are violated for the shared payload by a queue submission command, or if a signal operation is queued for a shared payload that is already signaled or has a pending signal operation, effects **must** be limited to one or more of the following:

- Returning `VK_ERROR_INITIALIZATION_FAILED` from the command which resulted in the violation.
- Losing the logical device on which the violation occurred immediately or at a future time, resulting in a `VK_ERROR_DEVICE_LOST` error from subsequent commands, including the one causing the violation.
- Continuing execution of the violating command or operation as if the semaphore wait completed successfully after an implementation-dependent timeout. In this case, the state of the payload becomes undefined, and future operations on semaphores sharing the payload will be subject to these same rules. The semaphore **must** be destroyed or have its payload replaced by an import operation to again have a well-defined state.

**Note**
These rules allow processes to synchronize access to shared memory without trusting each other. However, such processes must still be cautious not to use the shared semaphore for more than synchronizing access to the shared memory. For example, a process should not use a shared semaphore as part of an execution dependency chain that, when complete, leads to objects being destroyed, if it does not trust other processes sharing the semaphore payload.
When a semaphore is using an imported payload, its `VkExportSemaphoreCreateInfo::handleTypes` value is specified when creating the semaphore from which the payload was exported, rather than specified when creating the semaphore. Additionally, `VkExternalSemaphoreProperties::exportFromImportedHandleTypes` restricts which handle types can be exported from such a semaphore based on the specific handle type used to import the current payload. Passing a semaphore to `vkAcquireNextImageKHR` is equivalent to temporarily importing a semaphore payload to that semaphore.

**Note**
Because the exportable handle types of an imported semaphore correspond to its current imported payload, and `vkAcquireNextImageKHR` behaves the same as a temporary import operation for which the source semaphore is opaque to the application, applications have no way of determining whether any external handle types can be exported from a semaphore in this state. Therefore, applications must not attempt to export external handles from semaphores using a temporarily imported payload from `vkAcquireNextImageKHR`.

When importing a semaphore payload, it is the responsibility of the application to ensure the external handles meet all valid usage requirements. However, implementations must perform sufficient validation of external handles to ensure that the operation results in a valid semaphore which will not cause program termination, device loss, queue stalls, or corruption of other resources when used as allowed according to its import parameters, and excepting those side effects allowed for violations of the valid semaphore state for wait operations rules. If the external handle provided does not meet these requirements, the implementation must fail the semaphore payload import operation with the error code `VK_ERROR_INVALID_EXTERNAL_HANDLE`.

In addition, when importing a semaphore payload that is not compatible with the payload type corresponding to the `VkSemaphoreType` the semaphore was created with, the implementation may fail the semaphore payload import operation with the error code `VK_ERROR_INVALID_EXTERNAL_HANDLE`.

**Note**
As the introduction of the external semaphore handle type `VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_D3D12_FENCE_BIT` predates that of timeline semaphores, support for importing semaphore payloads from external handles of that type into semaphores created (implicitly or explicitly) with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_BINARY` is preserved for backwards compatibility. However, applications should prefer importing such handle types into semaphores created with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_TIMELINE`.

To import a semaphore payload from a Windows handle, call:

```c
// Provided by VK_KHR_external_semaphore_win32
VkResult vkImportSemaphoreWin32HandleKHR(
    VkDevice device,
    const VkImportSemaphoreWin32HandleInfoKHR* pImportSemaphoreWin32HandleInfo);
```

- `device` is the logical device that created the semaphore.
• **pImportSemaphoreWin32HandleInfo** is a pointer to a **VkImportSemaphoreWin32HandleInfoKHR** structure specifying the semaphore and import parameters.

Importing a semaphore payload from Windows handles does not transfer ownership of the handle to the Vulkan implementation. For handle types defined as NT handles, the application **must** release ownership using the **CloseHandle** system call when the handle is no longer needed.

Applications **can** import the same semaphore payload into multiple instances of Vulkan, into the same instance from which it was exported, and multiple times into a given Vulkan instance.

### Valid Usage (Implicit)

- **VUID-vkImportSemaphoreWin32HandleKHR-device-parameter**
  - **device** must be a valid **VkDevice** handle

- **VUID-vkImportSemaphoreWin32HandleKHR-pImportSemaphoreWin32HandleInfo-parameter**
  - **pImportSemaphoreWin32HandleInfo** must be a valid pointer to a valid **VkImportSemaphoreWin32HandleInfoKHR** structure

### Return Codes

**Success**
- **VK_SUCCESS**

**Failure**
- **VK_ERROR_OUT_OF_HOST_MEMORY**
- **VK_ERROR_INVALID_EXTERNAL_HANDLE**

The **VkImportSemaphoreWin32HandleInfoKHR** structure is defined as:

```c
// Provided by VK_KHR_external_semaphore_win32
typedef struct VkImportSemaphoreWin32HandleInfoKHR {
    VkStructureType          sType;
    const void*              pNext;
    VkSemaphore              semaphore;
    VkSemaphoreImportFlags   flags;
    VkExternalSemaphoreHandleTypeFlagBits handleType;
    HANDLE                    handle;
    LPCWSTR                   name;
} VkImportSemaphoreWin32HandleInfoKHR;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **semaphore** is the semaphore into which the payload will be imported.
• **flags** is a bitmask of `VkSemaphoreImportFlagBits` specifying additional parameters for the semaphore payload import operation.

• **handleType** is a `VkExternalSemaphoreHandleTypeFlagBits` value specifying the type of `handle`.

• **handle** is **NULL** or the external handle to import.

• **name** is **NULL** or a null-terminated UTF-16 string naming the underlying synchronization primitive to import.

The handle types supported by `handleType` are:

**Table 8. Handle Types Supported by `VkImportSemaphoreWin32HandleInfoKHR`**

<table>
<thead>
<tr>
<th>Handle Type</th>
<th>Transference</th>
<th>Permanence Supported</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_BIT</code></td>
<td>Reference</td>
<td>Temporary,Permanent</td>
</tr>
<tr>
<td><code>VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT</code></td>
<td>Reference</td>
<td>Temporary,Permanent</td>
</tr>
<tr>
<td><code>VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_D3D12_FENCE_BIT</code></td>
<td>Reference</td>
<td>Temporary,Permanent</td>
</tr>
</tbody>
</table>

**Valid Usage**

• VUID-VkImportSemaphoreWin32HandleInfoKHR-handleType-01140

  `handleType` must be a value included in the **Handle Types Supported by `VkImportSemaphoreWin32HandleInfoKHR`** table

• VUID-VkImportSemaphoreWin32HandleInfoKHR-handleType-01466

  If `handleType` is not `VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_BIT` or `VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_D3D12_FENCE_BIT`, `name` must be **NULL**

• VUID-VkImportSemaphoreWin32HandleInfoKHR-handleType-01467

  If `handle` is **NULL**, `name` must name a valid synchronization primitive of the type specified by `handleType`

• VUID-VkImportSemaphoreWin32HandleInfoKHR-handleType-01468

  If `name` is **NULL**, `handle` must be a valid handle of the type specified by `handleType`

• VUID-VkImportSemaphoreWin32HandleInfoKHR-handleType-01469

  If `handle` is not **NULL**, `name` must be **NULL**

• VUID-VkImportSemaphoreWin32HandleInfoKHR-handleType-01542

  If `handle` is not **NULL**, it must obey any requirements listed for `handleType` in **external semaphore handle types compatibility**

• VUID-VkImportSemaphoreWin32HandleInfoKHR-name-01543

  If `name` is not **NULL**, it must obey any requirements listed for `handleType` in **external semaphore handle types compatibility**

• VUID-VkImportSemaphoreWin32HandleInfoKHR-handleType-03261

  If `handleType` is `VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_BIT` or
VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT, the VkSemaphoreCreateInfo::flags field **must** match that of the semaphore from which handle or name was exported

- VUID-VkImportSemaphoreWin32HandleInfoKHR-handleType-03262
  If handleType is VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_BIT or VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT, the VkSemaphoreTypeCreateInfo::semaphoreType field **must** match that of the semaphore from which handle or name was exported.

- VUID-VkImportSemaphoreWin32HandleInfoKHR-flags-03322
  If flags contains VK_SEMAPHORE_IMPORT_TEMPORARY_BIT, the VkSemaphoreTypeCreateInfo::semaphoreType field of the semaphore from which handle or name was exported **must not** be VK_SEMAPHORE_TYPE_TIMELINE.

---

**Valid Usage (Implicit)**

- VUID-VkImportSemaphoreWin32HandleInfoKHR-sType-sType
  sType **must** be VK_STRUCTURE_TYPE_IMPORT_SEMAPHORE_WIN32_HANDLE_INFO_KHR

- VUID-VkImportSemaphoreWin32HandleInfoKHR-pNext-pNext
  pNext **must** be NULL

- VUID-VkImportSemaphoreWin32HandleInfoKHR-semaphore-parameter
  semaphore **must** be a valid VkSemaphore handle

- VUID-VkImportSemaphoreWin32HandleInfoKHR-flags-parameter
  flags **must** be a valid combination of VkSemaphoreImportFlagBits values

---

**Host Synchronization**

- Host access to semaphore **must** be externally synchronized.

To import a semaphore payload from a POSIX file descriptor, call:

```c
// Provided by VK_KHR_external_semaphore_fd
VkResult vkImportSemaphoreFdKHR(
    VkDevice device,          // Provided by VK_KHR_external_semaphore_fd
    const VkImportSemaphoreFdInfoKHR* pImportSemaphoreFdInfo);
```

- **device** is the logical device that created the semaphore.

- **pImportSemaphoreFdInfo** is a pointer to a VkImportSemaphoreFdInfoKHR structure specifying the semaphore and import parameters.

Importing a semaphore payload from a file descriptor transfers ownership of the file descriptor from the application to the Vulkan implementation. The application **must** not perform any operations on the file descriptor after a successful import.
Applications can import the same semaphore payload into multiple instances of Vulkan, into the same instance from which it was exported, and multiple times into a given Vulkan instance.

### Valid Usage

- **VUID-vkImportSemaphoreFdKHR-semaphore-01142**
  - semaphore must not be associated with any queue command that has not yet completed execution on that queue

### Valid Usage (Implicit)

- **VUID-vkImportSemaphoreFdKHR-device-parameter**
  - device must be a valid VkDevice handle
- **VUID-vkImportSemaphoreFdKHR-pImportSemaphoreFdInfo-parameter**
  - pImportSemaphoreFdInfo must be a valid pointer to a valid VkImportSemaphoreFdInfoKHR structure

### Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_INVALID_EXTERNAL_HANDLE

The VkImportSemaphoreFdInfoKHR structure is defined as:

```c
// Provided by VK_KHR_external_semaphore_fd
typedef struct VkImportSemaphoreFdInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkSemaphore semaphore;
    VkSemaphoreImportFlags flags;
    VkExternalSemaphoreHandleTypeFlagBits handleType;
    int fd;
} VkImportSemaphoreFdInfoKHR;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **semaphore** is the semaphore into which the payload will be imported.
- **flags** is a bitmask ofVkSemaphoreImportFlagBits specifying additional parameters for the semaphore payload import operation.
• **handleType** is a `VkExternalSemaphoreHandleTypeFlagBits` value specifying the type of `fd`.

• `fd` is the external handle to import.

The handle types supported by `handleType` are:

<table>
<thead>
<tr>
<th>Handle Type</th>
<th>Transference</th>
<th>Permanence Supported</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_FD_BIT</code></td>
<td>Reference</td>
<td>Temporary, Permanent</td>
</tr>
<tr>
<td><code>VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_SYNC_FD_BIT</code></td>
<td>Copy</td>
<td>Temporary</td>
</tr>
</tbody>
</table>

### Valid Usage

- **VUID-VkImportSemaphoreFdInfoKHR-handleType-01143**
  
  `handleType` **must** be a value included in the **Handle Types Supported by VkImportSemaphoreFdInfoKHR** table.

- **VUID-VkImportSemaphoreFdInfoKHR-fd-01544**
  
  `fd` **must** obey any requirements listed for `handleType` in external semaphore handle types compatibility.

- **VUID-VkImportSemaphoreFdInfoKHR-handleType-03263**
  
  If `handleType` is `VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_FD_BIT`, the `VkSemaphoreCreateInfo::flags` field **must** match that of the semaphore from which `fd` was exported.

- **VUID-VkImportSemaphoreFdInfoKHR-handleType-07307**
  
  If `handleType` refers to a handle type with copy payload transference semantics, `flags` **must** contain `VK_SEMAPHORE_IMPORT_TEMPORARY_BIT`.

- **VUID-VkImportSemaphoreFdInfoKHR-handleType-03264**
  
  If `handleType` is `VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_FD_BIT`, the `VkSemaphoreTypeCreateInfo::semaphoreType` field **must** match that of the semaphore from which `fd` was exported.

- **VUID-VkImportSemaphoreFdInfoKHR-flags-03323**
  
  If `flags` contains `VK_SEMAPHORE_IMPORT_TEMPORARY_BIT`, the `VkSemaphoreTypeCreateInfo::semaphoreType` field of the semaphore from which `fd` was exported **must** not be `VK_SEMAPHORE_TYPE_TIMELINE`.

If `handleType` is `VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_SYNC_FD_BIT`, the special value `-1` for `fd` is treated like a valid sync file descriptor referring to an object that has already signaled. The import operation will succeed and the `VkSemaphore` will have a temporarily imported payload as if a valid file descriptor had been provided.

---

**Note**

This special behavior for importing an invalid sync file descriptor allows easier interoperability with other system APIs which use the convention that an invalid
sync file descriptor represents work that has already completed and does not need to be waited for. It is consistent with the option for implementations to return a -1 file descriptor when exporting a VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_SYNC_FD_BIT from a VkSemaphore which is signaled.

### Valid Usage (Implicit)

- **VUID-VkImportSemaphoreFdInfoKHR-sType-sType**
  - `sType` must be VK_STRUCTURE_TYPE_IMPORT_SEMAPHORE_FD_INFO_KHR
- **VUID-VkImportSemaphoreFdInfoKHR-pNext-pNext**
  - `pNext` must be NULL
- **VUID-VkImportSemaphoreFdInfoKHR-semaphore-parameter**
  - `semaphore` must be a valid VkSemaphore handle
- **VUID-VkImportSemaphoreFdInfoKHR-flags-parameter**
  - `flags` must be a valid combination of VkSemaphoreImportFlagBits values
- **VUID-VkImportSemaphoreFdInfoKHR-handleType-parameter**
  - `handleType` must be a valid VkExternalSemaphoreHandleTypeFlagBits value

### Host Synchronization

- Host access to `semaphore` must be externally synchronized

To import a semaphore payload from a Zircon event handle, call:

```c
// Provided by VK_FUCHSIA_external_semaphore
VkResult vkImportSemaphoreZirconHandleFUCHSIA( VkDevice device,
 const VkImportSemaphoreZirconHandleInfoFUCHSIA* pImportSemaphoreZirconHandleInfo);
```

- `device` is the logical device that created the semaphore.
- `pImportSemaphoreZirconHandleInfo` is a pointer to a `VkImportSemaphoreZirconHandleInfoFUCHSIA` structure specifying the semaphore and import parameters.

Importing a semaphore payload from a Zircon event handle transfers ownership of the handle from the application to the Vulkan implementation. The application must not perform any operations on the handle after a successful import.

Applications can import the same semaphore payload into multiple instances of Vulkan, into the same instance from which it was exported, and multiple times into a given Vulkan instance.
Valid Usage

- VUID-vkImportSemaphoreZirconHandleFUCHSIA-semaphore-04764
  semaphore must not be associated with any queue command that has not yet completed execution on that queue

Valid Usage (Implicit)

- VUID-vkImportSemaphoreZirconHandleFUCHSIA-device-parameter
device must be a valid VkDevice handle

- VUID-vkImportSemaphoreZirconHandleFUCHSIA-pImportSemaphoreZirconHandleInfo-parameter
  pImportSemaphoreZirconHandleInfo must be a valid pointer to a valid VkImportSemaphoreZirconHandleInfoFUCHSIA structure

Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_INVALID_EXTERNAL_HANDLE

The VkImportSemaphoreZirconHandleInfoFUCHSIA structure is defined as:

```
// Provided by VK_FUCHSIA_external_semaphore
typedef struct VkImportSemaphoreZirconHandleInfoFUCHSIA {
    VkStructureType               sType;
    const void*                   pNext;
    VkSemaphore                   semaphore;
    VkSemaphoreImportFlags        flags;
    VkExternalSemaphoreHandleTypeFlagBits handleType;
    zx_handle_t                   zirconHandle;
} VkImportSemaphoreZirconHandleInfoFUCHSIA;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `semaphore` is the semaphore into which the payload will be imported.
- `flags` is a bitmask of VkSemaphoreImportFlagBits specifying additional parameters for the semaphore payload import operation.
- `handleType` is a VkExternalSemaphoreHandleTypeFlagBits value specifying the type of
• `zirconHandle` is the external handle to import.

The handle types supported by `handleType` are:

<table>
<thead>
<tr>
<th>Handle Type</th>
<th>Transference</th>
<th>Permanence Supported</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_ZIRCON_EVENT_BIT_FUCHSIA</td>
<td>Reference</td>
<td>Temporary, Permanent</td>
</tr>
</tbody>
</table>

## Valid Usage

- **VUID-VkImportSemaphoreZirconHandleInfoFUCHSIA-handleType-04765**
  - `handleType` must be a value included in the Table of Handle Types Supported by VkImportSemaphoreZirconHandleInfoFUCHSIA

- **VUID-VkImportSemaphoreZirconHandleInfoFUCHSIA-zirconHandle-04766**
  - `zirconHandle` must obey any requirements listed for `handleType` in external semaphore handle types compatibility

- **VUID-VkImportSemaphoreZirconHandleInfoFUCHSIA-zirconHandle-04767**
  - `zirconHandle` must have ZX_RIGHTS_BASIC and ZX_RIGHTS_SIGNAL rights

- **VUID-VkImportSemaphoreZirconHandleInfoFUCHSIA-semaphoreType-04768**
  - The `VkSemaphoreTypeCreateInfo::semaphoreType` field must not be VK_SEMAPHORE_TYPE_TIMELINE

## Valid Usage (Implicit)

- **VUID-VkImportSemaphoreZirconHandleInfoFUCHSIA-sType-sType**
  - `sType` must be VK_STRUCTURE_TYPE_IMPORT_SEMAPHORE_ZIRCON_HANDLE_INFO_FUCHSIA

- **VUID-VkImportSemaphoreZirconHandleInfoFUCHSIA-pNext-pNext**
  - `pNext` must be NULL

- **VUID-VkImportSemaphoreZirconHandleInfoFUCHSIA-semaphore-parameter**
  - `semaphore` must be a valid VkSemaphore handle

- **VUID-VkImportSemaphoreZirconHandleInfoFUCHSIA-flags-parameter**
  - `flags` must be a valid combination of VkSemaphoreImportFlagBits values

- **VUID-VkImportSemaphoreZirconHandleInfoFUCHSIA-handleType-parameter**
  - `handleType` must be a valid VkExternalSemaphoreHandleTypeFlagBits value

## Host Synchronization

- Host access to `semaphore` must be externally synchronized
Bits which can be set in

- VkImportSemaphoreWin32HandleInfoKHR::flags
- VkImportSemaphoreFdInfoKHR::flags
- VkImportSemaphoreZirconHandleInfoFUCHSIA::flags

specifying additional parameters of a semaphore import operation are:

```c
// Provided by VK_VERSION_1_1
typedef enum VkSemaphoreImportFlagBits {
    VK_SEMAPHORE_IMPORT_TEMPORARY_BIT = 0x00000001,
} VkSemaphoreImportFlagBits;
```

or the equivalent

```c
// Provided by VK_KHR_external_semaphore
typedef VkSemaphoreImportFlagBits VkSemaphoreImportFlagBitsKHR;
```

These bits have the following meanings:

- **VK_SEMAPHORE_IMPORT_TEMPORARY_BIT** specifies that the semaphore payload will be imported only temporarily, as described in Importing Semaphore Payloads, regardless of the permanence of handleType.

```c
// Provided by VK_VERSION_1_1
typedef VkFlags VkSemaphoreImportFlags;
```

or the equivalent

```c
// Provided by VK_KHR_external_semaphore
typedef VkSemaphoreImportFlags VkSemaphoreImportFlagsKHR;
```

**VkSemaphoreImportFlags** is a bitmask type for setting a mask of zero or more **VkSemaphoreImportFlagBits**.

### 7.5. Events

Events are a synchronization primitive that can be used to insert a fine-grained dependency between commands submitted to the same queue, or between the host and a queue. Events must not be used to insert a dependency between commands submitted to different queues. Events have two states - signaled and unsignaled. An application can signal or unsignal an event either on the host or on the device. A device can be made to wait for an event to become signaled before
executing further operations. No command exists to wait for an event to become signaled on the host, but the current state of an event can be queried.

Events are represented by \texttt{VkEvent} handles:

\begin{verbatim}
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkEvent)
\end{verbatim}

To create an event, call:

\begin{verbatim}
// Provided by VK_VERSION_1_0
VkResult vkCreateEvent(
    VkDevice device,
    const VkEventCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkEvent* pEvent);
\end{verbatim}

- \texttt{device} is the logical device that creates the event.
- \texttt{pCreateInfo} is a pointer to a \texttt{VkEventCreateInfo} structure containing information about how the event is to be created.
- \texttt{pAllocator} controls host memory allocation as described in the Memory Allocation chapter.
- \texttt{pEvent} is a pointer to a handle in which the resulting event object is returned.

When created, the event object is in the unsignaled state.

\section*{Valid Usage}

- VUID-vkCreateEvent-events-04468
  If the \texttt{VK_KHR_portability_subset} extension is enabled, and \texttt{VkPhysicalDevicePortabilitySubsetFeaturesKHR::events} is \texttt{VK_FALSE}, then the implementation does not support events, and \texttt{vkCreateEvent} must not be used.

\section*{Valid Usage (Implicit)}

- VUID-vkCreateEvent-device-parameter
  \texttt{device} must be a valid \texttt{VkDevice} handle

- VUID-vkCreateEvent-pCreateInfo-parameter
  \texttt{pCreateInfo} must be a valid pointer to a valid \texttt{VkEventCreateInfo} structure

- VUID-vkCreateEvent-pAllocator-parameter
  If \texttt{pAllocator} is not \texttt{NULL}, \texttt{pAllocator} must be a valid pointer to a valid \texttt{VkAllocationCallbacks} structure

- VUID-vkCreateEvent-pEvent-parameter
  \texttt{pEvent} must be a valid pointer to a \texttt{VkEvent} handle
Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The `VkEventCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkEventCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkEventCreateFlags flags;
} VkEventCreateInfo;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkEventCreateFlagBits` defining additional creation parameters.

Valid Usage

- **VUID-VkEventCreateInfo-pNext-06790**
  If the `pNext` chain includes a `VkExportMetalObjectCreateInfoEXT` structure, its `exportObjectType` member must be `VK_EXPORT_METAL_OBJECT_TYPE_METAL_SHARED_EVENT_BIT_EXT`.

Valid Usage (Implicit)

- **VUID-VkEventCreateInfo-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_EVENT_CREATE_INFO`

- **VUID-VkEventCreateInfo-pNext-pNext**
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkExportMetalObjectCreateInfoEXT` or `VkImportMetalSharedEventInfoEXT`.

- **VUID-VkEventCreateInfo-sType-unique**
  The `sType` value of each struct in the `pNext` chain must be unique, with the exception of structures of type `VkExportMetalObjectCreateInfoEXT`.

- **VUID-VkEventCreateInfo-flags-parameter**
  `flags` must be a valid combination of `VkEventCreateFlagBits` values.
typedef enum VkEventCreateFlagBits {
    VK_EVENT_CREATE_DEVICE_ONLY_BIT = 0x00000001,
    VK_EVENT_CREATE_DEVICE_ONLY_BIT_KHR = VK_EVENT_CREATE_DEVICE_ONLY_BIT,
} VkEventCreateFlagBits;

- `VK_EVENT_CREATE_DEVICE_ONLY_BIT` specifies that host event commands will not be used with this event.

typedef VkFlags VkEventCreateFlags;

VkEventCreateFlags is a bitmask type for setting a mask of VkEventCreateFlagBits.

To destroy an event, call:

void vkDestroyEvent(
    VkDevice device,
    VkEvent event,
    const VkAllocationCallbacks* pAllocator);

- `device` is the logical device that destroys the event.
- `event` is the handle of the event to destroy.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

Valid Usage

- VUID-vkDestroyEvent-event-01145
  All submitted commands that refer to `event` must have completed execution

- VUID-vkDestroyEvent-event-01146
  If `VkAllocationCallbacks` were provided when `event` was created, a compatible set of callbacks must be provided here

- VUID-vkDestroyEvent-event-01147
  If no `VkAllocationCallbacks` were provided when `event` was created, `pAllocator` must be NULL

Valid Usage (Implicit)

- VUID-vkDestroyEvent-device-parameter
  `device` must be a valid VkDevice handle
• **VUID-vkDestroyEvent-event-parameter**
  If `event` is not `VK_NULL_HANDLE`, `event` **must** be a valid `VkEvent` handle

• **VUID-vkDestroyEvent-pAllocator-parameter**
  If `pAllocator` is not `NULL`, `pAllocator` **must** be a valid pointer to a valid `VkAllocationCallbacks` structure

• **VUID-vkDestroyEvent-event-parent**
  If `event` is a valid handle, it **must** have been created, allocated, or retrieved from `device`

---

**Host Synchronization**

• Host access to `event` **must** be externally synchronized

To query the state of an event from the host, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkGetEventStatus(
    VkDevice device,
    VkEvent event);
```

• `device` is the logical device that owns the event.
• `event` is the handle of the event to query.

Upon success, `vkGetEventStatus` returns the state of the event object with the following return codes:

<table>
<thead>
<tr>
<th>Status</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_EVENT_SET</td>
<td>The event specified by <code>event</code> is signaled.</td>
</tr>
<tr>
<td>VK_EVENT_RESET</td>
<td>The event specified by <code>event</code> is unsignaled.</td>
</tr>
</tbody>
</table>

If a `vkCmdSetEvent` or `vkCmdResetEvent` command is in a command buffer that is in the **pending state**, then the value returned by this command **may** immediately be out of date.

The state of an event **can** be updated by the host. The state of the event is immediately changed, and subsequent calls to `vkGetEventStatus` will return the new state. If an event is already in the requested state, then updating it to the same state has no effect.

---

**Valid Usage**

• **VUID-vkGetEventStatus-event-03940**
  `event` **must** not have been created with `VK_EVENT_CREATE_DEVICE_ONLY_BIT`
Valid Usage (Implicit)

- VUID-vkGetEventStatus-device-parameter
  device must be a valid VkDevice handle

- VUID-vkGetEventStatus-event-parameter
  event must be a valid VkEvent handle

- VUID-vkGetEventStatus-event-parent
  event must have been created, allocated, or retrieved from device

Return Codes

Success
- VK_EVENT_SET
- VK_EVENT_RESET

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_DEVICE_LOST

To set the state of an event to signaled from the host, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkSetEvent(
    VkDevice device,
    VkEvent event);
```

- device is the logical device that owns the event.
- event is the event to set.

When vkSetEvent is executed on the host, it defines an event signal operation which sets the event to the signaled state.

If event is already in the signaled state when vkSetEvent is executed, then vkSetEvent has no effect, and no event signal operation occurs.

Note
If a command buffer is waiting for an event to be signaled from the host, the application must signal the event before submitting the command buffer, as described in the queue forward progress section.
Valid Usage

- VUID-vkSetEvent-event-03941
  *event must* not have been created with `VK_EVENT_CREATE_DEVICE_ONLY_BIT`

Valid Usage (Implicit)

- VUID-vkSetEvent-device-parameter
  *device must* be a valid `VkDevice` handle

- VUID-vkSetEvent-event-parameter
  *event must* be a valid `VkEvent` handle

- VUID-vkSetEvent-event-parent
  *event must* have been created, allocated, or retrieved from `device`

Host Synchronization

- Host access to *event must* be externally synchronized

Return Codes

Success
- `VK_SUCCESS`

Failure
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

To set the state of an event to unsignaled from the host, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkResetEvent(
    VkDevice device,
    VkEvent event);
```

- *device* is the logical device that owns the event.
- *event* is the event to reset.

When `vkResetEvent` is executed on the host, it defines an *event unsignal operation* which resets the event to the unsignaled state.

If *event* is already in the unsignaled state when `vkResetEvent` is executed, then `vkResetEvent` has no effect, and no event unsignal operation occurs.
Valid Usage

- **VUID-vkResetEvent-event-03821**
  There must be an execution dependency between `vkResetEvent` and the execution of any `vkCmdWaitEvents` that includes `event` in its `pEvents` parameter.

- **VUID-vkResetEvent-event-03822**
  There must be an execution dependency between `vkResetEvent` and the execution of any `vkCmdWaitEvents2` that includes `event` in its `pEvents` parameter.

- **VUID-vkResetEvent-event-03823**
  `event` must not have been created with `VK_EVENT_CREATE_DEVICE_ONLY_BIT`.

Valid Usage (Implicit)

- **VUID-vkResetEvent-device-parameter**
  `device` must be a valid `VkDevice` handle.

- **VUID-vkResetEvent-event-parameter**
  `event` must be a valid `VkEvent` handle.

- **VUID-vkResetEvent-event-parent**
  `event` must have been created, allocated, or retrieved from `device`.

Host Synchronization

- Host access to `event` must be externally synchronized.

Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

The state of an event can also be updated on the device by commands inserted in command buffers.

To signal an event from a device, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdSetEvent2(
    VkCommandBuffer commandBuffer,
    VkEvent event,
)
```
or the equivalent command

```c
// Provided by VK_KHR_synchronization2
void vkCmdSetEvent2KHR(
    VkCommandBuffer commandBuffer,
    VkEvent event,
    const VkDependencyInfo* pDependencyInfo);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `event` is the event that will be signaled.
- `pDependencyInfo` is a pointer to a `VkDependencyInfo` structure defining the first scopes of this operation.

When `vkCmdSetEvent2` is submitted to a queue, it defines the first half of memory dependencies defined by `pDependencyInfo`, as well as an event signal operation which sets the event to the signaled state. A memory dependency is defined between the event signal operation and commands that occur earlier in submission order.

The first **synchronization scope** and **access scope** are defined by the union of all the memory dependencies defined by `pDependencyInfo`, and are applied to all operations that occur earlier in submission order. **Queue family ownership transfers** and **image layout transitions** defined by `pDependencyInfo` are also included in the first scopes.

The second **synchronization scope** includes only the event signal operation, and any **queue family ownership transfers** and **image layout transitions** defined by `pDependencyInfo`.

The second **access scope** includes only **queue family ownership transfers** and **image layout transitions**.

Future `vkCmdWaitEvents2` commands rely on all values of each element in `pDependencyInfo` matching exactly with those used to signal the corresponding event. `vkCmdWaitEvents` must not be used to wait on the result of a signal operation defined by `vkCmdSetEvent2`.

**Note**

The extra information provided by `vkCmdSetEvent2` compared to `vkCmdSetEvent` allows implementations to more efficiently schedule the operations required to satisfy the requested dependencies. With `vkCmdSetEvent`, the full dependency information is not known until `vkCmdWaitEvents` is recorded, forcing implementations to insert the required operations at that point and not before.

If `event` is already in the signaled state when `vkCmdSetEvent2` is executed on the device, then `vkCmdSetEvent2` has no effect, no event signal operation occurs, and no dependency is generated.
Valid Usage

- VUID-vkCmdSetEvent2-synchronization2-03824
  The `synchronization2` feature must be enabled

- VUID-vkCmdSetEvent2-dependencyFlags-03825
  The `dependencyFlags` member of `pDependencyInfo` must be 0

- VUID-vkCmdSetEvent2-commandBuffer-03826
  The current device mask of `commandBuffer` must include exactly one physical device

- VUID-vkCmdSetEvent2-srcStageMask-03827
  The `srcStageMask` member of any element of the `pMemoryBarriers`, `pBufferMemoryBarriers`, or `pImageMemoryBarriers` members of `pDependencyInfo` must only include pipeline stages valid for the queue family that was used to create the command pool that `commandBuffer` was allocated from

- VUID-vkCmdSetEvent2-dstStageMask-03828
  The `dstStageMask` member of any element of the `pMemoryBarriers`, `pBufferMemoryBarriers`, or `pImageMemoryBarriers` members of `pDependencyInfo` must only include pipeline stages valid for the queue family that was used to create the command pool that `commandBuffer` was allocated from

Valid Usage (Implicit)

- VUID-vkCmdSetEvent2-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdSetEvent2-event-parameter
  `event` must be a valid `VkEvent` handle

- VUID-vkCmdSetEvent2-pDependencyInfo-parameter
  `pDependencyInfo` must be a valid pointer to a valid `VkDependencyInfo` structure

- VUID-vkCmdSetEvent2-commandBuffer-recording
  `commandBuffer` must be in the recording state

- VUID-vkCmdSetEvent2-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, compute, decode, or encode operations

- VUID-vkCmdSetEvent2-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdSetEvent2-commonparent
  Both of `commandBuffer`, and `event` must have been created, allocated, or retrieved from the same `VkDevice`

Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

### Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Outside</td>
<td>Both</td>
<td>Graphics</td>
<td>Synchronization</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td>Compute</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Decode</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Encode</td>
<td></td>
</tr>
</tbody>
</table>

The `VkDependencyInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkDependencyInfo {
    VkStructureType sType;
    const void* pNext;
    VkDependencyFlags dependencyFlags;
    uint32_t memoryBarrierCount;
    const VkMemoryBarrier2* pMemoryBarriers;
   .uint32_t bufferMemoryBarrierCount;
    const VkBufferMemoryBarrier2* pBufferMemoryBarriers;
    .uint32_t imageMemoryBarrierCount;
    const VkImageMemoryBarrier2* pImageMemoryBarriers;
} VkDependencyInfo;
```

or the equivalent

```c
// Provided by VK_KHR_synchronization2
typedef VkDependencyInfo VkDependencyInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `dependencyFlags` is a bitmask of `VkDependencyFlagBits` specifying how execution and memory dependencies are formed.
- `memoryBarrierCount` is the length of the `pMemoryBarriers` array.
- `pMemoryBarriers` is a pointer to an array of `VkMemoryBarrier2` structures defining memory dependencies between any memory accesses.
- `bufferMemoryBarrierCount` is the length of the `pBufferMemoryBarriers` array.
- `pBufferMemoryBarriers` is a pointer to an array of `VkBufferMemoryBarrier2` structures defining memory dependencies between buffer ranges.
• `imageMemoryBarrierCount` is the length of the `pImageMemoryBarriers` array.

• `pImageMemoryBarriers` is a pointer to an array of `VkImageMemoryBarrier2` structures defining memory dependencies between image subresources.

This structure defines a set of memory dependencies, as well as queue family transfer operations and image layout transitions.

Each member of `pMemoryBarriers`, `pBufferMemoryBarriers`, and `pImageMemoryBarriers` defines a separate memory dependency.

### Valid Usage (Implicit)

- **VUID-VkDependencyInfo-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_DEPENDENCY_INFO`

- **VUID-VkDependencyInfo-pNext-pNext**
  
  `pNext` must be `NULL`

- **VUID-VkDependencyInfo-dependencyFlags-parameter**
  
  `dependencyFlags` must be a valid combination of `VkDependencyFlagBits` values

- **VUID-VkDependencyInfo-pMemoryBarriers-parameter**
  
  If `memoryBarrierCount` is not 0, `pMemoryBarriers` must be a valid pointer to an array of `VkMemoryBarrier2` structures

- **VUID-VkDependencyInfo-pBufferMemoryBarriers-parameter**
  
  If `bufferMemoryBarrierCount` is not 0, `pBufferMemoryBarriers` must be a valid pointer to an array of `VkBufferMemoryBarrier2` structures

- **VUID-VkDependencyInfo-pImageMemoryBarriers-parameter**
  
  If `imageMemoryBarrierCount` is not 0, `pImageMemoryBarriers` must be a valid pointer to an array of `VkImageMemoryBarrier2` structures

To set the state of an event to signaled from a device, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdSetEvent(
    VkCommandBuffer commandBuffer,  // Provided by VK_VERSION_1_0
    VkEvent event,                  // Provided by VK_VERSION_1_0
    VkPipelineStageFlags stageMask  // Provided by VK_VERSION_1_0
);
```

• `commandBuffer` is the command buffer into which the command is recorded.

• `event` is the event that will be signaled.

• `stageMask` specifies the source stage mask used to determine the first synchronization scope.

`vkCmdSetEvent` behaves identically to `vkCmdSetEvent2`, except that it does not define an access scope, and must only be used with `vkCmdWaitEvents`, not `vkCmdWaitEvents2`. 
Valid Usage

• VUID-vkCmdSetEvent-stageMask-04090
  If the geometryShader feature is not enabled, stageMask must not contain
  VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT

• VUID-vkCmdSetEvent-stageMask-04091
  If the tessellationShader feature is not enabled, stageMask must not contain
  VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT or
  VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT

• VUID-vkCmdSetEvent-stageMask-04092
  If the conditionalRendering feature is not enabled, stageMask must not contain
  VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT

• VUID-vkCmdSetEvent-stageMask-04093
  If the fragmentDensityMap feature is not enabled, stageMask must not contain
  VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT

• VUID-vkCmdSetEvent-stageMask-04094
  If the transformFeedback feature is not enabled, stageMask must not contain
  VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT

• VUID-vkCmdSetEvent-stageMask-04095
  If the meshShader feature is not enabled, stageMask must not contain
  VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT

• VUID-vkCmdSetEvent-stageMask-04096
  If the taskShader feature is not enabled, stageMask must not contain
  VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT

• VUID-vkCmdSetEvent-stageMask-07318
  If neither the shadingRateImage or attachmentFragmentShadingRate are enabled, stageMask must not contain
  VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

• VUID-vkCmdSetEvent-stageMask-03937
  If the synchronization2 feature is not enabled, stageMask must not be 0

• VUID-vkCmdSetEvent-stageMask-07949
  If neither the VK_NV_ray_tracing extension or rayTracingPipeline feature are enabled, stageMask must not contain
  VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR

• VUID-vkCmdSetEvent-stageMask-06457
  Any pipeline stage included in stageMask must be supported by the capabilities of the queue family specified by the queueFamilyIndex member of the VkCommandPoolCreateInfo structure that was used to create the VkCommandPool that commandBuffer was allocated from, as specified in the table of supported pipeline stages

• VUID-vkCmdSetEvent-stageMask-01149
  stageMask must not include VK_PIPELINE_STAGE_HOST_BIT

• VUID-vkCmdSetEvent-commandBuffer-01152
  commandBuffer's current device mask must include exactly one physical device
Valid Usage (Implicit)

- VUID-vkCmdSetEvent-commandBuffer-parameter
  
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdSetEvent-event-parameter
  
  `event` must be a valid `VkEvent` handle

- VUID-vkCmdSetEvent-stageMask-parameter
  
  `stageMask` must be a valid combination of `VkPipelineStageFlagBits` values

- VUID-vkCmdSetEvent-commandBuffer-recording
  
  `commandBuffer` must be in the recording state

- VUID-vkCmdSetEvent-commandBuffer-cmdpool
  
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, compute, decode, or encode operations

- VUID-vkCmdSetEvent-renderpass
  
  This command must only be called outside of a render pass instance

- VUID-vkCmdSetEvent-commonparent
  
  Both of `commandBuffer`, and `event` must have been created, allocated, or retrieved from the same `VkDevice`

Host Synchronization

- Host access to `commandBuffer` must be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
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<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Outside</td>
<td>Both</td>
<td>Graphics Compute</td>
<td>Synchronization</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td>Encode</td>
<td></td>
</tr>
</tbody>
</table>

To unsignal the event from a device, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdResetEvent2(
    VkCommandBuffer commandBuffer,
    VkEvent event,
)
```
or the equivalent command

```c
// Provided by VK_KHR_synchronization2
void vkCmdResetEvent2KHR(
    VkCommandBuffer commandBuffer,
    VkEvent event,
    VkPipelineStageFlags2 stageMask);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `event` is the event that will be unsignaled.
- `stageMask` is a `VkPipelineStageFlags2` mask of pipeline stages used to determine the first synchronization scope.

When `vkCmdResetEvent2` is submitted to a queue, it defines an execution dependency on commands that were submitted before it, and defines an event unsignal operation which resets the event to the unsignaled state.

The first synchronization scope includes all commands that occur earlier in submission order. The synchronization scope is limited to operations by `stageMask` or stages that are logically earlier than `stageMask`.

The second synchronization scope includes only the event unsignal operation.

If `event` is already in the unsignaled state when `vkCmdResetEvent2` is executed on the device, then this command has no effect, no event unsignal operation occurs, and no execution dependency is generated.

### Valid Usage

- **VUID-vkCmdResetEvent2-stageMask-03929**
  If the `geometryShader` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT`

- **VUID-vkCmdResetEvent2-stageMask-03930**
  If the `tessellationShader` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT` or `VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT`

- **VUID-vkCmdResetEvent2-stageMask-03931**
  If the `conditionalRendering` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT`

- **VUID-vkCmdResetEvent2-stageMask-03932**
  If the `fragmentDensityMap` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT`

- **VUID-vkCmdResetEvent2-stageMask-03933**
If the `transformFeedback` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT`

- VUID-vkCmdResetEvent2-stageMask-03934
  If the `meshShader` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT`

- VUID-vkCmdResetEvent2-stageMask-03935
  If the `taskShader` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT`

- VUID-vkCmdResetEvent2-stageMask-07316
  If neither the `shadingRateImage` or `attachmentFragmentShadingRate` are enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`

- VUID-vkCmdResetEvent2-stageMask-04957
  If the `subpassShading` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI`

- VUID-vkCmdResetEvent2-stageMask-04995
  If the `invocationMask` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI`

- VUID-vkCmdResetEvent2-stageMask-07946
  If neither the `VK_NV_ray_tracing` extension or `rayTracingPipeline` feature are enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR`

- VUID-vkCmdResetEvent2-synchronization2-03829
  The `synchronization2` feature must be enabled

- VUID-vkCmdResetEvent2-stageMask-03830
  `stageMask` must not include `VK_PIPELINE_STAGE_2_HOST_BIT`

- VUID-vkCmdResetEvent2-event-03831
  There must be an execution dependency between `vkCmdResetEvent2` and the execution of any `vkCmdWaitEvents` that includes `event` in its `pEvents` parameter

- VUID-vkCmdResetEvent2-event-03832
  There must be an execution dependency between `vkCmdResetEvent2` and the execution of any `vkCmdWaitEvents2` that includes `event` in its `pEvents` parameter

- VUID-vkCmdResetEvent2-commandBuffer-03833
  `commandBuffer`'s current device mask must include exactly one physical device

---

**Valid Usage (Implicit)**

- VUID-vkCmdResetEvent2-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdResetEvent2-event-parameter
  `event` must be a valid `VkEvent` handle

- VUID-vkCmdResetEvent2-stageMask-parameter
  `stageMask` must be a valid combination of `VkPipelineStageFlagBits2` values
• VUID-vkCmdResetEvent2-commandBuffer-recording
commandBuffer must be in the recording state

• VUID-vkCmdResetEvent2-commandBuffer-cmdpool
The VkCommandPool that commandBuffer was allocated from must support graphics, compute, decode, or encode operations

• VUID-vkCmdResetEvent2-renderpass
This command must only be called outside of a render pass instance

• VUID-vkCmdResetEvent2-commonparent
Both of commandBuffer, and event must have been created, allocated, or retrieved from the same VkDevice

### Host Synchronization

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

### Command Properties

<table>
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<tr>
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<td>Primary</td>
<td>Outside</td>
<td>Both</td>
<td>Graphics Compute Decode Encode</td>
<td>Synchronization</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To set the state of an event to unsignaled from a device, call:

```c
// Provided by VK_VERSION_1_0
typedef void vkCmdResetEvent(
    VkCommandBuffer commandBuffer,
    VkEvent event,
    VkPipelineStageFlags stageMask);
```

• commandBuffer is the command buffer into which the command is recorded.

• event is the event that will be unsignaled.

• stageMask is a bitmask of VkPipelineStageFlagBits specifying the source stage mask used to determine when the event is unsignaled.

vkCmdResetEvent behaves identically to vkCmdResetEvent2.
Valid Usage

- VUID-vkCmdResetEvent-stageMask-04090
  If the `geometryShader` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT`

- VUID-vkCmdResetEvent-stageMask-04091
  If the `tessellationShader` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT` or `VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT`

- VUID-vkCmdResetEvent-stageMask-04092
  If the `conditionalRendering` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT`

- VUID-vkCmdResetEvent-stageMask-04093
  If the `fragmentDensityMap` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT`

- VUID-vkCmdResetEvent-stageMask-04094
  If the `transformFeedback` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT`

- VUID-vkCmdResetEvent-stageMask-04095
  If the `meshShader` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT`

- VUID-vkCmdResetEvent-stageMask-04096
  If the `taskShader` feature is not enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT`

- VUID-vkCmdResetEvent-stageMask-07318
  If neither the `shadingRateImage` or `attachmentFragmentShadingRate` are enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`

- VUID-vkCmdResetEvent-stageMask-03937
  If the `synchronization2` feature is not enabled, `stageMask` must not be 0

- VUID-vkCmdResetEvent-stageMask-07949
  If neither the `VK_NV_ray_tracing` extension or `rayTracingPipeline` feature are enabled, `stageMask` must not contain `VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR`

- VUID-vkCmdResetEvent-stageMask-06458
  Any pipeline stage included in `stageMask` must be supported by the capabilities of the queue family specified by the `queueFamilyIndex` member of the `VkCommandPoolCreateInfo` structure that was used to create the `VkCommandPool` that `commandBuffer` was allocated from, as specified in the table of supported pipeline stages

- VUID-vkCmdResetEvent-stageMask-01153
  `stageMask` must not include `VK_PIPELINE_STAGE_HOST_BIT`

- VUID-vkCmdResetEvent-event-03834
  There must be an execution dependency between `vkCmdResetEvent` and the execution of any `vkCmdWaitEvents` that includes `event` in its `pEvents` parameter
There must be an execution dependency between `vkCmdResetEvent` and the execution of any `vkCmdWaitEvents2` that includes `event` in its `pEvents` parameter.

`commandBuffer`'s current device mask must include exactly one physical device.

Valid Usage (Implicit)

- `commandBuffer` must be a valid `VkCommandBuffer` handle.
- `event` must be a valid `VkEvent` handle.
- `stageMask` must be a valid combination of `VkPipelineStageFlagBits` values.
- `commandBuffer` must be in the recording state.
- The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, compute, decode, or encode operations.
- This command must only be called outside of a render pass instance.
- Both of `commandBuffer` and `event` must have been created, allocated, or retrieved from the same `VkDevice`.

Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
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<tr>
<td>Primary Secondary</td>
<td>Outside</td>
<td>Both</td>
<td>Graphics, Compute, Decode, Encode</td>
<td>Synchronization</td>
</tr>
</tbody>
</table>
To wait for one or more events to enter the signaled state on a device, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdWaitEvents2(
    VkCommandBuffer commandBuffer,
    uint32_t eventCount,
    const VkEvent* pEvents,
    const VkDependencyInfo* pDependencyInfos);
```

or the equivalent command

```c
// Provided by VK_KHR_synchronization2
void vkCmdWaitEvents2KHR(
    VkCommandBuffer commandBuffer,
    uint32_t eventCount,
    const VkEvent* pEvents,
    const VkDependencyInfo* pDependencyInfos);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `eventCount` is the length of the `pEvents` array.
- `pEvents` is a pointer to an array of `eventCount` events to wait on.
- `pDependencyInfos` is a pointer to an array of `eventCount` `VkDependencyInfo` structures, defining the second synchronization scope.

When `vkCmdWaitEvents2` is submitted to a queue, it inserts memory dependencies according to the elements of `pDependencyInfos` and each corresponding element of `pEvents`. `vkCmdWaitEvents2` must not be used to wait on event signal operations occurring on other queues, or signal operations executed by `vkCmdSetEvent`.

The first synchronization scope and access scope of each memory dependency defined by any element `i` of `pDependencyInfos` are applied to operations that occurred earlier in submission order than the last event signal operation on element `i` of `pEvents`.

Signal operations for an event at index `i` are only included if:

- The event was signaled by a `vkCmdSetEvent2` command that occurred earlier in submission order with a `dependencyInfo` parameter exactly equal to the element of `pDependencyInfos` at index `i`; or

- The event was created without `VK_EVENT_CREATE_DEVICE_ONLY_BIT`, and the first synchronization scope defined by the element of `pDependencyInfos` at index `i` only includes host operations (`VK_PIPELINE_STAGE_2_HOST_BIT`).

The second synchronization scope and access scope of each memory dependency defined by any element `i` of `pDependencyInfos` are applied to operations that occurred later in submission order than `vkCmdWaitEvents2`.
vkCmdWaitEvents2 is used with vkCmdSetEvent2 to define a memory dependency between two sets of action commands, roughly in the same way as pipeline barriers, but split into two commands such that work between the two may execute unhindered.

Applications should be careful to avoid race conditions when using events. There is no direct ordering guarantee between vkCmdSetEvent2 and vkCmdResetEvent2, vkCmdResetEvent, or vkCmdSetEvent. Another execution dependency (e.g. a pipeline barrier or semaphore with VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT) is needed to prevent such a race condition.

### Valid Usage

- **VUID-vkCmdWaitEvents2-synchronization2-03836**
  The synchronization2 feature must be enabled

- **VUID-vkCmdWaitEvents2-pEvents-03837**
  Members of pEvents must not have been signaled by vkCmdSetEvent

- **VUID-vkCmdWaitEvents2-pEvents-03838**
  For any element i of pEvents, if that event is signaled by vkCmdSetEvent2, that command’s dependencyInfo parameter must be exactly equal to the ith element of pDependencyInfos

- **VUID-vkCmdWaitEvents2-pEvents-03839**
  For any element i of pEvents, if that event is signaled by vkCmdSetEvent2, that command’s dependencyInfo parameter must be exactly equal to the ith element of pDependencyInfos

- **VUID-vkCmdWaitEvents2-pEvents-03840**
  For any element i of pEvents, if barriers in the ith element of pDependencyInfos include only host operations, the ith element of pEvents must be signaled before vkCmdWaitEvents2 is executed

- **VUID-vkCmdWaitEvents2-pEvents-03841**
  For any element i of pEvents, if barriers in the ith element of pDependencyInfos do not include host operations, the ith element of pEvents must be signaled by a corresponding vkCmdSetEvent2 that occurred earlier in submission order

- **VUID-vkCmdWaitEvents2-srcStageMask-03842**
  The srcStageMask member of any element of the pMemoryBarriers, pBufferMemoryBarriers, or pImageMemoryBarriers members of pDependencyInfos must either include only pipeline stages valid for the queue family that was used to create the command pool that commandBuffer was allocated from, or include only VK_PIPELINE_STAGE_2_HOST_BIT

- **VUID-vkCmdWaitEvents2-dstStageMask-03843**
  The dstStageMask member of any element of the pMemoryBarriers, pBufferMemoryBarriers, or pImageMemoryBarriers members of pDependencyInfos must only include pipeline stages valid for the queue family that was used to create the command pool that commandBuffer
was allocated from

- VUID-vkCmdWaitEvents2-dependencyFlags-03844
  If `vkCmdWaitEvents2` is being called inside a render pass instance, the `srcStageMask` member of any element of the `pMemoryBarriers`, `pBufferMemoryBarriers`, or `pImageMemoryBarriers` members of `pDependencyInfos` must not include `VK_PIPELINE_STAGE_2_HOST_BIT`

- VUID-vkCmdWaitEvents2-commandBuffer-03846
  `commandBuffer`'s current device mask must include exactly one physical device

### Valid Usage (Implicit)

- VUID-vkCmdWaitEvents2-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdWaitEvents2-pEvents-parameter
  `pEvents` must be a valid pointer to an array of `eventCount` valid `VkEvent` handles

- VUID-vkCmdWaitEvents2-pDependencyInfos-parameter
  `pDependencyInfos` must be a valid pointer to an array of `eventCount` valid `VkDependencyInfo` structures

- VUID-vkCmdWaitEvents2-commandBuffer-recording
  `commandBuffer` must be in the recording state

- VUID-vkCmdWaitEvents2-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, compute, decode, or encode operations

- VUID-vkCmdWaitEvents2-eventCount-arraylength
  `eventCount` must be greater than 0

- VUID-vkCmdWaitEvents2-commonparent
  Both of `commandBuffer`, and the elements of `pEvents` must have been created, allocated, or retrieved from the same `VkDevice`

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized
Command Properties

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<td>Both</td>
<td>Graphics Compute</td>
<td>Synchronization</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td>Decode Encode</td>
<td></td>
</tr>
</tbody>
</table>

To wait for one or more events to enter the signaled state on a device, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdWaitEvents(
    VkCommandBuffer commandBuffer,
    uint32_t eventCount,
    const VkEvent* pEvents,
    VkPipelineStageFlags srcStageMask,
    VkPipelineStageFlags dstStageMask,
    uint32_t memoryBarrierCount,
    const VkMemoryBarrier* pMemoryBarriers,
    uint32_t bufferMemoryBarrierCount,
    const VkBufferMemoryBarrier* pBufferMemoryBarriers,
    uint32_t imageMemoryBarrierCount,
    constVkImageMemoryBarrier* pImageMemoryBarriers);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `eventCount` is the length of the `pEvents` array.
- `pEvents` is a pointer to an array of event object handles to wait on.
- `srcStageMask` is a bitmask of `VkPipelineStageFlagBits` specifying the source stage mask.
- `dstStageMask` is a bitmask of `VkPipelineStageFlagBits` specifying the destination stage mask.
- `memoryBarrierCount` is the length of the `pMemoryBarriers` array.
- `pMemoryBarriers` is a pointer to an array of `VkMemoryBarrier` structures.
- `bufferMemoryBarrierCount` is the length of the `pBufferMemoryBarriers` array.
- `pBufferMemoryBarriers` is a pointer to an array of `VkBufferMemoryBarrier` structures.
- `imageMemoryBarrierCount` is the length of the `pImageMemoryBarriers` array.
- `pImageMemoryBarriers` is a pointer to an array of `VkImageMemoryBarrier` structures.

`vkCmdWaitEvents` is largely similar to `vkCmdWaitEvents2`, but can only wait on signal operations defined by `vkCmdSetEvent`. As `vkCmdSetEvent` does not define any access scopes, `vkCmdWaitEvents` defines the first access scope for each event signal operation in addition to its own access scopes.

**Note**
Since `vkCmdSetEvent` does not have any dependency information beyond a stage mask, implementations do not have the same opportunity to perform availability and visibility operations or image layout transitions in advance as they do with `vkCmdSetEvent2` and `vkCmdWaitEvents2`.

When `vkCmdWaitEvents` is submitted to a queue, it defines a memory dependency between prior event signal operations on the same queue or the host, and subsequent commands. `vkCmdWaitEvents` must not be used to wait on event signal operations occurring on other queues.

The first synchronization scope only includes event signal operations that operate on members of `pEvents`, and the operations that happened-before the event signal operations. Event signal operations performed by `vkCmdSetEvent` that occur earlier in submission order are included in the first synchronization scope, if the logically latest pipeline stage in their `stageMask` parameter is logically earlier than or equal to the logically latest pipeline stage in `srcStageMask`. Event signal operations performed by `vkSetEvent` are only included in the first synchronization scope if `VK_PIPELINE_STAGE_HOST_BIT` is included in `srcStageMask`.

The second synchronization scope includes all commands that occur later in submission order. The second synchronization scope is limited to operations on the pipeline stages determined by the destination stage mask specified by `dstStageMask`.

The first access scope is limited to accesses in the pipeline stages determined by the source stage mask specified by `srcStageMask`. Within that, the first access scope only includes the first access scopes defined by elements of the `pMemoryBarriers`, `pBufferMemoryBarriers` and `pImageMemoryBarriers` arrays, which each define a set of memory barriers. If no memory barriers are specified, then the first access scope includes no accesses.

The second access scope is limited to accesses in the pipeline stages determined by the destination stage mask specified by `dstStageMask`. Within that, the second access scope only includes the second access scopes defined by elements of the `pMemoryBarriers`, `pBufferMemoryBarriers` and `pImageMemoryBarriers` arrays, which each define a set of memory barriers. If no memory barriers are specified, then the second access scope includes no accesses.

## Valid Usage

- **VUID-vkCmdWaitEvents-srcStageMask-04090**
  If the geometryShader feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT`

- **VUID-vkCmdWaitEvents-srcStageMask-04091**
  If the tessellationShader feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT` or `VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT`

- **VUID-vkCmdWaitEvents-srcStageMask-04092**
  If the conditionalRendering feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT`

- **VUID-vkCmdWaitEvents-srcStageMask-04093**
  If the fragmentDensityMap feature is not enabled, `srcStageMask` must not contain
• VUID-vkCmdWaitEvents-srcStageMask-04094
  If the transformFeedback feature is not enabled, srcStageMask must not contain VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT

• VUID-vkCmdWaitEvents-srcStageMask-04095
  If the meshShader feature is not enabled, srcStageMask must not contain VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT

• VUID-vkCmdWaitEvents-srcStageMask-04096
  If the taskShader feature is not enabled, srcStageMask must not contain VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT

• VUID-vkCmdWaitEvents-srcStageMask-07318
  If neither the shadingRateImage or attachmentFragmentShadingRate are enabled, srcStageMask must not contain VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

• VUID-vkCmdWaitEvents-srcStageMask-04097
  If the synchronization2 feature is not enabled, srcStageMask must not be 0

• VUID-vkCmdWaitEvents-srcStageMask-04098
  If the rayQuery feature is not enabled and a memory barrier srcAccessMask includes VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR, srcStageMask must not include any of the VK_PIPELINE_STAGE_*_SHADER_BIT stages except VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR

• VUID-vkCmdWaitEvents-dstStageMask-04090
  If the geometryShader feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT

• VUID-vkCmdWaitEvents-dstStageMask-04091
  If the tessellationShader feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT or VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT

• VUID-vkCmdWaitEvents-dstStageMask-04092
  If the conditionalRendering feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGECONDITIONAL_RENDERING_BIT_EXT

• VUID-vkCmdWaitEvents-dstStageMask-04093
  If the fragmentDensityMap feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT

• VUID-vkCmdWaitEvents-dstStageMask-04094
  If the transformFeedback feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT

• VUID-vkCmdWaitEvents-dstStageMask-04095
  If the meshShader feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT

• VUID-vkCmdWaitEvents-dstStageMask-04096
  If the taskShader feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT

• VUID-vkCmdWaitEvents-dstStageMask-04097
  If neither the shadingRateImage or attachmentFragmentShadingRate are enabled, dstStageMask must not contain VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR
• VUID-vkCmdWaitEvents-dstStageMask-04096
  If the taskShader feature is not enabled, dstStageMask must not contain
  VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT

• VUID-vkCmdWaitEvents-dstStageMask-07318
  If neither the shadingRateImage or attachmentFragmentShadingRate are enabled,
  dstStageMask must not contain
  VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

• VUID-vkCmdWaitEvents-dstStageMask-03937
  If the synchronization2 feature is not enabled, dstStageMask must not be 0

• VUID-vkCmdWaitEvents-dstStageMask-07949
  If neither the VK_NV_ray_tracing extension or rayTracingPipeline feature are enabled,
  dstStageMask must not contain
  VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR

• VUID-vkCmdWaitEvents-srcAccessMask-02815
  The srcAccessMask member of each element of pMemoryBarriers must only include access
  flags that are supported by one or more of the pipeline stages in srcStageMask, as specified
  in the table of supported access types

• VUID-vkCmdWaitEvents-dstAccessMask-02816
  The dstAccessMask member of each element of pMemoryBarriers must only include access
  flags that are supported by one or more of the pipeline stages in dstStageMask, as specified
  in the table of supported access types

• VUID-vkCmdWaitEvents-pBufferMemoryBarriers-02817
  For any element of pBufferMemoryBarriers, if its srcQueueFamilyIndex and
  dstQueueFamilyIndex members are equal, or if its srcQueueFamilyIndex is the queue family
  index that was used to create the command pool that commandBuffer was allocated from,
  then its srcAccessMask member must only contain access flags that are supported by one
  or more of the pipeline stages in srcStageMask, as specified in the table of supported access
  types

• VUID-vkCmdWaitEvents-pBufferMemoryBarriers-02818
  For any element of pBufferMemoryBarriers, if its srcQueueFamilyIndex and
  dstQueueFamilyIndex members are equal, or if its dstQueueFamilyIndex is the queue family
  index that was used to create the command pool that commandBuffer was allocated from,
  then its dstAccessMask member must only contain access flags that are supported by one
  or more of the pipeline stages in dstStageMask, as specified in the table of supported access
  types

• VUID-vkCmdWaitEvents-pImageMemoryBarriers-02819
  For any element of pImageMemoryBarriers, if its srcQueueFamilyIndex and
  dstQueueFamilyIndex members are equal, or if its srcQueueFamilyIndex is the queue family
index that was used to create the command pool that \texttt{commandBuffer} was allocated from, then its srcAccessMask member \textbf{must} only contain access flags that are supported by one or more of the pipeline stages in srcStageMask, as specified in the table of supported access types.

- VUID-vkCmdWaitEvents-pImageMemoryBarriers-02820
  For any element of pImageMemoryBarriers, if its srcQueueFamilyIndex and dstQueueFamilyIndex members are equal, or if its dstQueueFamilyIndex is the queue family index that was used to create the command pool that \texttt{commandBuffer} was allocated from, then its dstAccessMask member \textbf{must} only contain access flags that are supported by one or more of the pipeline stages in dstStageMask, as specified in the table of supported access types.

- VUID-vkCmdWaitEvents-srcStageMask-06459
  Any pipeline stage included in srcStageMask \textbf{must} be supported by the capabilities of the queue family specified by the queueFamilyIndex member of the VkCommandPoolCreateInfo structure that was used to create the \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from, as specified in the table of supported pipeline stages.

- VUID-vkCmdWaitEvents-dstStageMask-06460
  Any pipeline stage included in dstStageMask \textbf{must} be supported by the capabilities of the queue family specified by the queueFamilyIndex member of the \texttt{VkCommandPoolCreateInfo} structure that was used to create the \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from, as specified in the table of supported pipeline stages.

- VUID-vkCmdWaitEvents-srcStageMask-01158
  srcStageMask \textbf{must} be the bitwise OR of the stageMask parameter used in previous calls to vkCmdSetEvent with any of the elements of pEvents and VK_PIPELINE_STAGE_HOST_BIT if any of the elements of pEvents was set using vkSetEvent.

- VUID-vkCmdWaitEvents-srcQueueFamilyIndex-02803
  The srcQueueFamilyIndex and dstQueueFamilyIndex members of any element of pBufferMemoryBarriers or pImageMemoryBarriers \textbf{must} be equal.

- VUID-vkCmdWaitEvents-commandBuffer-01167
  \texttt{commandBuffer}’s current device mask \textbf{must} include exactly one physical device.

- VUID-vkCmdWaitEvents-pEvents-03847
  Elements of pEvents \textbf{must} not have been signaled by vkCmdSetEvent2.

**Valid Usage (Implicit)**

- VUID-vkCmdWaitEvents-commandBuffer-parameter
  \texttt{commandBuffer} \textbf{must} be a valid \texttt{VkCommandBuffer} handle.

- VUID-vkCmdWaitEvents-pEvents-parameter
  pEvents \textbf{must} be a valid pointer to an array of eventCount valid VkEvent handles.

- VUID-vkCmdWaitEvents-srcStageMask-parameter
**srcStageMask** must be a valid combination of **VkPipelineStageFlagBits** values

- **VUID-vkCmdWaitEvents-dstStageMask-parameter**
  dstStageMask must be a valid combination of **VkPipelineStageFlagBits** values

- **VUID-vkCmdWaitEvents-pMemoryBarriers-parameter**
  If memoryBarrierCount is not 0, pMemoryBarriers must be a valid pointer to an array of memoryBarrierCount valid **VkMemoryBarrier** structures

- **VUID-vkCmdWaitEvents-pBufferMemoryBarriers-parameter**
  If bufferMemoryBarrierCount is not 0, pBufferMemoryBarriers must be a valid pointer to an array of bufferMemoryBarrierCount valid **VkBufferMemoryBarrier** structures

- **VUID-vkCmdWaitEvents-pImageMemoryBarriers-parameter**
  If imageMemoryBarrierCount is not 0, pImageMemoryBarriers must be a valid pointer to an array of imageMemoryBarrierCount valid **VkImageMemoryBarrier** structures

- **VUID-vkCmdWaitEvents-commandBuffer-recording**
  commandBuffer must be in the recording state

- **VUID-vkCmdWaitEvents-commandBuffer-cmdpool**
  The **VkCommandPool** that commandBuffer was allocated from must support graphics, compute, decode, or encode operations

- **VUID-vkCmdWaitEvents-eventCount-arraylength**
  eventCount must be greater than 0

- **VUID-vkCmdWaitEvents-commonparent**
  Both of commandBuffer, and the elements of pEvents must have been created, allocated, or retrieved from the same **VkDevice**

**Host Synchronization**

- Host access to commandBuffer must be externally synchronized
- Host access to the **VkCommandPool** that commandBuffer was allocated from must be externally synchronized

**Command Properties**

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</tr>
</thead>
<tbody>
<tr>
<td>Primary Secondary</td>
<td>Both</td>
<td>Both</td>
<td>Graphics, Compute, Decode, Encode</td>
<td>Synchronization</td>
</tr>
</tbody>
</table>
7.6. Pipeline Barriers

To record a pipeline barrier, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdPipelineBarrier2(
    VkCommandBuffer commandBuffer,
    const VkDependencyInfo* pDependencyInfo);
```

or the equivalent command

```c
// Provided by VK_KHR_synchronization2
void vkCmdPipelineBarrier2KHR(
    VkCommandBuffer commandBuffer,
    const VkDependencyInfo* pDependencyInfo);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `pDependencyInfo` is a pointer to a `VkDependencyInfo` structure defining the scopes of this operation.

When `vkCmdPipelineBarrier2` is submitted to a queue, it defines memory dependencies between commands that were submitted to the same queue before it, and those submitted to the same queue after it.

The first synchronization scope and access scope of each memory dependency defined by `pDependencyInfo` are applied to operations that occurred earlier in submission order.

The second synchronization scope and access scope of each memory dependency defined by `pDependencyInfo` are applied to operations that occurred later in submission order.

If `vkCmdPipelineBarrier2` is recorded within a render pass instance, the synchronization scopes are limited to operations within the same subpass, or must follow the restrictions for Tile Image Access Synchronization if the render pass instance was started with `vkCmdBeginRendering`.

### Valid Usage

- **VUID-vkCmdPipelineBarrier2-None-07889**
  If `vkCmdPipelineBarrier2` is called within a render pass instance using a `VkRenderPass` object, the render pass must have been created with at least one subpass dependency that expresses a dependency from the current subpass to itself, does not include `VK_DEPENDENCY_BY_REGION_BIT` if this command does not, does not include `VK_DEPENDENCY_VIEW_LOCAL_BIT` if this command does not, and has synchronization scopes and access scopes that are all supersets of the scopes defined in this command.

- **VUID-vkCmdPipelineBarrier2-bufferMemoryBarrierCount-01178**
  If `vkCmdPipelineBarrier2` is called within a render pass instance using a `VkRenderPass` object, it must not include any buffer memory barriers.
If `vkCmdPipelineBarrier2` is called within a render pass instance using a `VkRenderPass` object, the `image` member of any image memory barrier included in this command **must** be an attachment used in the current subpass both as an input attachment, and as either a color or depth/stencil attachment.

If `vkCmdPipelineBarrier2` is called within a render pass instance, the `oldLayout` and `newLayout` members of any image memory barrier included in this command **must** be equal.

If `vkCmdPipelineBarrier2` is called within a render pass instance, the `srcQueueFamilyIndex` and `dstQueueFamilyIndex` members of any memory barrier included in this command **must** be equal.

If `vkCmdPipelineBarrier2` is called within a render pass instance started with `vkCmdBeginRendering`, it **must** adhere to the restrictions in Explicit Render Pass Tile Image Access Synchronization.

The `synchronization2` feature **must** be enabled.
The srcStageMask member of any element of the pMemoryBarriers, pBufferMemoryBarriers, or pImageMemoryBarriers members of pDependencyInfo must only include pipeline stages valid for the queue family that was used to create the command pool that commandBuffer was allocated from.

The dstStageMask member of any element of the pMemoryBarriers, pBufferMemoryBarriers, or pImageMemoryBarriers members of pDependencyInfo must only include pipeline stages valid for the queue family that was used to create the command pool that commandBuffer was allocated from.

Valid Usage (Implicit)

- VUID-vkCmdPipelineBarrier2-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdPipelineBarrier2-pDependencyInfo-parameter
  pDependencyInfo must be a valid pointer to a valid VkDependencyInfo structure

- VUID-vkCmdPipelineBarrier2-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdPipelineBarrier2-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support transfer, graphics, compute, decode, or encode operations

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
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<tbody>
<tr>
<td>Primary Secondary</td>
<td>Both</td>
<td>Both</td>
<td>Transfer Graphics</td>
<td>Synchronization</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compute Decode Encode</td>
<td></td>
</tr>
</tbody>
</table>

To record a pipeline barrier, call:
void vkCmdPipelineBarrier(
    VkCommandBuffer commandBuffer,
    VkPipelineStageFlags srcStageMask,
    VkPipelineStageFlags dstStageMask,
    VkDependencyFlags dependencyFlags,
    uint32_t memoryBarrierCount,
    const VkMemoryBarrier* pMemoryBarriers,
    uint32_t bufferMemoryBarrierCount,
    const VkBufferMemoryBarrier* pBufferMemoryBarriers,
    uint32_t imageMemoryBarrierCount,
    const VkImageMemoryBarrier* pImageMemoryBarriers);

- commandBuffer is the command buffer into which the command is recorded.
- srcStageMask is a bitmask of VkPipelineStageFlagBits specifying the source stages.
- dstStageMask is a bitmask of VkPipelineStageFlagBits specifying the destination stages.
- dependencyFlags is a bitmask of VkDependencyFlagBits specifying how execution and memory dependencies are formed.
- memoryBarrierCount is the length of the pMemoryBarriers array.
- pMemoryBarriers is a pointer to an array of VkMemoryBarrier structures.
- bufferMemoryBarrierCount is the length of the pBufferMemoryBarriers array.
- pBufferMemoryBarriers is a pointer to an array of VkBufferMemoryBarrier structures.
- imageMemoryBarrierCount is the length of the pImageMemoryBarriers array.
- pImageMemoryBarriers is a pointer to an array of VkImageMemoryBarrier structures.

vkCmdPipelineBarrier operates almost identically to vkCmdPipelineBarrier2, except that the scopes and barriers are defined as direct parameters rather than being defined by an VkDependencyInfo.

When vkCmdPipelineBarrier is submitted to a queue, it defines a memory dependency between commands that were submitted to the same queue before it, and those submitted to the same queue after it.

If vkCmdPipelineBarrier was recorded outside a render pass instance, the first synchronization scope includes all commands that occur earlier in submission order. If vkCmdPipelineBarrier was recorded inside a render pass instance, the first synchronization scope includes only commands that occur earlier in submission order within the same subpass. In either case, the first synchronization scope is limited to operations on the pipeline stages determined by the source stage mask specified by srcStageMask.

If vkCmdPipelineBarrier was recorded outside a render pass instance, the second synchronization scope includes all commands that occur later in submission order. If vkCmdPipelineBarrier was recorded inside a render pass instance, the second synchronization scope includes only commands that occur later in submission order within the same subpass. In either case, the second synchronization scope is limited to operations on the pipeline stages determined by the destination stage mask specified by dstStageMask.
The first access scope is limited to accesses in the pipeline stages determined by the source stage mask specified by `srcStageMask`. Within that, the first access scope only includes the first access scopes defined by elements of the `pMemoryBarriers`, `pBufferMemoryBarriers` and `pImageMemoryBarriers` arrays, which each define a set of memory barriers. If no memory barriers are specified, then the first access scope includes no accesses.

The second access scope is limited to accesses in the pipeline stages determined by the destination stage mask specified by `dstStageMask`. Within that, the second access scope only includes the second access scopes defined by elements of the `pMemoryBarriers`, `pBufferMemoryBarriers` and `pImageMemoryBarriers` arrays, which each define a set of memory barriers. If no memory barriers are specified, then the second access scope includes no accesses.

If `dependencyFlags` includes `VK_DEPENDENCY_BY_REGION_BIT`, then any dependency between framebuffer-space pipeline stages is framebuffer-local - otherwise it is framebuffer-global.

---

### Valid Usage

- VUID-vkCmdPipelineBarrier-srcStageMask-04090
  If the geometryShader feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT`.

- VUID-vkCmdPipelineBarrier-srcStageMask-04091
  If the tessellationShader feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT` or `VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT`.

- VUID-vkCmdPipelineBarrier-srcStageMask-04092
  If the conditionalRendering feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT`.

- VUID-vkCmdPipelineBarrier-srcStageMask-04093
  If the fragmentDensityMap feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT`.

- VUID-vkCmdPipelineBarrier-srcStageMask-04094
  If the transformFeedback feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT`.

- VUID-vkCmdPipelineBarrier-srcStageMask-04095
  If the meshShader feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT`.

- VUID-vkCmdPipelineBarrier-srcStageMask-04096
  If the taskShader feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT`.

- VUID-vkCmdPipelineBarrier-srcStageMask-07318
  If neither the shadingRateImage or attachmentFragmentShadingRate are enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`.

- VUID-vkCmdPipelineBarrier-srcStageMask-03937
  If the synchronization2 feature is not enabled, `srcStageMask` must not be 0.
If neither the VK_NV_ray_tracing extension or rayTracingPipeline feature are enabled, `srcStageMask must not contain VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR`.

If the rayQuery feature is not enabled and a memory barrier `srcAccessMask` includes `VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR`, `srcStageMask must not include any of the VK_PIPELINE_STAGE_*_SHADER_BIT stages except VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR`.

If the geometryShader feature is not enabled, `dstStageMask must not contain VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT`.

If the tessellationShader feature is not enabled, `dstStageMask must not contain VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT` or `VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT`.

If the conditionalRendering feature is not enabled, `dstStageMask must not contain VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT`.

If the transformFeedback feature is not enabled, `dstStageMask must not contain VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT`.

If the meshShader feature is not enabled, `dstStageMask must not contain VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT`.

If the taskShader feature is not enabled, `dstStageMask must not contain VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT`.

If the shadingRateImage or attachmentFragmentShadingRate are enabled, `dstStageMask must not contain VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`.

If the synchronization2 feature is not enabled, `dstStageMask must not be 0`.

If neither the VK_NV_ray_tracing extension or rayTracingPipeline feature are enabled, `dstStageMask must not contain VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR`.

If the rayQuery feature is not enabled and a memory barrier `dstAccessMask` includes `VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR`, `dstStageMask must not include any of the...`
VK_PIPELINE_STAGE_*_SHADER_BIT stages except VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR

- VUID-vkCmdPipelineBarrier-srcAccessMask-02815
  The `srcAccessMask` member of each element of `pMemoryBarriers` must only include access flags that are supported by one or more of the pipeline stages in `srcStageMask`, as specified in the table of supported access types.

- VUID-vkCmdPipelineBarrier-dstAccessMask-02816
  The `dstAccessMask` member of each element of `pMemoryBarriers` must only include access flags that are supported by one or more of the pipeline stages in `dstStageMask`, as specified in the table of supported access types.

- VUID-vkCmdPipelineBarrier-pBufferMemoryBarriers-02817
  For any element of `pBufferMemoryBarriers`, if its `srcQueueFamilyIndex` and `dstQueueFamilyIndex` members are equal, or if its `srcQueueFamilyIndex` is the queue family index that was used to create the command pool that `commandBuffer` was allocated from, then its `srcAccessMask` member must only contain access flags that are supported by one or more of the pipeline stages in `srcStageMask`, as specified in the table of supported access types.

- VUID-vkCmdPipelineBarrier-pBufferMemoryBarriers-02818
  For any element of `pBufferMemoryBarriers`, if its `srcQueueFamilyIndex` and `dstQueueFamilyIndex` members are equal, or if its `dstQueueFamilyIndex` is the queue family index that was used to create the command pool that `commandBuffer` was allocated from, then its `dstAccessMask` member must only contain access flags that are supported by one or more of the pipeline stages in `dstStageMask`, as specified in the table of supported access types.

- VUID-vkCmdPipelineBarrier-pImageMemoryBarriers-02819
  For any element of `pImageMemoryBarriers`, if its `srcQueueFamilyIndex` and `dstQueueFamilyIndex` members are equal, or if its `srcQueueFamilyIndex` is the queue family index that was used to create the command pool that `commandBuffer` was allocated from, then its `srcAccessMask` member must only contain access flags that are supported by one or more of the pipeline stages in `srcStageMask`, as specified in the table of supported access types.

- VUID-vkCmdPipelineBarrier-pImageMemoryBarriers-02820
  For any element of `pImageMemoryBarriers`, if its `srcQueueFamilyIndex` and `dstQueueFamilyIndex` members are equal, or if its `dstQueueFamilyIndex` is the queue family index that was used to create the command pool that `commandBuffer` was allocated from, then its `dstAccessMask` member must only contain access flags that are supported by one or more of the pipeline stages in `dstStageMask`, as specified in the table of supported access types.

- VUID-vkCmdPipelineBarrier-None-07889
  If `vkCmdPipelineBarrier` is called within a render pass instance using a `VkRenderPass` object, the render pass must have been created with at least one subpass dependency that expresses a dependency from the current subpass to itself, does not include `VK_DEPENDENCY_BY_REGION_BIT` if this command does not, does not include `VK_DEPENDENCY_VIEW_LOCAL_BIT` if this command does not, and has synchronization scopes.
and access scopes that are all supersets of the scopes defined in this command

- **VUID-vkCmdPipelineBarrier-bufferMemoryBarrierCount-01178**
  If `vkCmdPipelineBarrier` is called within a render pass instance using a `VkRenderPass` object, it **must** not include any buffer memory barriers

- **VUID-vkCmdPipelineBarrier-image-04073**
  If `vkCmdPipelineBarrier` is called within a render pass instance using a `VkRenderPass` object, the image member of any image memory barrier included in this command **must** be an attachment used in the current subpass both as an input attachment, and as either a color or depth/stencil attachment

- **VUID-vkCmdPipelineBarrier-oldLayout-01181**
  If `vkCmdPipelineBarrier` is called within a render pass instance, the `oldLayout` and `newLayout` members of any image memory barrier included in this command **must** be equal

- **VUID-vkCmdPipelineBarrier-srcQueueFamilyIndex-01182**
  If `vkCmdPipelineBarrier` is called within a render pass instance, the `srcQueueFamilyIndex` and `dstQueueFamilyIndex` members of any memory barrier included in this command **must** be equal

- **VUID-vkCmdPipelineBarrier-none-07890**
  If `vkCmdPipelineBarrier` is called within a render pass instance, and the source stage masks of any memory barriers include framebuffer-space stages, destination stage masks of all memory barriers **must** only include framebuffer-space stages

- **VUID-vkCmdPipelineBarrier-dependencyFlags-07891**
  If `vkCmdPipelineBarrier` is called within a render pass instance, and the source stage masks of any memory barriers include framebuffer-space stages, then `dependencyFlags` **must** include `VK_DEPENDENCY_BY_REGION_BIT`

- **VUID-vkCmdPipelineBarrier-none-07892**
  If `vkCmdPipelineBarrier` is called within a render pass instance, the source and destination stage masks of any memory barriers **must** only include graphics pipeline stages

- **VUID-vkCmdPipelineBarrier-dependencyFlags-01186**
  If `vkCmdPipelineBarrier` is called outside of a render pass instance, the dependency flags **must** not include `VK_DEPENDENCY_VIEW_LOCAL_BIT`

- **VUID-vkCmdPipelineBarrier-none-07893**
  If `vkCmdPipelineBarrier` is called inside a render pass instance, and there is more than one view in the current subpass, dependency flags **must** include `VK_DEPENDENCY_VIEW_LOCAL_BIT`

- **VUID-vkCmdPipelineBarrier-shaderTileImageColorReadAccess-08718**
  If `vkCmdPipelineBarrier` is called within a render pass instance and none of the `shaderTileImageColorReadAccess`, `shaderTileImageDepthReadAccess`, `shaderTileImageStencilReadAccess` features are enabled, the render pass **must** not have been started with `vkCmdBeginRendering`

- **VUID-vkCmdPipelineBarrier-none-08719**
  If `vkCmdPipelineBarrier` is called within a render pass instance started with `vkCmdBeginRendering`, it **must** adhere to the restrictions in Explicit Render Pass Tile Image Access Synchronization
Any pipeline stage included in srcStageMask must be supported by the capabilities of the queue family specified by the queueFamilyIndex member of the VkCommandPoolCreateInfo structure that was used to create the VkCommandPool that commandBuffer was allocated from, as specified in the table of supported pipeline stages.

Any pipeline stage included in dstStageMask must be supported by the capabilities of the queue family specified by the queueFamilyIndex member of the VkCommandPoolCreateInfo structure that was used to create the VkCommandPool that commandBuffer was allocated from, as specified in the table of supported pipeline stages.

Valid Usage (Implicit)

commandBuffer must be a valid VkCommandBuffer handle.
	srcStageMask must be a valid combination of VkPipelineStageFlagBits values.
	dstStageMask must be a valid combination of VkPipelineStageFlagBits values.

dependencyFlags must be a valid combination of VkDependencyFlagBits values.

If memoryBarrierCount is not 0, pMemoryBarriers must be a valid pointer to an array of memoryBarrierCount valid VkMemoryBarrier structures.

If bufferMemoryBarrierCount is not 0, pBufferMemoryBarriers must be a valid pointer to an array of bufferMemoryBarrierCount valid VkBufferMemoryBarrier structures.

If imageMemoryBarrierCount is not 0, pImageMemoryBarriers must be a valid pointer to an array of imageMemoryBarrierCount valid VkImageMemoryBarrier structures.

commandBuffer must be in the recording state.

The VkCommandPool that commandBuffer was allocated from must support transfer, graphics, compute, decode, or encode operations.

Host Synchronization

Host access to commandBuffer must be externally synchronized.

Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized.
### Command Properties

<table>
<thead>
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<th>Command Buffer Levels</th>
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<th>Supported Queue Types</th>
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<td>Both</td>
<td>Both</td>
<td>Transfer Graphics Compute Decode Encode</td>
<td>Synchronization</td>
</tr>
</tbody>
</table>

Bits which **can** be set in `vkCmdPipelineBarrier::dependencyFlags`, specifying how execution and memory dependencies are formed, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkDependencyFlagBits {
    VK_DEPENDENCY_BY_REGION_BIT = 0x00000001,
    // Provided by VK_VERSION_1_1
    VKDEPENDENCY_DEVICEGROUP_BIT = 0x00000002,
    // Provided by VK_VERSION_1_1
    VK_DEPENDENCY_DEVICEGROUP_BIT_KHR = VK_DEPENDENCY_DEVICEGROUP_BIT,
    // Provided by VK_KHR_multiview
    VKDEPENDENCY_FEEDBACK_LOOP_BIT_KHR = VK_DEPENDENCY_FEEDBACK_LOOP_BIT_EXT = 0x00000008,
    // Provided by VK_KHR_device_group
    VK_DEPENDENCY_VIEW_LOCAL_BIT_KHR = VK_DEPENDENCY_VIEW_LOCAL_BIT,
} VkDependencyFlagBits;
```

- **VK_DEPENDENCY_BY_REGION_BIT** specifies that dependencies will be framebuffer-local.
- **VK_DEPENDENCY_DEVICEGROUP_BIT** specifies that dependencies are non-device-local.
- **VK_DEPENDENCY_FEEDBACK_LOOP_BIT_KHR** specifies that the render pass will write to and read from the same image using the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` layout.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkDependencyFlags;
```

`VkDependencyFlags` is a bitmask type for setting a mask of zero or more `VkDependencyFlagBits`.

### 7.6.1. Explicit Render Pass Tile Image Access Synchronization

A fragment shader **can** declare `NonCoherentColorAttachmentReadEXT`, `NonCoherentDepthAttachmentReadEXT`, or `NonCoherentStencilAttachmentReadEXT` execution modes to enable non-coherent tile image reads for color, depth, or stencil, respectively. When non-coherent
tile image reads are enabled, writes via color, depth and stencil attachments are not automatically made visible to the corresponding attachment reads via tile images. For the writes to be made visible, an explicit memory dependency must be inserted between when the attachment is written to and when it is read from by later fragments. Such memory dependencies must be inserted every time a fragment will read values at a particular sample (x, y, layer, sample) coordinate, if those values have been written since the most recent pipeline barrier; or since the start of the render pass instance, if there have been no pipeline barriers since the start of the render pass instance. When such memory dependencies are used the values at all sample locations inside the fragment area are made visible, regardless of coverage.

To insert a memory dependency for explicit render pass tile image synchronization, call vkCmdPipelineBarrier2 inside a render pass instance started with vkCmdBeginRendering. The following restrictions apply for such pipeline barriers:

- dependencyFlags must include VK_DEPENDENCY_BY_REGION_BIT.
- The pipeline barriers can only include memory barriers. That is, buffer memory barriers and image memory barriers must not be used.
- The stages in VkMemoryBarrier2::srcStageMask and VkMemoryBarrier2::dstStageMask are restricted to framebuffer space stages.
- The access types in VkMemoryBarrier2::srcAccessMask and VkMemoryBarrier2::dstAccessMask are restricted to the following types: VK_ACCESS_2_COLOR_ATTACHMENT_READ_BIT, VK_ACCESS_2_COLOR_ATTACHMENT_WRITE_BIT, VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_READ_BIT, and VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT.

7.7. Memory Barriers

Memory barriers are used to explicitly control access to buffer and image subresource ranges. Memory barriers are used to transfer ownership between queue families, change image layouts, and define availability and visibility operations. They explicitly define the access types and buffer and image subresource ranges that are included in the access scopes of a memory dependency that is created by a synchronization command that includes them.

7.7.1. Global Memory Barriers

Global memory barriers apply to memory accesses involving all memory objects that exist at the time of its execution.

The VkMemoryBarrier2 structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkMemoryBarrier2 {
    VkStructureType sType;
    const void* pNext;
    VkPipelineStageFlags2 srcStageMask;
    VkAccessFlags2 srcAccessMask;
    VkPipelineStageFlags2 dstStageMask;
    VkAccessFlags2 dstAccessMask;
} VkMemoryBarrier2;
```
or the equivalent

```c
// Provided by VK_KHR_synchronization2
typedef VkMemoryBarrier2 VkMemoryBarrier2KHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `srcStageMask` is a `VkPipelineStageFlags2` mask of pipeline stages to be included in the first synchronization scope.
- `srcAccessMask` is a `VkAccessFlags2` mask of access flags to be included in the first access scope.
- `dstStageMask` is a `VkPipelineStageFlags2` mask of pipeline stages to be included in the second synchronization scope.
- `dstAccessMask` is a `VkAccessFlags2` mask of access flags to be included in the second access scope.

This structure defines a memory dependency affecting all device memory.

The first synchronization scope and access scope described by this structure include only operations and memory accesses specified by `srcStageMask` and `srcAccessMask`.

The second synchronization scope and access scope described by this structure include only operations and memory accesses specified by `dstStageMask` and `dstAccessMask`.

### Valid Usage

- **VUID-VkMemoryBarrier2-srcStageMask-03929**
  If the `geometryShader` feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT`

- **VUID-VkMemoryBarrier2-srcStageMask-03930**
  If the `tessellationShader` feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT` or `VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT`

- **VUID-VkMemoryBarrier2-srcStageMask-03931**
  If the `conditionalRendering` feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT`

- **VUID-VkMemoryBarrier2-srcStageMask-03932**
  If the `fragmentDensityMap` feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT`

- **VUID-VkMemoryBarrier2-srcStageMask-03933**
  If the `transformFeedback` feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT`

- **VUID-VkMemoryBarrier2-srcStageMask-03934**
If the meshShader feature is not enabled, srcStageMask must not contain

\( \text{VK\_PIPELINE\_STAGE\_2\_MESH\__SHADER\_BIT\_EXT} \)

- VUID-VkMemoryBarrier2-srcStageMask-03935
  If the taskShader feature is not enabled, srcStageMask must not contain

\( \text{VK\_PIPELINE\_STAGE\_2\_TASK\_SHADER\_BIT\_EXT} \)

- VUID-VkMemoryBarrier2-srcStageMask-07316
  If neither the shadingRateImage or attachmentFragmentShadingRate are enabled, srcStageMask must not contain

\( \text{VK\_PIPELINE\_STAGE\_2\_FRAGMENT\_SHADING:\_RATE\_ATTACHMENT\_BIT\_KHR} \)

- VUID-VkMemoryBarrier2-srcStageMask-04957
  If the subpassShading feature is not enabled, srcStageMask must not contain

\( \text{VK\_PIPELINE\_STAGE\_2\_SUBPASS\_SHADER\_BIT\_HUAWEI} \)

- VUID-VkMemoryBarrier2-srcStageMask-04995
  If the invocationMask feature is not enabled, srcStageMask must not contain

\( \text{VK\_PIPELINE\_STAGE\_2\_INVOCATION\_MASK\_BIT\_HUAWEI} \)

- VUID-VkMemoryBarrier2-srcStageMask-07946
  If neither the VK_NV_ray_tracing extension or rayTracingPipeline feature are enabled, srcStageMask must not contain

\( \text{VK\_PIPELINE\_STAGE\_2\_RAY\_TRACING\_SHADER\_BIT\_KHR} \)

- VUID-VkMemoryBarrier2-srcAccessMask-03900
  If srcAccessMask includes VK_ACCESS_2_INDIRECT_COMMAND_READ_BIT, srcStageMask must include

\( \text{VK\_PIPELINE\_STAGE\_2\_DRAW\_INDIRECT\_BIT}, \text{VK\_PIPELINE\_STAGE\_2\_ACCELERATION\_STRUCTURE\_BUILD\_BIT\_KHR}, \text{VK\_PIPELINE\_STAGE\_2\_ALL\_GRAPHICS\_BIT}, \text{or VK\_PIPELINE\_STAGE\_2\_ALL\_COMMANDS\_BIT} \)

- VUID-VkMemoryBarrier2-srcAccessMask-03901
  If srcAccessMask includes VK_ACCESS_2_INDEX_READ_BIT, srcStageMask must include

\( \text{VK\_PIPELINE\_STAGE\_2\_INDEX\_INPUT\_BIT}, \text{VK\_PIPELINE\_STAGE\_2\_VERTEX\_INPUT\_BIT}, \text{VK\_PIPELINE\_STAGE\_2\_ALL\_GRAPHICS\_BIT}, \text{or VK\_PIPELINE\_STAGE\_2\_ALL\_COMMANDS\_BIT} \)

- VUID-VkMemoryBarrier2-srcAccessMask-03902
  If srcAccessMask includes VK_ACCESS_2_VERTEX_ATTRIBUTE_READ_BIT, srcStageMask must include

\( \text{VK\_PIPELINE\_STAGE\_2\_VERTEX\_ATTRIBUTE\_INPUT\_BIT}, \text{VK\_PIPELINE\_STAGE\_2\_VERTEX\_INPUT\_BIT}, \text{VK\_PIPELINE\_STAGE\_2\_ALL\_GRAPHICS\_BIT}, \text{or VK\_PIPELINE\_STAGE\_2\_ALL\_COMMANDS\_BIT} \)

- VUID-VkMemoryBarrier2-srcAccessMask-03903
  If srcAccessMask includes VK_ACCESS_2_INPUT_ATTACHMENT_READ_BIT, srcStageMask must include

\( \text{VK\_PIPELINE\_STAGE\_2\_FRAGMENT\_SHADER\_BIT}, \text{VK\_PIPELINE\_STAGE\_2\_SUBPASS\_SHADER\_BIT\_HUAWEI}, \text{VK\_PIPELINE\_STAGE\_2\_ALL\_GRAPHICS\_BIT}, \text{or VK\_PIPELINE\_STAGE\_2\_ALL\_COMMANDS\_BIT} \)

- VUID-VkMemoryBarrier2-srcAccessMask-03904
  If srcAccessMask includes VK_ACCESS_2_UNIFORM_READ_BIT, srcStageMask must include

\( \text{VK\_PIPELINE\_STAGE\_2\_SHADER\_SAMPLED\_READ\_BIT} \text{, VK\_PIPELINE\_STAGE\_2\_ALL\_GRAPHICS\_BIT}, \text{or VK\_PIPELINE\_STAGE\_2\_ALL\_COMMANDS\_BIT} \text{, or one of the VK\_PIPELINE\_STAGE\_*\_SHADER\_BIT stages} \)

- VUID-VkMemoryBarrier2-srcAccessMask-03905
  If srcAccessMask includes VK_ACCESS_2_SHADER_SAMPLED_READ_BIT, srcStageMask must include

\( \text{VK\_PIPELINE\_STAGE\_2\_SHADER\_SAMPLED\_READ\_BIT} \text{, VK\_PIPELINE\_STAGE\_2\_ALL\_GRAPHICS\_BIT}, \text{or VK\_PIPELINE\_STAGE\_2\_ALL\_COMMANDS\_BIT} \text{, or one of the VK\_PIPELINE\_STAGE\_*\_SHADER\_BIT stages} \)
VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT, or one of the VK_PIPELINE_STAGE_*_SHADER_BIT stages

• VUID-VkMemoryBarrier2-srcAccessMask-03906
  If srcAccessMask includes VK_ACCESS_2_SHADER_STORAGE_READ_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT, or one of the VK_PIPELINE_STAGE_*_SHADER_BIT stages

• VUID-VkMemoryBarrier2-srcAccessMask-03907
  If srcAccessMask includes VK_ACCESS_2_SHADER_STORAGE_WRITE_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT, or one of the VK_PIPELINE_STAGE_*_SHADER_BIT stages

• VUID-VkMemoryBarrier2-srcAccessMask-07454
  If srcAccessMask includes VK_ACCESS_2_SHADER_READ_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR,
  VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT, or one of the VK_PIPELINE_STAGE_*_SHADER_BIT stages

• VUID-VkMemoryBarrier2-srcAccessMask-03909
  If srcAccessMask includes VK_ACCESS_2_SHADER_WRITE_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

• VUID-VkMemoryBarrier2-srcAccessMask-03910
  If srcAccessMask includes VK_ACCESS_2_COLOR_ATTACHMENT_READ_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT

• VUID-VkMemoryBarrier2-srcAccessMask-03911
  If srcAccessMask includes VK_ACCESS_2_COLOR_ATTACHMENT_WRITE_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT

• VUID-VkMemoryBarrier2-srcAccessMask-03912
  If srcAccessMask includes VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_READ_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT, VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT,
  VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

• VUID-VkMemoryBarrier2-srcAccessMask-03913
  If srcAccessMask includes VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT, VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT,
  VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

• VUID-VkMemoryBarrier2-srcAccessMask-03914
  If srcAccessMask includes VK_ACCESS_2_TRANSFER_READ_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_COPY_BIT, VK_PIPELINE_STAGE_2_BLIT_BIT,
  VK_PIPELINE_STAGE_2_RESOLVE_BIT, VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT,
  VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR,
  VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR, or
VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- VUID-VkMemoryBarrier2-srcAccessMask-03915
  If `srcAccessMask` includes `VK_ACCESS_2_TRANSFER_WRITE_BIT`, `srcStageMask` must include
  `VK_PIPELINE_STAGE_2_COPY_BIT`, `VK_PIPELINE_STAGE_2_BLIT_BIT`, `VK_PIPELINE_STAGE_2_RESOLVE_BIT`, `VK_PIPELINE_STAGE_2_CLEAR_BIT`, `VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkMemoryBarrier2-srcAccessMask-03916
  If `srcAccessMask` includes `VK_ACCESS_2_HOST_READ_BIT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_HOST_BIT`

- VUID-VkMemoryBarrier2-srcAccessMask-03917
  If `srcAccessMask` includes `VK_ACCESS_2_HOST_WRITE_BIT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_HOST_BIT`

- VUID-VkMemoryBarrier2-srcAccessMask-03918
  If `srcAccessMask` includes `VK_ACCESS_2_CONDITIONAL_RENDERING_READ_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkMemoryBarrier2-srcAccessMask-03919
  If `srcAccessMask` includes `VK_ACCESS_2_FRAGMENT_DENSITY_MAP_READ_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkMemoryBarrier2-srcAccessMask-03920
  If `srcAccessMask` includes `VK_ACCESS_2_SHADER_READ_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkMemoryBarrier2-srcAccessMask-04747
  If `srcAccessMask` includes `VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT`, `VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkMemoryBarrier2-srcAccessMask-03922
  If `srcAccessMask` includes `VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkMemoryBarrier2-srcAccessMask-03923
  If `srcAccessMask` includes `VK_ACCESS_2_SHADER_WRITE_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkMemoryBarrier2-srcAccessMask-04994
  If `srcAccessMask` includes `VK_ACCESS_2_INVOCATION_MASK_READ_BIT_HUAWEI`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI`
• VUID-VkMemoryBarrier2-srcAccessMask-03924
  If srcAccessMask includes VK_ACCESS_2_COMMAND_PREPROCESS_READ_BIT_NV, srcStageMask must include
  VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV or
  VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

• VUID-VkMemoryBarrier2-srcAccessMask-03925
  If srcAccessMask includes VK_ACCESS_2_COMMAND_PREPROCESS_WRITE_BIT_NV, srcStageMask must include
  VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV or
  VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

• VUID-VkMemoryBarrier2-srcAccessMask-03926
  If srcAccessMask includes VK_ACCESS_2_COLOR_ATTACHMENT_READ_NONCOHERENT_BIT_EXT, srcStageMask must include
  VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT
  VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

• VUID-VkMemoryBarrier2-srcAccessMask-03927
  If srcAccessMask includes VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR, srcStageMask must include
  VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR,
  VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR,
  VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT, or one of the VK_PIPELINE_STAGE_*_SHADER_BIT stages

• VUID-VkMemoryBarrier2-srcAccessMask-03928
  If srcAccessMask includes VK_ACCESS_2_ACCELERATION_STRUCTURE_WRITE_BIT_KHR, srcStageMask must include
  VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR

• VUID-VkMemoryBarrier2-srcAccessMask-06256
  If the rayQuery feature is not enabled and srcAccessMask includes
  VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR, srcStageMask must not include any of the
  VK_PIPELINE_STAGE_*_SHADER_BIT stages except
  VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR

• VUID-VkMemoryBarrier2-srcAccessMask-07272
  If srcAccessMask includes VK_ACCESS_2_SHADER_BINDING_TABLE_READ_BIT_KHR, srcStageMask must include
  VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT or
  VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR

• VUID-VkMemoryBarrier2-srcAccessMask-04858
  If srcAccessMask includes VK_ACCESS_2_VIDEO_DECODE_READ_BIT_KHR, srcStageMask must include
  VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR

• VUID-VkMemoryBarrier2-srcAccessMask-04859
  If srcAccessMask includes VK_ACCESS_2_VIDEO_DECODE_WRITE_BIT_KHR, srcStageMask must include
  VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR

• VUID-VkMemoryBarrier2-srcAccessMask-04860
  If srcAccessMask includes VK_ACCESS_2_VIDEO_ENCODE_READ_BIT_KHR, srcStageMask must include
  VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR

• VUID-VkMemoryBarrier2-srcAccessMask-04861
  If srcAccessMask includes VK_ACCESS_2_VIDEO_ENCODE_WRITE_BIT_KHR, srcStageMask must include
  VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR
If srcAccessMask includes VK_ACCESS_2_OPTICAL_FLOW_READ_BIT_NV, srcStageMask must include VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV.

If srcAccessMask includes VK_ACCESS_2_OPTICAL_FLOW_WRITE_BIT_NV, srcStageMask must include VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV.

If srcAccessMask includes VK_ACCESS_2_MICROMAP_WRITE_BIT_EXT, srcStageMask must include VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT.

If srcAccessMask includes VK_ACCESS_2_MICROMAP_READ_BIT_EXT, srcStageMask must include VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT or VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR.

If srcAccessMask includes VK_ACCESS_2_DESCRIPTOR_BUFFER_READ_BIT_EXT, srcStageMask must include VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT, or one of VK_PIPELINE_STAGE_*_SHADER_BIT stages.

If the geometryShader feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT.

If the tessellationShader feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT or VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT.

If the conditionalRendering feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT.

If the fragmentDensityMap feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT.

If the transformFeedback feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT.

If the meshShader feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT.

If the taskShader feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT.

If neither the shadingRateImage or attachmentFragmentShadingRate are enabled, dstStageMask must not contain VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR.
If the `subpassShading` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI`.

If the `invocationMask` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI`.

If neither the `VK_NV_ray_tracing` extension or `rayTracingPipeline` feature are enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR`.

If `dstAccessMask` includes `VK_ACCESS_2_INDIRECT_COMMAND_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

If `dstAccessMask` includes `VK_ACCESS_2_INDEX_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_INDEX_INPUT_BIT`, `VK_PIPELINE_STAGE_2_VERTEX_INPUT_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

If `dstAccessMask` includes `VK_ACCESS_2_VERTEX_ATTRIBUTE_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_VERTEX_ATTRIBUTE_INPUT_BIT`, `VK_PIPELINE_STAGE_2_VERTEX_INPUT_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

If `dstAccessMask` includes `VK_ACCESS_2_INPUT_ATTACHMENT_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT`, `VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

If `dstAccessMask` includes `VK_ACCESS_2_UNIFORM_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_2_*_SHADER_BIT` stages.

If `dstAccessMask` includes `VK_ACCESS_2_SHADER_SAMPLED_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_2_*_SHADER_BIT` stages.

If `dstAccessMask` includes `VK_ACCESS_2_SHADER_STORAGE_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_2_*_SHADER_BIT` stages.

If `dstAccessMask` includes `VK_ACCESS_2_SHADER_STORAGE_WRITE_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or
one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

- **VUID-VkMemoryBarrier2-dstAccessMask-07454**
  If `dstAccessMask` includes `VK_ACCESS_2_SHADER_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`, `VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

- **VUID-VkMemoryBarrier2-dstAccessMask-03909**
  If `dstAccessMask` includes `VK_ACCESS_2_SHADER_WRITE_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

- **VUID-VkMemoryBarrier2-dstAccessMask-03910**
  If `dstAccessMask` includes `VK_ACCESS_2_COLOR_ATTACHMENT_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT` `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- **VUID-VkMemoryBarrier2-dstAccessMask-03911**
  If `dstAccessMask` includes `VK_ACCESS_2_COLOR_ATTACHMENT_WRITE_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT` `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- **VUID-VkMemoryBarrier2-dstAccessMask-03912**
  If `dstAccessMask` includes `VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- **VUID-VkMemoryBarrier2-dstAccessMask-03913**
  If `dstAccessMask` includes `VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- **VUID-VkMemoryBarrier2-dstAccessMask-03914**
  If `dstAccessMask` includes `VK_ACCESS_2_TRANSFER_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_COPY_BIT`, `VK_PIPELINE_STAGE_2_BLIT_BIT`, `VK_PIPELINE_STAGE_2_RESOLVE_BIT`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- **VUID-VkMemoryBarrier2-dstAccessMask-03915**
  If `dstAccessMask` includes `VK_ACCESS_2_TRANSFER_WRITE_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_COPY_BIT`, `VK_PIPELINE_STAGE_2_BLIT_BIT`, `VK_PIPELINE_STAGE_2_RESOLVE_BIT`, `VK_PIPELINE_STAGE_2_CLEAR_BIT`, `VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`
If dstAccessMask includes VK_ACCESS_2_HOST_READ_BIT, dstStageMask must include VK_PIPELINE_STAGE_2_HOST_BIT

If dstAccessMask includes VK_ACCESS_2_HOST_WRITE_BIT, dstStageMask must include VK_PIPELINE_STAGE_2_HOST_BIT

If dstAccessMask includes VK_ACCESS_2_CONDITIONAL_RENDERING_READ_BIT_EXT, dstStageMask must include VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

If dstAccessMask includes VK_ACCESS_2_FRAGMENT_DENSITY_MAP_READ_BIT_EXT, dstStageMask must include VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

If dstAccessMask includes VK_ACCESS_2_TRANSFORM_FEEDBACK_WRITE_BIT_EXT, dstStageMask must include VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

If dstAccessMask includes VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT, dstStageMask must include VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT, VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

If dstAccessMask includes VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_WRITE_BIT_EXT, dstStageMask must include VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

If dstAccessMask includes VK_ACCESS_2_SHADING_RATE_IMAGE_READ_BIT_NV, dstStageMask must include VK_PIPELINE_STAGE_2_SHADING_RATE_IMAGE_BIT_NV, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

If dstAccessMask includes VK_ACCESS_2_INVOCATION_MASK_READ_BIT_HUAWEI, dstStageMask must include VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI

If dstAccessMask includes VK_ACCESS_2_COMMAND_PREPROCESS_READ_BIT_NV, dstStageMask must include VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

If dstAccessMask includes VK_ACCESS_2_COMMAND_PREPROCESS_WRITE_BIT_NV, dstStageMask must include VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

If dstAccessMask includes VK_ACCESS_2_COMMAND_PREPROCESS_WRITE_BIT_NV, dstStageMask must include VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT
If dstAccessMask includes VK_ACCESS_2_COLOR_ATTACHMENT_READ_NONCOHERENT_BIT_EXT, dstStageMask must include VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

• VUID-VkMemoryBarrier2-dstAccessMask-03927
  If dstAccessMask includes VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR, VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT, or one of the VK_PIPELINE_STAGE_*_SHADER_BIT stages

• VUID-VkMemoryBarrier2-dstAccessMask-03928
  If dstAccessMask includes VK_ACCESS_2_ACCELERATION_STRUCTURE_WRITE_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

• VUID-VkMemoryBarrier2-dstAccessMask-06256
  If the rayQuery feature is not enabled and dstAccessMask includes VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR, dstStageMask must not include any of the VK_PIPELINE_STAGE_*_SHADER_BIT stages except VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR

• VUID-VkMemoryBarrier2-dstAccessMask-07272
  If dstAccessMask includes VK_ACCESS_2_SHADER_BINDING_TABLE_READ_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT or VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR

• VUID-VkMemoryBarrier2-dstAccessMask-04858
  If dstAccessMask includes VK_ACCESS_2_VIDEO_DECODER_READ_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_VIDEO_DECODER_BIT_KHR

• VUID-VkMemoryBarrier2-dstAccessMask-04859
  If dstAccessMask includes VK_ACCESS_2_VIDEO_DECODER_WRITE_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_VIDEO_DECODER_BIT_KHR

• VUID-VkMemoryBarrier2-dstAccessMask-04860
  If dstAccessMask includes VK_ACCESS_2_VIDEO_ENCODER_READ_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_VIDEO_ENCODER_BIT_KHR

• VUID-VkMemoryBarrier2-dstAccessMask-04861
  If dstAccessMask includes VK_ACCESS_2_VIDEO_ENCODER_WRITE_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_VIDEO_ENCODER_BIT_KHR

• VUID-VkMemoryBarrier2-dstAccessMask-07455
  If dstAccessMask includes VK_ACCESS_2_OPTICAL_FLOW_READ_BIT_NV, dstStageMask must include VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV

• VUID-VkMemoryBarrier2-dstAccessMask-07456
  If dstAccessMask includes VK_ACCESS_2_OPTICAL_FLOW_WRITE_BIT_NV, dstStageMask must include VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV

• VUID-VkMemoryBarrier2-dstAccessMask-07457
  If dstAccessMask includes VK_ACCESS_2_MICROMAP_WRITE_BIT_EXT, dstStageMask must include
VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT

- VUID-VkMemoryBarrier2-dstAccessMask-07458
  If dstAccessMask includes VK_ACCESS_2_MICROMAP_READ_BIT_EXT, dstStageMask must include
  VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT
  or
  VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR

- VUID-VkMemoryBarrier2-dstAccessMask-08118
  If dstAccessMask includes VK_ACCESS_2_DESCRIPTOR_BUFFER_READ_BIT_EXT, dstStageMask must
  include VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT, or
  one of VK_PIPELINE_STAGE_*_SHADER_BIT stages

Valid Usage (Implicit)

- VUID-VkMemoryBarrier2-sType-sType
  sType must be VK_STRUCTURE_TYPE_MEMORY_BARRIER_2

- VUID-VkMemoryBarrier2-srcStageMask-parameter
  srcStageMask must be a valid combination of VkPipelineStageFlagBits2 values

- VUID-VkMemoryBarrier2-srcAccessMask-parameter
  srcAccessMask must be a valid combination of VkAccessFlagBits2 values

- VUID-VkMemoryBarrier2-dstStageMask-parameter
  dstStageMask must be a valid combination of VkPipelineStageFlagBits2 values

- VUID-VkMemoryBarrier2-dstAccessMask-parameter
  dstAccessMask must be a valid combination of VkAccessFlagBits2 values

The VkMemoryBarrier structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkMemoryBarrier {
  VkStructureType sType;
  const void* pNext;
  VkAccessFlags srcAccessMask;
  VkAccessFlags dstAccessMask;
} VkMemoryBarrier;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **srcAccessMask** is a bitmask of VkAccessFlagBits specifying a source access mask.
- **dstAccessMask** is a bitmask of VkAccessFlagBits specifying a destination access mask.

The first access scope is limited to access types in the source access mask specified by srcAccessMask.

The second access scope is limited to access types in the destination access mask specified by dstAccessMask.
Valid Usage (Implicit)

- VUID-VkMemoryBarrier-sType-sType
  
  *sType* must be `VK_STRUCTURE_TYPE_MEMORY_BARRIER`

- VUID-VkMemoryBarrier-pNext-pNext
  
  *pNext* must be `NULL`

- VUID-VkMemoryBarrier-srcAccessMask-parameter
  
  *srcAccessMask* must be a valid combination of `VkAccessFlagBits` values

- VUID-VkMemoryBarrier-dstAccessMask-parameter
  
  *dstAccessMask* must be a valid combination of `VkAccessFlagBits` values

### 7.7.2. Buffer Memory Barriers

Buffer memory barriers only apply to memory accesses involving a specific buffer range. That is, a memory dependency formed from a buffer memory barrier is **scoped** to access via the specified buffer range. Buffer memory barriers **can** also be used to define a queue family ownership transfer for the specified buffer range.

The `VkBufferMemoryBarrier2` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkBufferMemoryBarrier2 {
    VkStructureType sType;
    const void* pNext;
    VkPipelineStageFlags2 srcStageMask;
    VkAccessFlags2 srcAccessMask;
    VkPipelineStageFlags2 dstStageMask;
    VkAccessFlags2 dstAccessMask;
    uint32_t srcQueueFamilyIndex;
    uint32_t dstQueueFamilyIndex;
    VkBuffer buffer;
    VkDeviceSize offset;
    VkDeviceSize size;
} VkBufferMemoryBarrier2;
```

or the equivalent

```c
// Provided by VK_KHR_synchronization2
typedef VkBufferMemoryBarrier2 VkBufferMemoryBarrier2KHR;
```

- *sType* is a `VkStructureType` value identifying this structure.  
- *pNext* is `NULL` or a pointer to a structure extending this structure.  
- *srcStageMask* is a `VkPipelineStageFlags2` mask of pipeline stages to be included in the first synchronization scope.
• **srcAccessMask** is a `VkAccessFlags2` mask of access flags to be included in the first access scope.

• **dstStageMask** is a `VkPipelineStageFlags2` mask of pipeline stages to be included in the second synchronization scope.

• **dstAccessMask** is a `VkAccessFlags2` mask of access flags to be included in the second access scope.

• **srcQueueFamilyIndex** is the source queue family for a queue family ownership transfer.

• **dstQueueFamilyIndex** is the destination queue family for a queue family ownership transfer.

• **buffer** is a handle to the buffer whose backing memory is affected by the barrier.

• **offset** is an offset in bytes into the backing memory for **buffer**; this is relative to the base offset as bound to the buffer (see `vkBindBufferMemory`).

• **size** is a size in bytes of the affected area of backing memory for **buffer**, or **VK_WHOLE_SIZE** to use the range from **offset** to the end of the buffer.

This structure defines a memory dependency limited to a range of a buffer, and can define a queue family transfer operation for that range.

The first synchronization scope and access scope described by this structure include only operations and memory accesses specified by **srcStageMask** and **srcAccessMask**.

The second synchronization scope and access scope described by this structure include only operations and memory accesses specified by **dstStageMask** and **dstAccessMask**.

Both access scopes are limited to only memory accesses to **buffer** in the range defined by **offset** and **size**.

If **buffer** was created with **VK_SHARING_MODE_EXCLUSIVE**, and **srcQueueFamilyIndex** is not equal to **dstQueueFamilyIndex**, this memory barrier defines a queue family transfer operation. When executed on a queue in the family identified by **srcQueueFamilyIndex**, this barrier defines a queue family release operation for the specified buffer range, and the second synchronization and access scopes do not synchronize operations on that queue. When executed on a queue in the family identified by **dstQueueFamilyIndex**, this barrier defines a queue family acquire operation for the specified buffer range, and the first synchronization and access scopes do not synchronize operations on that queue.

A queue family transfer operation is also defined if the values are not equal, and either is one of the special queue family values reserved for external memory ownership transfers, as described in Queue Family Ownership Transfer. A queue family release operation is defined when **dstQueueFamilyIndex** is one of those values, and a queue family acquire operation is defined when **srcQueueFamilyIndex** is one of those values.

---

**Valid Usage**

• VUID-VkBufferMemoryBarrier2-srcStageMask-03929
  If the geometryShader feature is not enabled, **srcStageMask** must not contain `VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT`

• VUID-VkBufferMemoryBarrier2-srcStageMask-03930
  If the tessellationShader feature is not enabled, **srcStageMask** must not contain
VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT or
VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT

- VUID-VkBufferMemoryBarrier2-srcStageMask-03931
  If the conditionalRendering feature is not enabled, srcStageMask must not contain
  VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT

- VUID-VkBufferMemoryBarrier2-srcStageMask-03932
  If the fragmentDensityMap feature is not enabled, srcStageMask must not contain
  VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT

- VUID-VkBufferMemoryBarrier2-srcStageMask-03933
  If the transformFeedback feature is not enabled, srcStageMask must not contain
  VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT

- VUID-VkBufferMemoryBarrier2-srcStageMask-03934
  If the meshShader feature is not enabled, srcStageMask must not contain
  VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT

- VUID-VkBufferMemoryBarrier2-srcStageMask-03935
  If the taskShader feature is not enabled, srcStageMask must not contain
  VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT

- VUID-VkBufferMemoryBarrier2-srcStageMask-07316
  If neither the shadingRateImage or attachmentFragmentShadingRate are enabled,
  srcStageMask must not contain
  VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

- VUID-VkBufferMemoryBarrier2-srcStageMask-04957
  If the subpassShading feature is not enabled, srcStageMask must not contain
  VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI

- VUID-VkBufferMemoryBarrier2-srcStageMask-04995
  If the invocationMask feature is not enabled, srcStageMask must not contain
  VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI

- VUID-VkBufferMemoryBarrier2-srcStageMask-07946
  If neither the VK_NV_ray_tracing extension or rayTracingPipeline feature are enabled,
  srcStageMask must not contain
  VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR

- VUID-VkBufferMemoryBarrier2-srcAccessMask-03900
  If srcAccessMask includes VK_ACCESS_2_INDIRECT_COMMAND_READ_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR,
  VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- VUID-VkBufferMemoryBarrier2-srcAccessMask-03901
  If srcAccessMask includes VK_ACCESS_2_INDEX_READ_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_INDEX_INPUT_BIT, VK_PIPELINE_STAGE_2_VERTEX_INPUT_BIT,
  VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- VUID-VkBufferMemoryBarrier2-srcAccessMask-03902
  If srcAccessMask includes VK_ACCESS_2_VERTEX_ATTRIBUTE_READ_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_VERTEX_ATTRIBUTE_INPUT_BIT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or
VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- **VUID-VkBufferMemoryBarrier2-srcAccessMask-03903**
  If `srcAccessMask` includes `VK_ACCESS_2_INPUT_ATTACHMENT_READ_BIT`, `srcStageMask` must include 
  `VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT`, `VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- **VUID-VkBufferMemoryBarrier2-srcAccessMask-03904**
  If `srcAccessMask` includes `VK_ACCESS_2_UNIFORM_READ_BIT`, `srcStageMask` must include 
  `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

- **VUID-VkBufferMemoryBarrier2-srcAccessMask-03905**
  If `srcAccessMask` includes `VK_ACCESS_2_SHADER_SAMPLED_READ_BIT`, `srcStageMask` must include 
  `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

- **VUID-VkBufferMemoryBarrier2-srcAccessMask-03906**
  If `srcAccessMask` includes `VK_ACCESS_2_SHADER_STORAGE_READ_BIT`, `srcStageMask` must include 
  `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

- **VUID-VkBufferMemoryBarrier2-srcAccessMask-03907**
  If `srcAccessMask` includes `VK_ACCESS_2_SHADER_WRITE_BIT`, `srcStageMask` must include 
  `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

- **VUID-VkBufferMemoryBarrier2-srcAccessMask-03908**
  If `srcAccessMask` includes `VK_ACCESS_2_COLOR_ATTACHMENT_READ_BIT`, `srcStageMask` must include 
  `VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- **VUID-VkBufferMemoryBarrier2-srcAccessMask-03909**
  If `srcAccessMask` includes `VK_ACCESS_2_COLOR_ATTACHMENT_WRITE_BIT`, `srcStageMask` must include 
  `VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`
VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

• VUID-VkBufferMemoryBarrier2-srcAccessMask-03913
  If srcAccessMask includes VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT, srcStageMask must include VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT, VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT.

• VUID-VkBufferMemoryBarrier2-srcAccessMask-03914
  If srcAccessMask includes VK_ACCESS_2_TRANSFER_READ_BIT, srcStageMask must include VK_PIPELINE_STAGE_2_COPY_BIT, VK_PIPELINE_STAGE_2_BLIT_BIT, VK_PIPELINE_STAGE_2_RESOLVE_BIT, VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT.

• VUID-VkBufferMemoryBarrier2-srcAccessMask-03915
  If srcAccessMask includes VK_ACCESS_2_TRANSFER_WRITE_BIT, srcStageMask must include VK_PIPELINE_STAGE_2_COPY_BIT, VK_PIPELINE_STAGE_2_BLIT_BIT, VK_PIPELINE_STAGE_2_RESOLVE_BIT, VK_PIPELINE_STAGE_2_CLEAR_BIT, VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT.

• VUID-VkBufferMemoryBarrier2-srcAccessMask-03916
  If srcAccessMask includes VK_ACCESS_2_HOST_READ_BIT, srcStageMask must include VK_PIPELINE_STAGE_2_HOST_BIT.

• VUID-VkBufferMemoryBarrier2-srcAccessMask-03917
  If srcAccessMask includes VK_ACCESS_2_HOST_WRITE_BIT, srcStageMask must include VK_PIPELINE_STAGE_2_HOST_BIT.

• VUID-VkBufferMemoryBarrier2-srcAccessMask-03918
  If srcAccessMask includes VK_ACCESS_2_CONDITIONAL_RENDERING_READ_BIT_EXT, srcStageMask must include VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT.

• VUID-VkBufferMemoryBarrier2-srcAccessMask-03919
  If srcAccessMask includes VK_ACCESS_2_TRANSFORM_FEEDBACK_WRITE_BIT_EXT, srcStageMask must include VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT.

• VUID-VkBufferMemoryBarrier2-srcAccessMask-03920
  If srcAccessMask includes VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT, srcStageMask must include VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT, VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT.

• VUID-VkBufferMemoryBarrier2-srcAccessMask-04747
  If srcAccessMask includes VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT, srcStageMask must include VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT, VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT.
If `srcAccessMask` includes `VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_WRITE_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

If `srcAccessMask` includes `VK_ACCESS_2_SHADING_RATE_IMAGE_READ_BIT_NV`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_SHADING_RATE_IMAGE_BIT_NV`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

If `srcAccessMask` includes `VK_ACCESS_2_INVOCATION_MASK_READ_BIT_HUAWEI`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI`.

If `srcAccessMask` includes `VK_ACCESS_2_COMMAND_PREPROCESS_READ_BIT_NV`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV` or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

If `srcAccessMask` includes `VK_ACCESS_2_COMMAND_PREPROCESS_WRITE_BIT_NV`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV` or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

If `srcAccessMask` includes `VK_ACCESS_2_COLOR_ATTACHMENT_READ_NONCOHERENT_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT`.

If the rayQuery feature is not enabled and `srcAccessMask` includes `VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR`, `srcStageMask` must not include any of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages except `VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR`.

If `srcAccessMask` includes `VK_ACCESS_2_ACCELERATION_STRUCTURE_WRITE_BIT_KHR`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

If `srcAccessMask` includes `VK_ACCESS_2_SHADER_BINDING_TABLE_READ_BIT_KHR`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT` or `VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR`.

If the rayQuery feature is not enabled and `srcAccessMask` includes `VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR`, `srcStageMask` must not include any of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages except `VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR`.
If `srcAccessMask` includes `VK_ACCESS_2_VIDEO_DECODE_READ_BIT_KHR`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR`

- VUID-VkBufferMemoryBarrier2-srcAccessMask-04859
  If `srcAccessMask` includes `VK_ACCESS_2_VIDEO_DECODE_WRITE_BIT_KHR`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR`

- VUID-VkBufferMemoryBarrier2-srcAccessMask-04860
  If `srcAccessMask` includes `VK_ACCESS_2_VIDEO_ENCODE_READ_BIT_KHR`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR`

- VUID-VkBufferMemoryBarrier2-srcAccessMask-04861
  If `srcAccessMask` includes `VK_ACCESS_2_VIDEO_ENCODE_WRITE_BIT_KHR`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR`

- VUID-VkBufferMemoryBarrier2-srcAccessMask-07455
  If `srcAccessMask` includes `VK_ACCESS_2_OPTICAL_FLOW_READ_BIT_NV`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV`

- VUID-VkBufferMemoryBarrier2-srcAccessMask-07456
  If `srcAccessMask` includes `VK_ACCESS_2_OPTICAL_FLOW_WRITE_BIT_NV`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV`

- VUID-VkBufferMemoryBarrier2-srcAccessMask-07457
  If `srcAccessMask` includes `VK_ACCESS_2_MICROMAP_WRITE_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT`

- VUID-VkBufferMemoryBarrier2-srcAccessMask-07458
  If `srcAccessMask` includes `VK_ACCESS_2_MICROMAP_READ_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT` or `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`

- VUID-VkBufferMemoryBarrier2-srcAccessMask-08118
  If `srcAccessMask` includes `VK_ACCESS_2_DESCRIPTOR_BUFFER_READ_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

- VUID-VkBufferMemoryBarrier2-dstStageMask-03929
  If the geometryShader feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT`

- VUID-VkBufferMemoryBarrier2-dstStageMask-03930
  If the tessellationShader feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT` or `VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT`

- VUID-VkBufferMemoryBarrier2-dstStageMask-03931
  If the conditionalRendering feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT`

- VUID-VkBufferMemoryBarrier2-dstStageMask-03932
  If the fragmentDensityMap feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT`

- VUID-VkBufferMemoryBarrier2-dstStageMask-03933
If the `transformFeedback` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT`.

- **VUID-VkBufferMemoryBarrier2-dstStageMask-03934**

  If the `meshShader` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT`.

- **VUID-VkBufferMemoryBarrier2-dstStageMask-03935**

  If the `taskShader` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT`.

- **VUID-VkBufferMemoryBarrier2-dstStageMask-07316**

  If neither the `shadingRateImage` or `attachmentFragmentShadingRate` are enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`.

- **VUID-VkBufferMemoryBarrier2-dstStageMask-04957**

  If the `shadingRateImage` or `attachmentFragmentShadingRate` are enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`.

- **VUID-VkBufferMemoryBarrier2-dstStageMask-03900**

  If `dstAccessMask` includes `VK_ACCESS_2_INDIRECT_COMMAND_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

- **VUID-VkBufferMemoryBarrier2-dstAccessMask-03901**

  If `dstAccessMask` includes `VK_ACCESS_2_INDEX_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_INDEX_INPUT_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

- **VUID-VkBufferMemoryBarrier2-dstAccessMask-03902**

  If `dstAccessMask` includes `VK_ACCESS_2_VERTEX_ATTRIBUTE_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_VERTEX_ATTRIBUTE_INPUT_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

- **VUID-VkBufferMemoryBarrier2-dstAccessMask-03903**

  If `dstAccessMask` includes `VK_ACCESS_2_INPUT_ATTACHMENT_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT`, `VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

- **VUID-VkBufferMemoryBarrier2-dstAccessMask-03904**

  If `dstAccessMask` includes `VK_ACCESS_2_UNIFORM_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of
the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

- VUID-VkBufferMemoryBarrier2-dstAccessMask-03905
  If `dstAccessMask` includes `VK_ACCESS_2_SHADER_SAMPLED_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

- VUID-VkBufferMemoryBarrier2-dstAccessMask-03906
  If `dstAccessMask` includes `VK_ACCESS_2_SHADER_STORAGE_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

- VUID-VkBufferMemoryBarrier2-dstAccessMask-03907
  If `dstAccessMask` includes `VK_ACCESS_2_SHADER_STORAGE_WRITE_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

- VUID-VkBufferMemoryBarrier2-dstAccessMask-03908
  If `dstAccessMask` includes `VK_ACCESS_2_COLOR_ATTACHMENT_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkBufferMemoryBarrier2-dstAccessMask-03909
  If `dstAccessMask` includes `VK_ACCESS_2_COLOR_ATTACHMENT_WRITE_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkBufferMemoryBarrier2-dstAccessMask-03910
  If `dstAccessMask` includes `VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkBufferMemoryBarrier2-dstAccessMask-03911
  If `dstAccessMask` includes `VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkBufferMemoryBarrier2-dstAccessMask-03912
  If `dstAccessMask` includes `VK_ACCESS_2_TRANSFER_READ_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_COPY_BIT`, `VK_PIPELINE_STAGE_2_BLIT_BIT`,...
If `dstAccessMask` includes `VK_ACCESS_2_TRANSFER_WRITE_BIT`, `dstStageMask` **must** include

- `VK_PIPELINE_STAGE_2_COPY_BIT`,
- `VK_PIPELINE_STAGE_2_BLIT_BIT`,
- `VK_PIPELINE_STAGE_2_RESOLVE_BIT`,
- `VK_PIPELINE_STAGE_2_CLEAR_BIT`,
- `VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT`,
- `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`,
- `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR`, or
- `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

If `dstAccessMask` includes `VK_ACCESS_2_HOST_READ_BIT`, `dstStageMask` **must** include `VK_PIPELINE_STAGE_2_HOST_BIT`

If `dstAccessMask` includes `VK_ACCESS_2_HOST_WRITE_BIT`, `dstStageMask` **must** include `VK_PIPELINE_STAGE_2_HOST_BIT`

If `dstAccessMask` includes `VK_ACCESS_2_CONDITIONAL_RENDERING_READ_BIT_EXT`, `dstStageMask` **must** include

- `VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT`,
- `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`,
- `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

If `dstAccessMask` includes `VK_ACCESS_2_FRAGMENT_DENSITY_MAP_READ_BIT_EXT`, `dstStageMask` **must** include

- `VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT`,
- `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`,
- `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

If `dstAccessMask` includes `VK_ACCESS_2_TRANSFORM_FEEDBACK_WRITE_BIT_EXT`, `dstStageMask` **must** include

- `VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT`,
- `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`,
- `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

If `dstAccessMask` includes `VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT`, `dstStageMask` **must** include

- `VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT`,
- `VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT`,
- `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`,
- `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

If `dstAccessMask` includes `VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_WRITE_BIT_EXT`, `dstStageMask` **must** include

- `VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT`,
- `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`,
- `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

If `dstAccessMask` includes `VK_ACCESS_2_SHADING_RATE_IMAGE_READ_BIT_NV`, `dstStageMask` **must** include

- `VK_PIPELINE_STAGE_2_SHADING_RATE_IMAGE_BIT_NV`,
- `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`,
- `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

If `dstAccessMask` includes `VK_ACCESS_2_SHADING_RATE_IMAGE_READ_BIT_NV`, `dstStageMask` **must** include

- `VK_PIPELINE_STAGE_2_SHADING_RATE_IMAGE_BIT_NV`,
If \( \text{dstAccessMask} \) includes \( \text{VK_ACCESS_2_INVOCATION_MASK_READ\_BIT\_HUAWEI} \), \( \text{dstStageMask} \) must include \( \text{VK\_PIPELINE\_STAGE\_2\_INVOCATION\_MASK\_BIT\_HUAWEI} \)

- **VUID-VkBufferMemoryBarrier2-dstAccessMask-03924**
  If \( \text{dstAccessMask} \) includes \( \text{VK\_ACCESS\_2\_COMMAND\_PREPROCESS\_READ\_BIT\_NV} \), \( \text{dstStageMask} \) must include \( \text{VK\_PIPELINE\_STAGE\_2\_COMMAND\_PREPROCESS\_BIT\_NV} \) or \( \text{VK\_PIPELINE\_STAGE\_2\_ALL\_COMMANDS\_BIT} \)

- **VUID-VkBufferMemoryBarrier2-dstAccessMask-03925**
  If \( \text{dstAccessMask} \) includes \( \text{VK\_ACCESS\_2\_COMMAND\_PREPROCESS\_WRITE\_BIT\_NV} \), \( \text{dstStageMask} \) must include \( \text{VK\_PIPELINE\_STAGE\_2\_COMMAND\_PREPROCESS\_BIT\_NV} \) or \( \text{VK\_PIPELINE\_STAGE\_2\_ALL\_COMMANDS\_BIT} \)

- **VUID-VkBufferMemoryBarrier2-dstAccessMask-03926**
  If \( \text{dstAccessMask} \) includes \( \text{VK\_ACCESS\_2\_COLOR\_ATTACHMENT\_READ\_NONCOHERENT\_BIT\_EXT} \), \( \text{dstStageMask} \) must include \( \text{VK\_PIPELINE\_STAGE\_2\_COLOR\_ATTACHMENT\_OUTPUT\_BIT} \) or \( \text{VK\_PIPELINE\_STAGE\_2\_ALL\_GRAPHICS\_BIT} \) or \( \text{VK\_PIPELINE\_STAGE\_2\_ALL\_COMMANDS\_BIT} \)

- **VUID-VkBufferMemoryBarrier2-dstAccessMask-03927**
  If \( \text{dstAccessMask} \) includes \( \text{VK\_ACCESS\_2\_ACCELERATION\_STRUCTURE\_READ\_BIT\_KHR} \), \( \text{dstStageMask} \) must include \( \text{VK\_PIPELINE\_STAGE\_2\_ACCELERATION\_STRUCTURE\_BUILD\_BIT\_KHR} \), \( \text{VK\_PIPELINE\_STAGE\_2\_ACCELERATION\_STRUCTURE\_COPY\_BIT\_KHR} \), or one of the \( \text{VK\_PIPELINE\_STAGE\_*\_SHADER\_BIT} \) stages

- **VUID-VkBufferMemoryBarrier2-dstAccessMask-03928**
  If \( \text{dstAccessMask} \) includes \( \text{VK\_ACCESS\_2\_ACCELERATION\_STRUCTURE\_WRITE\_BIT\_KHR} \), \( \text{dstStageMask} \) must include \( \text{VK\_PIPELINE\_STAGE\_2\_ACCELERATION\_STRUCTURE\_COPY\_BIT\_KHR} \), or \( \text{VK\_PIPELINE\_STAGE\_2\_ALL\_COMMANDS\_BIT} \)

- **VUID-VkBufferMemoryBarrier2-dstAccessMask-06256**
  If the \( \text{rayQuery} \) feature is not enabled and \( \text{dstAccessMask} \) includes \( \text{VK\_ACCESS\_2\_ACCELERATION\_STRUCTURE\_READ\_BIT\_KHR} \), \( \text{dstStageMask} \) must not include any of the \( \text{VK\_PIPELINE\_STAGE\_*\_SHADER\_BIT} \) stages except \( \text{VK\_PIPELINE\_STAGE\_2\_RAY\_TRACING\_SHADER\_BIT\_KHR} \)

- **VUID-VkBufferMemoryBarrier2-dstAccessMask-07272**
  If \( \text{dstAccessMask} \) includes \( \text{VK\_ACCESS\_2\_SHADER\_BINDING\_TABLE\_READ\_BIT\_KHR} \), \( \text{dstStageMask} \) must include \( \text{VK\_PIPELINE\_STAGE\_2\_ALL\_COMMANDS\_BIT} \) or \( \text{VK\_PIPELINE\_STAGE\_2\_RAY\_TRACING\_SHADER\_BIT\_KHR} \)

- **VUID-VkBufferMemoryBarrier2-dstAccessMask-04858**
  If \( \text{dstAccessMask} \) includes \( \text{VK\_ACCESS\_2\_VIDEO\_DECODE\_READ\_BIT\_KHR} \), \( \text{dstStageMask} \) must include \( \text{VK\_PIPELINE\_STAGE\_2\_VIDEO\_DECODE\_BIT\_KHR} \)

- **VUID-VkBufferMemoryBarrier2-dstAccessMask-04859**
  If \( \text{dstAccessMask} \) includes \( \text{VK\_ACCESS\_2\_VIDEO\_DECODE\_WRITE\_BIT\_KHR} \), \( \text{dstStageMask} \) must include \( \text{VK\_PIPELINE\_STAGE\_2\_VIDEO\_DECODE\_BIT\_KHR} \)

- **VUID-VkBufferMemoryBarrier2-dstAccessMask-04860**
  If \( \text{dstAccessMask} \) includes \( \text{VK\_ACCESS\_2\_VIDEO\_ENCODE\_READ\_BIT\_KHR} \), \( \text{dstStageMask} \) must include \( \text{VK\_PIPELINE\_STAGE\_2\_VIDEO\_ENCODE\_BIT\_KHR} \)
• VUID-VkBufferMemoryBarrier2-dstAccessMask-04861
  If dstAccessMask includes VK_ACCESS_2_VIDEO_ENCODE_WRITE_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR

• VUID-VkBufferMemoryBarrier2-dstAccessMask-07455
  If dstAccessMask includes VK_ACCESS_2_OPTICAL_FLOW_READ_BIT_NV, dstStageMask must include VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV

• VUID-VkBufferMemoryBarrier2-dstAccessMask-07456
  If dstAccessMask includes VK_ACCESS_2_OPTICAL_FLOW_WRITE_BIT_NV, dstStageMask must include VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV

• VUID-VkBufferMemoryBarrier2-dstAccessMask-07457
  If dstAccessMask includes VK_ACCESS_2_MICROMAP_WRITE_BIT_EXT, dstStageMask must include VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT

• VUID-VkBufferMemoryBarrier2-dstAccessMask-07458
  If dstAccessMask includes VK_ACCESS_2_MICROMAP_READ_BIT_EXT, dstStageMask must include VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT
  or VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR

• VUID-VkBufferMemoryBarrier2-offset-01187
  offset must be less than the size of buffer

• VUID-VkBufferMemoryBarrier2-size-01188
  If size is not equal to VK_WHOLE_SIZE, size must be greater than 0

• VUID-VkBufferMemoryBarrier2-size-01189
  If size is not equal to VK_WHOLE_SIZE, size must be less than or equal to than the size of buffer minus offset

• VUID-VkBufferMemoryBarrier2-buffer-01931
  If buffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

• VUID-VkBufferMemoryBarrier2-buffer-09095
  If buffer was created with a sharing mode of VK_SHARING_MODE_EXCLUSIVE, and srcQueueFamilyIndex and dstQueueFamilyIndex are not equal, srcQueueFamilyIndex must be VK_QUEUE_FAMILY_EXTERNAL, VK_QUEUE_FAMILY_FOREIGN_EXT, or a valid queue family

• VUID-VkBufferMemoryBarrier2-buffer-09096
  If buffer was created with a sharing mode of VK_SHARING_MODE_EXCLUSIVE, and srcQueueFamilyIndex and dstQueueFamilyIndex are not equal, dstQueueFamilyIndex must be VK_QUEUE_FAMILY_EXTERNAL, VK_QUEUE_FAMILY_FOREIGN_EXT, or a valid queue family

• VUID-VkBufferMemoryBarrier2-srcQueueFamilyIndex-04087
  If srcQueueFamilyIndex is not equal to dstQueueFamilyIndex, at least one of srcQueueFamilyIndex or dstQueueFamilyIndex must not be VK_QUEUE_FAMILY_EXTERNAL or VK_QUEUE_FAMILY_FOREIGN_EXT
• VUID-VkBufferMemoryBarrier2-None-09097
  If the VK_KHR_external_memory extension is not enabled, and the value of
  VkApplicationInfo::apiVersion used to create the VkInstance is not greater than or equal
  to Version 1.1, srcQueueFamilyIndex must not be VK_QUEUE_FAMILY_EXTERNAL

• VUID-VkBufferMemoryBarrier2-None-09098
  If the VK_KHR_external_memory extension is not enabled, and the value of
  VkApplicationInfo::apiVersion used to create the VkInstance is not greater than or equal
  to Version 1.1, dstQueueFamilyIndex must not be VK_QUEUE_FAMILY_EXTERNAL

• VUID-VkBufferMemoryBarrier2-srcQueueFamilyIndex-09099
  If the VK_EXT_queue_family_foreign extension is not enabled srcQueueFamilyIndex must
  not be VK_QUEUE_FAMILY_FOREIGN_EXT

• VUID-VkBufferMemoryBarrier2-dstQueueFamilyIndex-09100
  If the VK_EXT_queue_family_foreign extension is not enabled dstQueueFamilyIndex must
  not be VK_QUEUE_FAMILY_FOREIGN_EXT

• VUID-VkBufferMemoryBarrier2-srcStageMask-03851
  If either srcStageMask or dstStageMask includes VK_PIPELINE_STAGE_2_HOST_BIT,
  srcQueueFamilyIndex and dstQueueFamilyIndex must be equal

• VUID-VkBufferMemoryBarrier2-sType-sType
  sType must be VK_STRUCTURE_TYPE_BUFFER_MEMORY_BARRIER_2

• VUID-VkBufferMemoryBarrier2-pNext-pNext
  pNext must be NULL or a pointer to a valid instance of
  VkExternalMemoryAcquireUnmodifiedEXT

• VUID-VkBufferMemoryBarrier2-sType-unique
  The sType value of each struct in the pNext chain must be unique

• VUID-VkBufferMemoryBarrier2-srcStageMask-parameter
  srcStageMask must be a valid combination of VkPipelineStageFlagBits2 values

• VUID-VkBufferMemoryBarrier2-srcAccessMask-parameter
  srcAccessMask must be a valid combination of VkAccessFlagBits2 values

• VUID-VkBufferMemoryBarrier2-dstStageMask-parameter
  dstStageMask must be a valid combination of VkPipelineStageFlagBits2 values

• VUID-VkBufferMemoryBarrier2-dstAccessMask-parameter
  dstAccessMask must be a valid combination of VkAccessFlagBits2 values

• VUID-VkBufferMemoryBarrier2-buffer-parameter
  buffer must be a valid VkBuffer handle

The VkBufferMemoryBarrier structure is defined as:

```c
// Provided by VK_VERSION_1_0
```
typedef struct VkBufferMemoryBarrier {
    VkStructureType sType;
    const void* pNext;
    VkAccessFlags srcAccessMask;
    VkAccessFlags dstAccessMask;
    uint32_t srcQueueFamilyIndex;
    uint32_t dstQueueFamilyIndex;
    VkBuffer buffer;
    VkDeviceSize offset;
    VkDeviceSize size;
} VkBufferMemoryBarrier;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `srcAccessMask` is a bitmask of `VkAccessFlagBits` specifying a source access mask.
- `dstAccessMask` is a bitmask of `VkAccessFlagBits` specifying a destination access mask.
- `srcQueueFamilyIndex` is the source queue family for a queue family ownership transfer.
- `dstQueueFamilyIndex` is the destination queue family for a queue family ownership transfer.
- `buffer` is a handle to the buffer whose backing memory is affected by the barrier.
- `offset` is an offset in bytes into the backing memory for `buffer`; this is relative to the base offset as bound to the buffer (see `vkBindBufferMemory`).
- `size` is a size in bytes of the affected area of backing memory for `buffer`, or `VK_WHOLE_SIZE` to use the range from `offset` to the end of the buffer.

The first access scope is limited to access to memory through the specified buffer range, via access types in the source access mask specified by `srcAccessMask`. If `srcAccessMask` includes `VK_ACCESS_HOST_WRITE_BIT`, a memory domain operation is performed where available memory in the host domain is also made available to the device domain.

The second access scope is limited to access to memory through the specified buffer range, via access types in the destination access mask specified by `dstAccessMask`. If `dstAccessMask` includes `VK_ACCESS_HOST_WRITE_BIT` or `VK_ACCESS_HOST_READ_BIT`, a memory domain operation is performed where available memory in the device domain is also made available to the host domain.

**Note**

When `VK_MEMORY_PROPERTY_HOST_COHERENT_BIT` is used, available memory in host domain is automatically made visible to host domain, and any host write is automatically made available to host domain.

If `srcQueueFamilyIndex` is not equal to `dstQueueFamilyIndex`, and `srcQueueFamilyIndex` is equal to the current queue family, then the memory barrier defines a queue family release operation for the specified buffer range, and the second access scope includes no access, as if `dstAccessMask` was 0.

If `dstQueueFamilyIndex` is not equal to `srcQueueFamilyIndex`, and `dstQueueFamilyIndex` is equal to the current queue family, then the memory barrier defines a queue family acquire operation for the
specified buffer range, and the first access scope includes no access, as if srcAccessMask was 0.

**Valid Usage**

- **VUID-VkBufferMemoryBarrier-offset-01187**
  
  Offset must be less than the size of buffer.

- **VUID-VkBufferMemoryBarrier-size-01188**
  
  If size is not equal to VK_WHOLE_SIZE, size must be greater than 0.

- **VUID-VkBufferMemoryBarrier-size-01189**
  
  If size is not equal to VK_WHOLE_SIZE, size must be less than or equal to the size of buffer minus offset.

- **VUID-VkBufferMemoryBarrier-buffer-01931**
  
  If buffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object.

- **VUID-VkBufferMemoryBarrier-buffer-09095**
  
  If buffer was created with a sharing mode of VK_SHARING_MODE_EXCLUSIVE, and srcQueueFamilyIndex and dstQueueFamilyIndex are not equal, srcQueueFamilyIndex must be VK_QUEUE_FAMILY_EXTERNAL, VK_QUEUE_FAMILY_FOREIGN_EXT, or a valid queue family.

- **VUID-VkBufferMemoryBarrier-buffer-09096**
  
  If buffer was created with a sharing mode of VK_SHARING_MODE_EXCLUSIVE, and srcQueueFamilyIndex and dstQueueFamilyIndex are not equal, dstQueueFamilyIndex must be VK_QUEUE_FAMILY_EXTERNAL, VK_QUEUE_FAMILY_FOREIGN_EXT, or a valid queue family.

- **VUID-VkBufferMemoryBarrier-srcQueueFamilyIndex-04087**
  
  If srcQueueFamilyIndex is not equal to dstQueueFamilyIndex, at least one of srcQueueFamilyIndex or dstQueueFamilyIndex must not be VK_QUEUE_FAMILY_EXTERNAL.

- **VUID-VkBufferMemoryBarrier-None-09097**
  
  If the VK_KHR_external_memory extension is not enabled, and the value of VkApplicationInfo::apiVersion used to create the VkInstance is not greater than or equal to Version 1.1, srcQueueFamilyIndex must not be VK_QUEUE_FAMILY_EXTERNAL.

- **VUID-VkBufferMemoryBarrier-None-09098**
  
  If the VK_KHR_external_memory extension is not enabled, and the value of VkApplicationInfo::apiVersion used to create the VkInstance is not greater than or equal to Version 1.1, dstQueueFamilyIndex must not be VK_QUEUE_FAMILY_EXTERNAL.

- **VUID-VkBufferMemoryBarrier-srcQueueFamilyIndex-09099**
  
  If the VK_EXT_queue_family_foreign extension is not enabled, srcQueueFamilyIndex must not be VK_QUEUE_FAMILY_FOREIGN_EXT.

- **VUID-VkBufferMemoryBarrier-dstQueueFamilyIndex-09100**
  
  If the VK_EXT_queue_family_foreign extension is not enabled, dstQueueFamilyIndex must not be VK_QUEUE_FAMILY_FOREIGN_EXT.

- **VUID-VkBufferMemoryBarrier-None-09049**
  
  If the synchronization2 feature is not enabled, and buffer was created with a sharing mode of VK_SHARING_MODE_CONCURRENT, at least one of srcQueueFamilyIndex and...
dstQueueFamilyIndex must be VK_QUEUE_FAMILY_IGNORED

• VUID-VkBufferMemoryBarrier-None-09050
  If the synchronization2 feature is not enabled, and buffer was created with a sharing mode of VK_SHARING_MODE_CONCURRENT, srcQueueFamilyIndex must be VK_QUEUE_FAMILY_IGNORED or VK_QUEUE_FAMILY_EXTERNAL

• VUID-VkBufferMemoryBarrier-None-09051
  If the synchronization2 feature is not enabled, and buffer was created with a sharing mode of VK_SHARING_MODE_CONCURRENT, dstQueueFamilyIndex must be VK_QUEUE_FAMILY_IGNORED or VK_QUEUE_FAMILY_EXTERNAL

Valid Usage (Implicit)

• VUID-VkBufferMemoryBarrier-sType-sType
  sType must be VK_STRUCTURE_TYPE_BUFFER_MEMORY_BARRIER

• VUID-VkBufferMemoryBarrier-pNext-pNext
  pNext must be NULL or a pointer to a valid instance of VkExternalMemoryAcquireUnmodifiedEXT

• VUID-VkBufferMemoryBarrier-sType-unique
  The sType value of each struct in the pNext chain must be unique

• VUID-VkBufferMemoryBarrier-buffer-parameter
  buffer must be a valid VkBuffer handle

VK_WHOLE_SIZE is a special value indicating that the entire remaining length of a buffer following a given offset should be used. It can be specified for VkBufferMemoryBarrier::size and other structures.

#define VK_WHOLE_SIZE (~0ULL)

7.7.3. Image Memory Barriers

Image memory barriers only apply to memory accesses involving a specific image subresource range. That is, a memory dependency formed from an image memory barrier is scoped to access via the specified image subresource range. Image memory barriers can also be used to define image layout transitions or a queue family ownership transfer for the specified image subresource range.

The VkImageMemoryBarrier2 structure is defined as:

// Provided by VK_VERSION_1_3
typedef struct VkImageMemoryBarrier2 {
  VkStructureType sType;
  const void* pNext;
  VkPipelineStageFlags2 srcStageMask;
}
VkAccessFlags2 srcAccessMask;
VkPipelineStageFlags2 dstStageMask;
VkAccessFlags2 dstAccessMask;
VkImageLayout oldLayout;
VkImageLayout newLayout;
uint32_t srcQueueFamilyIndex;
uint32_t dstQueueFamilyIndex;
VkImage image;
VkImageSubresourceRange subresourceRange;
} VkImageMemoryBarrier2;

or the equivalent

// Provided by VK_KHR_synchronization2
typedef VkImageMemoryBarrier2 VkImageMemoryBarrier2KHR;

• **sType** is a VkStructureType value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.
• **srcStageMask** is a VkPipelineStageFlags2 mask of pipeline stages to be included in the **first** synchronization scope.
• **srcAccessMask** is a VkAccessFlags2 mask of access flags to be included in the **first** access scope.
• **dstStageMask** is a VkPipelineStageFlags2 mask of pipeline stages to be included in the **second** synchronization scope.
• **dstAccessMask** is a VkAccessFlags2 mask of access flags to be included in the **second** access scope.
• **oldLayout** is the old layout in an **image layout transition**.
• **newLayout** is the new layout in an **image layout transition**.
• **srcQueueFamilyIndex** is the source queue family for a **queue family ownership transfer**.
• **dstQueueFamilyIndex** is the destination queue family for a **queue family ownership transfer**.
• **image** is a handle to the image affected by this barrier.
• **subresourceRange** describes the **image subresource range** within **image** that is affected by this barrier.

This structure defines a memory dependency limited to an image subresource range, and can define a queue family transfer operation and image layout transition for that subresource range.

The first synchronization scope and access scope described by this structure include only operations and memory accesses specified by **srcStageMask** and **srcAccessMask**.

The second synchronization scope and access scope described by this structure include only operations and memory accesses specified by **dstStageMask** and **dstAccessMask**.

Both access scopes are limited to only memory accesses to **image** in the subresource range defined by **subresourceRange**.
If `image` was created with `VK_SHARING_MODE_EXCLUSIVE`, and `srcQueueFamilyIndex` is not equal to `dstQueueFamilyIndex`, this memory barrier defines a queue family transfer operation. When executed on a queue in the family identified by `srcQueueFamilyIndex`, this barrier defines a queue family release operation for the specified image subresource range, and the second synchronization and access scopes do not synchronize operations on that queue. When executed on a queue in the family identified by `dstQueueFamilyIndex`, this barrier defines a queue family acquire operation for the specified image subresource range, and the first synchronization and access scopes do not synchronize operations on that queue.

A queue family transfer operation is also defined if the values are not equal, and either is one of the special queue family values reserved for external memory ownership transfers, as described in Queue Family Ownership Transfer. A queue family release operation is defined when `dstQueueFamilyIndex` is one of those values, and a queue family acquire operation is defined when `srcQueueFamilyIndex` is one of those values.

If `oldLayout` is not equal to `newLayout`, then the memory barrier defines an image layout transition for the specified image subresource range. If this memory barrier defines a queue family transfer operation, the layout transition is only executed once between the queues.

**Note**

When the old and new layout are equal, the layout values are ignored - data is preserved no matter what values are specified, or what layout the image is currently in.

If `image` has a multi-planar format and the image is disjoint, then including `VK_IMAGE_ASPECT_COLOR_BIT` in the aspectMask member of `subresourceRange` is equivalent to including `VK_IMAGE_ASPECT_PLANE_0_BIT`, `VK_IMAGE_ASPECT_PLANE_1_BIT`, and (for three-plane formats only) `VK_IMAGE_ASPECT_PLANE_2_BIT`.

### Valid Usage

- **VUID-VkImageMemoryBarrier2-srcStageMask-03929**
  If the geometryShader feature is not enabled, `srcStageMask` **must** not contain `VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT`

- **VUID-VkImageMemoryBarrier2-srcStageMask-03930**
  If the tessellationShader feature is not enabled, `srcStageMask` **must** not contain `VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT` or `VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT`

- **VUID-VkImageMemoryBarrier2-srcStageMask-03931**
  If the conditionalRendering feature is not enabled, `srcStageMask` **must** not contain `VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT`

- **VUID-VkImageMemoryBarrier2-srcStageMask-03932**
  If the fragmentDensityMap feature is not enabled, `srcStageMask` **must** not contain `VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT`

- **VUID-VkImageMemoryBarrier2-srcStageMask-03933**
  If the transformFeedback feature is not enabled, `srcStageMask` **must** not contain
VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT

- VUID-VkImageMemoryBarrier2-srcStageMask-03934
  If the meshShader feature is not enabled, srcStageMask must not contain
  VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT

- VUID-VkImageMemoryBarrier2-srcStageMask-03935
  If the taskShader feature is not enabled, srcStageMask must not contain
  VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT

- VUID-VkImageMemoryBarrier2-srcStageMask-07316
  If neither the shadingRateImage or attachmentFragmentShadingRate are enabled, srcStageMask must not contain
  VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

- VUID-VkImageMemoryBarrier2-srcStageMask-04957
  If the subpassShading feature is not enabled, srcStageMask must not contain
  VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI

- VUID-VkImageMemoryBarrier2-srcStageMask-04995
  If the invocationMask feature is not enabled, srcStageMask must not contain
  VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI

- VUID-VkImageMemoryBarrier2-srcStageMask-07946
  If neither the VK_NV_ray_tracing extension or rayTracingPipeline feature are enabled, srcStageMask must not contain
  VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR

- VUID-VkImageMemoryBarrier2-srcAccessMask-03900
  If srcAccessMask includes VK_ACCESS_2_INDIRECT_COMMAND_READ_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR,
  VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- VUID-VkImageMemoryBarrier2-srcAccessMask-03901
  If srcAccessMask includes VK_ACCESS_2_INDEX_READ_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_INDEX_INPUT_BIT, VK_PIPELINE_STAGE_2_VERTEX_INPUT_BIT,
  VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- VUID-VkImageMemoryBarrier2-srcAccessMask-03902
  If srcAccessMask includes VK_ACCESS_2_VERTEX_ATTRIBUTE_READ_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_VERTEX_ATTRIBUTE_INPUT_BIT, VK_PIPELINE_STAGE_2_VERTEX_INPUT_BIT,
  VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- VUID-VkImageMemoryBarrier2-srcAccessMask-03903
  If srcAccessMask includes VK_ACCESS_2_INPUT_ATTACHMENT_READ_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT, VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI,
  VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- VUID-VkImageMemoryBarrier2-srcAccessMask-03904
  If srcAccessMask includes VK_ACCESS_2_UNIFORM_READ_BIT, srcStageMask must include
  VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT, or one of
  the VK_PIPELINE_STAGE_*_SHADER_BIT stages
If `srcAccessMask` includes `VK_ACCESS_2_SHADER_SAMPLED_READ_BIT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages.

If `srcAccessMask` includes `VK_ACCESS_2_SHADER_STORAGE_READ_BIT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages.

If `srcAccessMask` includes `VK_ACCESS_2_SHADER_STORAGE_WRITE_BIT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages.

If `srcAccessMask` includes `VK_ACCESS_2_SHADER_READ_BIT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`, `VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages.

If `srcAccessMask` includes `VK_ACCESS_2_SHADER_WRITE_BIT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages.

If `srcAccessMask` includes `VK_ACCESS_2_COLOR_ATTACHMENT_READ_BIT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

If `srcAccessMask` includes `VK_ACCESS_2_COLOR_ATTACHMENT_WRITE_BIT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

If `srcAccessMask` includes `VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_READ_BIT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

If `srcAccessMask` includes `VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`.

If `srcAccessMask` includes `VK_ACCESS_2_TRANSFER_READ_BIT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_COPY_BIT`, `VK_PIPELINE_STAGE_2_BLIT_BIT`, `VK_PIPELINE_STAGE_2_RESOLVE_BIT`, or `VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT`.
If `srcAccessMask` includes `VK_ACCESS_2_TRANSFER_WRITE_BIT`, `srcStageMask` **must** include

- `VK_PIPELINE_STAGE_2_COPY_BIT`,
- `VK_PIPELINE_STAGE_2_BLIT_BIT`,
- `VK_PIPELINE_STAGE_2_RESOLVE_BIT`,
- `VK_PIPELINE_STAGE_2_CLEAR_BIT`,
- `VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT`,
- `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`,
- `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR`, or
- `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

If `srcAccessMask` includes `VK_ACCESS_2_HOST_READ_BIT`, `srcStageMask` **must** include

- `VK_PIPELINE_STAGE_2_HOST_BIT`

If `srcAccessMask` includes `VK_ACCESS_2_HOST_WRITE_BIT`, `srcStageMask` **must** include

- `VK_PIPELINE_STAGE_2_HOST_BIT`

If `srcAccessMask` includes `VK_ACCESS_2_CONDITIONAL_RENDERING_READ_BIT_EXT`, `srcStageMask` **must** include

- `VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT`,
- `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or
- `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

If `srcAccessMask` includes `VK_ACCESS_2_TRANSFORM_FEEDBACK_WRITE_BIT_EXT`, `srcStageMask` **must** include

- `VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT`,
- `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or
- `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

If `srcAccessMask` includes `VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT`, `srcStageMask` **must** include

- `VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT`,
- `VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT`,
- `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or
- `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

If `srcAccessMask` includes `VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_WRITE_BIT_EXT`, `srcStageMask` **must** include

- `VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT`,
- `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or
- `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

If `srcAccessMask` includes `VK_ACCESS_2_SHADING_RATE_IMAGE_READ_BIT_NV`, `srcStageMask` **must** include

- `VK_PIPELINE_STAGE_2_SHADING_RATE_IMAGE_BIT_NV`,
- `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or
- `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

If `srcAccessMask` includes `VK_ACCESS_2_INVOCATION_MASK_READ_BIT_HUAWEI`, `srcStageMask` **must** include

- `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or
- `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`
include VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI

- VUID-VkImageMemoryBarrier2-srcAccessMask-03924
  If `srcAccessMask` includes `VK_ACCESS_2_COMMAND_PREPROCESS_READ_BIT_NV`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV` or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkImageMemoryBarrier2-srcAccessMask-03925
  If `srcAccessMask` includes `VK_ACCESS_2_COMMAND_PREPROCESS_WRITE_BIT_NV`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV` or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkImageMemoryBarrier2-srcAccessMask-03926
  If `srcAccessMask` includes `VK_ACCESS_2_COLOR_ATTACHMENT_READ_NONCOHERENT_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkImageMemoryBarrier2-srcAccessMask-03927
  If `srcAccessMask` includes `VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

- VUID-VkImageMemoryBarrier2-srcAccessMask-03928
  If `srcAccessMask` includes `VK_ACCESS_2_ACCELERATION_STRUCTURE_WRITE_BIT_KHR`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR` or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

- VUID-VkImageMemoryBarrier2-srcAccessMask-06256
  If the rayQuery feature is not enabled and `srcAccessMask` includes `VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR`, `srcStageMask` must not include any of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages except `VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR`

- VUID-VkImageMemoryBarrier2-srcAccessMask-07272
  If `srcAccessMask` includes `VK_ACCESS_2_SHADER_BINDING_TABLE_READ_BIT_KHR`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT` or `VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR`

- VUID-VkImageMemoryBarrier2-srcAccessMask-04858
  If `srcAccessMask` includes `VK_ACCESS_2_VIDEO_DECODE_READ_BIT_KHR`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR`

- VUID-VkImageMemoryBarrier2-srcAccessMask-04859
  If `srcAccessMask` includes `VK_ACCESS_2_VIDEO_DECODE_WRITE_BIT_KHR`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_VIDEO_DECODER_BIT_KHR`

- VUID-VkImageMemoryBarrier2-srcAccessMask-04860
  If `srcAccessMask` includes `VK_ACCESS_2_VIDEO_ENCODE_READ_BIT_KHR`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR`

- VUID-VkImageMemoryBarrier2-srcAccessMask-04861
If `srcAccessMask` includes `VK_ACCESS_2_VIDEO_ENCODE_WRITE_BIT_KHR`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR`.

- **VUID-VkImageMemoryBarrier2-srcAccessMask-07455**
  If `srcAccessMask` includes `VK_ACCESS_2_OPTICAL_FLOW_READ_BIT_NV`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV`.

- **VUID-VkImageMemoryBarrier2-srcAccessMask-07456**
  If `srcAccessMask` includes `VK_ACCESS_2_OPTICAL_FLOW_WRITE_BIT_NV`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV`.

- **VUID-VkImageMemoryBarrier2-srcAccessMask-07457**
  If `srcAccessMask` includes `VK_ACCESS_2_MICROMAP_WRITE_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT`.

- **VUID-VkImageMemoryBarrier2-srcAccessMask-07458**
  If `srcAccessMask` includes `VK_ACCESS_2_MICROMAP_READ_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT` or `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`.

- **VUID-VkImageMemoryBarrier2-srcAccessMask-08118**
  If `srcAccessMask` includes `VK_ACCESS_2_DESCRIPTOR_BUFFER_READ_BIT_EXT`, `srcStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of `VK_PIPELINE_STAGE_*_SHADER_BIT` stages.

- **VUID-VkImageMemoryBarrier2-dstStageMask-03929**
  If the `geometryShader` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT`.

- **VUID-VkImageMemoryBarrier2-dstStageMask-03930**
  If the `tessellationShader` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT` or `VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT`.

- **VUID-VkImageMemoryBarrier2-dstStageMask-03931**
  If the `conditionalRendering` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT`.

- **VUID-VkImageMemoryBarrier2-dstStageMask-03932**
  If the `fragmentDensityMap` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT`.

- **VUID-VkImageMemoryBarrier2-dstStageMask-03933**
  If the `transformFeedback` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT`.

- **VUID-VkImageMemoryBarrier2-dstStageMask-03934**
  If the `meshShader` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT`.

- **VUID-VkImageMemoryBarrier2-dstStageMask-03935**
  If the `taskShader` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT`.

- **VUID-VkImageMemoryBarrier2-dstStageMask-07316**
If neither the `shadingRateImage` or `attachmentFragmentShadingRate` are enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2.FragmentShaderRateAttachment_BIT_KHR`.

- **VUID-VkImageMemoryBarrier2-dstStageMask-04957**
  If the `subpassShading` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2.SubpassShader_BIT_HUAWEI`.

- **VUID-VkImageMemoryBarrier2-dstStageMask-04995**
  If the `invocationMask` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2.InvocationMask_BIT_HUAWEI`.

- **VUID-VkImageMemoryBarrier2-dstStageMask-07946**
  If neither the `VK_NV_ray_tracing` extension or `rayTracingPipeline` feature are enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_2.RayTracingShader_BIT_KHR`.

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03900**
  If `dstAccessMask` includes `VK_ACCESS_2.IndirectCommand.Read_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2.DrawIndirect_BIT`, `VK_PIPELINE_STAGE_2.AccelerationStructureBuild_BIT_KHR`, `VK_PIPELINE_STAGE_2.AllGraphics_BIT`, or `VK_PIPELINE_STAGE_2.AllCommands_BIT`.

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03901**
  If `dstAccessMask` includes `VK_ACCESS_2.Index.Read_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2.IndexInput_BIT`, `VK_PIPELINE_STAGE_2.VertexInput_BIT`, `VK_PIPELINE_STAGE_2.AllGraphics_BIT`, or `VK_PIPELINE_STAGE_2.AllCommands_BIT`.

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03902**

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03903**
  If `dstAccessMask` includes `VK_ACCESS_2.InputAttachment.Read_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2.FragmentShader_BIT`, `VK_PIPELINE_STAGE_2.SubpassShader_BIT_HUAWEI`, `VK_PIPELINE_STAGE_2.AllGraphics_BIT`, or `VK_PIPELINE_STAGE_2.AllCommands_BIT`.

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03904**
  If `dstAccessMask` includes `VK_ACCESS_2.Uniform.Read_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2.AllGraphics_BIT`, `VK_PIPELINE_STAGE_2.AllCommands_BIT`, or one of the `VK_PIPELINE_STAGE_2.\*Shader_BIT` stages.

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03905**
  If `dstAccessMask` includes `VK_ACCESS_2.Shader.Sampled.Read_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2.AllGraphics_BIT`, `VK_PIPELINE_STAGE_2.AllCommands_BIT`, or one of the `VK_PIPELINE_STAGE_2.\*Shader_BIT` stages.

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03906**
  If `dstAccessMask` includes `VK_ACCESS_2.Shader.Storage.Read_BIT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2.AllGraphics_BIT`, `VK_PIPELINE_STAGE_2.AllCommands_BIT`, or one of the `VK_PIPELINE_STAGE_2.\*Shader_BIT` stages.
• **VUID-VkImageMemoryBarrier2-dstAccessMask-03907**
  If `dstAccessMask` includes `VK_ACCESS_2_SHADER_STORAGE_WRITE_BIT`, `dstStageMask` **must** include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

• **VUID-VkImageMemoryBarrier2-dstAccessMask-07454**
  If `dstAccessMask` includes `VK_ACCESS_2_SHADER_READ_BIT`, `dstStageMask` **must** include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`, `VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

• **VUID-VkImageMemoryBarrier2-dstAccessMask-03909**
  If `dstAccessMask` includes `VK_ACCESS_2_SHADER_WRITE_BIT`, `dstStageMask` **must** include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of the `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

• **VUID-VkImageMemoryBarrier2-dstAccessMask-03910**
  If `dstAccessMask` includes `VK_ACCESS_2_COLOR_ATTACHMENT_READ_BIT`, `dstStageMask` **must** include `VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

• **VUID-VkImageMemoryBarrier2-dstAccessMask-03911**
  If `dstAccessMask` includes `VK_ACCESS_2_COLOR_ATTACHMENT_WRITE_BIT`, `dstStageMask` **must** include `VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

• **VUID-VkImageMemoryBarrier2-dstAccessMask-03912**
  If `dstAccessMask` includes `VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_READ_BIT`, `dstStageMask` **must** include `VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

• **VUID-VkImageMemoryBarrier2-dstAccessMask-03913**
  If `dstAccessMask` includes `VK_ACCESS_2_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT`, `dstStageMask` **must** include `VK_PIPELINE_STAGE_2_EARLY_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_LATE_FRAGMENT_TESTS_BIT`, `VK_PIPELINE_STAGE_2_CLEAR_BIT`, `VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

• **VUID-VkImageMemoryBarrier2-dstAccessMask-03914**
  If `dstAccessMask` includes `VK_ACCESS_2_TRANSFER_READ_BIT`, `dstStageMask` **must** include `VK_PIPELINE_STAGE_2_COPY_BIT`, `VK_PIPELINE_STAGE_2_BLIT_BIT`, `VK_PIPELINE_STAGE_2_RESOLVE_BIT`, `VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`

• **VUID-VkImageMemoryBarrier2-dstAccessMask-03915**
  If `dstAccessMask` includes `VK_ACCESS_2_TRANSFER_WRITE_BIT`, `dstStageMask` **must** include `VK_PIPELINE_STAGE_2_COPY_BIT`, `VK_PIPELINE_STAGE_2_BLIT_BIT`, `VK_PIPELINE_STAGE_2_RESOLVE_BIT`, `VK_PIPELINE_STAGE_2_CLEAR_BIT`, `VK_PIPELINE_STAGE_2_ALL_TRANSFER_BIT`, `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`, or `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`
VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03916**
  If `dstAccessMask` includes `VK_ACCESS_2_HOST_READ_BIT`, `dstStageMask` must include VK_PIPELINE_STAGE_2_HOST_BIT

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03917**
  If `dstAccessMask` includes `VK_ACCESS_2_HOST_WRITE_BIT`, `dstStageMask` must include VK_PIPELINE_STAGE_2_HOST_BIT

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03918**
  If `dstAccessMask` includes `VK_ACCESS_2_CONDITIONAL_RENDERING_READ_BIT_EXT`, `dstStageMask` must include VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03919**
  If `dstAccessMask` includes `VK_ACCESS_2_FRAGMENT_DENSITY_MAP_READ_BIT_EXT`, `dstStageMask` must include VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03920**
  If `dstAccessMask` includes `VK_ACCESS_2_TRANSFORM_FEEDBACK_WRITE_BIT_EXT`, `dstStageMask` must include VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- **VUID-VkImageMemoryBarrier2-dstAccessMask-04747**
  If `dstAccessMask` includes `VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT`, `dstStageMask` must include VK_PIPELINE_STAGE_2_DRAW_INDIRECT_BIT, VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03922**
  If `dstAccessMask` includes `VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_WRITE_BIT_EXT`, `dstStageMask` must include VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03923**
  If `dstAccessMask` includes `VK_ACCESS_2_SHADING_RATE_IMAGE_READ_BIT_NV`, `dstStageMask` must include VK_PIPELINE_STAGE_2_SHADING_RATE_IMAGE_BIT_NV, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- **VUID-VkImageMemoryBarrier2-dstAccessMask-04994**
  If `dstAccessMask` includes `VK_ACCESS_2_INVOCATION_MASK_READ_BIT_HUAWEI`, `dstStageMask` must include VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03924**
  If `dstAccessMask` includes `VK_ACCESS_2_COMMAND_PREPROCESS_READ_BIT_NV`, `dstStageMask` must include VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

- **VUID-VkImageMemoryBarrier2-dstAccessMask-03925**
  If `dstAccessMask` includes `VK_ACCESS_2_COMMAND_PREPROCESS_WRITE_BIT_NV`, `dstStageMask` must include VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV or
VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

• VUID-VkImageMemoryBarrier2-dstAccessMask-03926
  If dstAccessMask includes VK_ACCESS_2_COLOR_ATTACHMENT_READ_NONCOHERENT_BIT_EXT, dstStageMask must include VK_PIPELINE_STAGE_2_COLOR_ATTACHMENT_OUTPUT_BIT, VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT, or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

• VUID-VkImageMemoryBarrier2-dstAccessMask-03927
  If dstAccessMask includes VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR, VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT, or one of the VK_PIPELINE_STAGE_*_SHADER_BIT stages

• VUID-VkImageMemoryBarrier2-dstAccessMask-03928
  If dstAccessMask includes VK_ACCESS_2_ACCELERATION_STRUCTURE_WRITE_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR, VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR or VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT

• VUID-VkImageMemoryBarrier2-dstAccessMask-06256
  If the rayQuery feature is not enabled and dstAccessMask includes VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR, dstStageMask must not include any of the VK_PIPELINE_STAGE_*_SHADER_BIT stages except VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR

• VUID-VkImageMemoryBarrier2-dstAccessMask-07272
  If dstAccessMask includes VK_ACCESS_2_SHADER_BINDING_TABLE_READ_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT or VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR

• VUID-VkImageMemoryBarrier2-dstAccessMask-04858
  If dstAccessMask includes VK_ACCESS_2_VIDEO_DECODE_READ_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR

• VUID-VkImageMemoryBarrier2-dstAccessMask-04859
  If dstAccessMask includes VK_ACCESS_2_VIDEO_DECODE_WRITE_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR

• VUID-VkImageMemoryBarrier2-dstAccessMask-04860
  If dstAccessMask includes VK_ACCESS_2_VIDEO_ENCODE_READ_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR

• VUID-VkImageMemoryBarrier2-dstAccessMask-04861
  If dstAccessMask includes VK_ACCESS_2_VIDEO_ENCODE_WRITE_BIT_KHR, dstStageMask must include VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR

• VUID-VkImageMemoryBarrier2-dstAccessMask-07455
  If dstAccessMask includes VK_ACCESS_2_OPTICAL_FLOW_READ_BIT_NV, dstStageMask must include VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV

• VUID-VkImageMemoryBarrier2-dstAccessMask-07456
  If dstAccessMask includes VK_ACCESS_2_OPTICAL_FLOW_WRITE_BIT_NV, dstStageMask must include VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV
If `dstAccessMask` includes `VK_ACCESS_2_MICROMAP_WRITE_BIT_EXT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT`

If `dstAccessMask` includes `VK_ACCESS_2_MICROMAP_READ_BIT_EXT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT` or `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`

If `dstAccessMask` includes `VK_ACCESS_2_DESCRIPTOR_BUFFER_READ_BIT_EXT`, `dstStageMask` must include `VK_PIPELINE_STAGE_2_ALL_GRAPHICS_BIT`, `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT`, or one of `VK_PIPELINE_STAGE_*_SHADER_BIT` stages

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL` then image must have been created with `VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT`

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL` then image must have been created with `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT`

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL` then image must have been created with `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT`

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL` then image must have been created with `VK_IMAGE_USAGE_SAMPLED_BIT` or `VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT`

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL` then image must have been created with `VK_IMAGE_USAGE_TRANSFER_SRC_BIT`

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL` then image must have been created with `VK_IMAGE_USAGE_TRANSFER_DST_BIT`
If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, `newLayout` must not be `VK_IMAGE_LAYOUT_UNDEFINED` or `VK_IMAGE_LAYOUT_PREINITIALIZED`.

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL` then image must have been created with `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT`.

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL` then image must have been created with `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT`.

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL` then image must have been created with at least one of `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT`, `VK_IMAGE_USAGE_SAMPLED_BIT`, or `VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT`.

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL` then image must have been created with `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT` set.

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL` then image must have been created with at least one of `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT`, `VK_IMAGE_USAGE_SAMPLED_BIT`, or `VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT`.

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL` then image must have been created with `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT` set.

If the `synchronization2` feature is not enabled, `oldLayout` must not be `VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL_KHR` or `VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR`.

If the `synchronization2` feature is not enabled, `newLayout` must not be `VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL_KHR` or `VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR`.
• VUID-VkImageMemoryBarrier2-srcQueueFamilyIndex-03938
  If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL, image must have been created with VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT or VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT.

• VUID-VkImageMemoryBarrier2-srcQueueFamilyIndex-03939
  If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL, image must have been created with at least one of VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT, VK_IMAGE_USAGE_SAMPLED_BIT, or VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT.

• VUID-VkImageMemoryBarrier2-oldLayout-02088
  If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_FRAGMENT_SHADING_RATE_ATTACHMENT_OPTIMAL_KHR then image must have been created with VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR set.

• VUID-VkImageMemoryBarrier2-image-09117
  If image was created with a sharing mode of VK_SHARING_MODE_EXCLUSIVE, and srcQueueFamilyIndex and dstQueueFamilyIndex are not equal, srcQueueFamilyIndex must be VK_QUEUE_FAMILY_EXTERNAL, VK_QUEUE_FAMILY_FOREIGN_EXT, or a valid queue family.

• VUID-VkImageMemoryBarrier2-image-09118
  If image was created with a sharing mode of VK_SHARING_MODE_EXCLUSIVE, and srcQueueFamilyIndex and dstQueueFamilyIndex are not equal, dstQueueFamilyIndex must be VK_QUEUE_FAMILY_EXTERNAL, VK_QUEUE_FAMILY_FOREIGN_EXT, or a valid queue family.

• VUID-VkImageMemoryBarrier2-srcQueueFamilyIndex-04070
  If srcQueueFamilyIndex is not equal to dstQueueFamilyIndex, at least one of srcQueueFamilyIndex or dstQueueFamilyIndex must not be VK_QUEUE_FAMILY_EXTERNAL or VK_QUEUE_FAMILY_FOREIGN_EXT.

• VUID-VkImageMemoryBarrier2-None-09119
  If the VK_KHR_external_memory extension is not enabled, and the value of VkApplicationInfo::apiVersion used to create the VkInstance is not greater than or equal to Version 1.1, srcQueueFamilyIndex must not be VK_QUEUE_FAMILY_EXTERNAL.

• VUID-VkImageMemoryBarrier2-None-09120
  If the VK_KHR_external_memory extension is not enabled, and the value of VkApplicationInfo::apiVersion used to create the VkInstance is not greater than or equal to Version 1.1, dstQueueFamilyIndex must not be VK_QUEUE_FAMILY_EXTERNAL.

• VUID-VkImageMemoryBarrier2-srcQueueFamilyIndex-09121
  If the VK_EXT_queue_family_foreign extension is not enabled, srcQueueFamilyIndex must not be VK_QUEUE_FAMILY_FOREIGN_EXT.

• VUID-VkImageMemoryBarrier2-dstQueueFamilyIndex-09122
  If the VK_EXT_queue_family_foreign extension is not enabled, dstQueueFamilyIndex must not be VK_QUEUE_FAMILY_FOREIGN_EXT.

• VUID-VkImageMemoryBarrier2-srcQueueFamilyIndex-07120
  If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer.
or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_VIDEO_DECODE_SRC_KHR then image must have been created with VK_IMAGE_USAGE_VIDEO_DECODE_SRC_BIT_KHR

• VUID-VkImageMemoryBarrier2-srcQueueFamilyIndex-07121
If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_VIDEO_DECODE_DST_KHR then image must have been created with VK_IMAGE_USAGE_VIDEO_DECODE_DST_BIT_KHR

• VUID-VkImageMemoryBarrier2-srcQueueFamilyIndex-07122
If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_VIDEO_DECODE_DPB_KHR then image must have been created with VK_IMAGE_USAGE_VIDEO_DECODE_DPB_BIT_KHR

• VUID-VkImageMemoryBarrier2-srcQueueFamilyIndex-07123
If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_VIDEO_ENCODE_SRC_KHR then image must have been created with VK_IMAGE_USAGE_VIDEO_ENCODE_SRC_BIT_KHR

• VUID-VkImageMemoryBarrier2-srcQueueFamilyIndex-07124
If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_VIDEO_ENCODE_DST_KHR then image must have been created with VK_IMAGE_USAGE_VIDEO_ENCODE_DST_BIT_KHR

• VUID-VkImageMemoryBarrier2-srcQueueFamilyIndex-07125
If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_VIDEO_ENCODE_DPB_KHR then image must have been created with VK_IMAGE_USAGE_VIDEO_ENCODE_DPB_BIT_KHR

• VUID-VkImageMemoryBarrier2-subresourceRange-01486
subresourceRange.baseMipLevel must be less than the mipLevels specified in VkImageCreateInfo when image was created

• VUID-VkImageMemoryBarrier2-subresourceRange-01724
If subresourceRange.levelCount is not VK_REMAINING_MIP_LEVELS,
subresourceRange.baseMipLevel + subresourceRange.levelCount must be less than or equal to the mipLevels specified in VkImageCreateInfo when image was created

• VUID-VkImageMemoryBarrier2-subresourceRange-01488
  subresourceRange.baseArrayLayer must be less than the arrayLayers specified in VkImageCreateInfo when image was created

• VUID-VkImageMemoryBarrier2-subresourceRange-01725
  If subresourceRange.layerCount is not VK_REMAINING_ARRAY_LAYERS, subresourceRange.baseArrayLayer + subresourceRange.layerCount must be less than or equal to the arrayLayers specified in VkImageCreateInfo when image was created

• VUID-VkImageMemoryBarrier2-image-01932
  If image is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

• VUID-VkImageMemoryBarrier2-image-09241
  If image has a color format that is single-plane, then the aspectMask member of subresourceRange must be VK_IMAGE_ASPECT_COLOR_BIT

• VUID-VkImageMemoryBarrier2-image-09242
  If image has a color format and is not disjoint, then the aspectMask member of subresourceRange must be VK_IMAGE_ASPECT_COLOR_BIT

• VUID-VkImageMemoryBarrier2-image-01672
  If image has a multi-planar format and the image is disjoint, then the aspectMask member of subresourceRange must include at least one multi-planar aspect mask bit or VK_IMAGE_ASPECT_COLOR_BIT

• VUID-VkImageMemoryBarrier2-image-03319
  If image has a depth/stencil format with both depth and stencil and the separateDepthStencilLayouts feature is enabled, then the aspectMask member of subresourceRange must include either or both VK_IMAGE_ASPECT_DEPTH_BIT and VK_IMAGE_ASPECT_STENCIL_BIT

• VUID-VkImageMemoryBarrier2-image-03320
  If image has a depth/stencil format with both depth and stencil and the separateDepthStencilLayouts feature is not enabled, then the aspectMask member of subresourceRange must include both VK_IMAGE_ASPECT_DEPTH_BIT and VK_IMAGE_ASPECT_STENCIL_BIT

• VUID-VkImageMemoryBarrier2-aspectMask-08702
  If the aspectMask member of subresourceRange includes VK_IMAGE_ASPECT_DEPTH_BIT, oldLayout and newLayout must not be one of VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL

• VUID-VkImageMemoryBarrier2-aspectMask-08703
  If the aspectMask member of subresourceRange includes VK_IMAGE_ASPECT_STENCIL_BIT, oldLayout and newLayout must not be one of VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL

• VUID-VkImageMemoryBarrier2-srcStageMask-03854
  If either srcStageMask or dstStageMask includes VK_PIPELINE_STAGE_2_HOST_BIT, srcQueueFamilyIndex and dstQueueFamilyIndex must be equal
If `srcStageMask` includes `VK_PIPELINE_STAGE_2_HOST_BIT`, and `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, `oldLayout` must be one of `VK_IMAGE_LAYOUT_PREINITIALIZED`, `VK_IMAGE_LAYOUT_UNDEFINED`, or `VK_IMAGE_LAYOUT_GENERAL`.

Valid Usage (Implicit)

- `sType` must be `VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER_2`
- Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkExternalMemoryAcquireUnmodifiedEXT` or `VkSampleLocationsInfoEXT`
- The `sType` value of each struct in the `pNext` chain must be unique
- `srcStageMask` must be a valid combination of `VkPipelineStageFlagBits2` values
- `srcAccessMask` must be a valid combination of `VkAccessFlagBits2` values
- `dstStageMask` must be a valid combination of `VkPipelineStageFlagBits2` values
- `dstAccessMask` must be a valid combination of `VkAccessFlagBits2` values
- `oldLayout` must be a valid `VkImageLayout` value
- `newLayout` must be a valid `VkImageLayout` value
- `image` must be a valid `VkImage` handle
- `subresourceRange` must be a valid `VkImageSubresourceRange` structure

The `VkImageMemoryBarrier` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkImageMemoryBarrier {
    VkStructureType sType;
    const void* pNext;
    VkAccessFlags srcAccessMask;
    VkAccessFlags dstAccessMask;
    VkImageLayout oldLayout;
} VkImageMemoryBarrier;
```
VkImageMemoryBarrier
{
    VkImageLayout newLayout;
    uint32_t srcQueueFamilyIndex;
    uint32_t dstQueueFamilyIndex;
    VkImage image;
    VkImageSubresourceRange subresourceRange;
} VkImageMemoryBarrier;

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **srcAccessMask** is a bitmask of **VkAccessFlagBits** specifying a **source access mask**.
- **dstAccessMask** is a bitmask of **VkAccessFlagBits** specifying a **destination access mask**.
- **oldLayout** is the old layout in an **image layout transition**.
- **newLayout** is the new layout in an **image layout transition**.
- **srcQueueFamilyIndex** is the source queue family for a **queue family ownership transfer**.
- **dstQueueFamilyIndex** is the destination queue family for a **queue family ownership transfer**.
- **image** is a handle to the image affected by this barrier.
- **subresourceRange** describes the **image subresource range** within **image** that is affected by this barrier.

The first **access scope** is limited to access to memory through the specified image subresource range, via access types in the **source access mask** specified by **srcAccessMask**. If **srcAccessMask** includes **VK_ACCESS_HOST_WRITE_BIT**, memory writes performed by that access type are also made visible, as that access type is not performed through a resource.

The second **access scope** is limited to access to memory through the specified image subresource range, via access types in the **destination access mask** specified by **dstAccessMask**. If **dstAccessMask** includes **VK_ACCESS_HOST_WRITE_BIT** or **VK_ACCESS_HOST_READ_BIT**, available memory writes are also made visible to accesses of those types, as those access types are not performed through a resource.

If **srcQueueFamilyIndex** is not equal to **dstQueueFamilyIndex**, and **srcQueueFamilyIndex** is equal to the current queue family, then the memory barrier defines a **queue family release operation** for the specified image subresource range, and the second access scope includes no access, as if **dstAccessMask** was **0**.

If **dstQueueFamilyIndex** is not equal to **srcQueueFamilyIndex**, and **dstQueueFamilyIndex** is equal to the current queue family, then the memory barrier defines a **queue family acquire operation** for the specified image subresource range, and the first access scope includes no access, as if **srcAccessMask** was **0**.

If the **synchronization2** feature is not enabled or **oldLayout** is not equal to **newLayout, oldLayout** and **newLayout** define an **image layout transition** for the specified image subresource range.

**Note**
If the **synchronization2** feature is enabled, when the old and new layout are equal, the layout values are ignored - data is preserved no matter what values are
If \textit{image} has a multi-planar format and the image is \textit{disjoint}, then including \texttt{VK_IMAGE_ASPECT_COLOR_BIT} in the \texttt{aspectMask} member of \texttt{subresourceRange} is equivalent to including \texttt{VK_IMAGE_ASPECT_PLANE_0_BIT}, \texttt{VK_IMAGE_ASPECT_PLANE_1_BIT}, and (for three-plane formats only) \texttt{VK_IMAGE_ASPECT_PLANE_2_BIT}.

### Valid Usage

- **VUID-VkImageMemoryBarrier-oldLayout-01208**
  If \texttt{srcQueueFamilyIndex} and \texttt{dstQueueFamilyIndex} define a queue family ownership transfer or \texttt{oldLayout} and \texttt{newLayout} define an image layout transition, and \texttt{oldLayout} or \texttt{newLayout} is \texttt{VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL} then \textit{image} must have been created with \texttt{VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT}

- **VUID-VkImageMemoryBarrier-oldLayout-01209**
  If \texttt{srcQueueFamilyIndex} and \texttt{dstQueueFamilyIndex} define a queue family ownership transfer or \texttt{oldLayout} and \texttt{newLayout} define an image layout transition, and \texttt{oldLayout} or \texttt{newLayout} is \texttt{VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL} then \textit{image} must have been created with \texttt{VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT}

- **VUID-VkImageMemoryBarrier-oldLayout-01210**
  If \texttt{srcQueueFamilyIndex} and \texttt{dstQueueFamilyIndex} define a queue family ownership transfer or \texttt{oldLayout} and \texttt{newLayout} define an image layout transition, and \texttt{oldLayout} or \texttt{newLayout} is \texttt{VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL} then \textit{image} must have been created with \texttt{VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT}

- **VUID-VkImageMemoryBarrier-oldLayout-01211**
  If \texttt{srcQueueFamilyIndex} and \texttt{dstQueueFamilyIndex} define a queue family ownership transfer or \texttt{oldLayout} and \texttt{newLayout} define an image layout transition, and \texttt{oldLayout} or \texttt{newLayout} is \texttt{VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL} then \textit{image} must have been created with \texttt{VK_IMAGE_USAGE_SAMPLED_BIT} or \texttt{VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT}

- **VUID-VkImageMemoryBarrier-oldLayout-01212**
  If \texttt{srcQueueFamilyIndex} and \texttt{dstQueueFamilyIndex} define a queue family ownership transfer or \texttt{oldLayout} and \texttt{newLayout} define an image layout transition, and \texttt{oldLayout} or \texttt{newLayout} is \texttt{VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL} then \textit{image} must have been created with \texttt{VK_IMAGE_USAGE_TRANSFER_SRC_BIT}

- **VUID-VkImageMemoryBarrier-oldLayout-01213**
  If \texttt{srcQueueFamilyIndex} and \texttt{dstQueueFamilyIndex} define a queue family ownership transfer or \texttt{oldLayout} and \texttt{newLayout} define an image layout transition, and \texttt{oldLayout} or \texttt{newLayout} is \texttt{VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL} then \textit{image} must have been created with \texttt{VK_IMAGE_USAGE_TRANSFER_DST_BIT}

- **VUID-VkImageMemoryBarrier-newLayout-01197**
  If \texttt{srcQueueFamilyIndex} and \texttt{dstQueueFamilyIndex} define a queue family ownership transfer or \texttt{oldLayout} and \texttt{newLayout} define an image layout transition, oldLayout must be \texttt{VK_IMAGE_LAYOUT_UNDEFINED} or the current layout of the image subresources affected by the barrier

- **VUID-VkImageMemoryBarrier-newLayout-01198**
If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, newLayout must not be VK_IMAGE_LAYOUT_UNDEFINED or VK_IMAGE_LAYOUT_PREINITIALIZED.

• VUID-VkImageMemoryBarrier-oldLayout-01658
  If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL then image must have been created with VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT.

• VUID-VkImageMemoryBarrier-oldLayout-01659
  If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL then image must have been created with VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT.

• VUID-VkImageMemoryBarrier-srcQueueFamilyIndex-04065
  If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL then image must have been created with at least one of VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT, VK_IMAGE_USAGE_SAMPLED_BIT, or VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT.

• VUID-VkImageMemoryBarrier-srcQueueFamilyIndex-04066
  If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL then image must have been created with VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT set.

• VUID-VkImageMemoryBarrier-srcQueueFamilyIndex-04067
  If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL then image must have been created with at least one of VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT, VK_IMAGE_USAGE_SAMPLED_BIT, or VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT.

• VUID-VkImageMemoryBarrier-srcQueueFamilyIndex-04068
  If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL then image must have been created with VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT set.

• VUID-VkImageMemoryBarrier-synchronization2-07793
  If the synchronization2 feature is not enabled, oldLayout must not be VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL_KHR or VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR.

• VUID-VkImageMemoryBarrier-synchronization2-07794
  If the synchronization2 feature is not enabled, newLayout must not be VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL_KHR or VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR.

• VUID-VkImageMemoryBarrier-srcQueueFamilyIndex-03938
  If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is
VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL, image **must** have been created with VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT or VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT

• VUID-VkImageMemoryBarrier-srcQueueFamilyIndex-03939
  If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL, image **must** have been created with at least one of VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT, VK_IMAGE_USAGE_SAMPLED_BIT, or VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT

• VUID-VkImageMemoryBarrier-oldLayout-02088
  If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_FRAGMENT_SHADING_RATE_ATTACHMENT_OPTIMAL_KHR then image **must** have been created with VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR set

• VUID-VkImageMemoryBarrier-image-09117
  If image was created with a sharing mode of VK_SHARING_MODE_EXCLUSIVE, and srcQueueFamilyIndex and dstQueueFamilyIndex are not equal, srcQueueFamilyIndex **must** be VK_QUEUE_FAMILY_EXTERNAL, VK_QUEUE_FAMILY_FOREIGN_EXT, or a valid queue family

• VUID-VkImageMemoryBarrier-image-09118
  If image was created with a sharing mode of VK_SHARING_MODE_EXCLUSIVE, and srcQueueFamilyIndex and dstQueueFamilyIndex are not equal, dstQueueFamilyIndex **must** be VK_QUEUE_FAMILY_EXTERNAL, VK_QUEUE_FAMILY_FOREIGN_EXT, or a valid queue family

• VUID-VkImageMemoryBarrier-srcQueueFamilyIndex-04070
  If srcQueueFamilyIndex is not equal to dstQueueFamilyIndex, at least one of srcQueueFamilyIndex or dstQueueFamilyIndex **must** not be VK_QUEUE_FAMILY_EXTERNAL or VK_QUEUE_FAMILY_FOREIGN_EXT

• VUID-VkImageMemoryBarrier-None-09119
  If the VK_KHR_external_memory extension is not enabled, and the value of VkApplicationInfo::apiVersion used to create the VkInstance is not greater than or equal to Version 1.1, srcQueueFamilyIndex **must** not be VK_QUEUE_FAMILY_EXTERNAL

• VUID-VkImageMemoryBarrier-None-09120
  If the VK_KHR_external_memory extension is not enabled, and the value of VkApplicationInfo::apiVersion used to create the VkInstance is not greater than or equal to Version 1.1, dstQueueFamilyIndex **must** not be VK_QUEUE_FAMILY_EXTERNAL

• VUID-VkImageMemoryBarrier-srcQueueFamilyIndex-09121
  If the VK_EXT_queue_family_foreign extension is not enabled srcQueueFamilyIndex **must** not be VK_QUEUE_FAMILY_FOREIGN_EXT

• VUID-VkImageMemoryBarrier-dstQueueFamilyIndex-09122
  If the VK_EXT_queue_family_foreign extension is not enabled dstQueueFamilyIndex **must** not be VK_QUEUE_FAMILY_FOREIGN_EXT

• VUID-VkImageMemoryBarrier-srcQueueFamilyIndex-07120
  If srcQueueFamilyIndex and dstQueueFamilyIndex define a queue family ownership transfer or oldLayout and newLayout define an image layout transition, and oldLayout or newLayout is VK_IMAGE_LAYOUT_VIDEO_DECODE_SRC_KHR then image **must** have been created with VK_IMAGE_USAGE_VIDEO_DECODE_SRC_BIT_KHR
If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_VIDEO_DECODE_DST_KHR` then image must have been created with `VK_IMAGE_USAGE_VIDEO_DECODE_DST_BIT_KHR`.

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_VIDEO_DECODE_DPB_KHR` then image must have been created with `VK_IMAGE_USAGE_VIDEO_DECODE_DPB_BIT_KHR`.

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_VIDEO_ENCODE_SRC_KHR` then image must have been created with `VK_IMAGE_USAGE_VIDEO_ENCODE_SRC_BIT_KHR`.

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_VIDEO_ENCODE_DST_KHR` then image must have been created with `VK_IMAGE_USAGE_VIDEO_ENCODE_DST_BIT_KHR`.

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_VIDEO_ENCODE_DPB_KHR` then image must have been created with `VK_IMAGE_USAGE_VIDEO_ENCODE_DPB_BIT_KHR`.

If `srcQueueFamilyIndex` and `dstQueueFamilyIndex` define a queue family ownership transfer or `oldLayout` and `newLayout` define an image layout transition, and `oldLayout` or `newLayout` is `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` then image must have been created with either the `VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT` or `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT` usage bits, and the `VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT` or `VK_IMAGE_USAGE_SAMPLED_BIT` usage bits, and the `VK_IMAGE_USAGE_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` usage bit.

If the `attachmentFeedbackLoopLayout` feature is not enabled, `newLayout` must not be `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT`.

If `subresourceRange.baseMipLevel` must be less than the `mipLevels` specified in `VkImageCreateInfo` when image was created.

If `subresourceRange.levelCount` is not `VK_REMAINING_MIP_LEVELS`, `subresourceRange.baseMipLevel + subresourceRange.levelCount` must be less than or equal to the `mipLevels` specified in `VkImageCreateInfo` when `image` was created.
subresourceRange.baseArrayLayer must be less than the arrayLayers specified in VkImageCreateInfo when image was created

- VUID-VkImageMemoryBarrier-subresourceRange-01725
  If subresourceRange.layerCount is not VK_REMAINING_ARRAY_LAYERS, subresourceRange.baseArrayLayer + subresourceRange.layerCount must be less than or equal to the arrayLayers specified in VkImageCreateInfo when image was created

- VUID-VkImageMemoryBarrier-image-01932
  If image is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-VkImageMemoryBarrier-image-09241
  If image has a color format that is single-plane, then the aspectMask member of subresourceRange must be VK_IMAGE_ASPECT_COLOR_BIT

- VUID-VkImageMemoryBarrier-image-09242
  If image has a color format and is not disjoint, then the aspectMask member of subresourceRange must be VK_IMAGE_ASPECT_COLOR_BIT

- VUID-VkImageMemoryBarrier-image-01672
  If image has a multi-planar format and the image is disjoint, then the aspectMask member of subresourceRange must include at least one multi-planar aspect mask bit or VK_IMAGE_ASPECT_COLOR_BIT

- VUID-VkImageMemoryBarrier-image-03319
  If image has a depth/stencil format with both depth and stencil and the separateDepthStencilLayouts feature is enabled, then the aspectMask member of subresourceRange must include either or both VK_IMAGE_ASPECT_DEPTH_BIT and VK_IMAGE_ASPECT_STENCIL_BIT

- VUID-VkImageMemoryBarrier-image-03320
  If image has a depth/stencil format with both depth and stencil and the separateDepthStencilLayouts feature is not enabled, then the aspectMask member of subresourceRange must include both VK_IMAGE_ASPECT_DEPTH_BIT and VK_IMAGE_ASPECT_STENCIL_BIT

- VUID-VkImageMemoryBarrier-aspectMask-08702
  If the aspectMask member of subresourceRange includes VK_IMAGE_ASPECT_DEPTH_BIT, oldLayout and newLayout must not be one of VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL

- VUID-VkImageMemoryBarrier-aspectMask-08703
  If the aspectMask member of subresourceRange includes VK_IMAGE_ASPECT_STENCIL_BIT, oldLayout and newLayout must not be one of VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL

- VUID-VkImageMemoryBarrier-None-09052
  If the synchronization2 feature is not enabled, and image was created with a sharing mode of VK_SHARING_MODE_CONCURRENT, at least one of srcQueueFamilyIndex and dstQueueFamilyIndex must be VK_QUEUE_FAMILY_IGNORED

- VUID-VkImageMemoryBarrier-None-09053
  If the synchronization2 feature is not enabled, and image was created with a sharing mode...
of VK_SHARING_MODE_CONCURRENT, srcQueueFamilyIndex must be VK_QUEUE_FAMILY_IGNORED or VK_QUEUE_FAMILY_EXTERNAL

- VUID-VkImageMemoryBarrier-None-09054
  If the synchronization feature is not enabled, and image was created with a sharing mode of VK_SHARING_MODE_CONCURRENT, dstQueueFamilyIndex must be VK_QUEUE_FAMILY_IGNORED or VK_QUEUE_FAMILY_EXTERNAL

**Valid Usage (Implicit)**

- VUID-VkImageMemoryBarrier-sType-sType
  sType must be VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER

- VUID-VkImageMemoryBarrier-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkExternalMemoryAcquireUnmodifiedEXT or VkSampleLocationsInfoEXT

- VUID-VkImageMemoryBarrier-sType-unique
  The sType value of each struct in the pNext chain must be unique

- VUID-VkImageMemoryBarrier-oldLayout-parameter
  oldLayout must be a valid VkImageLayout value

- VUID-VkImageMemoryBarrier-newLayout-parameter
  newLayout must be a valid VkImageLayout value

- VUID-VkImageMemoryBarrier-image-parameter
  image must be a valid VkImage handle

- VUID-VkImageMemoryBarrier-subresourceRange-parameter
  subresourceRange must be a valid VkImageSubresourceRange structure

To facilitate usage of images whose memory is initialized on the host, Vulkan allows image layout transitions to be performed by the host as well, albeit supporting limited layouts.

To perform an image layout transition on the host, call:

```c
// Provided by VK_EXT_host_image_copy
VkResult vkTransitionImageLayoutEXT(
    VkDevice device,
    uint32_t transitionCount,
    const VkHostImageLayoutTransitionInfoEXT* pTransitions);
```

- device is the device which owns pTransitions[i].image.
- transitionCount is the number of image layout transitions to perform.
- pTransitions is a pointer to an array of VkHostImageLayoutTransitionInfoEXT structures specifying the image and subresource ranges within them to transition.
Valid Usage (Implicit)

- VUID-vkTransitionImageLayoutEXT-device-parameter
  *device* must be a valid *VkDevice* handle

- VUID-vkTransitionImageLayoutEXT-pTransitions-parameter
  *pTransitions* must be a valid pointer to an array of *transitionCount* valid
  *VkHostImageLayoutTransitionInfoEXT* structures

- VUID-vkTransitionImageLayoutEXT-transitionCount-arraylength
  *transitionCount* must be greater than 0

Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_INITIALIZATION_FAILED
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_MEMORY_MAP_FAILED

The *VkHostImageLayoutTransitionInfoEXT* structure is defined as:

```c
// Provided by VK_EXT_host_image_copy
typedef struct VkHostImageLayoutTransitionInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkImage image;
    VkImageLayout oldLayout;
    VkImageLayout newLayout;
    VkImageSubresourceRange subresourceRange;
} VkHostImageLayoutTransitionInfoEXT;
```

- *sType* is a *VkStructureType* value identifying this structure.
- *pNext* is NULL or a pointer to a structure extending this structure.
- *image* is a handle to the image affected by this layout transition.
- *oldLayout* is the old layout in an *image layout transition*.
- *newLayout* is the new layout in an *image layout transition*.
- *subresourceRange* describes the *image subresource range* within *image* that is affected by this layout transition.

*vkTransitionImageLayoutEXT* does not check whether the device memory associated with an image is
currently in use before performing the layout transition. The application must guarantee that any previously submitted command that reads from or writes to this subresource has completed before the host performs the layout transition.

Note

Image layout transitions performed on the host do not require queue family ownership transfers as the physical layout of the image will not vary between queue families for the layouts supported by this function.

Valid Usage

- VUID-VkHostImageLayoutTransitionInfoEXT-image-09055
  image must have been created with VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT

- VUID-VkHostImageLayoutTransitionInfoEXT-subresourceRange-01486
  subresourceRange.baseMipLevel must be less than the mipLevels specified in VkImageCreateInfo when image was created

- VUID-VkHostImageLayoutTransitionInfoEXT-subresourceRange-01724
  If subresourceRange.levelCount is not VK_REMAINING_MIP_LEVELS,
  subresourceRange.baseMipLevel + subresourceRange.levelCount must be less than or equal to the mipLevels specified in VkImageCreateInfo when image was created

- VUID-VkHostImageLayoutTransitionInfoEXT-subresourceRange-01488
  subresourceRange.baseArrayLayer must be less than the arrayLayers specified in VkImageCreateInfo when image was created

- VUID-VkHostImageLayoutTransitionInfoEXT-subresourceRange-01725
  If subresourceRange.layerCount is not VK_REMAINING_ARRAY_LAYERS,
  subresourceRange.baseArrayLayer + subresourceRange.layerCount must be less than or equal to the arrayLayers specified in VkImageCreateInfo when image was created

- VUID-VkHostImageLayoutTransitionInfoEXT-image-01932
  If image is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-VkHostImageLayoutTransitionInfoEXT-image-09241
  If image has a color format that is single-plane, then the aspectMask member of subresourceRange must be VK_IMAGE_ASPECT_COLOR_BIT

- VUID-VkHostImageLayoutTransitionInfoEXT-image-09242
  If image has a color format and is not disjoint, then the aspectMask member of subresourceRange must be VK_IMAGE_ASPECT_COLOR_BIT

- VUID-VkHostImageLayoutTransitionInfoEXT-image-01672
  If image has a multi-planar format and the image is disjoint, then the aspectMask member of subresourceRange must include at least one multi-planar aspect mask bit or VK_IMAGE_ASPECT_COLOR_BIT

- VUID-VkHostImageLayoutTransitionInfoEXT-image-03319
  If image has a depth/stencil format with both depth and stencil and the separateDepthStencilLayouts feature is enabled, then the aspectMask member of
The `subresourceRange` must include either or both `VK_IMAGE_ASPECT_DEPTH_BIT` and `VK_IMAGE_ASPECT_STENCIL_BIT`.

- **VUID-VkHostImageLayoutTransitionInfoEXT-image-03320**
  If the image has a depth/stencil format with both depth and stencil and the separateDepthStencilLayouts feature is not enabled, then the `aspectMask` member of `subresourceRange` must include both `VK_IMAGE_ASPECT_DEPTH_BIT` and `VK_IMAGE_ASPECT_STENCIL_BIT`.

- **VUID-VkHostImageLayoutTransitionInfoEXT-aspectMask-08702**
  If the `aspectMask` member of `subresourceRange` includes `VK_IMAGE_ASPECT_DEPTH_BIT`, `oldLayout` and `newLayout` must not be one of `VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`.

- **VUID-VkHostImageLayoutTransitionInfoEXT-aspectMask-08703**
  If the `aspectMask` member of `subresourceRange` includes `VK_IMAGE_ASPECT_STENCIL_BIT`, `oldLayout` and `newLayout` must not be one of `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`.

- **VUID-VkHostImageLayoutTransitionInfoEXT-oldLayout-09229**
  `oldLayout` must be either `VK_IMAGE_LAYOUT_UNDEFINED` or the current layout of the image subresources as specified in `subresourceRange`.

- **VUID-VkHostImageLayoutTransitionInfoEXT-oldLayout-09230**
  If `oldLayout` is not `VK_IMAGE_LAYOUT_UNDEFINED` or `VK_IMAGE_LAYOUT_PREINITIALIZED`, it must be one of the layouts in `VkPhysicalDeviceHostImageCopyPropertiesEXT::pCopySrcLayouts`.

- **VUID-VkHostImageLayoutTransitionInfoEXT-newLayout-09057**
  `newLayout` must be one of the layouts in `VkPhysicalDeviceHostImageCopyPropertiesEXT::pCopyDstLayouts`.

---

**Valid Usage (Implicit)**

- **VUID-VkHostImageLayoutTransitionInfoEXT-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_HOST_IMAGE_LAYOUT_TRANSITION_INFO_EXT`.

- **VUID-VkHostImageLayoutTransitionInfoEXT-pNext-pNext**
  `pNext` must be `NULL`.

- **VUID-VkHostImageLayoutTransitionInfoEXT-image-parameter**
  `image` must be a valid `VkImage` handle.

- **VUID-VkHostImageLayoutTransitionInfoEXT-oldLayout-parameter**
  `oldLayout` must be a valid `VkImageLayout` value.

- **VUID-VkHostImageLayoutTransitionInfoEXT-newLayout-parameter**
  `newLayout` must be a valid `VkImageLayout` value.

- **VUID-VkHostImageLayoutTransitionInfoEXT-subresourceRange-parameter**
  `subresourceRange` must be a valid `VkImageSubresourceRange` structure.
7.7.4. Queue Family Ownership Transfer

Resources created with a `VkSharingMode` of `VK_SHARING_MODE_EXCLUSIVE` must have their ownership explicitly transferred from one queue family to another in order to access their content in a well-defined manner on a queue in a different queue family.

The special queue family index `VK_QUEUE_FAMILY_IGNORED` indicates that a queue family parameter or member is ignored.

```
#define VK_QUEUE_FAMILY_IGNORED           (~0U)
```

Resources shared with external APIs or instances using external memory must also explicitly manage ownership transfers between local and external queues (or equivalent constructs in external APIs) regardless of the `VkSharingMode` specified when creating them.

The special queue family index `VK_QUEUE_FAMILY_EXTERNAL` represents any queue external to the resource's current Vulkan instance, as long as the queue uses the same underlying device group or physical device, and the same driver version as the resource's `VkDevice`, as indicated by `VkPhysicalDeviceIDProperties::deviceUUID` and `VkPhysicalDeviceIDProperties::driverUUID`.

```
#define VK_QUEUE_FAMILY_EXTERNAL          (~1U)
```

or the equivalent

```
#define VK_QUEUE_FAMILY_EXTERNAL_KHR      VK_QUEUE_FAMILY_EXTERNAL
```

The special queue family index `VK_QUEUE_FAMILY_FOREIGN_EXT` represents any queue external to the resource's current Vulkan instance, regardless of the queue's underlying physical device or driver version. This includes, for example, queues for fixed-function image processing devices, media codec devices, and display devices, as well as all queues that use the same underlying device group or physical device, and the same driver version as the resource's `VkDevice`.

```
#define VK_QUEUE_FAMILY_FOREIGN_EXT       (~2U)
```

If memory dependencies are correctly expressed between uses of such a resource between two queues in different families, but no ownership transfer is defined, the contents of that resource are undefined for any read accesses performed by the second queue family.

**Note**

If an application does not need the contents of a resource to remain valid when transferring from one queue family to another, then the ownership transfer should be skipped.
Applications should expect transfers to/from `VK_QUEUE_FAMILY_FOREIGN_EXT` to be more expensive than transfers to/from `VK_QUEUE_FAMILY_EXTERNAL_KHR`.

A queue family ownership transfer consists of two distinct parts:

1. Release exclusive ownership from the source queue family
2. Acquire exclusive ownership for the destination queue family

An application **must** ensure that these operations occur in the correct order by defining an execution dependency between them, e.g. using a semaphore.

A *release operation* is used to release exclusive ownership of a range of a buffer or image subresource range. A release operation is defined by executing a buffer memory barrier (for a buffer range) or an image memory barrier (for an image subresource range) using a pipeline barrier command, on a queue from the source queue family. The `srcQueueFamilyIndex` parameter of the barrier **must** be set to the source queue family index, and the `dstQueueFamilyIndex` parameter to the destination queue family index. `dstAccessMask` is ignored for such a barrier, such that no visibility operation is executed - the value of this mask does not affect the validity of the barrier. The release operation happens-after the availability operation, and happens-before operations specified in the second synchronization scope of the calling command.

An *acquire operation* is used to acquire exclusive ownership of a range of a buffer or image subresource range. An acquire operation is defined by executing a buffer memory barrier (for a buffer range) or an image memory barrier (for an image subresource range) using a pipeline barrier command, on a queue from the destination queue family. The buffer range or image subresource range specified in an acquire operation **must** match exactly that of a previous release operation. The `srcQueueFamilyIndex` parameter of the barrier **must** be set to the source queue family index, and the `dstQueueFamilyIndex` parameter to the destination queue family index. `srcAccessMask` is ignored for such a barrier, such that no availability operation is executed - the value of this mask does not affect the validity of the barrier. The acquire operation happens-after operations in the first synchronization scope of the calling command, and happens-before the visibility operation.

**Note**

Whilst it is not invalid to provide destination or source access masks for memory barriers used for release or acquire operations, respectively, they have no practical effect. Access after a release operation has undefined results, and so visibility for those accesses has no practical effect. Similarly, write access before an acquire operation will produce undefined results for future access, so availability of those writes has no practical use. In an earlier version of the specification, these were required to match on both sides - but this was subsequently relaxed. These masks **should** be set to 0.

If the transfer is via an image memory barrier, and an image layout transition is desired, then the values of `oldLayout` and `newLayout` in the release operation's memory barrier **must** be equal to values of `oldLayout` and `newLayout` in the acquire operation's memory barrier. Although the image layout transition is submitted twice, it will only be executed once. A layout transition specified in this way happens-after the release operation and happens-before the acquire operation.
If the values of srcQueueFamilyIndex and dstQueueFamilyIndex are equal, no ownership transfer is performed, and the barrier operates as if they were both set to VK_QUEUE_FAMILY_IGNORED.

Queue family ownership transfers may perform read and write accesses on all memory bound to the image subresource or buffer range, so applications must ensure that all memory writes have been made available before a queue family ownership transfer is executed. Available memory is automatically made visible to queue family release and acquire operations, and writes performed by those operations are automatically made available.

Once a queue family has acquired ownership of a buffer range or image subresource range of a VK_SHARING_MODE_EXCLUSIVE resource, its contents are undefined to other queue families unless ownership is transferred. The contents of any portion of another resource which aliases memory that is bound to the transferred buffer or image subresource range are undefined after a release or acquire operation.

Note

Because events cannot be used directly for inter-queue synchronization, and because vkCmdSetEvent does not have the queue family index or memory barrier parameters needed by a release operation, the release and acquire operations of a queue family ownership transfer can only be performed using vkCmdPipelineBarrier.

An acquire operation may have a performance penalty when acquiring ownership of a subresource range from one of the special queue families reserved for external memory ownership transfers described above. The application can reduce the performance penalty in some cases by adding a VkExternalMemoryAcquireUnmodifiedEXT structure to thepNext chain of the acquire operation's memory barrier structure.

The VkExternalMemoryAcquireUnmodifiedEXT structure is defined as:

```c
// Provided by VK_EXT_external_memory_acquire_unmodified
typedef struct VkExternalMemoryAcquireUnmodifiedEXT {
    VkStructureType sType;
    const void* pNext;
    VkBool32 acquireUnmodifiedMemory;
} VkExternalMemoryAcquireUnmodifiedEXT;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- acquireUnmodifiedMemory specifies, if VK_TRUE, that no range of VkDeviceMemory bound to the resource of the memory barrier's subresource range was modified at any time since the resource's most recent release of ownership to the queue family specified by the memory barrier's srcQueueFamilyIndex. If VK_FALSE, it specifies nothing.

If the application releases ownership of the subresource range to one of the special queue families reserved for external memory ownership transfers with a memory barrier structure, and later re-acquires ownership from the same queue family with a memory barrier structure, and if no range
of VkDeviceMemory bound to the resource was modified at any time between the release operation and the acquire operation, then the application should add a VkExternalMemoryAcquireUnmodifiedEXT structure to the pNext chain of the acquire operation's memory barrier structure because this may reduce the performance penalty.

This struct is ignored if acquireUnmodifiedMemory is VK_FALSE. In particular, VK_FALSE does not specify that memory was modified.

This struct is ignored if the memory barrier's srcQueueFamilyIndex is not a special queue family reserved for external memory ownership transfers.

Note

The method by which the application determines whether memory was modified between the release operation and acquire operation is outside the scope of Vulkan.

For any Vulkan operation that accesses a resource, the application must not assume the implementation accesses the resource's memory as read-only, even for apparently read-only operations such as transfer commands and shader reads.

The validity of VkExternalMemoryAcquireUnmodifiedEXT::acquireUnmodifiedMemory is independent of memory ranges outside the ranges of VkDeviceMemory bound to the resource. In particular, it is independent of any implementation-private memory associated with the resource.

Valid Usage

• VUID-VkExternalMemoryAcquireUnmodifiedEXT-acquireUnmodifiedMemory-08922 If acquireUnmodifiedMemory is VK_TRUE, and the memory barrier's srcQueueFamilyIndex is a special queue family reserved for external memory ownership transfers (as described in Queue Family Ownership Transfer), then each range of VkDeviceMemory bound to the resource must have remained unmodified during all time since the resource's most recent release of ownership to the queue family.

Valid Usage (Implicit)

• VUID-VkExternalMemoryAcquireUnmodifiedEXT-sType-sType sType must be VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_ACQUIRE_UNMODIFIED_EXT

7.8. Wait Idle Operations

To wait on the host for the completion of outstanding queue operations for a given queue, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkQueueWaitIdle(
  VkQueue queue);
```
• queue is the queue on which to wait.

vkQueueWaitIdle is equivalent to having submitted a valid fence to every previously executed queue submission command that accepts a fence, then waiting for all of those fences to signal using vkWaitForFences with an infinite timeout and waitAll set to VK_TRUE.

Valid Usage (Implicit)

• VUID-vkQueueWaitIdle-queue-parameter queue must be a valid VkQueue handle

Host Synchronization

• Host access to queue must be externally synchronized

Command Properties

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<th>Render Pass Scope</th>
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<td>-</td>
<td>-</td>
<td>Any</td>
<td>-</td>
</tr>
</tbody>
</table>

Return Codes

Success

• VK_SUCCESS

Failure

• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY
• VK_ERROR_DEVICE_LOST

To wait on the host for the completion of outstanding queue operations for all queues on a given logical device, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkDeviceWaitIdle(
    VkDevice device);
```

• device is the logical device to idle.

vkDeviceWaitIdle is equivalent to calling vkQueueWaitIdle for all queues owned by device.
Valid Usage (Implicit)

- VUID-vkDeviceWaitIdle-device-parameter
  device must be a valid VkDevice handle

Host Synchronization

- Host access to all VkQueue objects created from device must be externally synchronized

Return Codes

Success
  - VK_SUCCESS

Failure
  - VK_ERROR_OUT_OF_HOST_MEMORY
  - VK_ERROR_OUT_OF_DEVICE_MEMORY
  - VK_ERROR_DEVICE_LOST

7.9. Host Write Ordering Guarantees

When batches of command buffers are submitted to a queue via a queue submission command, it defines a memory dependency with prior host operations, and execution of command buffers submitted to the queue.

The first synchronization scope includes execution of vkQueueSubmit on the host and anything that happened-before it, as defined by the host memory model.

Some systems allow writes that do not directly integrate with the host memory model; these have to be synchronized by the application manually. One example of this is non-temporal store instructions on x86; to ensure these happen-before submission, applications should call _mm_sfence().

The second synchronization scope includes all commands submitted in the same queue submission, and all commands that occur later in submission order.

The first access scope includes all host writes to mappable device memory that are available to the host memory domain.

The second access scope includes all memory access performed by the device.
7.10. Synchronization and Multiple Physical Devices

If a logical device includes more than one physical device, then fences, semaphores, and events all still have a single instance of the signaled state.

A fence becomes signaled when all physical devices complete the necessary queue operations.

Semaphore wait and signal operations all include a device index that is the sole physical device that performs the operation. These indices are provided in the `VkDeviceGroupSubmitInfo` and `VkDeviceGroupBindSparseInfo` structures. Semaphores are not exclusively owned by any physical device. For example, a semaphore can be signaled by one physical device and then waited on by a different physical device.

An event can only be waited on by the same physical device that signaled it (or the host).

7.11. Calibrated timestamps

In order to be able to correlate the time a particular operation took place at on timelines of different time domains (e.g. a device operation vs. a host operation), Vulkan allows querying calibrated timestamps from multiple time domains.

To query calibrated timestamps from a set of time domains, call:

```c
// Provided by VK_EXT_calibrated_timestamps
VkResult vkGetCalibratedTimestampsEXT(
    VkDevice device,
    uint32_t timestampCount,
    const VkCalibratedTimestampInfoEXT* pTimestampInfos,
    uint64_t* pTimestamps,
    uint64_t* pMaxDeviation);
```

- `device` is the logical device used to perform the query.
- `timestampCount` is the number of timestamps to query.
- `pTimestampInfos` is a pointer to an array of `timestampCount` `VkCalibratedTimestampInfoEXT` structures, describing the time domains the calibrated timestamps should be captured from.
- `pTimestamps` is a pointer to an array of `timestampCount` 64-bit unsigned integer values in which the requested calibrated timestamp values are returned.
- `pMaxDeviation` is a pointer to a 64-bit unsigned integer value in which the strictly positive maximum deviation, in nanoseconds, of the calibrated timestamp values is returned.

**Note**
The maximum deviation may vary between calls to `vkGetCalibratedTimestampsEXT` even for the same set of time domains due to implementation and platform specific reasons. It is the application’s responsibility to assess whether the returned maximum deviation makes the timestamp values suitable for any particular purpose and can choose to re-issue the timestamp calibration call.
pursuing a lower deviation value.

Calibrated timestamp values can be extrapolated to estimate future coinciding timestamp values, however, depending on the nature of the time domains and other properties of the platform extrapolating values over a sufficiently long period of time may no longer be accurate enough to fit any particular purpose, so applications are expected to re-calibrate the timestamps on a regular basis.

Valid Usage

- VUID-vkGetCalibratedTimestampsEXT-timeDomain-09246
  The timeDomain value of each VkCalibratedTimestampInfoEXT in pTimestampInfos must be unique

Valid Usage (Implicit)

- VUID-vkGetCalibratedTimestampsEXT-device-parameter
device must be a valid VkDevice handle
- VUID-vkGetCalibratedTimestampsEXT-pTimestampInfos-parameter
  pTimestampInfos must be a valid pointer to an array of timestampCount valid VkCalibratedTimestampInfoEXT structures
- VUID-vkGetCalibratedTimestampsEXT-pTimestamps-parameter
  pTimestamps must be a valid pointer to an array of timestampCount uint64_t values
- VUID-vkGetCalibratedTimestampsEXT-pMaxDeviation-parameter
  pMaxDeviation must be a valid pointer to a uint64_t value
- VUID-vkGetCalibratedTimestampsEXT-timestampCount-arraylength
  timestampCount must be greater than 0

Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkCalibratedTimestampInfoEXT structure is defined as:

```c
// Provided by VK_EXT_calibrated_timestamps
typedef struct VkCalibratedTimestampInfoEXT {
    VkStructureType     sType;
    const void*         pNext;
} VkCalibratedTimestampInfoEXT;
```
VkTimeDomainEXT  timeDomain;
} VkCalibratedTimestampInfoEXT;

- *sType* is a VkStructureType value identifying this structure.
- *pNext* is NULL or a pointer to a structure extending this structure.
- *timeDomain* is a VkTimeDomainEXT value specifying the time domain from which the calibrated timestamp value should be returned.

**Valid Usage**

- VUID-VkCalibratedTimestampInfoEXT-timeDomain-02354
  
  *timeDomain* must be one of the VkTimeDomainEXT values returned by vkGetPhysicalDeviceCalibrateableTimeDomainsEXT

**Valid Usage (Implicit)**

- VUID-VkCalibratedTimestampInfoEXT-sType-sType
  
  *sType* must be VK_STRUCTURE_TYPE_CALIBRATED_TIMESTAMP_INFO_EXT

- VUID-VkCalibratedTimestampInfoEXT-pNext-pNext
  
  *pNext* must be NULL

- VUID-VkCalibratedTimestampInfoEXT-timeDomain-parameter

  *timeDomain* must be a valid VkTimeDomainEXT value

The set of supported time domains consists of:

```
// Provided by VK_EXT_calibrated_timestamps
typedef enum VkTimeDomainEXT {
    VK_TIME_DOMAIN_DEVICE_EXT = 0,
    VK_TIME_DOMAIN_CLOCK_MONOTONIC_EXT = 1,
    VK_TIME_DOMAIN_CLOCK_MONOTONIC_RAW_EXT = 2,
    VK_TIME_DOMAIN_QUERY_PERFORMANCE_COUNTER_EXT = 3,
} VkTimeDomainEXT;
```

- **VK_TIME_DOMAIN_DEVICE_EXT** specifies the device time domain. Timestamp values in this time domain use the same units and are comparable with device timestamp values captured using vkCmdWriteTimestamp or vkCmdWriteTimestamp2 and are defined to be incrementing according to the timestampPeriod of the device.

- **VK_TIME_DOMAIN_CLOCK_MONOTONIC_EXT** specifies the CLOCK_MONOTONIC time domain available on POSIX platforms. Timestamp values in this time domain are in units of nanoseconds and are comparable with platform timestamp values captured using the POSIX clock_gettime API as computed by this example:

  ```
  Note
  ```
An implementation supporting `VK_EXT_calibrated_timestamps` will use the same time domain for all its `VkQueue` so that timestamp values reported for `VK_TIME_DOMAIN_DEVICE_EXT` can be matched to any timestamp captured through `vkCmdWriteTimestamp` or `vkCmdWriteTimestamp2`.

```c
struct timespec tv;
clock_gettime(CLOCK_MONOTONIC, &tv);
return tv.tv_nsec + tv.tv_sec*1000000000ull;
```

- `VK_TIME_DOMAIN_CLOCK_MONOTONIC_RAW_EXT` specifies the CLOCK_MONOTONIC_RAW time domain available on POSIX platforms. Timestamp values in this time domain are in units of nanoseconds and are comparable with platform timestamp values captured using the POSIX `clock_gettime` API as computed by this example:

```c
struct timespec tv;
clock_gettime(CLOCK_MONOTONIC_RAW, &tv);
return tv.tv_nsec + tv.tv_sec*1000000000ull;
```

- `VK_TIME_DOMAIN_QUERY_PERFORMANCE_COUNTER_EXT` specifies the performance counter (QPC) time domain available on Windows. Timestamp values in this time domain are in the same units as those provided by the Windows `QueryPerformanceCounter` API and are comparable with platform timestamp values captured using that API as computed by this example:

```c
LARGE_INTEGER counter;
QueryPerformanceCounter(&counter);
return counter.QuadPart;
```
Chapter 8. Render Pass

Draw commands must be recorded within a render pass instance. Each render pass instance defines a set of image resources, referred to as attachments, used during rendering.

To begin a render pass instance, call:

```
// Provided by VK_VERSION_1_3
void vkCmdBeginRendering(
    VkCommandBuffer commandBuffer,
    const VkRenderingInfo* pRenderingInfo);
```

or the equivalent command

```
// Provided by VK_KHR_dynamic_rendering
void vkCmdBeginRenderingKHR(
    VkCommandBuffer commandBuffer,
    const VkRenderingInfo* pRenderingInfo);
```

- commandBuffer is the command buffer in which to record the command.
- pRenderingInfo is a pointer to a VkRenderingInfo structure specifying details of the render pass instance to begin.

After beginning a render pass instance, the command buffer is ready to record draw commands.

If pRenderingInfo->flags includes VK_RENDERING_RESUMING_BIT then this render pass is resumed from a render pass instance that has been suspended earlier in submission order.

---

### Valid Usage

- VUID-vkCmdBeginRendering-dynamicRendering-06446
  The dynamicRendering feature must be enabled

- VUID-vkCmdBeginRendering-commandBuffer-06068
  If commandBuffer is a secondary command buffer, pRenderingInfo->flags must not include
  VK_RENDERING_CONTENTS_SECONDARY_COMMAND_BUFFERS_BIT

---

### Valid Usage (Implicit)

- VUID-vkCmdBeginRendering-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdBeginRendering-pRenderingInfo-parameter
  pRenderingInfo must be a valid pointer to a valid VkRenderingInfo structure

- VUID-vkCmdBeginRendering-commandBuffer-recording

---

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**commandBuffer** must be in the **recording state**

- VUID-vkCmdBeginRendering-commandBuffer-cmdpool
  The **VkCommandPool** that **commandBuffer** was allocated from must support graphics operations

- VUID-vkCmdBeginRendering-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdBeginRendering-videocoding
  This command must only be called outside of a video coding scope

---

**Host Synchronization**

- Host access to **commandBuffer** must be externally synchronized

- Host access to the **VkCommandPool** that **commandBuffer** was allocated from must be externally synchronized

---

**Command Properties**

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The **VkRenderingInfo** structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkRenderingInfo {
    VkStructureType sType;
    const void* pNext;
    VkRenderingFlags flags;
    VkRect2D renderArea;
    uint32_t layerCount;
    uint32_t viewMask;
    const VkRenderingAttachmentInfo* pColorAttachments;
    const VkRenderingAttachmentInfo* pDepthAttachment;
    const VkRenderingAttachmentInfo* pStencilAttachment;
} VkRenderingInfo;
```

or the equivalent

```c
// Provided by VK_KHR_dynamic_rendering, VK_KHR_dynamic_rendering with VK_QCOM_tile_properties
```
typedef VkRenderingInfo VkRenderingInfoKHR;

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is a bitmask of *VkRenderingFlagBits*.
- **renderArea** is the render area that is affected by the render pass instance.
- **layerCount** is the number of layers rendered to in each attachment when **viewMask** is 0.
- **viewMask** is the view mask indicating the indices of attachment layers that will be rendered when it is not 0.
- **colorAttachmentCount** is the number of elements in **pColorAttachments**.
- **pColorAttachments** is a pointer to an array of colorAttachmentCount *VkRenderingAttachmentInfo* structures describing any color attachments used.
- **pDepthAttachment** is a pointer to a *VkRenderingAttachmentInfo* structure describing a depth attachment.
- **pStencilAttachment** is a pointer to a *VkRenderingAttachmentInfo* structure describing a stencil attachment.

If **viewMask** is not 0, multiview is enabled.

If there is an instance of *VkDeviceGroupRenderPassBeginInfo* included in the **pNext** chain and its **deviceRenderAreaCount** member is not 0, then **renderArea** is ignored, and the render area is defined per-device by that structure.

If multiview is enabled, and the multiviewPerViewRenderAreas feature is enabled, and there is an instance of *VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM* included in the **pNext** chain with **perViewRenderAreaCount** not equal to 0, then the elements of *VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM::pPerViewRenderAreas** override **renderArea** and define a render area for each view. In this case, **renderArea** must be set to an area at least as large as the union of all the per-view render areas.

Each element of the **pColorAttachments** array corresponds to an output location in the shader, i.e. if the shader declares an output variable decorated with a **Location** value of **X**, then it uses the attachment provided in **pColorAttachments[X]**. If the **imageView** member of any element of **pColorAttachments** is **VK_NULL_HANDLE**, writes to the corresponding location by a fragment are discarded.

### Valid Usage

- **VUID-VkRenderingInfo-viewMask-06069**
  If **viewMask** is 0, **layerCount** must not be 0
- **VUID-VkRenderingInfo-multisampledRenderToSingleSampled-06857**
  If none of the **VK_AMD_mixed_attachment_samples** extension, the **VK_NV_framebuffer_mixed_samples** extension, or the **multisampledRenderToSingleSampled** feature are enabled, **imageView** members of **pDepthAttachment**, **pStencilAttachment**, and...
elements of `pColorAttachments` that are not `VK_NULL_HANDLE` must have been created with the same `sampleCount`

- **VUID-VkRenderingInfo-None-08994**
  If `VkDeviceGroupRenderPassBeginInfo::deviceRenderAreaCount` is 0, `renderArea.extent.width` must be greater than 0

- **VUID-VkRenderingInfo-None-08995**
  If `VkDeviceGroupRenderPassBeginInfo::deviceRenderAreaCount` is 0, `renderArea.extent.height` must be greater than 0

- **VUID-VkRenderingInfo-imageView-06858**
  If `multisampled-render-to-single-sampled` is enabled, then all attachments referenced by `imageView` members of `pDepthAttachment`, `pStencilAttachment`, and elements of `pColorAttachments` that are not `VK_NULL_HANDLE` must have a sample count that is either `VK_SAMPLE_COUNT_1_BIT` or equal to `VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples`

- **VUID-VkRenderingInfo-imageView-06859**
  If `multisampled-render-to-single-sampled` is enabled, then all attachments referenced by `imageView` members of `pDepthAttachment`, `pStencilAttachment`, and elements of `pColorAttachments` that are not `VK_NULL_HANDLE` and have a sample count of `VK_SAMPLE_COUNT_1_BIT` must have been created with `VK_IMAGE_CREATE_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_BIT_EXT` in their `VkImageCreateInfo::flags`

- **VUID-VkRenderingInfo-pNext-06077**
  If the `pNext` chain does not contain `VkDeviceGroupRenderPassBeginInfo` or its `deviceRenderAreaCount` member is equal to 0, `renderArea.offset.x` must be greater than or equal to 0

- **VUID-VkRenderingInfo-pNext-06078**
  If the `pNext` chain does not contain `VkDeviceGroupRenderPassBeginInfo` or its `deviceRenderAreaCount` member is equal to 0, `renderArea.offset.y` must be greater than or equal to 0

- **VUID-VkRenderingInfo-pNext-07815**
  If the `pNext` chain does not contain `VkDeviceGroupRenderPassBeginInfo` or its `deviceRenderAreaCount` member is equal to 0, the sum of `renderArea.extent.width` and `renderArea.offset.x` must be less than or equal to `maxFramebufferWidth`

- **VUID-VkRenderingInfo-pNext-07816**
  If the `pNext` chain does not contain `VkDeviceGroupRenderPassBeginInfo` or its `deviceRenderAreaCount` member is equal to 0, the sum of `renderArea.extent.height` and `renderArea.offset.y` must be less than or equal to `maxFramebufferHeight`

- **VUID-VkRenderingInfo-pNext-06079**
  If the `pNext` chain does not contain `VkDeviceGroupRenderPassBeginInfo` or its `deviceRenderAreaCount` member is equal to 0, the width of the `imageView` member of any element of `pColorAttachments`, `pDepthAttachment`, or `pStencilAttachment` that is not `VK_NULL_HANDLE` must be greater than or equal to `renderArea.offset.x + renderArea.extent.width`

- **VUID-VkRenderingInfo-pNext-06080**
If the `pNext` chain does not contain `VkDeviceGroupRenderPassBeginInfo` or its `deviceRenderAreaCount` member is equal to 0, the height of the `imageView` member of any element of `pColorAttachments`, `pDepthAttachment`, or `pStencilAttachment` that is not `VK_NULL_HANDLE` must be greater than or equal to `renderArea.offset.y + renderArea.extent.height`.

- **VUID-VkRenderingInfo-pNext-06083**
  If the `pNext` chain contains `VkDeviceGroupRenderPassBeginInfo`, the width of the `imageView` member of any element of `pColorAttachments`, `pDepthAttachment`, or `pStencilAttachment` that is not `VK_NULL_HANDLE` must be greater than or equal to the sum of the `offset.x` and `extent.width` members of each element of `pDeviceRenderAreas`.

- **VUID-VkRenderingInfo-pNext-06084**
  If the `pNext` chain contains `VkDeviceGroupRenderPassBeginInfo`, the height of the `imageView` member of any element of `pColorAttachments`, `pDepthAttachment`, or `pStencilAttachment` that is not `VK_NULL_HANDLE` must be greater than or equal to the sum of the `offset.y` and `extent.height` members of each element of `pDeviceRenderAreas`.

- **VUID-VkRenderingInfo-pDepthAttachment-06085**
  If neither `pDepthAttachment` or `pStencilAttachment` are NULL and the `imageView` member of either structure is not `VK_NULL_HANDLE`, the `imageView` member of each structure must be the same.

- **VUID-VkRenderingInfo-pDepthAttachment-06086**
  If neither `pDepthAttachment` or `pStencilAttachment` are NULL, and the `resolveMode` member of each is not `VK_RESOLVE_MODE_NONE`, the `resolveImageView` member of each structure must be the same.

- **VUID-VkRenderingInfo-colorAttachmentCount-06087**
  If `colorAttachmentCount` is not 0 and the `imageView` member of an element of `pColorAttachments` is not `VK_NULL_HANDLE`, that `imageView` must have been created with `VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT`.

- **VUID-VkRenderingInfo-pDepthAttachment-06547**
  If `pDepthAttachment` is not NULL and `pDepthAttachment->imageView` is not `VK_NULL_HANDLE`, `pDepthAttachment->imageView` must have been created with a format that includes a depth component.

- **VUID-VkRenderingInfo-pDepthAttachment-06088**
  If `pDepthAttachment` is not NULL and `pDepthAttachment->imageView` is not `VK_NULL_HANDLE`, `pDepthAttachment->imageView` must have been created with `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT`.

- **VUID-VkRenderingInfo-pStencilAttachment-06548**
  If `pStencilAttachment` is not NULL and `pStencilAttachment->imageView` is not `VK_NULL_HANDLE`, `pStencilAttachment->imageView` must have been created with a format that includes a stencil aspect.

- **VUID-VkRenderingInfo-pStencilAttachment-06089**
  If `pStencilAttachment` is not NULL and `pStencilAttachment->imageView` is not `VK_NULL_HANDLE`, `pStencilAttachment->imageView` must have been created with a stencil usage including `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT`.

- **VUID-VkRenderingInfo-colorAttachmentCount-06090**
If `colorAttachmentCount` is not 0 and the `imageView` member of an element of `pColorAttachments` is not `VK_NULL_HANDLE`, the layout member of that element of `pColorAttachments` must not be `VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`.

- **VUID-VkRenderingInfo-colorAttachmentCount-06091**
  If `colorAttachmentCount` is not 0 and the `imageView` member of an element of `pColorAttachments` is not `VK_NULL_HANDLE`, if the `resolveMode` member of that element of `pColorAttachments` is not `VK_RESOLVE_MODE_NONE`, its `resolveImageLayout` member must not be `VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`.

- **VUID-VkRenderingInfo-pDepthAttachment-06092**
  If `pDepthAttachment` is not `NULL` and the `pDepthAttachment->imageView` member is not `VK_NULL_HANDLE`, `pDepthAttachment->layout` must not be `VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL`.

- **VUID-VkRenderingInfo-pDepthAttachment-06093**
  If `pDepthAttachment` is not `NULL`, the `pDepthAttachment->imageView` member is not `VK_NULL_HANDLE`, and the `pDepthAttachment->resolveMode` member is not `VK_RESOLVE_MODE_NONE`, `pDepthAttachment->resolveImageLayout` must not be `VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL`.

- **VUID-VkRenderingInfo-pStencilAttachment-06094**
  If `pStencilAttachment` is not `NULL` and the `pStencilAttachment->imageView` member is not `VK_NULL_HANDLE`, `pStencilAttachment->layout` must not be `VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL`.

- **VUID-VkRenderingInfo-pStencilAttachment-06095**
  If `pStencilAttachment` is not `NULL`, the `pStencilAttachment->imageView` member is not `VK_NULL_HANDLE`, and the `pStencilAttachment->resolveMode` member is not `VK_RESOLVE_MODE_NONE`, `pStencilAttachment->resolveImageLayout` must not be `VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL`.

- **VUID-VkRenderingInfo-colorAttachmentCount-06096**
  If `colorAttachmentCount` is not 0 and the `imageView` member of an element of `pColorAttachments` is not `VK_NULL_HANDLE`, the layout member of that element of `pColorAttachments` must not be `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`.

- **VUID-VkRenderingInfo-colorAttachmentCount-06097**
  If `colorAttachmentCount` is not 0 and the `imageView` member of an element of `pColorAttachments` is not `VK_NULL_HANDLE`, if the `resolveMode` member of that element of `pColorAttachments` is not `VK_RESOLVE_MODE_NONE`, its `resolveImageLayout` member must not be `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`.

- **VUID-VkRenderingInfo-pDepthAttachment-06098**
  If `pDepthAttachment` is not `NULL`, the `pDepthAttachment->imageView` member is not `VK_NULL_HANDLE`, and the `pDepthAttachment->resolveMode` member is not `VK_RESOLVE_MODE_NONE`, `pDepthAttachment->resolveImageLayout` must not be `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`.

- **VUID-VkRenderingInfo-pStencilAttachment-06099**
  If `pStencilAttachment` is not `NULL`, the `pStencilAttachment->imageView` member is not `VK_NULL_HANDLE`, `pStencilAttachment->layout` must not be `VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL`.
and pStencilAttachment->resolveMode is not VK_RESOLVE_MODE_NONE, pStencilAttachment->resolveImageLayout must not be VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL

• VUID-VkRenderingContext-colorAttachmentCount-06100
  If colorAttachmentCount is not 0 and the imageView member of an element of pColorAttachments is not VK_NULL_HANDLE, the layout member of that element of pColorAttachments must not be VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL, VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL, or VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL

• VUID-VkRenderingContext-colorAttachmentCount-06101
  If colorAttachmentCount is not 0 and the imageView member of an element of pColorAttachments is not VK_NULL_HANDLE, if the resolveMode member of that element of pColorAttachments is not VK_RESOLVE_MODE_NONE, its resolveImageLayout member must not be VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL, VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL, or VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL

• VUID-VkRenderingContext-pDepthAttachment-07732
  If pDepthAttachment is not NULL and pDepthAttachment->imageView is not VK_NULL_HANDLE, pDepthAttachment->layout must not be VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL

• VUID-VkRenderingContext-pDepthAttachment-07733
  If pDepthAttachment is not NULL, pDepthAttachment->imageView is not VK_NULL_HANDLE, and pDepthAttachment->resolveMode is not VK_RESOLVE_MODE_NONE, pDepthAttachment->resolveImageLayout must not be VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL

• VUID-VkRenderingContext-pStencilAttachment-07734
  If pStencilAttachment is not NULL and pStencilAttachment->imageView is not VK_NULL_HANDLE, pStencilAttachment->layout must not be VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL or VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL

• VUID-VkRenderingContext-pStencilAttachment-07735
  If pStencilAttachment is not NULL, pStencilAttachment->imageView is not VK_NULL_HANDLE, and pStencilAttachment->resolveMode is not VK_RESOLVE_MODE_NONE, pStencilAttachment->resolveImageLayout must not be VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL or VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL

• VUID-VkRenderingContext-pDepthAttachment-06102
  If pDepthAttachment is not NULL and pDepthAttachment->imageView is not VK_NULL_HANDLE, pDepthAttachment->resolveMode must be one of the bits set in VkPhysicalDeviceDepthStencilResolveProperties::supportedDepthResolveModes

• VUID-VkRenderingContext-pStencilAttachment-06103
  If pStencilAttachment is not NULL and pStencilAttachment->imageView is not VK_NULL_HANDLE, pStencilAttachment->resolveMode must be one of the bits set in VkPhysicalDeviceDepthStencilResolveProperties::supportedStencilResolveModes

• VUID-VkRenderingContext-pDepthAttachment-06104
  If pDepthAttachment or pStencilAttachment are both not NULL, pDepthAttachment->imageView
and pStencilAttachment->imageView are both not VK_NULL_HANDLE, and VkPhysicalDeviceDepthStencilResolveProperties::independentResolveNone is VK_FALSE, the resolveMode of both structures must be the same value

- VUID-VkRenderingInfo-pDepthAttachment-06105
  If pDepthAttachment or pStencilAttachment are both not NULL, pDepthAttachment->imageView and pStencilAttachment->imageView are both not VK_NULL_HANDLE, VkPhysicalDeviceDepthStencilResolveProperties::independentResolve is VK_FALSE, and the resolveMode of neither structure is VK_RESOLVE_MODE_NONE, the resolveMode of both structures must be the same value

- VUID-VkRenderingInfo-colorAttachmentCount-06106
colorAttachmentCount must be less than or equal to VkPhysicalDeviceLimits::maxColorAttachments

- VUID-VkRenderingInfo-imageView-06107
  If the imageView member of a VkRenderingFragmentDensityMapAttachmentInfoEXT structure included in the pNext chain is not VK_NULL_HANDLE, and the fragmentDensityMapNonSubsampledImages feature is not enabled, valid imageView and resolveImageView members of pDepthAttachment, pStencilAttachment, and each element of pColorAttachments must be a VkImageView created with VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT

- VUID-VkRenderingInfo-imageView-06108
  If the imageView member of a VkRenderingFragmentDensityMapAttachmentInfoEXT structure included in the pNext chain is not VK_NULL_HANDLE, and viewMask is not 0, imageView must have a layerCount greater than or equal to the index of the most significant bit in viewMask

- VUID-VkRenderingInfo-imageView-06109
  If the imageView member of a VkRenderingFragmentDensityMapAttachmentInfoEXT structure included in the pNext chain is not VK_NULL_HANDLE, and viewMask is 0, imageView must have a layerCount equal to 1

- VUID-VkRenderingInfo-pNext-06112
  If the pNext chain does not contain VkDeviceGroupRenderPassBeginInfo or its deviceRenderAreaCount member is equal to 0 and the imageView member of a VkRenderingFragmentDensityMapAttachmentInfoEXT structure included in the pNext chain is not VK_NULL_HANDLE, imageView must have a width greater than or equal to \[
\left\lfloor \frac{\text{renderArea}_x + \text{renderArea}_width}{\text{maxFragmentDensityTextureSize}_width} \right\rfloor
\]

- VUID-VkRenderingInfo-pNext-06113
  If the pNext chain contains a VkDeviceGroupRenderPassBeginInfo structure, its deviceRenderAreaCount member is not 0, and the imageView member of a VkRenderingFragmentDensityMapAttachmentInfoEXT structure included in the pNext chain is not VK_NULL_HANDLE, imageView must have a width greater than or equal to \[
\left\lfloor \frac{pDeviceRenderArea_x + pDeviceRenderArea_width}{\text{maxFragmentDensityTextureSize}_width} \right\rfloor
\]
  for each element of pDeviceRenderAreas

- VUID-VkRenderingInfo-pNext-06114
  If the pNext chain does not contain VkDeviceGroupRenderPassBeginInfo or its deviceRenderAreaCount member is equal to 0 and the imageView member of a VkRenderingFragmentDensityMapAttachmentInfoEXT structure included in the pNext chain is not VK_NULL_HANDLE, imageView must have a height greater than or equal to
If the `pNext` chain contains a `VkDeviceGroupRenderPassBeginInfo` structure, its `deviceRenderAreaCount` member is not 0, and the `imageView` member of a `VkRenderingFragmentDensityMapAttachmentInfoEXT` structure included in the `pNext` chain is not `VK_NULL_HANDLE`, `imageView` must have a height greater than or equal to \[
\left\lfloor \frac{\text{renderAreaY} + \text{renderAreaHeight}}{\text{maxFragmentDensityTexelSize.height}} \right\rfloor \]
for each element of `pDeviceRenderAreas`.

If the `imageView` member of a `VkRenderingFragmentDensityMapAttachmentInfoEXT` structure included in the `pNext` chain is not `VK_NULL_HANDLE`, it must not be equal to the `imageView` or `resolveImageView` member of `pDepthAttachment`, `pStencilAttachment`, or any element of `pColorAttachments`.

If the `pNext` chain does not contain `VkDeviceGroupRenderPassBeginInfo` or its `deviceRenderAreaCount` member is equal to 0 and the `imageView` member of a `VkRenderingFragmentShadingRateAttachmentInfoKHR` structure included in the `pNext` chain is not `VK_NULL_HANDLE`, `imageView` must have a width greater than or equal to \[
\left\lfloor \frac{\text{shadingRateAreaX} + \text{renderAreaX}}{\text{shadingRateAttachment TexelSize.width}} \right\rfloor \]
for each element of `pDeviceRenderAreas`.

If the `pNext` chain contains a `VkDeviceGroupRenderPassBeginInfo` structure, its `deviceRenderAreaCount` member is not 0, and the `imageView` member of a `VkRenderingFragmentShadingRateAttachmentInfoKHR` structure included in the `pNext` chain is not `VK_NULL_HANDLE`, `imageView` must have a width greater than or equal to \[
\left\lfloor \frac{\text{shadingRateAreaX} + \text{renderAreaX}}{\text{shadingRateAttachment TexelSize.width}} \right\rfloor \]
for each element of `pDeviceRenderAreas`.

If the `pNext` chain does not contain `VkDeviceGroupRenderPassBeginInfo` or its `deviceRenderAreaCount` member is equal to 0 and the `imageView` member of a `VkRenderingFragmentShadingRateAttachmentInfoKHR` structure included in the `pNext` chain is not `VK_NULL_HANDLE`, `imageView` must have a height greater than or equal to \[
\left\lfloor \frac{\text{renderAreaY} + \text{renderAreaHeight}}{\text{shadingRateAttachment TexelSize.height}} \right\rfloor \]
\nlayerCount must be less than or equal to `maxFramebufferLayers`.

If the `imageView` member of a `VkRenderingFragmentShadingRateAttachmentInfoKHR` structure included in the `pNext` chain is not `VK_NULL_HANDLE`, and `viewMask` is 0, `imageView` must have a `layerCount` that is either equal to 1 or greater than or equal to `layerCount`. 
If the `imageView` member of a `VkRenderingFragmentShadingRateAttachmentInfoKHR` structure included in the `pNext` chain is not `VK_NULL_HANDLE`, and `viewMask` is not `0`, `imageView` must have a `layerCount` that either equal to `1` or greater than or equal to the index of the most significant bit in `viewMask`.

- **VUID-VkRenderingInfo-imageView-06125**
  If the `imageView` member of a `VkRenderingFragmentShadingRateAttachmentInfoKHR` structure included in the `pNext` chain is not `VK_NULL_HANDLE`, it must not be equal to the `imageView` or `resolveImageView` member of `pDepthAttachment`, `pStencilAttachment`, or any element of `pColorAttachments`.

- **VUID-VkRenderingInfo-imageView-06126**
  If the `imageView` member of a `VkRenderingFragmentShadingRateAttachmentInfoKHR` structure included in the `pNext` chain is not `VK_NULL_HANDLE`, it must not be equal to the `imageView` member of a `VkRenderingFragmentDensityMapAttachmentInfoEXT` structure included in the `pNext` chain.

- **VUID-VkRenderingInfo-multiview-06127**
  If the `multiview` feature is not enabled, `viewMask` must be `0`.

- **VUID-VkRenderingInfo-viewMask-06128**
  The index of the most significant bit in `viewMask` must be less than `maxMultiviewViewCount`.

- **VUID-VkRenderingInfo-perViewRenderAreaCount-07857**
  If the `perViewRenderAreaCount` member of a `VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM` structure included in the `pNext` chain is not `0`, then the `multiviewPerViewRenderAreas` feature must be enabled.

- **VUID-VkRenderingInfo-perViewRenderAreaCount-07858**
  If the `perViewRenderAreaCount` member of a `VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM` structure included in the `pNext` chain is not `0`, then `renderArea` must specify a render area that includes the union of all per view render areas.

- **VUID-VkRenderingInfo-None-09044**
  Valid attachments specified by this structure must not be bound to memory locations that are bound to any other valid attachments specified by this structure.

---

**Valid Usage (Implicit)**

- **VUID-VkRenderingInfo-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_RENDERING_INFO`.

- **VUID-VkRenderingInfo-pNext-pNext**
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkDeviceGroupRenderPassBeginInfo`, `VkMultisampledRenderToSingleSampledInfoEXT`, `VkMultiviewPerViewAttributesInfoNVX`, `VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM`, `VkRenderingFragmentDensityMapAttachmentInfoEXT`, `VkRenderingFragmentShadingRateAttachmentInfoKHR`, or...
• **VUID-VkRenderingInfo-sType-unique**
The `sType` value of each struct in the `pNext` chain must be unique.

• **VUID-VkRenderingInfo-flags-parameter**
  `flags` must be a valid combination of `VkRenderingFlagBits` values.

• **VUID-VkRenderingInfo-pColorAttachments-parameter**
  If `colorAttachmentCount` is not 0, `pColorAttachments` must be a valid pointer to an array of `colorAttachmentCount` valid `VkRenderingAttachmentInfo` structures.

• **VUID-VkRenderingInfo-pDepthAttachment-parameter**
  If `pDepthAttachment` is not `NULL`, `pDepthAttachment` must be a valid pointer to a valid `VkRenderingAttachmentInfo` structure.

• **VUID-VkRenderingInfo-pStencilAttachment-parameter**
  If `pStencilAttachment` is not `NULL`, `pStencilAttachment` must be a valid pointer to a valid `VkRenderingAttachmentInfo` structure.

Bits which can be set in `VkRenderingInfo::flags` describing additional properties of the render pass are:

```c
// Provided by VK_VERSION_1_3
typedef enum VkRenderingFlagBits {
    VK_RENDERING_CONTENTS_SECONDARY_COMMAND_BUFFERS_BIT = 0x00000001,
    VK_RENDERING_SUSPENDING_BIT = 0x00000002,
    VK_RENDERING_RESUMING_BIT = 0x00000004,
} VkRenderingFlagBits;
```

or the equivalent

```c
// Provided by VK_KHR_dynamic_rendering
typedef VkRenderingFlagBits VkRenderingFlagBitsKHR;
```

- **VK_RENDERING_CONTENTS_SECONDARY_COMMAND_BUFFERS_BIT** specifies that draw calls for the render pass instance will be recorded in secondary command buffers.
- **VK_RENDERING_RESUMING_BIT** specifies that the render pass instance is resuming an earlier suspended render pass instance.
- **VK_RENDERING_SUSPENDING_BIT** specifies that the render pass instance will be suspended.
- **VK_RENDERING_ENABLE_LEGACY_DITHERING_BIT_EXT** specifies that Legacy Dithering is enabled for the render pass instance.
The contents of `pRenderingInfo` must match between suspended render pass instances and the render pass instances that resume them, other than the presence or absence of the `VK_RENDERING_RESUMING_BIT`, `VK_RENDERING_SUSPENDING_BIT`, and `VK_RENDERING_CONTENTS_SECONDARY_COMMAND_BUFFERS_BIT` flags. No action or synchronization commands, or other render pass instances, are allowed between suspending and resuming render pass instances.

```c
// Provided by VK_VERSION_1_3
typedef VkFlags VkRenderFlags;
```

or the equivalent

```c
// Provided by VK_KHR_dynamic_rendering
typedef VkRenderFlags VkRenderFlagsKHR;
```

`VkRenderFlags` is a bitmask type for setting a mask of zero or more `VkRenderFlagBits`.

The `VkRenderingAttachmentInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkRenderingAttachmentInfo {  
VkStructureType sType;
const void* pNext;
VkImageView imageView;
VkImageLayout imageLayout;
VkResolveModeFlagBits resolveMode;
VkImageView resolveImageView;
VkImageLayout resolveImageLayout;
VkAttachmentLoadOp loadOp;
VkAttachmentStoreOp storeOp;
VkClearValue clearValue;
} VkRenderingAttachmentInfo;
```

or the equivalent

```c
// Provided by VK_KHR_dynamic_rendering
typedef VkRenderingAttachmentInfo VkRenderingAttachmentInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `imageView` is the image view that will be used for rendering.
- `imageLayout` is the layout that `imageView` will be in during rendering.
- `resolveMode` is a `VkResolveModeFlagBits` value defining how multisampled data written to `imageView` will be resolved.
• **resolveImageView** is an image view used to write resolved multisample data at the end of rendering.

• **resolveImageLayout** is the layout that **resolveImageView** will be in during rendering.

• **loadOp** is a **VkAttachmentLoadOp** value defining the load operation for the attachment.

• **storeOp** is a **VkAttachmentStoreOp** value defining the store operation for the attachment.

• **clearValue** is a **VkClearValue** structure defining values used to clear **imageView** when **loadOp** is **VK_ATTACHMENT_LOAD_OP_CLEAR**.

Values in **imageView** are loaded and stored according to the values of **loadOp** and **storeOp**, within the render area for each device specified in **VkRenderingInfo**. If **imageView** is **VK_NULL_HANDLE**, other members of this structure are ignored; writes to this attachment will be discarded, and no load, store, or multisample resolve operations will be performed.

If **resolveMode** is **VK_RESOLVE_MODE_NONE**, then **resolveImageView** is ignored. If **resolveMode** is not **VK_RESOLVE_MODE_NONE**, and **resolveImageView** is not **VK_NULL_HANDLE**, a render pass multisample resolve operation is defined for the attachment subresource.

**Note**

The resolve mode and store operation are independent; it is valid to write both resolved and unresolved values, and equally valid to discard the unresolved values while writing the resolved ones.

Store and resolve operations are only performed at the end of a render pass instance that does not specify the **VK_RENDERING_SUSPENDING_BIT_KHR** flag.

Load operations are only performed at the beginning of a render pass instance that does not specify the **VK_RENDERING_RESUMING_BIT_KHR** flag.

Image contents at the end of a suspended render pass instance remain defined for access by a resuming render pass instance.

### Valid Usage

- **VUID-VkRenderingAttachmentInfo-imageView-06129**
  If **imageView** is not **VK_NULL_HANDLE** and has a non-integer color format, **resolveMode** must be **VK_RESOLVE_MODE_NONE** or **VK_RESOLVE_MODE_AVERAGE_BIT**

- **VUID-VkRenderingAttachmentInfo-imageView-06130**
  If **imageView** is not **VK_NULL_HANDLE** and has an integer color format, **resolveMode** must be **VK_RESOLVE_MODE_NONE** or **VK_RESOLVE_MODE_SAMPLE_ZERO_BIT**

- **VUID-VkRenderingAttachmentInfo-imageView-06861**
  If **imageView** is not **VK_NULL_HANDLE**, **resolveMode** is not **VK_RESOLVE_MODE_NONE**, and the **pNext** chain of **VkRenderingInfo** does not include a **VkMultisampledRenderToSingleSampledInfoEXT** structure with the **multisampledRenderToSingleSampledEnable** field equal to **VK_TRUE**, **imageView** must not have a sample count of **VK_SAMPLE_COUNT_1_BIT**
If `imageView` is not `VK_NULL_HANDLE`, `resolveMode` is not `VK_RESOLVE_MODE_NONE`, and the `pNext` chain of `VkRenderingInfo` does not include a `VkMultisampledRenderToSingleSampledInfoEXT` structure with the `multisampledRenderToSingleSampledEnable` field equal to `VK_TRUE`, `resolveImageView` must not be `VK_NULL_HANDLE`.

If `imageView` is not `VK_NULL_HANDLE`, `resolveMode` is not `VK_RESOLVE_MODE_NONE`, the `pNext` chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with the `multisampledRenderToSingleSampledEnable` field equal to `VK_TRUE`, and `imageView` has a sample count of `VK_SAMPLE_COUNT_1_BIT`, `resolveImageView` must be `VK_NULL_HANDLE`.

If `imageView` is not `VK_NULL_HANDLE`, `resolveImageView` is not `VK_NULL_HANDLE`, and `resolveMode` is not `VK_RESOLVE_MODE_NONE`, `resolveImageView` must have a sample count of `VK_SAMPLE_COUNT_1_BIT`.

If `imageView` is not `VK_NULL_HANDLE`, `resolveImageView` is not `VK_NULL_HANDLE`, and `resolveMode` is not `VK_RESOLVE_MODE_NONE`, `imageView` and `resolveImageView` must have the same `VkFormat`.

If `imageView` is not `VK_NULL_HANDLE`, `imageLayout` must not be `VK_IMAGE_LAYOUT_UNDEFINED`, `VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL`, `VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL`, `VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL`, or `VK_IMAGE_LAYOUT_PREINITIALIZED`.

If `imageView` is not `VK_NULL_HANDLE` and `resolveMode` is not `VK_RESOLVE_MODE_NONE`, `resolveImageLayout` must not be `VK_IMAGE_LAYOUT_UNDEFINED`, `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, `VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL`, `VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL`, `VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL`, or `VK_IMAGE_LAYOUT_PREINITIALIZED`.

If `imageView` is not `VK_NULL_HANDLE` and `resolveMode` is not `VK_RESOLVE_MODE_NONE`, `resolveImageLayout` must not be `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL` or `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`.

If `imageView` is not `VK_NULL_HANDLE`, `imageLayout` must not be `VK_IMAGE_LAYOUT_SHADING_RATE_OPTIMAL_NV`.

If `imageView` is not `VK_NULL_HANDLE` and `resolveMode` is not `VK_RESOLVE_MODE_NONE`, `resolveImageLayout` must not be `VK_IMAGE_LAYOUT_SHADING_RATE_OPTIMAL_NV`.

If `imageView` is not `VK_NULL_HANDLE`, `imageLayout` must not be `VK_IMAGE_LAYOUT_FRAGMENT_DENSITY_MAP_OPTIMAL_EXT`.
If `imageView` is not `VK_NULL_HANDLE` and `resolveMode` is not `VK_RESOLVE_MODE_NONE`, `resolveImageLayout` must not be `VK_IMAGE_LAYOUT_FRAGMENT_DENSITY_MAP_OPTIMAL_EXT`.

- VUID-VkRenderingAttachmentInfo-imageView-06142
  If `imageView` is not `VK_NULL_HANDLE` and `resolveMode` is not `VK_RESOLVE_MODE_NONE`, `resolveImageLayout` must not be `VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR`.

- VUID-VkRenderingAttachmentInfo-imageView-06143
  If `imageView` is not `VK_NULL_HANDLE`, `imageLayout` must not be `VK_IMAGE_LAYOUT_FRAGMENT_SHADING_RATE_ATTACHMENT_OPTIMAL_KHR`.

- VUID-VkRenderingAttachmentInfo-imageView-06144
  If `imageView` is not `VK_NULL_HANDLE` and `resolveMode` is not `VK_RESOLVE_MODE_NONE`, `resolveImageLayout` must not be `VK_IMAGE_LAYOUT_FRAGMENT_SHADING_RATE_ATTACHMENT_OPTIMAL_KHR`.

- VUID-VkRenderingAttachmentInfo-imageView-06145
  If `imageView` is not `VK_NULL_HANDLE`, `imageLayout` must not be `VK_IMAGE_LAYOUT_PRESENT_SRC_KHR`.

- VUID-VkRenderingAttachmentInfo-imageView-06146
  If `imageView` is not `VK_NULL_HANDLE` and `resolveMode` is not `VK_RESOLVE_MODE_NONE`, `resolveImageLayout` must not be `VK_IMAGE_LAYOUT_PRESENT_SRC_KHR`.

Valid Usage (Implicit)

- VUID-VkRenderingAttachmentInfo-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_RENDERING_ATTACHMENT_INFO`.

- VUID-VkRenderingAttachmentInfo-pNext-pNext
  `pNext` must be `NULL`.

- VUID-VkRenderingAttachmentInfo-imageView-parameter
  If `imageView` is not `VK_NULL_HANDLE`, `imageView` must be a valid `VkImageView` handle.

- VUID-VkRenderingAttachmentInfo-imageLayout-parameter
  `imageLayout` must be a valid `VkImageLayout` value.

- VUID-VkRenderingAttachmentInfo-resolveMode-parameter
  If `resolveMode` is not `0`, `resolveMode` must be a valid `VkResolveModeFlagBits` value.

- VUID-VkRenderingAttachmentInfo-resolveImageView-parameter
  If `resolveImageView` is not `VK_NULL_HANDLE`, `resolveImageView` must be a valid `VkImageView` handle.

- VUID-VkRenderingAttachmentInfo-resolveImageLayout-parameter
  `resolveImageLayout` must be a valid `VkImageLayout` value.

- VUID-VkRenderingAttachmentInfo-loadOp-parameter
  `loadOp` must be a valid `VkAttachmentLoadOp` value.

- VUID-VkRenderingAttachmentInfo-storeOp-parameter
  `storeOp` must be a valid `VkAttachmentStoreOp` value.

- VUID-VkRenderingAttachmentInfo-clearValue-parameter
clearValue must be a valid VkClearValue union

- VUID-VkRenderingAttachmentInfo-commonparent
  Both of imageView, and resolveImageView that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice

The VkRenderingFragmentShadingRateAttachmentInfoKHR structure is defined as:

// Provided by VK_KHR_dynamic_rendering with VK_KHR_fragment_shading_rate
typedef struct VkRenderingFragmentShadingRateAttachmentInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkImageView imageView;
    VkImageLayout imageLayout;
    VkExtent2D shadingRateAttachmentTexelSize;
} VkRenderingFragmentShadingRateAttachmentInfoKHR;

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- imageView is the image view that will be used as a fragment shading rate attachment.
- imageLayout is the layout that imageView will be in during rendering.
- shadingRateAttachmentTexelSize specifies the number of pixels corresponding to each texel in imageView.

This structure can be included in the pNext chain of VkRenderingInfo to define a fragment shading rate attachment. If imageView is VK_NULL_HANDLE, or if this structure is not specified, the implementation behaves as if a valid shading rate attachment was specified with all texels specifying a single pixel per fragment.

Valid Usage

- VUID-VkRenderingFragmentShadingRateAttachmentInfoKHR-imageView-06147
  If imageView is not VK_NULL_HANDLE, layout must be VK_IMAGE_LAYOUT_GENERAL or VK_IMAGE_LAYOUT_FRAGMENT_SHADING_RATE_ATTACHMENT_OPTIMAL_KHR

- VUID-VkRenderingFragmentShadingRateAttachmentInfoKHR-imageView-06148
  If imageView is not VK_NULL_HANDLE, it must have been created with VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

- VUID-VkRenderingFragmentShadingRateAttachmentInfoKHR-imageView-06149
  If imageView is not VK_NULL_HANDLE, shadingRateAttachmentTexelSize.width must be a power of two value

- VUID-VkRenderingFragmentShadingRateAttachmentInfoKHR-imageView-06150
  If imageView is not VK_NULL_HANDLE, shadingRateAttachmentTexelSize.width must be less than or equal to maxFragmentShadingRateAttachmentTexelSize.width

- VUID-VkRenderingFragmentShadingRateAttachmentInfoKHR-imageView-06151
If `imageView` is not `VK_NULL_HANDLE`, `shadingRateAttachmentTexelSize.width` **must** be

greater than or equal to `minFragmentShadingRateAttachmentTexelSize.width`.

• **VUID-VkRenderingFragmentShadingRateAttachmentInfoKHR-imageView-06152**

If `imageView` is not `VK_NULL_HANDLE`, `shadingRateAttachmentTexelSize.height` **must** be a

power of two value.

• **VUID-VkRenderingFragmentShadingRateAttachmentInfoKHR-imageView-06153**

If `imageView` is not `VK_NULL_HANDLE`, `shadingRateAttachmentTexelSize.height` **must** be

less than or equal to `maxFragmentShadingRateAttachmentTexelSize.height`.

• **VUID-VkRenderingFragmentShadingRateAttachmentInfoKHR-imageView-06154**

If `imageView` is not `VK_NULL_HANDLE`, `shadingRateAttachmentTexelSize.height` **must** be

greater than or equal to `minFragmentShadingRateAttachmentTexelSize.height`.

• **VUID-VkRenderingFragmentShadingRateAttachmentInfoKHR-imageView-06155**

If `imageView` is not `VK_NULL_HANDLE`, the quotient of `shadingRateAttachmentTexelSize.width` and

`shadingRateAttachmentTexelSize.height` **must** be less than or equal to `maxFragmentShadingRateAttachmentTexelSizeAspectRatio`.

• **VUID-VkRenderingFragmentShadingRateAttachmentInfoKHR-imageView-06156**

If `imageView` is not `VK_NULL_HANDLE`, the quotient of `shadingRateAttachmentTexelSize.height` and `shadingRateAttachmentTexelSize.width` **must** be less than or equal to `maxFragmentShadingRateAttachmentTexelSizeAspectRatio`.

**Valid Usage (Implicit)**

• **VUID-VkRenderingFragmentShadingRateAttachmentInfoKHR-sType-sType**

  `sType` **must** be `VK_STRUCTURE_TYPE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_INFO_KHR`.

• **VUID-VkRenderingFragmentShadingRateAttachmentInfoKHR-imageView-parameter**

  If `imageView` is not `VK_NULL_HANDLE`, `imageView` **must** be a valid `VkImageView` handle.

• **VUID-VkRenderingFragmentShadingRateAttachmentInfoKHR-imageLayout-parameter**

  `imageLayout` **must** be a valid `VkImageLayout` value.

The `VkRenderingFragmentDensityMapAttachmentInfoEXT` structure is defined as:

```c
// Provided by VK_KHR_dynamic_rendering with VK_EXT_fragment_density_map
typedef struct VkRenderingFragmentDensityMapAttachmentInfoEXT {
    VkStructureType   sType;
    const void*       pNext;
    VkImageView       imageView;
    VkImageLayout     imageLayout;
} VkRenderingFragmentDensityMapAttachmentInfoEXT;
```

• `sType` is a `VkStructureType` value identifying this structure.

• `pNext` is `NULL` or a pointer to a structure extending this structure.

• `imageView` is the image view that will be used as a fragment density map attachment.
• imageLayout is the layout that imageView will be in during rendering.

This structure can be included in the pNext chain of VkRenderingInfo to define a fragment density map. If this structure is not included in the pNext chain, imageView is treated as VK_NULL_HANDLE.

Valid Usage

• VUID-VkRenderingFragmentDensityMapAttachmentInfoEXT-imageView-06157
  If imageView is not VK_NULL_HANDLE, layout must be VK_IMAGE_LAYOUT_GENERAL or VK_IMAGE_LAYOUT_FRAGMENT_DENSITY_MAP_OPTIMAL_EXT

• VUID-VkRenderingFragmentDensityMapAttachmentInfoEXT-imageView-06158
  If imageView is not VK_NULL_HANDLE, it must have been created with VK_IMAGE_USAGE_FRAGMENT_DENSITY_MAP_BIT_EXT

• VUID-VkRenderingFragmentDensityMapAttachmentInfoEXT-imageView-06159
  If imageView is not VK_NULL_HANDLE, it must not have been created with VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT

• VUID-VkRenderingFragmentDensityMapAttachmentInfoEXT-apiVersion-07908
  If VK_KHR_multiview is not enabled, VkPhysicalDeviceProperties::apiVersion is less than Vulkan 1.1, and imageView is not VK_NULL_HANDLE, it must have a layerCount equal to 1

Valid Usage (Implicit)

• VUID-VkRenderingFragmentDensityMapAttachmentInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_INFO_EXT

• VUID-VkRenderingFragmentDensityMapAttachmentInfoEXT-imageView-parameter
  imageView must be a valid VkImageView handle

• VUID-VkRenderingFragmentDensityMapAttachmentInfoEXT-imageLayout-parameter
  imageLayout must be a valid VkImageLayout value

To query the render area granularity for a render pass instance, call:

```c
// Provided by VK_KHR_maintenance5
void vkGetRenderingAreaGranularityKHR(
  VkDevice device,
  const VkRenderingAreaInfoKHR* pRenderingAreaInfo,
  VkExtent2D* pGranularity);
```

• device is the logical device that owns the render pass instance.

• pRenderingAreaInfo is a pointer to a VkRenderingAreaInfoKHR structure specifying details of the render pass instance to query the render area granularity for.

• pGranularity is a pointer to a VkExtent2D structure in which the granularity is returned.

The conditions leading to an optimal renderArea are:
• the offset.x member in renderArea is a multiple of the width member of the returned VkExtent2D (the horizontal granularity).

• the offset.y member in renderArea is a multiple of the height member of the returned VkExtent2D (the vertical granularity).

• either the extent.width member in renderArea is a multiple of the horizontal granularity or offset.x+extent.width is equal to the width of the framebuffer in the VkRenderPassBeginInfo.

• either the extent.height member in renderArea is a multiple of the vertical granularity or offset.y+extent.height is equal to the height of the framebuffer in the VkRenderPassBeginInfo.

Valid Usage (Implicit)

• VUID-vkGetRenderingAreaGranularityKHR-device-parameter
device must be a valid VkDevice handle

• VUID-vkGetRenderingAreaGranularityKHR-pRenderingAreaInfo-parameter
pRenderingAreaInfo must be a valid pointer to a valid VkRenderingAreaInfoKHR structure

• VUID-vkGetRenderingAreaGranularityKHR-pGranularity-parameter
pGranularity must be a valid pointer to a VkExtent2D structure

The VkRenderingAreaInfoKHR structure is defined as:

```c
// Provided by VK_KHR_maintenance5
typedef struct VkRenderingAreaInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t viewMask;
    uint32_t colorAttachmentCount;
    const VkFormat* pColorAttachmentFormats;
    VkFormat depthAttachmentFormat;
    VkFormat stencilAttachmentFormat;
} VkRenderingAreaInfoKHR;
```

• sType is a VkStructureType value identifying this structure.

• pNext is NULL or a pointer to a structure extending this structure.

• viewMask is the viewMask used for rendering.

• colorAttachmentCount is the number of entries in pColorAttachmentFormats.

• pColorAttachmentFormats is a pointer to an array of VkFormat values defining the format of color attachments used in the render pass instance.

• depthAttachmentFormat is a VkFormat value defining the format of the depth attachment used in the render pass instance.

• stencilAttachmentFormat is a VkFormat value defining the format of the stencil attachment used in the render pass instance.
Valid Usage (Implicit)

- VUID-VkRenderingAreaInfoKHR-sType-sType
  
  *sType must be VK_STRUCTURE_TYPE_RENDERING_AREA_INFO_KHR*

- VUID-VkRenderingAreaInfoKHR-pNext-pNext
  
  *pNext must be NULL*

To end a render pass instance, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdEndRendering(
    VkCommandBuffer commandBuffer);
```

or the equivalent command

```c
// Provided by VK_KHR_dynamic_rendering
void vkCmdEndRenderingKHR(
    VkCommandBuffer commandBuffer);
```

- *commandBuffer* is the command buffer in which to record the command.

If the value of *pRenderingInfo->flags* used to begin this render pass instance included *VK_RENDERING_SUSPENDING_BIT*, then this render pass is suspended and will be resumed later in submission order.

Valid Usage

- VUID-vkCmdEndRendering-None-06161
  The current render pass instance must have been begun with *vkCmdBeginRendering*

- VUID-vkCmdEndRendering-commandBuffer-06162
  The current render pass instance must have been begun in *commandBuffer*

- VUID-vkCmdEndRendering-None-06781
  This command must not be recorded when transform feedback is active

- VUID-vkCmdEndRendering-None-06999
  If *vkCmdBeginQuery* was called within the render pass, the corresponding *vkCmdEndQuery* must have been called subsequently within the same subpass

Valid Usage (Implicit)

- VUID-vkCmdEndRendering-commandBuffer-parameter
  *commandBuffer must be a valid VkCommandBuffer handle*

- VUID-vkCmdEndRendering-commandBuffer-recording
**commandBuffer** must be in the *recording state*

- VUID-vkCmdEndRendering-commandBuffer-cmdpool
  The *VkCommandPool* that **commandBuffer** was allocated from must support graphics operations
- VUID-vkCmdEndRendering-renderpass
  This command must only be called inside of a render pass instance
- VUID-vkCmdEndRendering-videocoding
  This command must only be called outside of a video coding scope

**Host Synchronization**

- Host access to **commandBuffer** must be externally synchronized
- Host access to the *VkCommandPool* that **commandBuffer** was allocated from must be externally synchronized

**Command Properties**

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**Note**

For more complex rendering graphs, it is possible to pre-define a static *render pass* object, which as well as allowing draw commands, allows the definition of framebuffer-local dependencies between multiple subpasses. These objects have a lot of setup cost compared to **vkCmdBeginRendering**, but use of subpass dependencies can confer important performance benefits on some devices.

The *VkTilePropertiesQCOM* structure is defined as:

```c
// Provided by VK_QCOM_tile_properties
typedef struct VkTilePropertiesQCOM {
    VkStructureType sType;
    void* pNext;
    VkExtent3D tileSize;
    VkExtent2D apronSize;
    VkOffset2D origin;
} VkTilePropertiesQCOM;
```

- **sType** is a *VkStructureType* value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.
• `tileSize` is the dimensions of a tile, with width and height describing the width and height of a tile in pixels, and depth corresponding to the number of slices the tile spans.
• `apronSize` is the dimension of the apron.
• `origin` is the top-left corner of the first tile in attachment space.

All tiles will be tightly packed around the first tile, with edges being multiples of tile width and/or height from the origin.

---

**Note**
Reported value for `apronSize` will be zero and its functionality will be described in a future extension.

---

### Valid Usage (Implicit)

- VUID-VkTilePropertiesQCOM-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_TILE_PROPERTIES_QCOM`
- VUID-VkTilePropertiesQCOM-pNext-pNext
  - `pNext` must be `NULL`

To query the tile properties when using dynamic rendering, call:

```c
// Provided by VK_QCOM_tile_properties
VkResult vkGetDynamicRenderingTilePropertiesQCOM(
    VkDevice device,
    const VkRenderingInfo* pRenderingInfo,
    VkTilePropertiesQCOM* pProperties);
```

- `device` is a logical device associated with the render pass.
- `pRenderingInfo` is a pointer to the `VkRenderingInfo` structure specifying details of the render pass instance in dynamic rendering.
- `pProperties` is a pointer to a `VkTilePropertiesQCOM` structure in which the properties are returned.

---

### Valid Usage (Implicit)

- VUID-vkGetDynamicRenderingTilePropertiesQCOM-device-parameter
  - `device` must be a valid `VkDevice` handle
- VUID-vkGetDynamicRenderingTilePropertiesQCOM-pRenderingInfo-parameter
  - `pRenderingInfo` must be a valid pointer to a valid `VkRenderingInfo` structure
- VUID-vkGetDynamicRenderingTilePropertiesQCOM-pProperties-parameter
  - `pProperties` must be a valid pointer to a `VkTilePropertiesQCOM` structure

---
8.1. Render Pass Objects

A render pass object represents a collection of attachments, subpasses, and dependencies between the subpasses, and describes how the attachments are used over the course of the subpasses.

Render passes are represented by `VkRenderPass` handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkRenderPass)
```

An attachment description describes the properties of an attachment including its format, sample count, and how its contents are treated at the beginning and end of each render pass instance.

A subpass represents a phase of rendering that reads and writes a subset of the attachments in a render pass. Rendering commands are recorded into a particular subpass of a render pass instance.

A subpass description describes the subset of attachments that is involved in the execution of a subpass. Each subpass can read from some attachments as input attachments, write to some as color attachments or depth/stencil attachments, perform shader resolve operations to color_attachments or depth/stencil_attachments, and perform multisample resolve operations to resolve attachments. A subpass description can also include a set of preserve attachments, which are attachments that are not read or written by the subpass but whose contents must be preserved throughout the subpass.

A subpass uses an attachment if the attachment is a color, depth/stencil, resolve, depth/stencil resolve, fragment shading rate, or input attachment for that subpass (as determined by the `pColorAttachments`, `pDepthStencilAttachment`, `pResolveAttachments`, `VkSubpassDescriptionDepthStencilResolve::pDepthStencilResolveAttachment`, `VkFragmentShadingRateAttachmentInfoKHR::pFragmentShadingRateAttachment->attachment`, and `pInputAttachments` members of `VkSubpassDescription`, respectively). A subpass does not use an attachment if that attachment is preserved by the subpass. The first use of an attachment is in the lowest numbered subpass that uses that attachment. Similarly, the last use of an attachment is in the highest numbered subpass that uses that attachment.

The subpasses in a render pass all render to the same dimensions, and fragments for pixel (x,y,layer) in one subpass can only read attachment contents written by previous subpasses at that same (x,y,layer) location. For multi-pixel fragments, the pixel read from an input attachment is selected from the pixels covered by that fragment in an implementation-dependent manner. However, this selection must be made consistently for any fragment with the same shading rate for the lifetime of the `VkDevice`. 
By describing a complete set of subpasses in advance, render passes provide the implementation an opportunity to optimize the storage and transfer of attachment data between subpasses.

In practice, this means that subpasses with a simple framebuffer-space dependency may be merged into a single tiled rendering pass, keeping the attachment data on-chip for the duration of a render pass instance. However, it is also quite common for a render pass to only contain a single subpass.

Subpass dependencies describe execution and memory dependencies between subpasses.

A subpass dependency chain is a sequence of subpass dependencies in a render pass, where the source subpass of each subpass dependency (after the first) equals the destination subpass of the previous dependency.

Execution of subpasses may overlap or execute out of order with regards to other subpasses, unless otherwise enforced by an execution dependency. Each subpass only respects submission order for commands recorded in the same subpass, and the vkCmdBeginRenderPass and vkCmdEndRenderPass commands that delimit the render pass - commands within other subpasses are not included. This affects most other implicit ordering guarantees.

A render pass describes the structure of subpasses and attachments independent of any specific image views for the attachments. The specific image views that will be used for the attachments, and their dimensions, are specified in VkFramebuffer objects. Framebuffers are created with respect to a specific render pass that the framebuffer is compatible with (see Render Pass Compatibility). Collectively, a render pass and a framebuffer define the complete render target state for one or more subpasses as well as the algorithmic dependencies between the subpasses.

The various pipeline stages of the drawing commands for a given subpass may execute concurrently and/or out of order, both within and across drawing commands, whilst still respecting pipeline order. However for a given (x,y,layer,sample) sample location, certain per-sample operations are performed in rasterization order.

VK_ATTACHMENT_UNUSED is a constant indicating that a render pass attachment is not used.

```c
#define VK_ATTACHMENT_UNUSED (~0U)
```

## 8.2. Render Pass Creation

To create a render pass, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkCreateRenderPass(
    VkDevice device,
    const VkRenderPassCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
)`
- `device` is the logical device that creates the render pass.
- `pCreateInfo` is a pointer to a `VkRenderPassCreateInfo` structure describing the parameters of the render pass.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pRenderPass` is a pointer to a `VkRenderPass` handle in which the resulting render pass object is returned.

### Valid Usage (Implicit)

- VUID-vkCreateRenderPass-device-parameter
  
  `device` must be a valid `VkDevice` handle

- VUID-vkCreateRenderPass-pCreateInfo-parameter
  
  `pCreateInfo` must be a valid pointer to a valid `VkRenderPassCreateInfo` structure

- VUID-vkCreateRenderPass-pAllocator-parameter
  
  If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

- VUID-vkCreateRenderPass-pRenderPass-parameter
  
  `pRenderPass` must be a valid pointer to a `VkRenderPass` handle

### Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

The `VkRenderPassCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkRenderPassCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkRenderPassCreateFlags flags;
    uint32_t attachmentCount;
    const VkAttachmentDescription* pAttachments;
    uint32_t subpassCount;
    const VkSubpassDescription* pSubpasses;
    uint32_t dependencyCount;
    const VkSubpassDependency* pDependencies;
} VkRenderPassCreateInfo;
```
• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **flags** is a bitmask of `VkRenderPassCreateFlagBits`.

• **attachmentCount** is the number of attachments used by this render pass.

• **pAttachments** is a pointer to an array of `attachmentCount` `VkAttachmentDescription` structures describing the attachments used by the render pass.

• **subpassCount** is the number of subpasses to create.

• **pSubpasses** is a pointer to an array of `subpassCount` `VkSubpassDescription` structures describing each subpass.

• **dependencyCount** is the number of memory dependencies between pairs of subpasses.

• **pDependencies** is a pointer to an array of `dependencyCount` `VkSubpassDependency` structures describing dependencies between pairs of subpasses.

**Note**

Care should be taken to avoid a data race here; if any subpasses access attachments with overlapping memory locations, and one of those accesses is a write, a subpass dependency needs to be included between them.

---

**Valid Usage**

• **VUID-VkRenderPassCreateInfo-attachment-00834**
  If the **attachment** member of any element of `pInputAttachments`, `pColorAttachments`, `pResolveAttachments` or `pDepthStencilAttachment`, or any element of `pPreserveAttachments` in any element of `pSubpasses` is not `VK_ATTACHMENT_UNUSED`, then it **must** be less than `attachmentCount`.

• **VUID-VkRenderPassCreateInfo-fragmentDensityMapAttachment-06471**
  If the `pNext` chain includes a `VkRenderPassFragmentDensityMapCreateInfoEXT` structure and the **fragmentDensityMapAttachment** member is not `VK_ATTACHMENT_UNUSED`, then **attachment** must be less than `attachmentCount`.

• **VUID-VkRenderPassCreateInfo-pAttachments-00836**
  For any member of `pAttachments` with a `loadOp` equal to `VK_ATTACHMENT_LOAD_OP_CLEAR`, the first use of that attachment **must** not specify a `layout` equal to `VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`.

• **VUID-VkRenderPassCreateInfo-pAttachments-02511**
  For any member of `pAttachments` with a `stencilLoadOp` equal to `VK_ATTACHMENT_LOAD_OP_CLEAR`, the first use of that attachment **must** not specify a `layout` equal to `VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`.

• **VUID-VkRenderPassCreateInfo-pAttachments-01566**

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For any member of `pAttachments` with a `loadOp` equal to `VK_ATTACHMENT_LOAD_OP_CLEAR`, the first use of that attachment **must** not specify a `layout` equal to `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`.

- **VUID-VkRenderPassCreateInfo-pAttachments-01567**
  For any member of `pAttachments` with a `stencilLoadOp` equal to `VK_ATTACHMENT_LOAD_OP_CLEAR`, the first use of that attachment **must** not specify a `layout` equal to `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`.

- **VUID-VkRenderPassCreateInfo-pNext-01926**
  If the `pNext` chain includes a `VkRenderPassInputAttachmentAspectCreateInfo` structure, the `subpass` member of each element of its `pAspectReferences` member **must** be less than `subpassCount`.

- **VUID-VkRenderPassCreateInfo-pNext-01927**
  If the `pNext` chain includes a `VkRenderPassInputAttachmentAspectCreateInfo` structure, the `inputAttachmentIndex` member of each element of its `pAspectReferences` member **must** be less than the value of `inputAttachmentCount` in the element of `pSubpasses` identified by its `subpass` member.

- **VUID-VkRenderPassCreateInfo-pNext-01963**
  If the `pNext` chain includes a `VkRenderPassInputAttachmentAspectCreateInfo` structure, for any element of the `pInputAttachments` member of any element of `pSubpasses` where the `attachment` member is not `VK_ATTACHMENT_UNUSED`, the `aspectMask` member of the corresponding element of `VkRenderPassInputAttachmentAspectCreateInfo`: `pAspectReferences` **must** only include aspects that are present in images of the format specified by the element of `pAttachments` at `attachment`.

- **VUID-VkRenderPassCreateInfo-pNext-01928**
  If the `pNext` chain includes a `VkRenderPassMultiviewCreateInfo` structure, and its `subpassCount` member is not zero, that member **must** be equal to the value of `subpassCount`.

- **VUID-VkRenderPassCreateInfo-pNext-01929**
  If the `pNext` chain includes a `VkRenderPassMultiviewCreateInfo` structure, if its `dependencyCount` member is not zero, it **must** be equal to `dependencyCount`.

- **VUID-VkRenderPassCreateInfo-pNext-02512**
  If the `pNext` chain includes a `VkRenderPassMultiviewCreateInfo` structure, for any element of its `pDependencies` with a `dependencyFlags` member that does not include `VK_DEPENDENCY_VIEW_LOCAL_BIT`, the corresponding element of the `pViewOffsets` member of that `VkRenderPassMultiviewCreateInfo` instance **must** be 0.

- **VUID-VkRenderPassCreateInfo-pNext-02513**
  If the `pNext` chain includes a `VkRenderPassMultiviewCreateInfo` structure, elements of its `pViewMasks` member **must** either all be 0, or all not be 0.

- **VUID-VkRenderPassCreateInfo-pNext-02514**
  If the `pNext` chain includes a `VkRenderPassMultiviewCreateInfo` structure, and each element of its `pViewMasks` member is 0, the `dependencyFlags` member of each element of
pDependencies must not include VK_DEPENDENCY_VIEW_LOCAL_BIT

- VUID-VkRenderPassCreateInfo-pNext-02515
  If the pNext chain includes a VkRenderPassMultiviewCreateInfo structure, and each element of its pViewMasks member is 0, its correlationMaskCount member must be 0

- VUID-VkRenderPassCreateInfo-pDependencies-00837
  For any element of pDependencies, if the srcSubpass is not VK_SUBPASS_EXTERNAL, all stage flags included in the srcStageMask member of that dependency must be a pipeline stage supported by the pipeline identified by the pipelineBindPoint member of the source subpass

- VUID-VkRenderPassCreateInfo-pDependencies-00838
  For any element of pDependencies, if the dstSubpass is not VK_SUBPASS_EXTERNAL, all stage flags included in the dstStageMask member of that dependency must be a pipeline stage supported by the pipeline identified by the pipelineBindPoint member of the destination subpass

- VUID-VkRenderPassCreateInfo-pDependencies-06866
  For any element of pDependencies, if its srcSubpass is not VK_SUBPASS_EXTERNAL, it must be less than subpassCount

- VUID-VkRenderPassCreateInfo-pDependencies-06867
  For any element of pDependencies, if its dstSubpass is not VK_SUBPASS_EXTERNAL, it must be less than subpassCount

Valid Usage (Implicit)

- VUID-VkRenderPassCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_RENDER_PASS_CREATE_INFO

- VUID-VkRenderPassCreateInfo-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkRenderPassFragmentDensityMapCreateInfoEXT, VkRenderPassInputAttachmentAspectCreateInfo, or VkRenderPassMultiviewCreateInfo

- VUID-VkRenderPassCreateInfo-sType-unique
  The sType value of each struct in the pNext chain must be unique

- VUID-VkRenderPassCreateInfo-flags-parameter
  flags must be a valid combination of VkRenderPassCreateFlagBits values

- VUID-VkRenderPassCreateInfo-pAttachments-parameter
  If attachmentCount is not 0, pAttachments must be a valid pointer to an array of attachmentCount valid VkAttachmentDescription structures

- VUID-VkRenderPassCreateInfo-pSubpasses-parameter
  pSubpasses must be a valid pointer to an array of subpassCount valid VkSubpassDescription structures

- VUID-VkRenderPassCreateInfo-pDependencies-parameter
  If dependencyCount is not 0, pDependencies must be a valid pointer to an array of dependencyCount valid VkSubpassDependency structures
Bits which can be set in VkRenderPassCreateInfo::flags, describing additional properties of the render pass, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkRenderPassCreateFlagBits {
    // Provided by VK_QCOM_render_pass_transform
    VK_RENDER_PASS_CREATE_TRANSFORM_BIT_QCOM = 0x00000002,
} VkRenderPassCreateFlagBits;
```

• **VK_RENDER_PASS_CREATE_TRANSFORM_BIT_QCOM** specifies that the created render pass is compatible with render pass transform.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkRenderPassCreateFlags;
```

VkRenderPassCreateFlags is a bitmask type for setting a mask of zero or more VkRenderPassCreateFlagBits.

If the VkRenderPassCreateInfo::pNext chain includes a VkRenderPassMultiviewCreateInfo structure, then that structure includes an array of view masks, view offsets, and correlation masks for the render pass.

The VkRenderPassMultiviewCreateInfo structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkRenderPassMultiviewCreateInfo {
    VkStructureType sType;
    const void* pNext;
    uint32_t subpassCount;
    const uint32_t* pViewMasks;
    uint32_t dependencyCount;
    const int32_t* pViewOffsets;
    uint32_t correlationMaskCount;
    const uint32_t* pCorrelationMasks;
} VkRenderPassMultiviewCreateInfo;
```

or the equivalent

```c
// Provided by VK_KHR_multiview
typedef VkRenderPassMultiviewCreateInfo VkRenderPassMultiviewCreateInfoKHR;
```

• **sType** is a VkStructureType value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.

• `subpassCount` is zero or the number of subpasses in the render pass.

• `pViewMasks` is a pointer to an array of `subpassCount` view masks, where each mask is a bitfield of view indices describing which views rendering is broadcast to in each subpass, when multiview is enabled. If `subpassCount` is zero, each view mask is treated as zero.

• `dependencyCount` is zero or the number of dependencies in the render pass.

• `pViewOffsets` is a pointer to an array of `dependencyCount` view offsets, one for each dependency. If `dependencyCount` is zero, each dependency’s view offset is treated as zero. Each view offset controls which views in the source subpass the views in the destination subpass depend on.

• `correlationMaskCount` is zero or the number of correlation masks.

• `pCorrelationMasks` is a pointer to an array of `correlationMaskCount` view masks indicating sets of views that may be more efficient to render concurrently.

When a subpass uses a non-zero view mask, multiview functionality is considered to be enabled. Multiview is all-or-nothing for a render pass - that is, either all subpasses must have a non-zero view mask (though some subpasses may have only one view) or all must be zero. Multiview causes all drawing and clear commands in the subpass to behave as if they were broadcast to each view, where a view is represented by one layer of the framebuffer attachments. All draws and clears are broadcast to each view index whose bit is set in the view mask. The view index is provided in the `ViewIndex` shader input variable, and color, depth/stencil, and input attachments all read/write the layer of the framebuffer corresponding to the view index.

If the view mask is zero for all subpasses, multiview is considered to be disabled and all drawing commands execute normally, without this additional broadcasting.

Some implementations may not support multiview in conjunction with mesh shaders, geometry shaders or tessellation shaders.

When multiview is enabled, the `VK_DEPENDENCY_VIEW_LOCAL_BIT` bit in a dependency can be used to express a view-local dependency, meaning that each view in the destination subpass depends on a single view in the source subpass. Unlike pipeline barriers, a subpass dependency can potentially have a different view mask in the source subpass and the destination subpass. If the dependency is view-local, then each view (dstView) in the destination subpass depends on the view dstView + `pViewOffsets[dependency]` in the source subpass. If there is not such a view in the source subpass, then this dependency does not affect that view in the destination subpass. If the dependency is not view-local, then all views in the destination subpass depend on all views in the source subpass, and the view offset is ignored. A non-zero view offset is not allowed in a self-dependency.

The elements of `pCorrelationMasks` are a set of masks of views indicating that views in the same mask may exhibit spatial coherency between the views, making it more efficient to render them concurrently. Correlation masks must not have a functional effect on the results of the multiview rendering.

When multiview is enabled, at the beginning of each subpass all non-render pass state is undefined. In particular, each time `vkCmdBeginRenderPass` or `vkCmdNextSubpass` is called the graphics pipeline must be bound, any relevant descriptor sets or vertex/index buffers must be bound, and any relevant dynamic state or push constants must be set before they are used.
A multiview subpass can declare that its shaders will write per-view attributes for all views in a single invocation, by setting the VK_SUBPASS_DESCRIPTION_PER_VIEW_ATTRIBUTES_BIT_NVX bit in the subpass description. The only supported per-view attributes are position and viewport mask, and per-view position and viewport masks are written to output array variables decorated with PositionPerViewNV and ViewportMaskPerViewNV, respectively. If VK_NV_viewport_array2 is not supported and enabled, ViewportMaskPerViewNV must not be used. Values written to elements of PositionPerViewNV and ViewportMaskPerViewNV must not depend on the ViewIndex. The shader must also write to an output variable decorated with Position, and the value written to Position must equal the value written to PositionPerViewNV[ViewIndex]. Similarly, if ViewportMaskPerViewNV is written to then the shader must also write to an output variable decorated with ViewportMaskNV, and the value written to ViewportMaskNV must equal the value written to ViewportMaskPerViewNV[ViewIndex]. Implementations will either use values taken from Position and ViewportMaskNV and invoke the shader once for each view, or will use values taken from PositionPerViewNV and ViewportMaskPerViewNV and invoke the shader fewer times. The values written to Position and ViewportMaskNV must not depend on the values written to PositionPerViewNV and ViewportMaskPerViewNV, or vice versa (to allow compilers to eliminate the unused outputs). All attributes that do not have *PerViewNV counterparts must not depend on ViewIndex.

Per-view attributes are all-or-nothing for a subpass. That is, all pipelines compiled against a subpass that includes the VK_SUBPASS_DESCRIPTION_PER_VIEW_ATTRIBUTES_BIT_NVX bit must write per-view attributes to the *PerViewNV[] shader outputs, in addition to the non-per-view (e.g. Position) outputs. Pipelines compiled against a subpass that does not include this bit must not include the *PerViewNV[] outputs in their interfaces.

Valid Usage

- VUID-VkRenderPassMultiviewCreateInfo-pCorrelationMasks-00841
  Each view index must not be set in more than one element of pCorrelationMasks

- VUID-VkRenderPassMultiviewCreateInfo-multiview-06555
  If the multiview feature is not enabled, each element of pViewMasks must be 0

- VUID-VkRenderPassMultiviewCreateInfo-pViewMasks-06697
  The index of the most significant bit in each element of pViewMasks must be less than maxMultiviewViewCount

Valid Usage (Implicit)

- VUID-VkRenderPassMultiviewCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_RENDER_PASS_MULTIVIEW_CREATE_INFO

- VUID-VkRenderPassMultiviewCreateInfo-pViewMasks-parameter
  If subpassCount is not 0, pViewMasks must be a valid pointer to an array of subpassCount uint32_t values

- VUID-VkRenderPassMultiviewCreateInfo-pViewOffsets-parameter
  If dependencyCount is not 0, pViewOffsets must be a valid pointer to an array of dependencyCount int32_t values
If `correlationMaskCount` is not 0, `pCorrelationMasks` must be a valid pointer to an array of `correlationMaskCount uint32_t` values.

The `VkMultiviewPerViewAttributesInfoNVX` structure is defined as:

```c
// Provided by VK_KHR_dynamic_rendering with VK_NVX_multiview_per_view_attributes
typedef struct VkMultiviewPerViewAttributesInfoNVX {
    VkStructureType sType;
    const void* pNext;
    VkBool32 perViewAttributes;
    VkBool32 perViewAttributesPositionXOnly;
} VkMultiviewPerViewAttributesInfoNVX;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `perViewAttributes` specifies that shaders compiled for this pipeline write the attributes for all views in a single invocation of each vertex processing stage. All pipelines executed within a render pass instance that includes this bit must write per-view attributes to the *PerViewNV[] shader outputs, in addition to the non-per-view (e.g. Position) outputs.
- `perViewAttributesPositionXOnly` specifies that shaders compiled for this pipeline use per-view positions which only differ in value in the x component. Per-view viewport mask can also be used.

When dynamic render pass instances are being used, instead of specifying `VK_SUBPASS_DESCRIPTION_PER_VIEW_ATTRIBUTES_BIT_NVX` or `VK_SUBPASS_DESCRIPTION_PER_VIEW_POSITION_X_ONLY_BIT_NVX` in the subpass description flags, the per-attribute properties of the render pass instance must be specified by the `VkMultiviewPerViewAttributesInfoNVX` structure. Include the `VkMultiviewPerViewAttributesInfoNVX` structure in the `pNext` chain of `VkGraphicsPipelineCreateInfo` when creating a graphics pipeline for dynamic rendering, `VkRenderingInfo` when starting a dynamic render pass instance, and `VkCommandBufferInheritanceInfo` when specifying the dynamic render pass instance parameters for secondary command buffers.

**Valid Usage (Implicit)**

- `VUID-VkMultiviewPerViewAttributesInfoNVX-sType-sType
  sType must be VK_STRUCTURE_TYPE_MULTIVIEW_PER_VIEW_ATTRIBUTES_INFO_NVX`

If the `VkRenderPassCreateInfo::pNext` chain includes a `VkRenderPassFragmentDensityMapCreateInfoEXT` structure, then that structure includes a fragment density map attachment for the render pass.

The `VkRenderPassFragmentDensityMapCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_fragment_density_map
```
typedef struct VkRenderPassFragmentDensityMapCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkAttachmentReference fragmentDensityMapAttachment;
} VkRenderPassFragmentDensityMapCreateInfoEXT;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `fragmentDensityMapAttachment` is the fragment density map to use for the render pass.

The fragment density map is read at an implementation-dependent time with the following constraints determined by the attachment’s image view flags:

- `VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DYNAMIC_BIT_EXT` specifies that the fragment density map will be read by the device during `VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT`.
- `VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DEFERRED_BIT_EXT` specifies that the fragment density map will be read by the host during `vkEndCommandBuffer` of the primary command buffer that the render pass is recorded into.
- Otherwise the fragment density map will be read by the host during `vkCmdBeginRenderPass`.

The fragment density map may additionally be read by the device during `VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT` for any mode.

If this structure is not present, it is as if `fragmentDensityMapAttachment` was given as `VK_ATTACHMENT_UNUSED`.

**Valid Usage**

- VUID-VkRenderPassFragmentDensityMapCreateInfoEXT-fragmentDensityMapAttachment-02548
  If `fragmentDensityMapAttachment` is not `VK_ATTACHMENT_UNUSED`, `fragmentDensityMapAttachment` must not be an element of `VkSubpassDescription::pInputAttachments`, `VkSubpassDescription::pColorAttachments`, `VkSubpassDescription::pResolveAttachments`, `VkSubpassDescription::pDepthStencilAttachment`, or ` VkSubpassDescription::pPreserveAttachments` for any subpass.

- VUID-VkRenderPassFragmentDensityMapCreateInfoEXT-fragmentDensityMapAttachment-02549
  If `fragmentDensityMapAttachment` is not `VK_ATTACHMENT_UNUSED`, layout must be equal to `VK_IMAGE_LAYOUT_FRAGMENT_DENSITY_MAP_OPTIMAL_EXT`, or `VK_IMAGE_LAYOUT_GENERAL`.

- VUID-VkRenderPassFragmentDensityMapCreateInfoEXT-fragmentDensityMapAttachment-02550
  If `fragmentDensityMapAttachment` is not `VK_ATTACHMENT_UNUSED`, `fragmentDensityMapAttachment` must reference an attachment with a `loadOp` equal to `VK_ATTACHMENT_LOAD_OP_LOAD` or `VK_ATTACHMENT_LOAD_OP_DONT_CARE`.

- VUID-VkRenderPassFragmentDensityMapCreateInfoEXT-
If `fragmentDensityMapAttachment` is not `VK_ATTACHMENT_UNUSED`, `fragmentDensityMapAttachment` must reference an attachment with a `storeOp` equal to `VK_ATTACHMENT_STORE_OP_DONT_CARE`.

**Valid Usage (Implicit)**

- `VUID-VkRenderPassFragmentDensityMapCreateInfoEXT-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_RENDER_PASS_FRAGMENT_DENSITY_MAP_CREATE_INFO_EXT`

- `VUID-VkRenderPassFragmentDensityMapCreateInfoEXT-fragmentDensityMapAttachment-parameter`  
  `fragmentDensityMapAttachment` must be a valid `VkAttachmentReference` structure

The `VkAttachmentDescription` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkAttachmentDescription {
    VkAttachmentDescriptionFlags  flags;
    VkFormat                      format;
    VkSampleCountFlagBits         samples;
    VkAttachmentLoadOp           loadOp;
    VkAttachmentStoreOp          storeOp;
    VkAttachmentLoadOp           stencilLoadOp;
    VkAttachmentStoreOp          stencilStoreOp;
    VkImageLayout                 initialLayout;
    VkImageLayout                 finalLayout;
} VkAttachmentDescription;
```

- `flags` is a bitmask of `VkAttachmentDescriptionFlagBits` specifying additional properties of the attachment.
- `format` is a `VkFormat` value specifying the format of the image view that will be used for the attachment.
- `samples` is a `VkSampleCountFlagBits` value specifying the number of samples of the image.
- `loadOp` is a `VkAttachmentLoadOp` value specifying how the contents of color and depth components of the attachment are treated at the beginning of the subpass where it is first used.
- `storeOp` is a `VkAttachmentStoreOp` value specifying how the contents of color and depth components of the attachment are treated at the end of the subpass where it is last used.
- `stencilLoadOp` is a `VkAttachmentLoadOp` value specifying how the contents of stencil components of the attachment are treated at the beginning of the subpass where it is first used.
- `stencilStoreOp` is a `VkAttachmentStoreOp` value specifying how the contents of stencil components of the attachment are treated at the end of the last subpass where it is used.
- `initialLayout` is the layout the attachment image subresource will be in when a render pass instance begins.
• **finalLayout** is the layout the attachment image subresource will be transitioned to when a render pass instance ends.

If the attachment uses a color format, then **loadOp** and **storeOp** are used, and **stencilLoadOp** and **stencilStoreOp** are ignored. If the format has depth and/or stencil components, **loadOp** and **storeOp** apply only to the depth data, while **stencilLoadOp** and **stencilStoreOp** define how the stencil data is handled. **loadOp** and **stencilLoadOp** define the load operations for the attachment. **storeOp** and **stencilStoreOp** define the store operations for the attachment. If an attachment is not used by any subpass, **loadOp**, **storeOp**, **stencilStoreOp**, and **stencilLoadOp** will be ignored for that attachment, and no load or store ops will be performed. However, any transition specified by **initialLayout** and **finalLayout** will still be executed.

If **flags** includes **VK_ATTACHMENT_DESCRIPTION_MAY_ALIAS_BIT**, then the attachment is treated as if it shares physical memory with another attachment in the same render pass. This information limits the ability of the implementation to reorder certain operations (like layout transitions and the loadOp) such that it is not improperly reordered against other uses of the same physical memory via a different attachment. This is described in more detail below.

If a render pass uses multiple attachments that alias the same device memory, those attachments **must** each include the **VK_ATTACHMENT_DESCRIPTION_MAY_ALIAS_BIT** bit in their attachment description flags. Attachments aliasing the same memory occurs in multiple ways:

- Multiple attachments being assigned the same image view as part of framebuffer creation.
- Attachments using distinct image views that correspond to the same image subresource of an image.
- Attachments using views of distinct image subresources which are bound to overlapping memory ranges.

**Note**

Render passes **must** include subpass dependencies (either directly or via a subpass dependency chain) between any two subpasses that operate on the same attachment or aliasing attachments and those subpass dependencies **must** include execution and memory dependencies separating uses of the aliases, if at least one of those subpasses writes to one of the aliases. These dependencies **must** not include the **VK_DEPENDENCY_BY_REGION_BIT** if the aliases are views of distinct image subresources which overlap in memory.

Multiple attachments that alias the same memory **must** not be used in a single subpass. A given attachment index **must** not be used multiple times in a single subpass, with one exception: two subpass attachments **can** use the same attachment index if at least one use is as an input attachment and neither use is as a resolve or preserve attachment. In other words, the same view **can** be used simultaneously as an input and color or depth/stencil attachment, but **must** not be used as multiple color or depth/stencil attachments nor as resolve or preserve attachments.

If a set of attachments alias each other, then all except the first to be used in the render pass **must** use an **initialLayout** of **VK_IMAGE_LAYOUT_UNDEFINED**, since the earlier uses of the other aliases make their contents undefined. Once an alias has been used and a different alias has been used after it, the first alias **must** not be used in any later subpasses. However, an application **can** assign the same

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image view to multiple aliasing attachment indices, which allows that image view to be used multiple times even if other aliases are used in between.

Note

Once an attachment needs the VK_ATTACHMENT_DESCRIPTION_MAY_ALIAS_BIT bit, there should be no additional cost of introducing additional aliases, and using these additional aliases may allow more efficient clearing of the attachments on multiple uses via VK_ATTACHMENT_LOAD_OP_CLEAR.

Valid Usage

- VUID-VkAttachmentDescription-format-06698
  format must not be VK_FORMAT_UNDEFINED

- VUID-VkAttachmentDescription-format-06699
  If format includes a color or depth component and loadOp is VK_ATTACHMENT_LOAD_OP_LOAD, then initialLayout must not be VK_IMAGE_LAYOUT_UNDEFINED

- VUID-VkAttachmentDescription-finalLayout-00843
  finalLayout must not be VK_IMAGE_LAYOUT_UNDEFINED or VK_IMAGE_LAYOUT_PREINITIALIZED

- VUID-VkAttachmentDescription-format-03280
  If format is a color format, initialLayout must not be VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL

- VUID-VkAttachmentDescription-format-03281
  If format is a depth/stencil format, initialLayout must not be VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL

- VUID-VkAttachmentDescription-format-03282
  If format is a color format, finalLayout must not be VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL

- VUID-VkAttachmentDescription-format-03283
  If format is a depth/stencil format, finalLayout must not be VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL

- VUID-VkAttachmentDescription-format-06487
  If format is a color format, initialLayout must not be VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL or VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL

- VUID-VkAttachmentDescription-format-06488
  If format is a color format, finalLayout must not be VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL or VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL

- VUID-VkAttachmentDescription-separateDepthStencilLayouts-03284
  If the separateDepthStencilLayouts feature is not enabled, initialLayout must not be VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL,
• **VUID-VkAttachmentDescription-separateDepthStencilLayouts-03285**
If the separateDepthStencilLayouts feature is not enabled, finalLayout must not be
VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL,
VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL, or
VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL,

• **VUID-VkAttachmentDescription-format-03286**
If format is a color format, initialLayout must not be
VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL,
VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL, or
VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL,

• **VUID-VkAttachmentDescription-format-03287**
If format is a color format, finalLayout must not be
VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL,
VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL, or
VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL,

• **VUID-VkAttachmentDescription-format-06906**
If format is a depth/stencil format which includes both depth and stencil components, initialLayout must not be
VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL or
VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL,

• **VUID-VkAttachmentDescription-format-06907**
If format is a depth/stencil format which includes both depth and stencil components, finalLayout must not be
VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL or
VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL,

• **VUID-VkAttachmentDescription-format-03290**
If format is a depth/stencil format which includes only the depth component, initialLayout must not be
VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL or
VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL,

• **VUID-VkAttachmentDescription-format-03291**
If format is a depth/stencil format which includes only the depth component, finalLayout must not be
VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL or
VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL,

• **VUID-VkAttachmentDescription-synchronization2-06908**
If the synchronization2 feature is not enabled, initialLayout must not be
VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL_KHR or VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR,

• **VUID-VkAttachmentDescription-synchronization2-06909**
If the synchronization2 feature is not enabled, finalLayout must not be
VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL_KHR or VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR,

• **VUID-VkAttachmentDescription-attachmentFeedbackLoopLayout-07309**
If the attachmentFeedbackLoopLayout feature is not enabled, initialLayout must not be
VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT,

• **VUID-VkAttachmentDescription-attachmentFeedbackLoopLayout-07310**
If the `attachmentFeedbackLoopLayout` feature is not enabled, `finalLayout` must not be `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT`

- **VUID-VkAttachmentDescription-samples-08745**
  `samples` must be a bit value that is set in `imageCreateSampleCounts` (as defined in Image Creation Limits) for the given `format`

- **VUID-VkAttachmentDescription-format-06700**
  If `format` includes a stencil component and `stencilLoadOp` is `VK_ATTACHMENT_LOAD_OP_LOAD`, then `initialLayout` must not be `VK_IMAGE_LAYOUT_UNDEFINED`

- **VUID-VkAttachmentDescription-format-03292**
  If `format` is a depth/stencil format which includes only the stencil component, `initialLayout` must not be `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`

- **VUID-VkAttachmentDescription-format-03293**
  If `format` is a depth/stencil format which includes only the stencil component, `finalLayout` must not be `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`

- **VUID-VkAttachmentDescription-format-06242**
  If `format` is a depth/stencil format which includes both depth and stencil components, `initialLayout` must not be `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`

- **VUID-VkAttachmentDescription-format-06243**
  If `format` is a depth/stencil format which includes both depth and stencil components, `finalLayout` must not be `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_READONLY_OPTIMAL`

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**Valid Usage (Implicit)**

- **VUID-VkAttachmentDescription-flags-parameter**
  `flags` must be a valid combination of `VkAttachmentDescriptionFlagBits` values

- **VUID-VkAttachmentDescription-format-parameter**
  `format` must be a valid `VkFormat` value

- **VUID-VkAttachmentDescription-samples-parameter**
  `samples` must be a valid `VkSampleCountFlagBits` value

- **VUID-VkAttachmentDescription-loadOp-parameter**
  `loadOp` must be a valid `VkAttachmentLoadOp` value

- **VUID-VkAttachmentDescription-storeOp-parameter**
  `storeOp` must be a valid `VkAttachmentStoreOp` value

- **VUID-VkAttachmentDescription-stencilLoadOp-parameter**
  `stencilLoadOp` must be a valid `VkAttachmentLoadOp` value

- **VUID-VkAttachmentDescription-stencilStoreOp-parameter**
  `stencilStoreOp` must be a valid `VkAttachmentStoreOp` value

- **VUID-VkAttachmentDescription-initialLayout-parameter**
InitialLayout must be a valid VkImageLayout value

- VUID-VkAttachmentDescription-finalLayout-parameter

FinalLayout must be a valid VkImageLayout value

Bits which can be set in VkAttachmentDescription::flags, describing additional properties of the attachment, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkAttachmentDescriptionFlagBits {
    VK_ATTACHMENT_DESCRIPTION_MAY_ALIAS_BIT = 0x00000001,
} VkAttachmentDescriptionFlagBits;
```

- **VK_ATTACHMENT_DESCRIPTION_MAY_ALIAS_BIT** specifies that the attachment aliases the same device memory as other attachments.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkAttachmentDescriptionFlags;
```

**VkAttachmentDescriptionFlags** is a bitmask type for setting a mask of zero or more **VkAttachmentDescriptionFlagBits**.

The **VkRenderPassInputAttachmentAspectCreateInfo** structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkRenderPassInputAttachmentAspectCreateInfo {
    VkStructureType sType;
    const void* pNext;
    uint32_t aspectReferenceCount;
    const VkInputAttachmentAspectReference* pAspectReferences;
} VkRenderPassInputAttachmentAspectCreateInfo;
```

or the equivalent

```c
// Provided by VK_KHR_maintenance2
typedef VkRenderPassInputAttachmentAspectCreateInfo
VkRenderPassInputAttachmentAspectCreateInfoKHR;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **aspectReferenceCount** is the number of elements in the **pAspectReferences** array.
- **pAspectReferences** is a pointer to an array of **aspectReferenceCount** VkInputAttachmentAspectReference structures containing a mask describing which aspect(s) can be accessed for a given input attachment within a given subpass.
To specify which aspects of an input attachment can be read, add a `VkRenderPassInputAttachmentAspectCreateInfo` structure to the `pNext` chain of the `VkRenderPassCreateInfo` structure:

An application can access any aspect of an input attachment that does not have a specified aspect mask in the `pAspectReferences` array. Otherwise, an application must not access aspect(s) of an input attachment other than those in its specified aspect mask.

### Valid Usage (Implicit)

- **VUID-VkRenderPassInputAttachmentAspectCreateInfo-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_RENDER_PASS_INPUT_ATTACHMENT_ASPECT_CREATE_INFO`

- **VUID-VkRenderPassInputAttachmentAspectCreateInfo-pAspectReferences-parameter**
  - `pAspectReferences` must be a valid pointer to an array of `aspectReferenceCount` valid `VkInputAttachmentAspectReference` structures

- **VUID-VkRenderPassInputAttachmentAspectCreateInfo-aspectReferenceCount-arraylength**
  - `aspectReferenceCount` must be greater than 0

The `VkInputAttachmentAspectReference` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkInputAttachmentAspectReference {
    uint32_t subpass;
    uint32_t inputAttachmentIndex;
    VkImageAspectFlags aspectMask;
} VkInputAttachmentAspectReference;
```

or the equivalent

```c
// Provided by VK_KHR_maintenance2
typedef VkInputAttachmentAspectReference VkInputAttachmentAspectReferenceKHR;
```

- `subpass` is an index into the `pSubpasses` array of the parent `VkRenderPassCreateInfo` structure.
- `inputAttachmentIndex` is an index into the `pInputAttachments` of the specified subpass.
- `aspectMask` is a mask of which aspect(s) can be accessed within the specified subpass.

This structure specifies an aspect mask for a specific input attachment of a specific subpass in the render pass.

`subpass` and `inputAttachmentIndex` index into the render pass as:

```c
createInfo->pSubpasses[subpass].pInputAttachments[inputAttachmentIndex]
```
Valid Usage

• VUID-VkInputAttachmentAspectReference-aspectMask-01964
  aspectMask must not include VK_IMAGE_ASPECT_METADATA_BIT

• VUID-VkInputAttachmentAspectReference-aspectMask-02250
  aspectMask must not include VK_IMAGE_ASPECT_MEMORY_PLANE_i_BIT_EXT for any index i

Valid Usage (Implicit)

• VUID-VkInputAttachmentAspectReference-aspectMask-parameter
  aspectMask must be a valid combination of VkImageAspectFlagBits values

• VUID-VkInputAttachmentAspectReference-aspectMask-requiredbitmask
  aspectMask must not be 0

The VkSubpassDescription structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkSubpassDescription {
    VkSubpassDescriptionFlags flags;
    VkPipelineBindPoint pipelineBindPoint;
    uint32_t inputAttachmentCount;
    const VkAttachmentReference* pInputAttachments;
    uint32_t colorAttachmentCount;
    const VkAttachmentReference* pColorAttachments;
    const VkAttachmentReference* pResolveAttachments;
    const VkAttachmentReference* pDepthStencilAttachment;
    preserveAttachmentCount;
    const uint32_t* pPreserveAttachments;
} VkSubpassDescription;
```

• flags is a bitmask of VkSubpassDescriptionFlagBits specifying usage of the subpass.

• pipelineBindPoint is a VkPipelineBindPoint value specifying the pipeline type supported for this subpass.

• inputAttachmentCount is the number of input attachments.

• pInputAttachments is a pointer to an array of VkAttachmentReference structures defining the input attachments for this subpass and their layouts.

• colorAttachmentCount is the number of color attachments.

• pColorAttachments is a pointer to an array of colorAttachmentCount VkAttachmentReference structures defining the color attachments for this subpass and their layouts.

• pResolveAttachments is NULL or a pointer to an array of colorAttachmentCount VkAttachmentReference structures defining the resolve attachments for this subpass and their layouts.
• **pDepthStencilAttachment** is a pointer to a `VkAttachmentReference` structure specifying the depth/stencil attachment for this subpass and its layout.

• **preserveAttachmentCount** is the number of preserved attachments.

• **pPreserveAttachments** is a pointer to an array of `preserveAttachmentCount` render pass attachment indices identifying attachments that are not used by this subpass, but whose contents must be preserved throughout the subpass.

Each element of the **pInputAttachments** array corresponds to an input attachment index in a fragment shader, i.e. if a shader declares an image variable decorated with a `InputAttachmentIndex` value of `X`, then it uses the attachment provided in **pInputAttachments**[`X`]. Input attachments must also be bound to the pipeline in a descriptor set. If the attachment member of any element of **pInputAttachments** is **VK_ATTACHMENT_UNUSED**, the application must not read from the corresponding input attachment index. Fragment shaders can use subpass input variables to access the contents of an input attachment at the fragment's (x, y, layer) framebuffer coordinates. Input attachments must not be used by any subpasses within a render pass that enables render pass transform.

Each element of the **pColorAttachments** array corresponds to an output location in the shader, i.e. if the shader declares an output variable decorated with a `Location` value of `X`, then it uses the attachment provided in **pColorAttachments**[`X`]. If the attachment member of any element of **pColorAttachments** is **VK_ATTACHMENT_UNUSED**, or if Color Write Enable has been disabled for the corresponding attachment index, then writes to the corresponding location by a fragment shader are discarded.

If **flags** does not include **VK_SUBPASS_DESCRIPTION_SHADER_RESOLVE_BIT_QCOM**, and if **pResolveAttachments** is not **NULL**, each of its elements corresponds to a color attachment (the element in **pColorAttachments** at the same index), and a multisample resolve operation is defined for each attachment unless the resolve attachment index is **VK_ATTACHMENT_UNUSED**.

Similarly, if **flags** does not include **VK_SUBPASS_DESCRIPTION_SHADER_RESOLVE_BIT_QCOM**, and **VkSubpassDescriptionDepthStencilResolve::pDepthStencilResolveAttachment** is not **NULL** and does not have the value **VK_ATTACHMENT_UNUSED**, it corresponds to the depth/stencil attachment in **pDepthStencilAttachment**, and multisample resolve operation for depth and stencil are defined by **VkSubpassDescriptionDepthStencilResolve::depthResolveMode** and **VkSubpassDescriptionDepthStencilResolve::stencilResolveMode**, respectively. If **VkSubpassDescriptionDepthStencilResolve::depthResolveMode** is **VK_RESOLVE_MODE_NONE** or the **pDepthStencilResolveAttachment** does not have a depth aspect, no resolve operation is performed for the depth attachment. If **VkSubpassDescriptionDepthStencilResolve::stencilResolveMode** is **VK_RESOLVE_MODE_NONE** or the **pDepthStencilResolveAttachment** does not have a stencil aspect, no resolve operation is performed for the stencil attachment.

If the image subresource range referenced by the depth/stencil attachment is created with **VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT**, then the multisample resolve operation uses the sample locations state specified in the **sampleLocationsInfo** member of the element of the **VkRenderPassSampleLocationsBeginInfoEXT::pPostSubpassSampleLocations** for the subpass.

If **pDepthStencilAttachment** is **NULL**, or if its attachment index is **VK_ATTACHMENT_UNUSED**, it indicates that no depth/stencil attachment will be used in the subpass.
The contents of an attachment within the render area become undefined at the start of a subpass $S$ if all of the following conditions are true:

- The attachment is used as a color, depth/stencil, or resolve attachment in any subpass in the render pass.
- There is a subpass $S_1$ that uses or preserves the attachment, and a subpass dependency from $S_1$ to $S$.
- The attachment is not used or preserved in subpass $S$.

In addition, the contents of an attachment within the render area become undefined at the start of a subpass $S$ if all of the following conditions are true:

- $VK\_SUBPASS\_DESCRIPTION\_SHADER\_RESOLVE\_BIT\_QCOM$ is set.
- The attachment is used as a color or depth/stencil in the subpass.

Once the contents of an attachment become undefined in subpass $S$, they remain undefined for subpasses in subpass dependency chains starting with subpass $S$ until they are written again. However, they remain valid for subpasses in other subpass dependency chains starting with subpass $S_1$ if those subpasses use or preserve the attachment.

### Valid Usage

- **VUID-VkSubpassDescription-attachment-06912**
  If the `attachment` member of an element of `pInputAttachments` is not `VK\_ATTACHMENT\_UNUSED`, its `layout` member must not be `VK\_IMAGE\_LAYOUT\_COLOR\_ATTACHMENT\_OPTIMAL` or `VK\_IMAGE\_LAYOUT\_DEPTH\_STENCIL\_ATTACHMENT\_OPTIMAL`.

- **VUID-VkSubpassDescription-attachment-06913**
  If the `attachment` member of an element of `pColorAttachments` is not `VK\_ATTACHMENT\_UNUSED`, its `layout` member must not be `VK\_IMAGE\_LAYOUT\_DEPTH\_STENCIL\_ATTACHMENT\_OPTIMAL` or `VK\_IMAGE\_LAYOUT\_SHADER\_READ\_ONLY\_OPTIMAL`.

- **VUID-VkSubpassDescription-attachment-06914**
  If the `attachment` member of an element of `pResolveAttachments` is not `VK\_ATTACHMENT\_UNUSED`, its `layout` member must not be `VK\_IMAGE\_LAYOUT\_DEPTH\_STENCIL\_ATTACHMENT\_OPTIMAL` or `VK\_IMAGE\_LAYOUT\_SHADER\_READ\_ONLY\_OPTIMAL`.

- **VUID-VkSubpassDescription-attachment-06915**
  If the `attachment` member of `pDepthStencilAttachment` is not `VK\_ATTACHMENT\_UNUSED`, its `layout` member must not be `VK\_IMAGE\_LAYOUT\_COLOR\_ATTACHMENT\_OPTIMAL` or `VK\_IMAGE\_LAYOUT\_SHADER\_READ\_ONLY\_OPTIMAL`.

- **VUID-VkSubpassDescription-attachment-06916**
  If the `attachment` member of an element of `pColorAttachments` is not `VK\_ATTACHMENT\_UNUSED`, its `layout` member must not be `VK\_IMAGE\_LAYOUT\_DEPTH\_ATTACHMENT\_STENCIL\_READ\_ONLY\_OPTIMAL` or `VK\_IMAGE\_LAYOUT\_DEPTH\_READ\_ONLY\_STENCIL\_ATTACHMENT\_OPTIMAL`.

- **VUID-VkSubpassDescription-attachment-06917**
If the attachment member of an element of `pResolveAttachments` is not `VK_ATTACHMENT_UNUSED`, its layout member **must not be** `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`.

- **VUID-VkSubpassDescription-attachment-06918**
  
  If the attachment member of an element of `pInputAttachments` is not `VK_ATTACHMENT_UNUSED`, its layout member **must not be** `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL`.

- **VUID-VkSubpassDescription-attachment-06919**
  
  If the attachment member of an element of `pColorAttachments` is not `VK_ATTACHMENT_UNUSED`, its layout member **must not be** `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL`, `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, `VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL`, or `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`.

- **VUID-VkSubpassDescription-attachment-06920**
  
  If the attachment member of an element of `pResolveAttachments` is not `VK_ATTACHMENT_UNUSED`, its layout member **must not be** `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL`, `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, or `VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL`.

- **VUID-VkSubpassDescription-attachment-06921**
  
  If the attachment member of an element of `pResolveAttachments` is not `VK_ATTACHMENT_UNUSED`, its layout member **must not be** `VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR`.

- **VUID-VkSubpassDescription-attachment-06922**
  
  If the attachment member of an element of `pResolveAttachments` is not `VK_ATTACHMENT_UNUSED`, its layout member **must not be** `VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR`.

- **VUID-VkSubpassDescription-pipelineBindPoint-04952**
  
  `pipelineBindPoint` **must be** `VK_PIPELINE_BIND_POINT_GRAPHICS` or `VK_PIPELINE_BIND_POINT_SUBPASS_SHADING_HUAWEI`.

- **VUID-VkSubpassDescription-colorAttachmentCount-00845**
  
  `colorAttachmentCount` **must be** less than or equal to `VkPhysicalDeviceLimits::maxColorAttachments`.

- **VUID-VkSubpassDescription-loadOp-00846**
  
  If the first use of an attachment in this render pass is as an input attachment, and the attachment is not also used as a color or depth/stencil attachment in the same subpass, then `loadOp` **must not be** `VK_ATTACHMENT_LOAD_OP_CLEAR`.

- **VUID-VkSubpassDescription-pResolveAttachments-00847**
  
  If `pResolveAttachments` is not `NULL`, for each resolve attachment that is not `VK_ATTACHMENT_UNUSED`, the corresponding color attachment **must not be** `VK_ATTACHMENT_UNUSED`. 
• VUID-VkSubpassDescription-pResolveAttachments-00848
  If `pResolveAttachments` is not `NULL`, for each resolve attachment that is not `VK_ATTACHMENT_UNUSED`, the corresponding color attachment must not have a sample count of `VK_SAMPLE_COUNT_1_BIT`.

• VUID-VkSubpassDescription-pResolveAttachments-00849
  If `pResolveAttachments` is not `NULL`, each resolve attachment that is not `VK_ATTACHMENT_UNUSED` must have a sample count of `VK_SAMPLE_COUNT_1_BIT`.

• VUID-VkSubpassDescription-pResolveAttachments-00850
  If `pResolveAttachments` is not `NULL`, each resolve attachment that is not `VK_ATTACHMENT_UNUSED` must have the same `VkFormat` as its corresponding color attachment.

• VUID-VkSubpassDescription-pColorAttachments-06868
  If neither the `VK_AMD_mixed_attachment_samples` extension nor the `VK_NV_framebuffer_mixed_samples` extension is enabled, all attachments in `pColorAttachments` that are not `VK_ATTACHMENT_UNUSED` must have the same sample count.

• VUID-VkSubpassDescription-pInputAttachments-02647
  All attachments in `pInputAttachments` that are not `VK_ATTACHMENT_UNUSED` must have image formats whose potential format features contain at least `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT` or `VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT`.

• VUID-VkSubpassDescription-pColorAttachments-02648
  All attachments in `pColorAttachments` that are not `VK_ATTACHMENT_UNUSED` must have image formats whose potential format features contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT`.

• VUID-VkSubpassDescription-pResolveAttachments-02649
  All attachments in `pResolveAttachments` that are not `VK_ATTACHMENT_UNUSED` must have image formats whose potential format features contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT`.

• VUID-VkSubpassDescription-pDepthStencilAttachment-02650
  If `pDepthStencilAttachment` is not `NULL` and the attachment is not `VK_ATTACHMENT_UNUSED` then it must have an image format whose potential format features contain `VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT`.

• VUID-VkSubpassDescription-linearColorAttachment-06496
  If the `linearColorAttachment` feature is enabled and the image is created with `VK_IMAGE_TILING_LINEAR`, all attachments in `pInputAttachments` that are not `VK_ATTACHMENT_UNUSED` must have image formats whose potential format features must contain `VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV`.

• VUID-VkSubpassDescription-linearColorAttachment-06497
  If the `linearColorAttachment` feature is enabled and the image is created with `VK_IMAGE_TILING_LINEAR`, all attachments in `pColorAttachments` that are not `VK_ATTACHMENT_UNUSED` must have image formats whose potential format features must contain `VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV`.

• VUID-VkSubpassDescription-linearColorAttachment-06498
  If the `linearColorAttachment` feature is enabled and the image is created with `VK_IMAGE_TILING_LINEAR`, all attachments in `pResolveAttachments` that are not
**VK_ATTACHMENT_UNUSED** must have image formats whose potential format features must contain **VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV**.

- **VUID-VkSubpassDescription-pColorAttachments-01506**
  If the **VK_AMD_mixed_attachment_samples** extension is enabled, all attachments in **pColorAttachments** that are not **VK_ATTACHMENT_UNUSED** must have a sample count that is smaller than or equal to the sample count of **pDepthStencilAttachment** if it is not **VK_ATTACHMENT_UNUSED**.

- **VUID-VkSubpassDescription-pDepthStencilAttachment-01418**
  If neither the **VK_AMD_mixed_attachment_samples** nor the **VK_NV_framebuffer_mixed_samples** extensions are enabled, and if **pDepthStencilAttachment** is not **VK_ATTACHMENT_UNUSED** and any attachments in **pColorAttachments** are not **VK_ATTACHMENT_UNUSED**, they must have the same sample count.

- **VUID-VkSubpassDescription-attachment-00853**
  Each element of **pPreserveAttachments** must not be **VK_ATTACHMENT_UNUSED**.

- **VUID-VkSubpassDescription-pPreserveAttachments-00854**
  Each element of **pPreserveAttachments** must not also be an element of any other member of the subpass description.

- **VUID-VkSubpassDescription-layout-02519**
  If any attachment is used by more than one **VkAttachmentReference** member, then each use must use the same layout.

- **VUID-VkSubpassDescription-flags-00856**
  If **flags** includes **VK_SUBPASS_DESCRIPTION_PER_VIEW_POSITION_X_ONLY_BIT_NVX**, it must also include **VK_SUBPASS_DESCRIPTION_PER_VIEW_ATTRIBUTES_BIT_NVX**.

- **VUID-VkSubpassDescription-flags-03341**
  If **flags** includes **VK_SUBPASS_DESCRIPTION_SHADER_RESOLVE_BIT_QCOM**, and if **pResolveAttachments** is not NULL, then each resolve attachment must be **VK_ATTACHMENT_UNUSED**.

- **VUID-VkSubpassDescription-flags-03343**
  If **flags** includes **VK_SUBPASS_DESCRIPTION_SHADER_RESOLVE_BIT_QCOM**, then the subpass must be the last subpass in a subpass dependency chain.

- **VUID-VkSubpassDescription-pInputAttachments-02868**
  If the render pass is created with **VK_RENDER_PASS_CREATE_TRANSFORM_BIT_QCOM**, each of the elements of **pInputAttachments** must be **VK_ATTACHMENT_UNUSED**.

- **VUID-VkSubpassDescription-pDepthStencilAttachment-04438**
  **pDepthStencilAttachment** and **pColorAttachments** must not contain references to the same attachment.

---

**Valid Usage (Implicit)**

- **VUID-VkSubpassDescription-flags-parameter**
  **flags** must be a valid combination of **VkSubpassDescriptionFlagBits** values.

- **VUID-VkSubpassDescription-pipelineBindPoint-parameter**
pipelineBindPoint must be a valid VkPipelineBindPoint value

- VUID-VkSubpassDescription-pInputAttachments-parameter
  If inputAttachmentCount is not 0, pInputAttachments must be a valid pointer to an array of inputAttachmentCount valid VkAttachmentReference structures

- VUID-VkSubpassDescription-pColorAttachments-parameter
  If colorAttachmentCount is not 0, pColorAttachments must be a valid pointer to an array of colorAttachmentCount valid VkAttachmentReference structures

- VUID-VkSubpassDescription-pResolveAttachments-parameter
  If colorAttachmentCount is not 0, and pResolveAttachments is not NULL, pResolveAttachments must be a valid pointer to an array of colorAttachmentCount valid VkAttachmentReference structures

- VUID-VkSubpassDescription-pDepthStencilAttachment-parameter
  If pDepthStencilAttachment is not NULL, pDepthStencilAttachment must be a valid pointer to a valid VkAttachmentReference structure

- VUID-VkSubpassDescription-pPreserveAttachments-parameter
  If preserveAttachmentCount is not 0, pPreserveAttachments must be a valid pointer to an array of preserveAttachmentCount uint32_t values

Bits which can be set in VkSubpassDescription::flags, specifying usage of the subpass, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkSubpassDescriptionFlagBits {
    // Provided by VK_NVX_multiview_per_view_attributes
    VK_SUBPASS_DESCRIPTION_PER_VIEW_ATTRIBUTES_BIT_NVX = 0x00000001,
    // Provided by VK_NVX_multiview_per_view_attributes
    VK_SUBPASS_DESCRIPTION_PER_VIEW_POSITION_X_ONLY_BIT_NVX = 0x00000002,
    // Provided by VK_QCOM_render_pass_shader_resolve
    VK_SUBPASS_DESCRIPTION_FRAGMENT_REGION_BIT_QCOM = 0x00000004,
    // Provided by VK_QCOM_render_pass_shader_resolve
    VK_SUBPASS_DESCRIPTION_SHADER_RESOLVE_BIT_QCOM = 0x00000008,
    // Provided by VK_EXT_rasterization_order_attachment_access
    VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_COLOR_ACCESS_BIT_EXT = 0x00000010,
    // Provided by VK_EXT_rasterization_order_attachment_access
    VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT = 0x00000020,
    // Provided by VK_EXT_rasterization_order_attachment_access
    VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT = 0x00000040,
    // Provided by VK_EXT_legacy_dithering
    VK_SUBPASS_DESCRIPTION_ENABLE_LEGACY_DITHERING_BIT_EXT = 0x00000080,
    // Provided by VK_ARM_rasterization_order_attachment_access
    VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_COLOR_ACCESS_BIT_ARM = VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_COLOR_ACCESS_BIT_EXT,
    // Provided by VK_ARM_rasterization_order_attachment_access
    VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_ARM = VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT,
    // Provided by VK_ARM_rasterization_order_attachment_access
    VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_ARM = VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT,
};
```
VK_SUBPASS_DESCRIPTION_PER_VIEW_ATTRIBUTES_BIT_NVX specifies that shaders compiled for this subpass write the attributes for all views in a single invocation of each pre-rasterization shader stage. All pipelines compiled against a subpass that includes this bit must write per-view attributes to the *PerViewNV[] shader outputs, in addition to the non-per-view (e.g. Position) outputs.

VK_SUBPASS_DESCRIPTION_PER_VIEW_POSITION_X_ONLY_BIT_NVX specifies that shaders compiled for this subpass use per-view positions which only differ in value in the x component. Per-view viewport mask can also be used.

VK_SUBPASS_DESCRIPTION_FRAGMENT_REGION_BIT_QCOM specifies that the framebuffer region is the fragment region, that is, the minimum region dependencies are by pixel rather than by sample, such that any fragment shader invocation can access any sample associated with that fragment shader invocation.

VK_SUBPASS_DESCRIPTION_SHADER_RESOLVE_BIT_QCOM specifies that the subpass performs shader resolve operations.

VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_COLOR_ACCESS_BIT_EXT specifies that this subpass supports pipelines created with VK_PIPELINE_COLOR_BLEND_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_BIT_EXT.

VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT specifies that this subpass supports pipelines created with VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT.

VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT specifies that this subpass supports pipelines created with VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT.

VK_SUBPASS_DESCRIPTION_ENABLE_LEGACY_DITHERING_BIT_EXT specifies that Legacy Dithering is enabled for this subpass.

**Note**

Shader resolve operations allow for custom resolve operations, but overwriting pixels may have a performance and/or power cost. Furthermore, since the content of any depth stencil attachment or color attachment is undefined at the beginning of a shader resolve subpass, any depth testing, stencil testing, or blending operation which sources these undefined values also has undefined result value.

typedef VkFlags VkSubpassDescriptionFlags;

VkSubpassDescriptionFlags is a bitmask type for setting a mask of zero or more
The `VkAttachmentReference` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkAttachmentReference {
    uint32_t attachment;
    VkImageLayout layout;
} VkAttachmentReference;
```

- `attachment` is either an integer value identifying an attachment at the corresponding index in `VkRenderPassCreateInfo::pAttachments`, or `VK_ATTACHMENT_UNUSED` to signify that this attachment is not used.
- `layout` is a `VkImageLayout` value specifying the layout the attachment uses during the subpass.

### Valid Usage

- **VUID-VkAttachmentReference-layout-03077**
  If `attachment` is not `VK_ATTACHMENT_UNUSED`, `layout` must not be `VK_IMAGE_LAYOUT_UNDEFINED`, `VK_IMAGE_LAYOUT_PREINITIALIZED`, or `VK_IMAGE_LAYOUT_PRESENT_SRC_KHR`.

- **VUID-VkAttachmentReference-separateDepthStencilLayouts-03313**
  If the `separateDepthStencilLayouts` feature is not enabled, and `attachment` is not `VK_ATTACHMENT_UNUSED`, `layout` must not be `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL`, `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, `VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL`, or `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`.

- **VUID-VkAttachmentReference-synchronization2-06910**
  If the `synchronization2` feature is not enabled, `layout` must not be `VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL_KHR` or `VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR`.

- **VUID-VkAttachmentReference-attachmentFeedbackLoopLayout-07311**
  If the `attachmentFeedbackLoopLayout` feature is not enabled, `layout` must not be `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT`.

### Valid Usage (Implicit)

- **VUID-VkAttachmentReference-layout-parameter**
  `layout` must be a valid `VkImageLayout` value.

`VK_SUBPASS_EXTERNAL` is a special subpass index value expanding synchronization scope outside a subpass. It is described in more detail by `VkSubpassDependency`.

```c
#define VK_SUBPASS_EXTERNAL (~0U)
```

The `VkSubpassDependency` structure is defined as:
typedef struct VkSubpassDependency {
    uint32_t srcSubpass;
    uint32_t dstSubpass;
    VkPipelineStageFlags srcStageMask;
    VkPipelineStageFlags dstStageMask;
    VkAccessFlags srcAccessMask;
    VkAccessFlags dstAccessMask;
    VkDependencyFlags dependencyFlags;
} VkSubpassDependency;

- **srcSubpass** is the subpass index of the first subpass in the dependency, or **VK_SUBPASS_EXTERNAL**.
- **dstSubpass** is the subpass index of the second subpass in the dependency, or **VK_SUBPASS_EXTERNAL**.
- **srcStageMask** is a bitmask of **VkPipelineStageFlagBits** specifying the source stage mask.
- **dstStageMask** is a bitmask of **VkPipelineStageFlagBits** specifying the destination stage mask.
- **srcAccessMask** is a bitmask of **VkAccessFlagBits** specifying a source access mask.
- **dstAccessMask** is a bitmask of **VkAccessFlagBits** specifying a destination access mask.
- **dependencyFlags** is a bitmask of **VkDependencyFlagBits**.

If **srcSubpass** is equal to **dstSubpass** then the **VkSubpassDependency** does not directly define a dependency. Instead, it enables pipeline barriers to be used in a render pass instance within the identified subpass, where the scopes of one pipeline barrier must be a subset of those described by one subpass dependency. Subpass dependencies specified in this way that include framebuffer-space stages in the **srcStageMask** must only include framebuffer-space stages in **dstStageMask**, and must include **VK_DEPENDENCY_BY_REGION_BIT**. When a subpass dependency is specified in this way for a subpass that has more than one view in its view mask, its **dependencyFlags** must include **VK_DEPENDENCY_VIEW_LOCAL_BIT**.

If **srcSubpass** and **dstSubpass** are not equal, when a render pass instance which includes a subpass dependency is submitted to a queue, it defines a dependency between the subpasses identified by **srcSubpass** and **dstSubpass**.

If **srcSubpass** is equal to **VK_SUBPASS_EXTERNAL**, the first synchronization scope includes commands that occur earlier in submission order than the **vkCmdBeginRenderPass** used to begin the render pass instance. Otherwise, the first set of commands includes all commands submitted as part of the subpass instance identified by **srcSubpass** and any load, store, or multisample resolve operations on attachments used in **srcSubpass**. In either case, the first synchronization scope is limited to operations on the pipeline stages determined by the source stage mask specified by **srcStageMask**.

If **dstSubpass** is equal to **VK_SUBPASS_EXTERNAL**, the second synchronization scope includes commands that occur later in submission order than the **vkCmdEndRenderPass** used to end the render pass instance. Otherwise, the second set of commands includes all commands submitted as part of the subpass instance identified by **dstSubpass** and any load, store, and multisample resolve operations on attachments used in **dstSubpass**. In either case, the second synchronization scope is limited to operations on the pipeline stages determined by the destination stage mask specified by **dstStageMask**.
The first access scope is limited to accesses in the pipeline stages determined by the source stage mask specified by \textit{srcStageMask}. It is also limited to access types in the source access mask specified by \textit{srcAccessMask}.

The second access scope is limited to accesses in the pipeline stages determined by the destination stage mask specified by \textit{dstStageMask}. It is also limited to access types in the destination access mask specified by \textit{dstAccessMask}.

The availability and visibility operations defined by a subpass dependency affect the execution of image layout transitions within the render pass.

\textit{Note}

For non-attachment resources, the memory dependency expressed by subpass dependency is nearly identical to that of a \textit{VkMemoryBarrier} (with matching \textit{srcAccessMask} and \textit{dstAccessMask} parameters) submitted as a part of a \textit{vkCmdPipelineBarrier} (with matching \textit{srcStageMask} and \textit{dstStageMask} parameters). The only difference being that its scopes are limited to the identified subpasses rather than potentially affecting everything before and after.

For attachments however, subpass dependencies work more like a \textit{VkImageMemoryBarrier} defined similarly to the \textit{VkMemoryBarrier} above, the queue family indices set to \texttt{VK_QUEUE_FAMILY_IGNORED}, and layouts as follows:

- The equivalent to \textit{oldLayout} is the attachment's layout according to the subpass description for \textit{srcSubpass}.
- The equivalent to \textit{newLayout} is the attachment's layout according to the subpass description for \textit{dstSubpass}.

\textbf{Valid Usage}

- \textbf{VUID-VkSubpassDependency-srcStageMask-04090}
  If the \textit{geometryShader} feature is not enabled, \textit{srcStageMask} must not contain \texttt{VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT}

- \textbf{VUID-VkSubpassDependency-srcStageMask-04091}
  If the \textit{tessellationShader} feature is not enabled, \textit{srcStageMask} must not contain \texttt{VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT} or \texttt{VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT}

- \textbf{VUID-VkSubpassDependency-srcStageMask-04092}
  If the \textit{conditionalRendering} feature is not enabled, \textit{srcStageMask} must not contain \texttt{VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT}

- \textbf{VUID-VkSubpassDependency-srcStageMask-04093}
  If the \textit{fragmentDensityMap} feature is not enabled, \textit{srcStageMask} must not contain \texttt{VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT}

- \textbf{VUID-VkSubpassDependency-srcStageMask-04094}
If the `transformFeedback` feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT`

- VUID-VkSubpassDependency-srcStageMask-04095
  If the `meshShader` feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT`

- VUID-VkSubpassDependency-srcStageMask-04096
  If the `taskShader` feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT`

- VUID-VkSubpassDependency-srcStageMask-07318
  If neither the `shadingRateImage` or `attachmentFragmentShadingRate` are enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`

- VUID-VkSubpassDependency-srcStageMask-03937
  If the `synchronization2` feature is not enabled, `srcStageMask` must not be 0

- VUID-VkSubpassDependency-srcStageMask-07949
  If neither the `VK_NV_ray_tracing` extension or `rayTracingPipeline` feature are enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR`

- VUID-VkSubpassDependency-dstStageMask-04090
  If the `geometryShader` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT`

- VUID-VkSubpassDependency-dstStageMask-04091
  If the `tessellationShader` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT` or `VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT`

- VUID-VkSubpassDependency-dstStageMask-04092
  If the `conditionalRendering` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT`

- VUID-VkSubpassDependency-dstStageMask-04093
  If the `fragmentDensityMap` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT`

- VUID-VkSubpassDependency-dstStageMask-04094
  If the `transformFeedback` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT`

- VUID-VkSubpassDependency-dstStageMask-04095
  If the `meshShader` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT`

- VUID-VkSubpassDependency-dstStageMask-04096
  If the `taskShader` feature is not enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT`

- VUID-VkSubpassDependency-dstStageMask-07318
  If neither the `shadingRateImage` or `attachmentFragmentShadingRate` are enabled, `dstStageMask` must not contain
If the `synchronization2` feature is not enabled, `dstStageMask` must not be 0.

If neither the `VK_NV_ray_tracing` extension or `rayTracingPipeline` feature are enabled, `dstStageMask` must not contain `VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR`.

`srcSubpass` must be less than or equal to `dstSubpass`, unless one of them is `VK_SUBPASS_EXTERNAL`, to avoid cyclic dependencies and ensure a valid execution order.

`srcSubpass` and `dstSubpass` must not both be equal to `VK_SUBPASS_EXTERNAL`.

If `srcSubpass` is equal to `dstSubpass` and `srcStageMask` includes a framebuffer-space stage, `dstStageMask` must only contain framebuffer-space stages.

Any access flag included in `srcAccessMask` must be supported by one of the pipeline stages in `srcStageMask`, as specified in the table of supported access types.

Any access flag included in `dstAccessMask` must be supported by one of the pipeline stages in `dstStageMask`, as specified in the table of supported access types.

If `srcSubpass` equals `dstSubpass`, and `srcStageMask` and `dstStageMask` both include a framebuffer-space stage, then `dependencyFlags` must include `VK_DEPENDENCY_BY_REGION_BIT`.

If `dependencyFlags` includes `VK_DEPENDENCY_VIEW_LOCAL_BIT`, `srcSubpass` must not be equal to `VK_SUBPASS_EXTERNAL`.

If `dependencyFlags` includes `VK_DEPENDENCY_VIEW_LOCAL_BIT`, `dstSubpass` must not be equal to `VK_SUBPASS_EXTERNAL`.

If `srcSubpass` equals `dstSubpass` and that subpass has more than one bit set in the view mask, then `dependencyFlags` must include `VK_DEPENDENCY_VIEW_LOCAL_BIT`.

Valid Usage (Implicit)

`srcStageMask` must be a valid combination of `VkPipelineStageFlagBits` values.

`dstStageMask` must be a valid combination of `VkPipelineStageFlagBits` values.

`srcAccessMask` must be a valid combination of `VkAccessFlagBits` values.
When multiview is enabled, the execution of the multiple views of one subpass may not occur simultaneously or even back-to-back, and rather may be interleaved with the execution of other subpasses. The load and store operations apply to attachments on a per-view basis. For example, an attachment using `VK_ATTACHMENT_LOAD_OP_CLEAR` will have each view cleared on first use, but the first use of one view may be temporally distant from the first use of another view.

**Note**

A good mental model for multiview is to think of a multiview subpass as if it were a collection of individual (per-view) subpasses that are logically grouped together and described as a single multiview subpass in the API. Similarly, a multiview attachment can be thought of like several individual attachments that happen to be layers in a single image. A view-local dependency between two multiview subpasses acts like a set of one-to-one dependencies between corresponding pairs of per-view subpasses. A view-global dependency between two multiview subpasses acts like a set of $N \times M$ dependencies between all pairs of per-view subpasses in the source and destination. Thus, it is a more compact representation which also makes clear the commonality and reuse that is present between views in a subpass. This interpretation motivates the answers to questions like “when does the load op apply” - it is on the first use of each view of an attachment, as if each view was a separate attachment.

The content of each view follows the description in attachment content behavior. In particular, if an attachment is preserved, all views within the attachment are preserved.

If any two subpasses of a render pass activate transform feedback to the same bound transform feedback buffers, a subpass dependency must be included (either directly or via some intermediate subpasses) between them.

If there is no subpass dependency from `VK_SUBPASS_EXTERNAL` to the first subpass that uses an attachment, then an implicit subpass dependency exists from `VK_SUBPASS_EXTERNAL` to the first subpass it is used in. The implicit subpass dependency only exists if there exists an automatic layout transition away from `initialLayout`. The subpass dependency operates as if defined with the following parameters:

```c
VkSubpassDependency implicitDependency = {
    .srcSubpass = VK_SUBPASS_EXTERNAL,
    .dstSubpass = firstSubpass, // First subpass attachment is used in
    .srcStageMask = VK_PIPELINE_STAGE_NONE,
    .dstStageMask = VK_PIPELINE_STAGE_ALL_COMMANDS_BIT,
    .srcAccessMask = 0,
    .dstAccessMask = VK_ACCESS_INPUT_ATTACHMENT_READ_BIT
}
```
Similarly, if there is no subpass dependency from the last subpass that uses an attachment to `VK_SUBPASS_EXTERNAL`, then an implicit subpass dependency exists from the last subpass it is used in to `VK_SUBPASS_EXTERNAL`. The implicit subpass dependency only exists if there exists an automatic layout transition into `finalLayout`. The subpass dependency operates as if defined with the following parameters:

```c
VkSubpassDependency implicitDependency = {
    .srcSubpass = lastSubpass, // Last subpass attachment is used in
    .dstSubpass = VK_SUBPASS_EXTERNAL,
    .srcStageMask = VK_PIPELINE_STAGE_ALL_COMMANDS_BIT,
    .dstStageMask = VK_PIPELINE_STAGE_NONE,
    .srcAccessMask = VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT |
                     VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT,
    .dstAccessMask = 0,
    .dependencyFlags = 0
};
```

As subpasses may overlap or execute out of order with regards to other subpasses unless a subpass dependency chain describes otherwise, the layout transitions required between subpasses cannot be known to an application. Instead, an application provides the layout that each attachment must be in at the start and end of a render pass, and the layout it must be in during each subpass it is used in. The implementation then must execute layout transitions between subpasses in order to guarantee that the images are in the layouts required by each subpass, and in the final layout at the end of the render pass.

Automatic layout transitions apply to the entire image subresource attached to the framebuffer. If multiview is not enabled and the attachment is a view of a 1D or 2D image, the automatic layout transitions apply to the number of layers specified by `VkFramebufferCreateInfo::layers`. If multiview is enabled and the attachment is a view of a 1D or 2D image, the automatic layout transitions apply to the layers corresponding to views which are used by some subpass in the render pass, even if that subpass does not reference the given attachment. If the attachment view is a 2D or 2D array view of a 3D image, even if the attachment view only refers to a subset of the slices of the selected mip level of the 3D image, automatic layout transitions apply to the entire subresource referenced which is the entire mip level in this case.

Automatic layout transitions away from the layout used in a subpass happen-after the availability operations for all dependencies with that subpass as the `srcSubpass`.

Automatic layout transitions into the layout used in a subpass happen-before the visibility operations for all dependencies with that subpass as the `dstSubpass`.  

```c
VK_ACCESS_COLOR_ATTACHMENT_READ_BIT |  
VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT |  
VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_READ_BIT |  
VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT,
    .dependencyFlags = 0
};
```
Automatic layout transitions away from `initialLayout` happen-after the availability operations for all dependencies with a `srcSubpass` equal to `VK_SUBPASS_EXTERNAL`, where `dstSubpass` uses the attachment that will be transitioned. For attachments created with `VK_ATTACHMENT_DESCRIPTION_MAY_ALIAS_BIT`, automatic layout transitions away from `initialLayout` happen-after the availability operations for all dependencies with a `srcSubpass` equal to `VK_SUBPASS_EXTERNAL`, where `dstSubpass` uses any aliased attachment.

Automatic layout transitions into `finalLayout` happen-before the visibility operations for all dependencies with a `dstSubpass` equal to `VK_SUBPASS_EXTERNAL`, where `srcSubpass` uses the attachment that will be transitioned. For attachments created with `VK_ATTACHMENT_DESCRIPTION_MAY_ALIAS_BIT`, automatic layout transitions into `finalLayout` happen-before the visibility operations for all dependencies with a `dstSubpass` equal to `VK_SUBPASS_EXTERNAL`, where `srcSubpass` uses any aliased attachment.

The image layout of the depth aspect of a depth/stencil attachment referring to an image created with `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` is dependent on the last sample locations used to render to the attachment, thus automatic layout transitions use the sample locations state specified in `VkRenderPassSampleLocationsBeginInfoEXT`.

Automatic layout transitions of an attachment referring to a depth/stencil image created with `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` use the sample locations the image subresource range referenced by the attachment was last rendered with. If the current render pass does not use the attachment as a depth/stencil attachment in any subpass that happens-before, the automatic layout transition uses the sample locations state specified in the `sampleLocationsInfo` member of the element of the `VkRenderPassSampleLocationsBeginInfoEXT::pAttachmentInitialSampleLocations` array for which the `attachmentIndex` member equals the attachment index of the attachment, if one is specified. Otherwise, the automatic layout transition uses the sample locations state specified in the `sampleLocationsInfo` member of the element of the `VkRenderPassSampleLocationsBeginInfoEXT::pPostSubpassSampleLocations` array for which the `subpassIndex` member equals the index of the subpass that last used the attachment as a depth/stencil attachment, if one is specified.

If no sample locations state has been specified for an automatic layout transition performed on an attachment referring to a depth/stencil image created with `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` the contents of the depth aspect of the depth/stencil attachment become undefined as if the layout of the attachment was transitioned from the `VK_IMAGE_LAYOUT_UNDEFINED` layout.

If two subpasses use the same attachment, and both subpasses use the attachment in a read-only layout, no subpass dependency needs to be specified between those subpasses. If an implementation treats those layouts separately, it must insert an implicit subpass dependency between those subpasses to separate the uses in each layout. The subpass dependency operates as if defined with the following parameters:

```cpp
// Used for input attachments
VkPipelineStageFlags inputAttachmentStages = VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT;
VkAccessFlags inputAttachmentDstAccess = VK_ACCESS_INPUT_ATTACHMENT_READ_BIT;

// Used for depth/stencil attachments
```
VkPipelineStageFlags depthStencilAttachmentStages =
    VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT |
    VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT;
VkAccessFlags depthStencilAttachmentDstAccess =
    VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_READ_BIT;

VkSubpassDependency implicitDependency = {
    .srcSubpass = firstSubpass;
    .dstSubpass = secondSubpass;
    .srcStageMask = inputAttachmentStages | depthStencilAttachmentStages;
    .dstStageMask = inputAttachmentStages | depthStencilAttachmentStages;
    .srcAccessMask = 0;
    .dstAccessMask = inputAttachmentDstAccess | depthStencilAttachmentDstAccess;
    .dependencyFlags = 0;
};

When drawing using shader objects, or when the graphics pipeline is created with
VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT set in VkPipelineDynamicStateCreateInfo ::pDynamicStates, the application must specify which types of attachments that are written to during
a render pass will also be accessed as non-attachments in the render pass.

To dynamically set whether a pipeline can access a resource as a non-attachment while it is also
used as an attachment that is written to, call:

// Provided by VK_EXT_attachment_feedback_loop_dynamic_state
void vkCmdSetAttachmentFeedbackLoopEnableEXT(  
    VkCommandBuffer commandBuffer,  
    VkImageAspectFlags aspectMask);

• commandBuffer is the command buffer into which the command will be recorded.
• aspectMask specifies the types of attachments for which feedback loops will be enabled.  
  Attachment types whose aspects are not included in aspectMask will have feedback loops
  disabled.

For attachments that are written to in a render pass, only attachments with the aspects specified in
aspectMask can be accessed as non-attachments by subsequent drawing commands.

Valid Usage

• VUID-vkCmdSetAttachmentFeedbackLoopEnableEXT-attachmentFeedbackLoopDynamicState-08862
  The attachmentFeedbackLoopDynamicState feature must be enabled

• VUID-vkCmdSetAttachmentFeedbackLoopEnableEXT-aspectMask-08863
  aspectMask must only include VK_IMAGE_ASPECT_NONE, VK_IMAGE_ASPECT_COLOR_BIT,
  VK_IMAGE_ASPECT_DEPTH_BIT, and VK_IMAGE_ASPECT_STENCIL_BIT

• VUID-vkCmdSetAttachmentFeedbackLoopEnableEXT-attachmentFeedbackLoopLayout-
If the attachmentFeedbackLoopLayout feature is not enabled, aspectMask must be VK_IMAGE_ASPECT_NONE

Valid Usage (Implicit)

- VUID-vkCmdSetAttachmentFeedbackLoopEnableEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle
- VUID-vkCmdSetAttachmentFeedbackLoopEnableEXT-aspectMask-parameter
  aspectMask must be a valid combination of VkImageAspectFlagBits values
- VUID-vkCmdSetAttachmentFeedbackLoopEnableEXT-commandBuffer-recording
  commandBuffer must be in the recording state
- VUID-vkCmdSetAttachmentFeedbackLoopEnableEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations
- VUID-vkCmdSetAttachmentFeedbackLoopEnableEXT-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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A more extensible version of render pass creation is also defined below.

To create a render pass, call:

```c
// Provided by VK_VERSION_1_2
VkResult vkCreateRenderPass2(
    VkDevice device,
    const VkRenderPassCreateInfo2* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkRenderPass* pRenderPass);
```
or the equivalent command

```c
VkResult vkCreateRenderPass2KHR(
    VkDevice device,
    const VkRenderPassCreateInfo2* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkRenderPass* pRenderPass);
```

- `device` is the logical device that creates the render pass.
- `pCreateInfo` is a pointer to a `VkRenderPassCreateInfo2` structure describing the parameters of the render pass.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pRenderPass` is a pointer to a `VkRenderPass` handle in which the resulting render pass object is returned.

This command is functionally identical to `vkCreateRenderPass`, but includes extensible sub-structures that include `sType` and `pNext` parameters, allowing them to be more easily extended.

### Valid Usage (Implicit)

- VUID-vkCreateRenderPass2-device-parameter
  
  `device` must be a valid `VkDevice` handle

- VUID-vkCreateRenderPass2-pCreateInfo-parameter
  
  `pCreateInfo` must be a valid pointer to a valid `VkRenderPassCreateInfo2` structure

- VUID-vkCreateRenderPass2-pAllocator-parameter
  
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

- VUID-vkCreateRenderPass2-pRenderPass-parameter
  
  `pRenderPass` must be a valid pointer to a `VkRenderPass` handle

### Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

The `VkRenderPassCreateInfo2` structure is defined as:

```c
// Provided by VK_VERSION_1_2
```
```c
typedef struct VkRenderPassCreateInfo2 {
    VkStructureType sType;
    const void* pNext;
    VkRenderPassCreateFlags flags;
    uint32_t attachmentCount;
    const VkAttachmentDescription2* pAttachments;
    uint32_t subpassCount;
    const VkSubpassDescription2* pSubpasses;
    uint32_t dependencyCount;
    const VkSubpassDependency2* pDependencies;
    uint32_t correlatedViewMaskCount;
    const uint32_t* pCorrelatedViewMasks;
} VkRenderPassCreateInfo2;
```

or the equivalent

```c
// Provided by VK_KHR_create_renderpass2
typedef VkRenderPassCreateInfo2 VkRenderPassCreateInfo2KHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **attachmentCount** is the number of attachments used by this render pass.
- **pAttachments** is a pointer to an array of `attachmentCount` `VkAttachmentDescription2` structures describing the attachments used by the render pass.
- **subpassCount** is the number of subpasses to create.
- **pSubpasses** is a pointer to an array of `subpassCount` `VkSubpassDescription2` structures describing each subpass.
- **dependencyCount** is the number of dependencies between pairs of subpasses.
- **pDependencies** is a pointer to an array of `dependencyCount` `VkSubpassDependency2` structures describing dependencies between pairs of subpasses.
- **correlatedViewMaskCount** is the number of correlation masks.
- **pCorrelatedViewMasks** is a pointer to an array of view masks indicating sets of views that may be more efficient to render concurrently.

Parameters defined by this structure with the same name as those in `VkRenderPassCreateInfo` have the identical effect to those parameters; the child structures are variants of those used in `VkRenderPassCreateInfo` which add `sType` and `pNext` parameters, allowing them to be extended.

If the `VkSubpassDescription2::viewMask` member of any element of `pSubpasses` is not zero, *multiview* functionality is considered to be enabled for this render pass.

`correlatedViewMaskCount` and `pCorrelatedViewMasks` have the same effect as `VkRenderPassMultiviewCreateInfo::correlationMaskCount` and `VkRenderPassMultiviewCreateInfo`
Valid Usage

- **VUID-VkRenderPassCreateInfo2-None-03049**
  If any two subpasses operate on attachments with overlapping ranges of the same `VkDeviceMemory` object, and at least one subpass writes to that area of `VkDeviceMemory`, a subpass dependency **must** be included (either directly or via some intermediate subpasses) between them.

- **VUID-VkRenderPassCreateInfo2-attachment-03050**
  If the attachment member of any element of `pInputAttachments`, `pColorAttachments`, `pResolveAttachments` or `pDepthStencilAttachment`, or the attachment indexed by any element of `pPreserveAttachments` in any element of `pSubpasses` is bound to a range of a `VkDeviceMemory` object that overlaps with any other attachment in any subpass (including the same subpass), the `VkAttachmentDescription2` structures describing them **must** include `VK_ATTACHMENT_DESCRIPTION_MAY_ALIAS_BIT` in flags.

- **VUID-VkRenderPassCreateInfo2-attachment-03051**
  If the attachment member of any element of `pInputAttachments`, `pColorAttachments`, `pResolveAttachments` or `pDepthStencilAttachment`, or any element of `pPreserveAttachments` in any element of `pSubpasses` is not `VK_ATTACHMENT_UNUSED`, then it **must** be less than `attachmentCount`.

- **VUID-VkRenderPassCreateInfo2-fragmentDensityMapAttachment-06472**
  If the `pNext` chain includes a `VkRenderPassFragmentDensityMapCreateInfoEXT` structure and the `fragmentDensityMapAttachment` member is not `VK_ATTACHMENT_UNUSED`, then attachment **must** be less than `attachmentCount`.

- **VUID-VkRenderPassCreateInfo2-pSubpasses-06473**
  If the `pSubpasses` `pNext` chain includes a `VkSubpassDescriptionDepthStencilResolve` structure and the `pDepthStencilResolveAttachment` member is not `NULL` and does not have the value `VK_ATTACHMENT_UNUSED`, then attachment **must** be less than `attachmentCount`.

- **VUID-VkRenderPassCreateInfo2-pAttachments-02522**
  For any member of `pAttachments` with a `loadOp` equal to `VK_ATTACHMENT_LOAD_OP_CLEAR`, the first use of that attachment **must** not specify a layout equal to `VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL`, `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, or `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`.

- **VUID-VkRenderPassCreateInfo2-pAttachments-02523**
  For any member of `pAttachments` with a `stencilLoadOp` equal to `VK_ATTACHMENT_LOAD_OP_CLEAR`, the first use of that attachment **must** not specify a layout equal to `VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL`, `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, or `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`.

- **VUID-VkRenderPassCreateInfo2-pDependencies-03054**
  For any element of `pDependencies`, if the `srcSubpass` is not `VK_SUBPASS_EXTERNAL`, all stage flags included in the `srcStageMask` member of that dependency **must** be a pipeline stage supported by the pipeline identified by the `pipelineBindPoint` member of the source.
subpass

- **VUID-VkRenderPassCreateInfo2-pDependencies-03055**
  For any element of `pDependencies`, if the `dstSubpass` is not `VK_SUBPASS_EXTERNAL`, all stage flags included in the `dstStageMask` member of that dependency must be a pipeline stage supported by the pipeline identified by the `pipelineBindPoint` member of the destination subpass.

- **VUID-VkRenderPassCreateInfo2-pCorrelatedViewMasks-03056**
  The set of bits included in any element of `pCorrelatedViewMasks` must not overlap with the set of bits included in any other element of `pCorrelatedViewMasks`.

- **VUID-VkRenderPassCreateInfo2-viewMask-03057**
  If the `viewMask` member of all elements of `pSubpasses` is 0, `correlatedViewMaskCount` must be 0.

- **VUID-VkRenderPassCreateInfo2-viewMask-03058**
  The `viewMask` member of all elements of `pSubpasses` must either all be 0, or all not be 0.

- **VUID-VkRenderPassCreateInfo2-viewMask-03059**
  If the `viewMask` member of all elements of `pSubpasses` is 0, the `dependencyFlags` member of any element of `pDependencies` must not include `VK_DEPENDENCY_VIEW_LOCAL_BIT`.

- **VUID-VkRenderPassCreateInfo2-pDependencies-03060**
  For any element of `pDependencies` where its `srcSubpass` member equals its `dstSubpass` member, if the `viewMask` member of the corresponding element of `pSubpasses` includes more than one bit, its `dependencyFlags` member must include `VK_DEPENDENCY_VIEW_LOCAL_BIT`.

- **VUID-VkRenderPassCreateInfo2-attachment-02525**
  If the `attachment` member of any element of the `pInputAttachments` member of any element of `pSubpasses` is not `VK_ATTACHMENT_UNUSED`, the `aspectMask` member of that element of `pInputAttachments` must only include aspects that are present in images of the format specified by the element of `pAttachments` specified by `attachment`.

- **VUID-VkRenderPassCreateInfo2-srcSubpass-02526**
  The `srcSubpass` member of each element of `pDependencies` must be less than `subpassCount`.

- **VUID-VkRenderPassCreateInfo2-dstSubpass-02527**
  The `dstSubpass` member of each element of `pDependencies` must be less than `subpassCount`.

- **VUID-VkRenderPassCreateInfo2-pAttachments-04585**
  If any element of `pAttachments` is used as a fragment shading rate attachment in any subpass, it must not be used as any other attachment in the render pass.

- **VUID-VkRenderPassCreateInfo2-flags-04521**
  If `flags` includes `VK_RENDER_PASS_CREATE_TRANSFORM_BIT_QCOM`, an element of `pSubpasses` includes an instance of `VkFragmentShadingRateAttachmentInfoKHR` in its `pNext` chain, and the `pFragmentShadingRateAttachment` member of that structure is not equal to `NULL`, the attachment member of `pFragmentShadingRateAttachment` must be `VK_ATTACHMENT_UNUSED`.

- **VUID-VkRenderPassCreateInfo2-pAttachments-04586**
  If any element of `pAttachments` is used as a fragment shading rate attachment in any
subpass, it must have an image format whose potential format features contain
VK_FORMAT_FEATURE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

- VUID-VkRenderPassCreateInfo2-rasterizationSamples-04905
  If the pipeline is being created with fragment shader state, and the
  VK_QCOM_render_pass_shader_resolve extension is enabled, and if subpass has any input
  attachments, and if the subpass description contains
  VK_SUBPASS_DESCRIPTION_FRAGMENT_REGION_BIT_QCOM, then the sample count of the input
  attachments must equal rasterizationSamples

- VUID-VkRenderPassCreateInfo2-sampleShadingEnable-04906
  If the pipeline is being created with fragment shader state, and the
  VK_QCOM_render_pass_shader_resolve extension is enabled, and if subpass has any input
  attachments, and if the subpass description contains
  VK_SUBPASS_DESCRIPTION_FRAGMENT_REGION_BIT_QCOM, then sampleShadingEnable
  must be false

- VUID-VkRenderPassCreateInfo2-flags-04907
  If flags includes VK_SUBPASS_DESCRIPTION_SHADER_RESOLVE_BIT_QCOM, and if
  pResolveAttachments is not NULL, then each resolve attachment must be
  VK_ATTACHMENT_UNUSED

- VUID-VkRenderPassCreateInfo2-flags-04908
  If flags includes VK_SUBPASS_DESCRIPTION_SHADER_RESOLVE_BIT_QCOM, and if
  pDepthStencilResolveAttachment is not NULL, then the depth/stencil resolve attachment
  must be VK_ATTACHMENT_UNUSED

- VUID-VkRenderPassCreateInfo2-flags-04909
  If flags includes VK_SUBPASS_DESCRIPTION_SHADER_RESOLVE_BIT_QCOM, then the subpass
  must be the last subpass in a subpass dependency chain

- VUID-VkRenderPassCreateInfo2-attachment-06244
  If the attachment member of the pDepthStencilAttachment member of an element of
  pSubpasses is not VK_ATTACHMENT_UNUSED, the layout member of that same structure is either
  VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL,
  and the pNext chain of that structure does not include a
  VkAttachmentReferenceStencilLayout structure, then the element of pAttachments with an
  index equal to attachment must not have a format that includes both depth and stencil
  components

- VUID-VkRenderPassCreateInfo2-attachment-06245
  If the attachment member of the pDepthStencilAttachment member of an element of
  pSubpasses is not VK_ATTACHMENT_UNUSED and the layout member of that same structure is
  either VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL or
  VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL, then the element of pAttachments with an
  index equal to attachment must have a format that includes only a stencil component

- VUID-VkRenderPassCreateInfo2-attachment-06246
  If the attachment member of the pDepthStencilAttachment member of an element of
  pSubpasses is not VK_ATTACHMENT_UNUSED and the layout member of that same structure is
  either VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL or
  VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL, then the element of pAttachments with an
  index equal to attachment must not have a format that includes only a stencil component
Valid Usage (Implicit)

- VUID-VkRenderPassCreateInfo2-sType-sType
  The \texttt{sType} \textbf{must} be \texttt{VK_STRUCTURE_TYPE_RENDER_PASS_CREATE_INFO_2}

- VUID-VkRenderPassCreateInfo2-pNext-pNext
  Each \texttt{pNext} member of any structure (including this one) in the \texttt{pNext} chain \textbf{must} be either \texttt{NULL} or a pointer to a valid instance of \texttt{VkRenderPassCreationControlEXT}, \texttt{VkRenderPassCreationFeedbackCreateInfoEXT}, or \texttt{VkRenderPassFragmentDensityMapCreateInfoEXT}

- VUID-VkRenderPassCreateInfo2-sType-unique
  The \texttt{sType} value of each struct in the \texttt{pNext} chain \textbf{must} be unique

- VUID-VkRenderPassCreateInfo2-flags-parameter
  \texttt{flags} \textbf{must} be a valid combination of \texttt{VkRenderPassCreateFlagBits} values

- VUID-VkRenderPassCreateInfo2-pAttachments-parameter
  If \texttt{attachmentCount} is not \texttt{0}, \texttt{pAttachments} \textbf{must} be a valid pointer to an array of \texttt{attachmentCount} valid \texttt{VkAttachmentDescription2} structures

- VUID-VkRenderPassCreateInfo2-pSubpasses-parameter
  \texttt{pSubpasses} \textbf{must} be a valid pointer to an array of \texttt{subpassCount} valid \texttt{VkSubpassDescription2} structures

- VUID-VkRenderPassCreateInfo2-pDependencies-parameter
  If \texttt{dependencyCount} is not \texttt{0}, \texttt{pDependencies} \textbf{must} be a valid pointer to an array of \texttt{dependencyCount} valid \texttt{VkSubpassDependency2} structures

- VUID-VkRenderPassCreateInfo2-pCorrelatedViewMasks-parameter
  If \texttt{correlatedViewMaskCount} is not \texttt{0}, \texttt{pCorrelatedViewMasks} \textbf{must} be a valid pointer to an array of \texttt{correlatedViewMaskCount \texttt{uint32_t}} values

- VUID-VkRenderPassCreateInfo2-subpassCount-arraylength
  \texttt{subpassCount} \textbf{must} be greater than \texttt{0}

The \texttt{VkAttachmentDescription2} structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkAttachmentDescription2 {
    VkStructureType sType;
    const void* pNext;
    VkAttachmentDescriptionFlags flags;
    VkFormat format;
    VkSampleCountFlagBits samples;
    VkAttachmentLoadOp loadOp;
    VkAttachmentStoreOp storeOp;
    VkAttachmentLoadOp stencilLoadOp;
    VkAttachmentStoreOp stencilStoreOp;
    VkImageLayout initialLayout;
    VkImageLayout finalLayout;
} VkAttachmentDescription2;
```
or the equivalent

```c
// Provided by VK_KHR_create_renderpass2
typedef VkAttachmentDescription2 VkAttachmentDescription2KHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is a bitmask of `VkAttachmentDescriptionFlagBits` specifying additional properties of the attachment.
- **format** is a `VkFormat` value specifying the format of the image that will be used for the attachment.
- **samples** is a `VkSampleCountFlagBits` value specifying the number of samples of the image.
- **loadOp** is a `VkAttachmentLoadOp` value specifying how the contents of color and depth components of the attachment are treated at the beginning of the subpass where it is first used.
- **storeOp** is a `VkAttachmentStoreOp` value specifying how the contents of color and depth components of the attachment are treated at the end of the subpass where it is last used.
- **stencilLoadOp** is a `VkAttachmentLoadOp` value specifying how the contents of stencil components of the attachment are treated at the beginning of the subpass where it is first used.
- **stencilStoreOp** is a `VkAttachmentStoreOp` value specifying how the contents of stencil components of the attachment are treated at the end of the last subpass where it is used.
- **initialLayout** is the layout the attachment image subresource will be in when a render pass instance begins.
- **finalLayout** is the layout the attachment image subresource will be transitioned to when a render pass instance ends.

Parameters defined by this structure with the same name as those in `VkAttachmentDescription` have the identical effect to those parameters.

If the `separateDepthStencilLayouts` feature is enabled, and **format** is a depth/stencil format, **initialLayout** and **finalLayout** can be set to a layout that only specifies the layout of the depth aspect.

If the `pNext` chain includes a `VkAttachmentDescriptionStencilLayout` structure, then the **stencilInitialLayout** and **stencilFinalLayout** members specify the initial and final layouts of the stencil aspect of a depth/stencil format, and **initialLayout** and **finalLayout** only apply to the depth aspect. For depth-only formats, the `VkAttachmentDescriptionStencilLayout` structure is ignored. For stencil-only formats, the initial and final layouts of the stencil aspect are taken from the `VkAttachmentDescriptionStencilLayout` structure if present, or **initialLayout** and **finalLayout** if not present.

If **format** is a depth/stencil format, and either **initialLayout** or **finalLayout** does not specify a layout for the stencil aspect, then the application **must** specify the initial and final layouts of the stencil aspect.
aspect by including a `VkAttachmentDescriptionStencilLayout` structure in the `pNext` chain.

### Valid Usage

- **VUID-VkAttachmentDescription2-format-06698**
  - `format must` not be `VK_FORMAT_UNDEFINED`

- **VUID-VkAttachmentDescription2-format-06699**
  - If `format` includes a color or depth component and `loadOp` is `VK_ATTACHMENT_LOAD_OP_LOAD`, then `initialLayout must` not be `VK_IMAGE_LAYOUT_UNDEFINED`

- **VUID-VkAttachmentDescription2-finalLayout-00843**
  - `finalLayout must` not be `VK_IMAGE_LAYOUT_UNDEFINED` or `VK_IMAGE_LAYOUT_PREINITIALIZED`

- **VUID-VkAttachmentDescription2-format-03280**
  - If `format` is a color format, `initialLayout must` not be `VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`

- **VUID-VkAttachmentDescription2-format-03281**
  - If `format` is a depth/stencil format, `initialLayout must` not be `VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL`

- **VUID-VkAttachmentDescription2-format-03282**
  - If `format` is a color format, `finalLayout must` not be `VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`

- **VUID-VkAttachmentDescription2-format-03283**
  - If `format` is a depth/stencil format, `finalLayout must` not be `VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL`

- **VUID-VkAttachmentDescription2-format-06487**
  - If `format` is a color format, `initialLayout must` not be `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`

- **VUID-VkAttachmentDescription2-format-06488**
  - If `format` is a color format, `finalLayout must` not be `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`

- **VUID-VkAttachmentDescription2-separateDepthStencilLayouts-03284**
  - If the `separateDepthStencilLayouts` feature is not enabled, `initialLayout must` not be `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL` or `VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`

- **VUID-VkAttachmentDescription2-separateDepthStencilLayouts-03285**
  - If the `separateDepthStencilLayouts` feature is not enabled, `finalLayout must` not be `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL` or `VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL` or `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`
- **VUID-VkAttachmentDescription2-format-03286**
  If *format* is a color format, *initialLayout* must not be
  
  VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL,
  VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL, or
  VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL

- **VUID-VkAttachmentDescription2-format-03287**
  If *format* is a color format, *finalLayout* must not be
  
  VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL,
  VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL, or
  VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL

- **VUID-VkAttachmentDescription2-format-06906**
  If *format* is a depth/stencil format which includes both depth and stencil components, *initialLayout* must not be
  
  VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL or
  VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL

- **VUID-VkAttachmentDescription2-format-06907**
  If *format* is a depth/stencil format which includes both depth and stencil components, *finalLayout* must not be
  
  VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL or
  VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL

- **VUID-VkAttachmentDescription2-format-03290**
  If *format* is a depth/stencil format which includes only the depth component, *initialLayout* must not be
  
  VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL or
  VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL

- **VUID-VkAttachmentDescription2-format-03291**
  If *format* is a depth/stencil format which includes only the depth component, *finalLayout* must not be
  
  VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL or
  VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL

- **VUID-VkAttachmentDescription2-synchronization2-06908**
  If the *synchronization2* feature is not enabled, *initialLayout* must not be
  
  VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL_KHR or VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR

- **VUID-VkAttachmentDescription2-synchronization2-06909**
  If the *synchronization2* feature is not enabled, *finalLayout* must not be
  
  VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL_KHR or VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR

- **VUID-VkAttachmentDescription2-attachmentFeedbackLoopLayout-07309**
  If the *attachmentFeedbackLoopLayout* feature is not enabled, *initialLayout* must not be
  
  VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT

- **VUID-VkAttachmentDescription2-attachmentFeedbackLoopLayout-07310**
  If the *attachmentFeedbackLoopLayout* feature is not enabled, *finalLayout* must not be
  
  VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT

- **VUID-VkAttachmentDescription2-samples-08745**
  *samples* must be a bit value that is set in *imageCreateSampleCounts* (as defined in *Image Creation Limits*) for the given *format*

- **VUID-VkAttachmentDescription2-pNext-06704**
  If the *pNext* chain does not include a *VkAttachmentDescriptionStencilLayout* structure,
format includes a stencil component, and stencilLoadOp is VK_ATTACHMENT_LOAD_OP_LOAD, then initialLayout must not be VK_IMAGE_LAYOUT_UNDEFINED

- VUID-VkAttachmentDescription2-pNext-06705
  If the pNext chain does includes a VkAttachmentDescriptionStencilLayout structure, format includes a stencil component, and stencilLoadOp is VK_ATTACHMENT_LOAD_OP_LOAD, then VkAttachmentDescriptionStencilLayout::stencilInitialLayout must not be VK_IMAGE_LAYOUT_UNDEFINED

- VUID-VkAttachmentDescription2-format-06249
  If format is a depth/stencil format which includes both depth and stencil components, and initialLayout is VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL, the pNext chain must include a VkAttachmentDescriptionStencilLayout structure

- VUID-VkAttachmentDescription2-format-06250
  If format is a depth/stencil format which includes both depth and stencil components, and finalLayout is VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL, the pNext chain must include a VkAttachmentDescriptionStencilLayout structure

- VUID-VkAttachmentDescription2-format-06247
  If the pNext chain does not include a VkAttachmentDescriptionStencilLayout structure and format only includes a stencil component, initialLayout must not be VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL

- VUID-VkAttachmentDescription2-format-06248
  If the pNext chain does not include a VkAttachmentDescriptionStencilLayout structure and format only includes a stencil component, finalLayout must not be VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL

### Valid Usage (Implicit)

- VUID-VkAttachmentDescription2-sType-sType
  sType must be VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_2

- VUID-VkAttachmentDescription2-pNext-pNext
  pNext must be NULL or a pointer to a valid instance of VkAttachmentDescriptionStencilLayout

- VUID-VkAttachmentDescription2-sType-unique
  The sType value of each struct in the pNext chain must be unique

- VUID-VkAttachmentDescription2-flags-parameter
  flags must be a valid combination of VkAttachmentDescriptionFlagBits values

- VUID-VkAttachmentDescription2-format-parameter
  format must be a valid VkFormat value

- VUID-VkAttachmentDescription2-samples-parameter
  samples must be a valid VkSampleCountFlagBits value

- VUID-VkAttachmentDescription2-loadOp-parameter
loadOp must be a valid VkAttachmentLoadOp value

- VUID-VkAttachmentDescription2-storeOp-parameter
  storeOp must be a valid VkAttachmentStoreOp value

- VUID-VkAttachmentDescription2-stencilLoadOp-parameter
  stencilLoadOp must be a valid VkAttachmentLoadOp value

- VUID-VkAttachmentDescription2-stencilStoreOp-parameter
  stencilStoreOp must be a valid VkAttachmentStoreOp value

- VUID-VkAttachmentDescription2-initialLayout-parameter
  initialLayout must be a valid VkImageLayout value

- VUID-VkAttachmentDescription2-finalLayout-parameter
  finalLayout must be a valid VkImageLayout value

The VkAttachmentDescriptionStencilLayout structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkAttachmentDescriptionStencilLayout {
    VkStructureType sType;
    void* pNext;
    VkImageLayout stencilInitialLayout;
    VkImageLayout stencilFinalLayout;
} VkAttachmentDescriptionStencilLayout;
```

or the equivalent

```c
// Provided by VK_KHR_separate_depth_stencil_layouts
typedef VkAttachmentDescriptionStencilLayout VkAttachmentDescriptionStencilLayoutKHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- stencilInitialLayout is the layout the stencil aspect of the attachment image subresource will be in when a render pass instance begins.
- stencilFinalLayout is the layout the stencil aspect of the attachment image subresource will be transitioned to when a render pass instance ends.

Valid Usage

- VUID-VkAttachmentDescriptionStencilLayout-stencilInitialLayout-03308
  stencilInitialLayout must not be VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL,
  VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL,
  VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL,
  VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL,
  VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL,
  VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL,
  or
VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL

- VUID-VkAttachmentDescriptionStencilLayout-stencilFinalLayout-03309
  stencilFinalLayout must not be VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL, or VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL

- VUID-VkAttachmentDescriptionStencilLayout-stencilFinalLayout-03310
  stencilFinalLayout must not be VK_IMAGE_LAYOUT_UNDEFINED or VK_IMAGE_LAYOUT_PREINITIALIZED

Valid Usage (Implicit)

- VUID-VkAttachmentDescriptionStencilLayout-sType-sType
  sType must be VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_STENCIL_LAYOUT

- VUID-VkAttachmentDescriptionStencilLayout-stencilInitialLayout-parameter
  stencilInitialLayout must be a valid VkImageLayout value

- VUID-VkAttachmentDescriptionStencilLayout-stencilFinalLayout-parameter
  stencilFinalLayout must be a valid VkImageLayout value

The VkSubpassDescription2 structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkSubpassDescription2 {
    VkStructureType sType;
    const void* pNext;
    VkSubpassDescriptionFlags flags;
    VkPipelineBindPoint pipelineBindPoint;
    uint32_t viewMask;
    uint32_t inputAttachmentCount;
    const VkAttachmentReference2* pInputAttachments;
    uint32_t colorAttachmentCount;
    const VkAttachmentReference2* pColorAttachments;
    const VkAttachmentReference2* pResolveAttachments;
    const VkAttachmentReference2* pDepthStencilAttachment;
    uint32_t preserveAttachmentCount;
    const uint32_t* pPreserveAttachments;
} VkSubpassDescription2;
```

or the equivalent

```c
// Provided by VK_KHR_create_renderpass2
typedef VkSubpassDescription2 VkSubpassDescription2KHR;
```
• **sType** is a VkStructureType value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **flags** is a bitmask of VkSubpassDescriptionFlagBits specifying usage of the subpass.

• **pipelineBindPoint** is a VkPipelineBindPoint value specifying the pipeline type supported for this subpass.

• **viewMask** is a bitfield of view indices describing which views rendering is broadcast to in this subpass, when multiview is enabled.

• **inputAttachmentCount** is the number of input attachments.

• **pInputAttachments** is a pointer to an array of VkAttachmentReference2 structures defining the input attachments for this subpass and their layouts.

• **colorAttachmentCount** is the number of color attachments.

• **pColorAttachments** is a pointer to an array of colorAttachmentCount VkAttachmentReference2 structures defining the color attachments for this subpass and their layouts.

• **pResolveAttachments** is NULL or a pointer to an array of colorAttachmentCount VkAttachmentReference2 structures defining the resolve attachments for this subpass and their layouts.

• **pDepthStencilAttachment** is a pointer to a VkAttachmentReference2 structure specifying the depth/stencil attachment for this subpass and its layout.

• **preserveAttachmentCount** is the number of preserved attachments.

• **pPreserveAttachments** is a pointer to an array of preserveAttachmentCount render pass attachment indices identifying attachments that are not used by this subpass, but whose contents must be preserved throughout the subpass.

Parameters defined by this structure with the same name as those in VkSubpassDescription have the identical effect to those parameters.

viewMask has the same effect for the described subpass as VkRenderPassMultiviewCreateInfo::pViewMasks has on each corresponding subpass.

If a VkFragmentShadingRateAttachmentInfoKHR structure is included in the pNext chain, pFragmentShadingRateAttachment is not NULL, and its attachment member is not VK_ATTACHMENT_UNUSED, the identified attachment defines a fragment shading rate attachment for that subpass.

---

**Valid Usage**

- VUID-VkSubpassDescription2-attachment-06912
  If the attachment member of an element of pInputAttachments is not VK_ATTACHMENT_UNUSED, its layout member must not be VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL.

- VUID-VkSubpassDescription2-attachment-06913
  If the attachment member of an element of pColorAttachments is not VK_ATTACHMENT_UNUSED, its layout member must not be VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL.
• VUID-VkSubpassDescription2-attachment-06914
  If the attachment member of an element of pResolveAttachments is not
  VK_ATTACHMENT_UNUSED, its layout member must not be
  VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL or
  VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL

• VUID-VkSubpassDescription2-attachment-06915
  If the attachment member of pDepthStencilAttachment is not VK_ATTACHMENT_UNUSED, its layout
  member must not be VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL or
  VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL

• VUID-VkSubpassDescription2-attachment-06916
  If the attachment member of an element of pColorAttachments is not VK_ATTACHMENT_UNUSED,
  its layout member must not be
  VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL or
  VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL

• VUID-VkSubpassDescription2-attachment-06917
  If the attachment member of an element of pResolveAttachments is not
  VK_ATTACHMENT_UNUSED, its layout member must not be
  VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL or
  VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL

• VUID-VkSubpassDescription2-attachment-06918
  If the attachment member of an element of pInputAttachments is not VK_ATTACHMENT_UNUSED,
  its layout member must not be VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_ATTACHMENT_OPTIMAL

• VUID-VkSubpassDescription2-attachment-06919
  If the attachment member of an element of pColorAttachments is not VK_ATTACHMENT_UNUSED,
  its layout member must not be
  VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL, or
  VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL

• VUID-VkSubpassDescription2-attachment-06920
  If the attachment member of an element of pResolveAttachments is not
  VK_ATTACHMENT_UNUSED, its layout member must not be
  VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL, or
  VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL

• VUID-VkSubpassDescription2-attachment-06921
  If the attachment member of an element of pInputAttachments is not VK_ATTACHMENT_UNUSED,
  its layout member must not be VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL_KHR

• VUID-VkSubpassDescription2-attachment-06922
  If the attachment member of an element of pColorAttachments is not VK_ATTACHMENT_UNUSED,
  its layout member must not be VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR

• VUID-VkSubpassDescription2-attachment-06923
  If the attachment member of an element of pResolveAttachments is not
  VK_ATTACHMENT_UNUSED, its layout member must not be
  VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR
If the attachment member of pDepthStencilAttachment is not VK_ATTACHMENT_UNUSED and its pNext chain includes a VkAttachmentReferenceStencilLayout structure, the layout member of pDepthStencilAttachment must not be VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL or VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL.

pipelineBindPoint must be VK_PIPELINE_BIND_POINT_GRAPHICS or VK_PIPELINE_BIND_POINT_SUBPASS_SHADING_HUAWEI.

colorAttachmentCount must be less than or equal to VkPhysicalDeviceLimits::maxColorAttachments.

If the first use of an attachment in this render pass is as an input attachment, and the attachment is not also used as a color or depth/stencil attachment in the same subpass, then loadOp must not be VK_ATTACHMENT_LOAD_OP_CLEAR.

If pResolveAttachments is not NULL, for each resolve attachment that does not have the value VK_ATTACHMENT_UNUSED, the corresponding color attachment must not have the value VK_ATTACHMENT_UNUSED.

If pResolveAttachments is not NULL, for each resolve attachment that is not VK_ATTACHMENT_UNUSED, the corresponding color attachment must not have a sample count of VK_SAMPLE_COUNT_1_BIT.

Each element of pResolveAttachments must have the same VkFormat as its corresponding color attachment.

If none of the VK_AMD_mixed_attachment_samples extension, the VK_NV_framebuffer_mixed_samples extension, or the multisampledRenderToSingleSampled feature are enabled, all attachments in pColorAttachments that are not VK_ATTACHMENT_UNUSED must have the same sample count.

All attachments in pInputAttachments that are not VK_ATTACHMENT_UNUSED must have image formats whose potential format features contain at least VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT or VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT.

All attachments in pColorAttachments that are not VK_ATTACHMENT_UNUSED must have image formats whose potential format features contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT.
• VUID-VkSubpassDescription2-pResolveAttachments-02899

All attachments in pResolveAttachments that are not VK_ATTACHMENT_UNUSED must have image formats whose potential format features contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT.

• VUID-VkSubpassDescription2-pDepthStencilAttachment-02900

If pDepthStencilAttachment is not NULL and the attachment is not VK_ATTACHMENT_UNUSED then it must have an image format whose potential format features contain VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT.

• VUID-VkSubpassDescription2-linearColorAttachment-06499

If the linearColorAttachment feature is enabled and the image is created with VK_IMAGE_TILING_LINEAR, all attachments in pInputAttachments that are not VK_ATTACHMENT_UNUSED must have image formats whose potential format features must contain VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV.

• VUID-VkSubpassDescription2-linearColorAttachment-06500

If the linearColorAttachment feature is enabled and the image is created with VK_IMAGE_TILING_LINEAR, all attachments in pColorAttachments that are not VK_ATTACHMENT_UNUSED must have image formats whose potential format features must contain VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV.

• VUID-VkSubpassDescription2-linearColorAttachment-06501

If the linearColorAttachment feature is enabled and the image is created with VK_IMAGE_TILING_LINEAR, all attachments in pResolveAttachments that are not VK_ATTACHMENT_UNUSED must have image formats whose potential format features must contain VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV.

• VUID-VkSubpassDescription2-pColorAttachments-03070

If the VK_AMD_mixed_attachment_samples extension is enabled, all attachments in pColorAttachments that are not VK_ATTACHMENT_UNUSED must have a sample count that is smaller than or equal to the sample count of pDepthStencilAttachment if it is not VK_ATTACHMENT_UNUSED.

• VUID-VkSubpassDescription2-pNext-06870

If the pNext chain includes a VkMultisampledRenderToSingleSampledInfoEXT structure with multisampledRenderToSingleSampledEnable equal to VK_TRUE, then all attachments in pColorAttachments and pDepthStencilAttachment that are not VK_ATTACHMENT_UNUSED must have a sample count that is either VK_SAMPLE_COUNT_1_BIT or equal to VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples.

• VUID-VkSubpassDescription2-pNext-06871

If the pNext chain includes a VkMultisampledRenderToSingleSampledInfoEXT structure with multisampledRenderToSingleSampledEnable equal to VK_TRUE, and pDepthStencilAttachment is not NULL, does not have the value VK_ATTACHMENT_UNUSED, and has a sample count of VK_SAMPLE_COUNT_1_BIT, the pNext chain must also include a VkSubpassDescriptionDepthStencilResolve structure with pDepthStencilResolveAttachment that is either NULL or has the value VK_ATTACHMENT_UNUSED.

• VUID-VkSubpassDescription2-multisampledRenderToSingleSampled-06872

If none of the VK_AMD_mixed_attachment_samples extension, the VK_NV_framebuffer_mixed_samples extension, or the multisampledRenderToSingleSampled feature are enabled, all attachments in pDepthStencilAttachment or pColorAttachments that...
are not `VK_ATTACHMENT_UNUSED` must have the same sample count

- **VUID-VkSubpassDescription2-attachment-03073**
  Each element of `pPreserveAttachments` must not be `VK_ATTACHMENT_UNUSED`

- **VUID-VkSubpassDescription2-pPreserveAttachments-03074**
  Each element of `pPreserveAttachments` must not also be an element of any other member of the subpass description

- **VUID-VkSubpassDescription2-layout-02528**
  If any attachment is used by more than one `VkAttachmentReference2` member, then each use must use the same layout

- **VUID-VkSubpassDescription2-flags-03076**
  If `flags` includes `VK_SUBPASS_DESCRIPTION_PER_VIEW_POSITION_X_ONLY_BIT_NVX`, it must also include `VK_SUBPASS_DESCRIPTION_PER_VIEW_ATTRIBUTES_BIT_NVX`

- **VUID-VkSubpassDescription2-attachment-02799**
  If the `attachment` member of any element of `pInputAttachments` is not `VK_ATTACHMENT_UNUSED`, then the `aspectMask` member must be a valid combination of `VkImageAspectFlagBits`

- **VUID-VkSubpassDescription2-attachment-02800**
  If the `attachment` member of any element of `pInputAttachments` is not `VK_ATTACHMENT_UNUSED`, then the `aspectMask` member must not be 0

- **VUID-VkSubpassDescription2-attachment-02801**
  If the `attachment` member of any element of `pInputAttachments` is not `VK_ATTACHMENT_UNUSED`, then the `aspectMask` member must not include `VK_IMAGE_ASPECT_METADATA_BIT`

- **VUID-VkSubpassDescription2-attachment-04563**
  If the `attachment` member of any element of `pInputAttachments` is not `VK_ATTACHMENT_UNUSED`, then the `aspectMask` member must not include `VK_IMAGE_ASPECT_MEMORY_PLANE_i_BIT_EXT` for any index `i`

- **VUID-VkSubpassDescription2-pDepthStencilAttachment-04440**
  An attachment must not be used in both `pDepthStencilAttachment` and `pColorAttachments`

- **VUID-VkSubpassDescription2-multiview-06558**
  If the multiview feature is not enabled, `viewMask` must be 0

- **VUID-VkSubpassDescription2-viewMask-06706**
  The index of the most significant bit in `viewMask` must be less than `maxMultiviewViewCount`

---

**Valid Usage (Implicit)**

- **VUID-VkSubpassDescription2-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_SUBPASS_DESCRIPTION_2`

- **VUID-VkSubpassDescription2-pNext-pNext**
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkFragmentShadingRateAttachmentInfoKHR`, `VkMultisampledRenderToSingleSampledInfoEXT`, `VkRenderPassCreationControlEXT`, `VkRenderPassSubpassFeedbackCreateInfoEXT`, or `VkSubpassDescriptionDepthStencilResolve`
• VUID-VkSubpassDescription2-sType-unique
  The sType value of each struct in the pNext chain must be unique.

• VUID-VkSubpassDescription2-flags-parameter
  flags must be a valid combination of VkSubpassDescriptionFlagBits values.

• VUID-VkSubpassDescription2-pipelineBindPoint-parameter
  pipelineBindPoint must be a valid VkPipelineBindPoint value.

• VUID-VkSubpassDescription2-pInputAttachments-parameter
  If inputAttachmentCount is not 0, pInputAttachments must be a valid pointer to an array of inputAttachmentCount valid VkAttachmentReference2 structures.

• VUID-VkSubpassDescription2-pColorAttachments-parameter
  If colorAttachmentCount is not 0, pColorAttachments must be a valid pointer to an array of colorAttachmentCount valid VkAttachmentReference2 structures.

• VUID-VkSubpassDescription2-pResolveAttachments-parameter
  If colorAttachmentCount is not 0, and pResolveAttachments is not NULL, pResolveAttachments must be a valid pointer to an array of colorAttachmentCount valid VkAttachmentReference2 structures.

• VUID-VkSubpassDescription2-pDepthStencilAttachment-parameter
  If pDepthStencilAttachment is not NULL, pDepthStencilAttachment must be a valid pointer to a valid VkAttachmentReference2 structure.

• VUID-VkSubpassDescription2-pPreserveAttachments-parameter
  If preserveAttachmentCount is not 0, pPreserveAttachments must be a valid pointer to an array of preserveAttachmentCount uint32_t values.

The VkSubpassDescriptionDepthStencilResolve structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkSubpassDescriptionDepthStencilResolve {
    VkStructureType sType;
    const void* pNext;
    VkResolveModeFlagBits depthResolveMode;
    VkResolveModeFlagBits stencilResolveMode;
    const VkAttachmentReference2* pDepthStencilResolveAttachment;
} VkSubpassDescriptionDepthStencilResolve;
```

or the equivalent

```c
// Provided by VK_KHR_depth_stencil_resolve
typedef VkSubpassDescriptionDepthStencilResolve
    VkSubpassDescriptionDepthStencilResolveKHR;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• depthResolveMode is a VkResolveModeFlagBits value describing the depth resolve mode.
• **stencilResolveMode** is a `VkResolveModeFlagBits` value describing the stencil resolve mode.

• **pDepthStencilResolveAttachment** is NULL or a pointer to a `VkAttachmentReference2` structure defining the depth/stencil resolve attachment for this subpass and its layout.

If the **pNext** chain of `VkSubpassDescription2` includes a `VkSubpassDescriptionDepthStencilResolve` structure, then that structure describes **multisample resolve operations** for the depth/stencil attachment in a subpass. If this structure is not included in the **pNext** chain of `VkSubpassDescription2`, or if it is and either **pDepthStencilResolveAttachment** is NULL or its attachment index is `VK_ATTACHMENT_UNUSED`, it indicates that no depth/stencil resolve attachment will be used in the subpass.

### Valid Usage

- **VUID-VkSubpassDescriptionDepthStencilResolve-pDepthStencilResolveAttachment-03177**
  If **pDepthStencilResolveAttachment** is not NULL and does not have the value `VK_ATTACHMENT_UNUSED`, **pDepthStencilAttachment** must not be NULL or have the value `VK_ATTACHMENT_UNUSED`.

- **VUID-VkSubpassDescriptionDepthStencilResolve-pDepthStencilResolveAttachment-03179**
  If **pDepthStencilResolveAttachment** is not NULL and does not have the value `VK_ATTACHMENT_UNUSED`, **pDepthStencilAttachment** must not have a sample count of `VK_SAMPLE_COUNT_1_BIT`.

- **VUID-VkSubpassDescriptionDepthStencilResolve-pDepthStencilResolveAttachment-03180**
  If **pDepthStencilResolveAttachment** is not NULL and does not have the value `VK_ATTACHMENT_UNUSED`, **pDepthStencilResolveAttachment** must have a sample count of `VK_SAMPLE_COUNT_1_BIT`.

- **VUID-VkSubpassDescriptionDepthStencilResolve-pDepthStencilResolveAttachment-02651**
  If **pDepthStencilResolveAttachment** is not NULL and does not have the value `VK_ATTACHMENT_UNUSED` then it must have an image format whose potential format features contain `VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT`.

- **VUID-VkSubpassDescriptionDepthStencilResolve-pDepthStencilResolveAttachment-03181**
  If **pDepthStencilResolveAttachment** is not NULL and does not have the value `VK_ATTACHMENT_UNUSED` and **VkFormat** of **pDepthStencilResolveAttachment** has a depth component, then the **VkFormat** of **pDepthStencilAttachment** must have a depth component with the same number of bits and numeric format.

- **VUID-VkSubpassDescriptionDepthStencilResolve-pDepthStencilResolveAttachment-03182**
  If **pDepthStencilResolveAttachment** is not NULL and does not have the value `VK_ATTACHMENT_UNUSED`, and **VkFormat** of **pDepthStencilResolveAttachment** has a stencil component, then the **VkFormat** of **pDepthStencilAttachment** must have a stencil component with the same number of bits and numeric format.

- **VUID-VkSubpassDescriptionDepthStencilResolve-pDepthStencilResolveAttachment-03178**
  If **pDepthStencilResolveAttachment** is not NULL and does not have the value `VK_ATTACHMENT_UNUSED`, **depthResolveMode** and **stencilResolveMode** must not both be `VK_RESOLVE_MODE_NONE`.

- **VUID-VkSubpassDescriptionDepthStencilResolve-depthResolveMode-03183**
If `pDepthStencilResolveAttachment` is not NULL and does not have the value
`VK_ATTACHMENT_UNUSED` and the `VkFormat` of `pDepthStencilResolveAttachment` has a depth
component, then the value of `depthResolveMode` must be one of the bits set in
`VkPhysicalDeviceDepthStencilResolveProperties::supportedDepthResolveModes` or
`VK_RESOLVE_MODE_NONE`

- VUID-VkSubpassDescriptionDepthStencilResolve-stencilResolveMode-03184
  If `pDepthStencilResolveAttachment` is not NULL and does not have the value
  `VK_ATTACHMENT_UNUSED` and the `VkFormat` of `pDepthStencilResolveAttachment` has a stencil
  component, then the value of `stencilResolveMode` must be one of the bits set in
  `VkPhysicalDeviceDepthStencilResolveProperties::supportedStencilResolveModes` or
  `VK_RESOLVE_MODE_NONE`

- VUID-VkSubpassDescriptionDepthStencilResolve-pDepthStencilResolveAttachment-03185
  If `pDepthStencilResolveAttachment` is not NULL and does not have the value
  `VK_ATTACHMENT_UNUSED`, the `VkFormat` of `pDepthStencilResolveAttachment` has both depth and
  stencil components, `VkPhysicalDeviceDepthStencilResolveProperties::independentResolve` is
  `VK_FALSE`, and `VkPhysicalDeviceDepthStencilResolveProperties::independentResolveNone` is
  `VK_FALSE`, then the values of `depthResolveMode` and `stencilResolveMode` must be identical
  or one of them must be `VK_RESOLVE_MODE_NONE`

- VUID-VkSubpassDescriptionDepthStencilResolve-pNext-06873
  If the `pNext` chain of `VkSubpassDescription2` includes a
  `VkMultisampledRenderToSingleSampledInfoEXT` structure, the
  `multisampledRenderToSingleSampledEnable` field is `VK_TRUE`, and `pDepthStencilAttachment`
  is not NULL and does not have the value `VK_ATTACHMENT_UNUSED`, `depthResolveMode` and
  `stencilResolveMode` must not both be `VK_RESOLVE_MODE_NONE`

- VUID-VkSubpassDescriptionDepthStencilResolve-pNext-06874
  If the `pNext` chain of `VkSubpassDescription2` includes a
  `VkMultisampledRenderToSingleSampledInfoEXT` structure whose
  `multisampledRenderToSingleSampledEnable` field is `VK_TRUE`, and `pDepthStencilAttachment`
  is not NULL, does not have the value `VK_ATTACHMENT_UNUSED`, and has a `VkFormat` that has a
  depth component, then the value of `depthResolveMode` must be one of the bits set in
  `VkPhysicalDeviceDepthStencilResolveProperties::supportedDepthResolveModes` or
  `VK_RESOLVE_MODE_NONE`

- VUID-VkSubpassDescriptionDepthStencilResolve-pNext-06875
  If the `pNext` chain of `VkSubpassDescription2` includes a
  `VkMultisampledRenderToSingleSampledInfoEXT` structure whose
  `multisampledRenderToSingleSampledEnable` field is `VK_TRUE`, and `pDepthStencilAttachment`
  is not NULL, does not have the value `VK_ATTACHMENT_UNUSED`, and has a `VkFormat` with a stencil
  component, then the value of `stencilResolveMode` must be one of the bits set in
  `VkPhysicalDeviceDepthStencilResolveProperties::supportedStencilResolveModes` or
VK_RESOLVE_MODE_NONE

- VUID-VkSubpassDescriptionDepthStencilResolve-pNext-06876
  If the pNext chain of VkSubpassDescription2 includes a VkMultisampledRenderToSingleSampledInfoEXT structure whose multisampledRenderToSingleSampledEnable field is VK_TRUE, pDepthStencilAttachment is not NULL, does not have the value VK_ATTACHMENT_UNUSED, and has a VkFormat with both depth and stencil components, and both VkPhysicalDeviceDepthStencilResolveProperties::independentResolve and VkPhysicalDeviceDepthStencilResolveProperties::independentResolveNone are VK_FALSE, then the values of depthResolveMode and stencilResolveMode must be identical.

- VUID-VkSubpassDescriptionDepthStencilResolve-pNext-06877
  If the pNext chain of VkSubpassDescription2 includes a VkMultisampledRenderToSingleSampledInfoEXT structure whose multisampledRenderToSingleSampledEnable field is VK_TRUE, pDepthStencilAttachment is not NULL, does not have the value VK_ATTACHMENT_UNUSED, and has a VkFormat with both depth and stencil components, VkPhysicalDeviceDepthStencilResolveProperties::independentResolve is VK_FALSE, and VkPhysicalDeviceDepthStencilResolveProperties::independentResolveNone is VK_TRUE, then the values of depthResolveMode and stencilResolveMode must be identical or one of them must be VK_RESOLVE_MODE_NONE.

Valid Usage (Implicit)

- VUID-VkSubpassDescriptionDepthStencilResolve-sType-sType
  sType must be VK_STRUCTURE_TYPE_SUBPASS_DESCRIPTION_DEPTH_STENCIL_RESOLVE

- VUID-VkSubpassDescriptionDepthStencilResolve-pDepthStencilResolveAttachment-parameter
  If pDepthStencilResolveAttachment is not NULL, pDepthStencilResolveAttachment must be a valid pointer to a valid VkAttachmentReference2 structure.

The VkFragmentShadingRateAttachmentInfoKHR structure is defined as:

```c
// Provided by VK_KHR_fragment_shading_rate
typedef struct VkFragmentShadingRateAttachmentInfoKHR {
    VkStructureType sType;
    const void* pNext;
    const VkAttachmentReference2* pFragmentShadingRateAttachment;
    VkExtent2D shadingRateAttachmentTexelSize;
} VkFragmentShadingRateAttachmentInfoKHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- pFragmentShadingRateAttachment is NULL or a pointer to a VkAttachmentReference2 structure defining the fragment shading rate attachment for this subpass.
• shadingRateAttachmentTexelSize specifies the size of the portion of the framebuffer corresponding to each texel in pFragmentShadingRateAttachment.

If no shading rate attachment is specified, or if this structure is not specified, the implementation behaves as if a valid shading rate attachment was specified with all texels specifying a single pixel per fragment.

**Valid Usage**

- **VUID-VkFragmentShadingRateAttachmentInfoKHR-pFragmentShadingRateAttachment-04524**
  If pFragmentShadingRateAttachment is not NULL and its attachment member is not VK_ATTACHMENT_UNUSED, its layout member **must** be equal to VK_IMAGE_LAYOUT_GENERAL or VK_IMAGE_LAYOUT_FRAGMENT_SHADING_RATE_ATTACHMENT_OPTIMAL_KHR

- **VUID-VkFragmentShadingRateAttachmentInfoKHR-pFragmentShadingRateAttachment-04525**
  If pFragmentShadingRateAttachment is not NULL and its attachment member is not VK_ATTACHMENT_UNUSED, shadingRateAttachmentTexelSize.width **must** be a power of two value

- **VUID-VkFragmentShadingRateAttachmentInfoKHR-pFragmentShadingRateAttachment-04526**
  If pFragmentShadingRateAttachment is not NULL and its attachment member is not VK_ATTACHMENT_UNUSED, shadingRateAttachmentTexelSize.width **must** be less than or equal to maxFragmentShadingRateAttachmentTexelSize.width

- **VUID-VkFragmentShadingRateAttachmentInfoKHR-pFragmentShadingRateAttachment-04527**
  If pFragmentShadingRateAttachment is not NULL and its attachment member is not VK_ATTACHMENT_UNUSED, shadingRateAttachmentTexelSize.width **must** be greater than or equal to minFragmentShadingRateAttachmentTexelSize.width

- **VUID-VkFragmentShadingRateAttachmentInfoKHR-pFragmentShadingRateAttachment-04528**
  If pFragmentShadingRateAttachment is not NULL and its attachment member is not VK_ATTACHMENT_UNUSED, shadingRateAttachmentTexelSize.height **must** be a power of two value

- **VUID-VkFragmentShadingRateAttachmentInfoKHR-pFragmentShadingRateAttachment-04529**
  If pFragmentShadingRateAttachment is not NULL and its attachment member is not VK_ATTACHMENT_UNUSED, shadingRateAttachmentTexelSize.height **must** be less than or equal to maxFragmentShadingRateAttachmentTexelSize.height

- **VUID-VkFragmentShadingRateAttachmentInfoKHR-pFragmentShadingRateAttachment-04530**
  If pFragmentShadingRateAttachment is not NULL and its attachment member is not VK_ATTACHMENT_UNUSED, shadingRateAttachmentTexelSize.height **must** be greater than or equal to minFragmentShadingRateAttachmentTexelSize.height
04531

If `pFragmentShadingRateAttachment` is not `NULL` and its `attachment` member is not `VK_ATTACHMENT_UNUSED`, the quotient of `shadingRateAttachmentTexelSize.width` and `shadingRateAttachmentTexelSize.height` must be less than or equal to `maxFragmentShadingRateAttachmentTexelSizeAspectRatio`

- VUID-VkFragmentShadingRateAttachmentInfoKHR-pFragmentShadingRateAttachment-04532

If `pFragmentShadingRateAttachment` is not `NULL` and its `attachment` member is not `VK_ATTACHMENT_UNUSED`, the quotient of `shadingRateAttachmentTexelSize.height` and `shadingRateAttachmentTexelSize.width` must be less than or equal to `maxFragmentShadingRateAttachmentTexelSizeAspectRatio`

**Valid Usage (Implicit)**

- VUID-VkFragmentShadingRateAttachmentInfoKHR-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_FRAGMENT_SHADING_RATE_ATTACHMENT_INFO_KHR`

- VUID-VkFragmentShadingRateAttachmentInfoKHR-pFragmentShadingRateAttachment-parameter
  If `pFragmentShadingRateAttachment` is not `NULL`, `pFragmentShadingRateAttachment` must be a valid pointer to a valid `VkAttachmentReference2` structure

If the `pNext` chain of `VkSubpassDescription2` or `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure, then that structure describes how multisampled rendering is performed on single sampled attachments in that subpass.

The `VkMultisampledRenderToSingleSampledInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_multisampled_render_to_single_sampled
typedef struct VkMultisampledRenderToSingleSampledInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkBool32 multisampledRenderToSingleSampledEnable;
    VkSampleCountFlagBits rasterizationSamples;
} VkMultisampledRenderToSingleSampledInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `multisampledRenderToSingleSampledEnable` controls whether multisampled rendering to single-sampled attachments is performed as described below.
- `rasterizationSamples` is a `VkSampleCountFlagBits` specifying the number of samples used in rasterization.
Valid Usage

- VUID-VkMultisampledRenderToSingleSampledInfoEXT-rasterizationSamples-06878
  The value of `rasterizationSamples` must not be `VK_SAMPLE_COUNT_1_BIT`

- VUID-VkMultisampledRenderToSingleSampledInfoEXT-pNext-06880
  If added to the `pNext` chain of `VkRenderingInfo`, each `imageView` member of any element of
  `VkRenderingInfo::pColorAttachments`, `VkRenderingInfo::pDepthAttachment`, or
  `VkRenderingInfo::pStencilAttachment` that is not `VK_NULL_HANDLE` must have a format
  that supports the sample count specified in `rasterizationSamples`

Valid Usage (Implicit)

- VUID-VkMultisampledRenderToSingleSampledInfoEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_INFO_EXT`

- VUID-VkMultisampledRenderToSingleSampledInfoEXT-rasterizationSamples-parameter
  `rasterizationSamples` must be a valid `VkSampleCountFlagBits` value

If the `pNext` chain of `VkSubpassDescription2` or `VkRenderingInfo` includes a
`VkMultisampledRenderToSingleSampledInfoEXT` structure whose
`multisampledRenderToSingleSampledEnable` field is `VK_TRUE`, the graphics pipelines must have
`VkGraphicsPipelineCreateInfo::rasterizationSamples` equal to
`VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples`, and the subpass attachments can have a sample count of `VK_SAMPLE_COUNT_1_BIT`. For attachments with a sample count of `VK_SAMPLE_COUNT_1_BIT`, multisampled rendering is performed to an intermediate multisampled image with `VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples` samples, implicitly allocated by the implementation for the duration of the subpass. For such attachments:

- If `loadOp` equals to `VK_ATTACHMENT_LOAD_OP_LOAD`, samples of the implicit image are initialized by
  replicating the value from the corresponding pixel in the attachment.

- If `storeOp` or `stencilStoreOp` is equal to `VK_ATTACHMENT_STORE_OP_STORE`, the implicit image is
  implicitly resolved prior to storage in the attachment.

Memory constraints due to high primitive counts may result in an implicit split of the subpass. This is the equivalent of partial rasterization of geometry in a render pass that ends in `storeOp` and `stencilStoreOp` equal to `VK_ATTACHMENT_STORE_OP_STORE`, followed by another render pass with `loadOp` and `stencilLoadOp` equal to `VK_ATTACHMENT_LOAD_OP_LOAD` with appropriate barriers in between. When `VkMultisampledRenderToSingleSampledInfoEXT` is used, the implementation is allowed to resolve attachments with a sample count of `VK_SAMPLE_COUNT_1_BIT` and lose multisampled data on such splits. The implementation may similarly split the render pass at subpass boundaries even if they use the same value for `VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples`.

The `VkAttachmentReference2` structure is defined as:

```c
// Provided by VK_VERSION_1_2
```
```
typedef struct VkAttachmentReference2 {
    VkStructureType sType;
    const void* pNext;
    uint32_t attachment;
    VkImageLayout layout;
    VkImageAspectFlags aspectMask;
} VkAttachmentReference2;
```

or the equivalent

```
// Provided by VK_KHR_create_renderpass2
typedef VkAttachmentReference2 VkAttachmentReference2KHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **attachment** is either an integer value identifying an attachment at the corresponding index in `VkRenderPassCreateInfo2::pAttachments`, or `VK_ATTACHMENT_UNUSED` to signify that this attachment is not used.
- **layout** is a `VkImageLayout` value specifying the layout the attachment uses during the subpass.
- **aspectMask** is a mask of which aspect(s) **can** be accessed within the specified subpass as an input attachment.

Parameters defined by this structure with the same name as those in `VkAttachmentReference` have the identical effect to those parameters.

**aspectMask** is ignored when this structure is used to describe anything other than an input attachment reference.

If the `separateDepthStencilLayouts` feature is enabled, and **attachment** has a depth/stencil format, **layout** can be set to a layout that only specifies the layout of the depth aspect.

If **layout** only specifies the layout of the depth aspect of the attachment, the layout of the stencil aspect is specified by the **stencilLayout** member of a `VkAttachmentReferenceStencilLayout` structure included in the **pNext** chain. Otherwise, **layout** describes the layout for all relevant image aspects.

### Valid Usage

- **VUID-VkAttachmentReference2-layout-03077**
  If **attachment** is not `VK_ATTACHMENT_UNUSED`, **layout** must not be `VK_IMAGE_LAYOUT_UNDEFINED`, `VK_IMAGE_LAYOUT_PREINITIALIZED`, or `VK_IMAGE_LAYOUT_PRESENT_SRC_KHR`

- **VUID-VkAttachmentReference2-separateDepthStencilLayouts-03313**
  If the `separateDepthStencilLayouts` feature is not enabled, and **attachment** is not `VK_ATTACHMENT_UNUSED`, **layout** must not be `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL`, `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, `VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL`, or `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`,
• VUID-VkAttachmentReference2-synchronization2-06910
  If the synchronization2 feature is not enabled, layout must not be
  VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL_KHR or VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR

• VUID-VkAttachmentReference2-attachmentFeedbackLoopLayout-07311
  If the attachmentFeedbackLoopLayout feature is not enabled, layout must not be
  VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT

## Valid Usage (Implicit)

• VUID-VkAttachmentReference2-sType-sType
  `sType` must be VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_2

• VUID-VkAttachmentReference2-pNext-pNext
  `pNext` must be NULL or a pointer to a valid instance of
  VkAttachmentReferenceStencilLayout

• VUID-VkAttachmentReference2-sType-unique
  The `sType` value of each struct in the `pNext` chain must be unique

• VUID-VkAttachmentReference2-layout-parameter
  layout must be a valid VkImageLayout value

The VkAttachmentReferenceStencilLayout structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkAttachmentReferenceStencilLayout {
    VkStructureType sType;
    void* pNext;
    VkImageLayout stencilLayout;
} VkAttachmentReferenceStencilLayout;
```

or the equivalent

```c
// Provided by VK_KHR_separate_depthStencil_layouts
typedef VkAttachmentReferenceStencilLayout VkAttachmentReferenceStencilLayoutKHR;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `stencilLayout` is a VkImageLayout value specifying the layout the stencil aspect of the
  attachment uses during the subpass.

## Valid Usage

• VUID-VkAttachmentReferenceStencilLayout-stencilLayout-03318
  `stencilLayout` must not be VK_IMAGE_LAYOUT_UNDEFINED, VK_IMAGE_LAYOUT_PREINITIALIZED,
VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL,
VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL,
VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL,
VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL,
VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL,
VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL, or
VK_IMAGE_LAYOUT_PRESENT_SRC_KHR

Valid Usage (Implicit)

• VUID-VkAttachmentReferenceStencilLayout-sType-sType
  sType must be VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_STENCIL_LAYOUT

• VUID-VkAttachmentReferenceStencilLayout-stencilLayout-parameter
  stencilLayout must be a valid VkImageLayout value

The VkSubpassDependency2 structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkSubpassDependency2 {
    VkStructureType sType;
    const void* pNext;
    uint32_t srcSubpass;
    uint32_t dstSubpass;
    VkPipelineStageFlags srcStageMask;
    VkPipelineStageFlags dstStageMask;
    VkAccessFlags srcAccessMask;
    VkAccessFlags dstAccessMask;
    VkDependencyFlags dependencyFlags;
    int32_t viewOffset;
} VkSubpassDependency2;
```

or the equivalent

```c
// Provided by VK_KHR_create_renderpass2
typedef VkSubpassDependency2 VkSubpassDependency2KHR;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• srcSubpass is the subpass index of the first subpass in the dependency, or VK_SUBPASS_EXTERNAL.
• dstSubpass is the subpass index of the second subpass in the dependency, or VK_SUBPASS_EXTERNAL.
• srcStageMask is a bitmask of VkPipelineStageFlagBits specifying the source stage mask.
• dstStageMask is a bitmask of VkPipelineStageFlagBits specifying the destination stage mask.
• `srcAccessMask` is a bitmask of `VkAccessFlagBits` specifying a source access mask.
• `dstAccessMask` is a bitmask of `VkAccessFlagBits` specifying a destination access mask.
• `dependencyFlags` is a bitmask of `VkDependencyFlagBits`.
• `viewOffset` controls which views in the source subpass the views in the destination subpass depend on.

Parameters defined by this structure with the same name as those in `VkSubpassDependency` have the identical effect to those parameters.

`viewOffset` has the same effect for the described subpass dependency as `VkRenderPassMultiviewCreateInfo::pViewOffsets` has on each corresponding subpass dependency.

If a `VkMemoryBarrier2` is included in the `pNext` chain, `srcStageMask`, `dstStageMask`, `srcAccessMask`, and `dstAccessMask` parameters are ignored. The synchronization and access scopes instead are defined by the parameters of `VkMemoryBarrier2`.

### Valid Usage

- **VUID-VkSubpassDependency2-srcStageMask-04090**
  If the geometryShader feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT`

- **VUID-VkSubpassDependency2-srcStageMask-04091**
  If the tessellationShader feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT` or `VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT`

- **VUID-VkSubpassDependency2-srcStageMask-04092**
  If the conditionalRendering feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT`

- **VUID-VkSubpassDependency2-srcStageMask-04093**
  If the fragmentDensityMap feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT`

- **VUID-VkSubpassDependency2-srcStageMask-04094**
  If the transformFeedback feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT`

- **VUID-VkSubpassDependency2-srcStageMask-04095**
  If the meshShader feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT`

- **VUID-VkSubpassDependency2-srcStageMask-04096**
  If the taskShader feature is not enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT`

- **VUID-VkSubpassDependency2-srcStageMask-07318**
  If neither the shadingRateImage or attachmentFragmentShadingRate are enabled, `srcStageMask` must not contain `VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`
• VUID-VkSubpassDependency2-srcStageMask-03937
  If the synchronization feature is not enabled, srcStageMask must not be 0

• VUID-VkSubpassDependency2-srcStageMask-07949
  If neither the VK_NV_ray_tracing extension or rayTracingPipeline feature are enabled, srcStageMask must not contain VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR

• VUID-VkSubpassDependency2-dstStageMask-04090
  If the geometryShader feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT

• VUID-VkSubpassDependency2-dstStageMask-04091
  If the tessellationShader feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT or VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT

• VUID-VkSubpassDependency2-dstStageMask-04092
  If the conditionalRendering feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT

• VUID-VkSubpassDependency2-dstStageMask-04093
  If the fragmentDensityMap feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT

• VUID-VkSubpassDependency2-dstStageMask-04094
  If the transformFeedback feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT

• VUID-VkSubpassDependency2-dstStageMask-04095
  If the meshShader feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT

• VUID-VkSubpassDependency2-dstStageMask-04096
  If the taskShader feature is not enabled, dstStageMask must not contain VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT

• VUID-VkSubpassDependency2-dstStageMask-07318
  If neither the shadingRateImage or attachmentFragmentShadingRate are enabled, dstStageMask must not contain VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

• VUID-VkSubpassDependency2-dstStageMask-03937
  If the synchronization feature is not enabled, dstStageMask must not be 0

• VUID-VkSubpassDependency2-dstStageMask-07949
  If neither the VK_NV_ray_tracing extension or rayTracingPipeline feature are enabled, dstStageMask must not contain VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR

• VUID-VkSubpassDependency2-srcSubpass-03084
  srcSubpass must be less than or equal to dstSubpass, unless one of them is VK_SUBPASS_EXTERNAL, to avoid cyclic dependencies and ensure a valid execution order

• VUID-VkSubpassDependency2-srcSubpass-03085
  srcSubpass and dstSubpass must not both be equal to VK_SUBPASS_EXTERNAL

• VUID-VkSubpassDependency2-srcSubpass-06810
If \texttt{srcSubpass} is equal to \texttt{dstSubpass} and \texttt{srcStageMask} includes a framebuffer-space stage, \texttt{dstStageMask} must only contain framebuffer-space stages

- **VUID-VkSubpassDependency2-srcAccessMask-03088**: Any access flag included in \texttt{srcAccessMask} must be supported by one of the pipeline stages in \texttt{srcStageMask}, as specified in the table of supported access types.

- **VUID-VkSubpassDependency2-dstAccessMask-03089**: Any access flag included in \texttt{dstAccessMask} must be supported by one of the pipeline stages in \texttt{dstStageMask}, as specified in the table of supported access types.

- **VUID-VkSubpassDependency2-dependencyFlags-03090**: If \texttt{dependencyFlags} includes \texttt{VK_DEPENDENCY_VIEW_LOCAL_BIT}, \texttt{srcSubpass} must not be equal to \texttt{VK_SUBPASS_EXTERNAL}.

- **VUID-VkSubpassDependency2-dependencyFlags-03091**: If \texttt{dependencyFlags} includes \texttt{VK_DEPENDENCY_VIEW_LOCAL_BIT}, \texttt{dstSubpass} must not be equal to \texttt{VK_SUBPASS_EXTERNAL}.

- **VUID-VkSubpassDependency2-srcSubpass-02245**: If \texttt{srcSubpass} equals \texttt{dstSubpass}, and \texttt{srcStageMask} and \texttt{dstStageMask} both include a framebuffer-space stage, then \texttt{dependencyFlags} must include \texttt{VK_DEPENDENCY_BY_REGION_BIT}.

- **VUID-VkSubpassDependency2-viewOffset-02530**: If \texttt{viewOffset} is not equal to 0, \texttt{srcSubpass} must not be equal to \texttt{dstSubpass}.

- **VUID-VkSubpassDependency2-dependencyFlags-03092**: If \texttt{dependencyFlags} does not include \texttt{VK_DEPENDENCY_VIEW_LOCAL_BIT}, \texttt{viewOffset} must be 0.

### Valid Usage (Implicit)

- **VUID-VkSubpassDependency2-sType-sType**: \texttt{sType} must be \texttt{VK_STRUCTURE_TYPE_SUBPASS_DEPENDENCY_2}.

- **VUID-VkSubpassDependency2-pNext-pNext**: \texttt{pNext} must be \texttt{NULL} or a pointer to a valid instance of \texttt{VkMemoryBarrier2}.

- **VUID-VkSubpassDependency2-sType-unique**: The \texttt{sType} value of each struct in the \texttt{pNext} chain must be unique.

- **VUID-VkSubpassDependency2-srcStageMask-parameter**: \texttt{srcStageMask} must be a valid combination of \texttt{VkPipelineStageFlagBits} values.

- **VUID-VkSubpassDependency2-dstStageMask-parameter**: \texttt{dstStageMask} must be a valid combination of \texttt{VkPipelineStageFlagBits} values.

- **VUID-VkSubpassDependency2-srcAccessMask-parameter**: \texttt{srcAccessMask} must be a valid combination of \texttt{VkAccessFlagBits} values.

- **VUID-VkSubpassDependency2-dstAccessMask-parameter**: \texttt{dstAccessMask} must be a valid combination of \texttt{VkAccessFlagBits} values.

- **VUID-VkSubpassDependency2-dependencyFlags-parameter**: \texttt{dependencyFlags} must be a valid combination of \texttt{VkDependencyFlagBits} values.
To destroy a render pass, call:

```c
// Provided by VK_VERSION_1_0
void vkDestroyRenderPass(
    VkDevice device,
    VkRenderPass renderPass,
    const VkAllocationCallbacks* pAllocator);
```

- **device** is the logical device that destroys the render pass.
- **renderPass** is the handle of the render pass to destroy.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.

**Valid Usage**

- VUID-vkDestroyRenderPass-renderPass-00873
  All submitted commands that refer to **renderPass** must have completed execution.

- VUID-vkDestroyRenderPass-renderPass-00874
  If **VkAllocationCallbacks** were provided when **renderPass** was created, a compatible set of callbacks must be provided here.

- VUID-vkDestroyRenderPass-renderPass-00875
  If no **VkAllocationCallbacks** were provided when **renderPass** was created, **pAllocator** must be **NULL**.

**Valid Usage (Implicit)**

- VUID-vkDestroyRenderPass-device-parameter
  **device** must be a valid **VkDevice** handle.

- VUID-vkDestroyRenderPass-renderPass-parameter
  If **renderPass** is not **VK_NULL_HANDLE**, **renderPass** must be a valid **VkRenderPass** handle.

- VUID-vkDestroyRenderPass-pAllocator-parameter
  If **pAllocator** is not **NULL**, **pAllocator** must be a valid pointer to a valid **VkAllocationCallbacks** structure.

- VUID-vkDestroyRenderPass-renderPass-parent
  If **renderPass** is a valid handle, it must have been created, allocated, or retrieved from **device**.

**Host Synchronization**

- Host access to **renderPass** must be externally synchronized.
8.3. Render Pass Compatibility

Framebuffers and graphics pipelines are created based on a specific render pass object. They must only be used with that render pass object, or one compatible with it.

Two attachment references are compatible if they have matching format and sample count, or are both VK_ATTACHMENT_UNUSED or the pointer that would contain the reference is NULL.

Two arrays of attachment references are compatible if all corresponding pairs of attachments are compatible. If the arrays are of different lengths, attachment references not present in the smaller array are treated as VK_ATTACHMENT_UNUSED.

Two render passes are compatible if their corresponding color, input, resolve, and depth/stencil attachment references are compatible and if they are otherwise identical except for:

- Initial and final image layout in attachment descriptions
- Load and store operations in attachment descriptions
- Image layout in attachment references

As an additional special case, if two render passes have a single subpass, the resolve attachment reference and depth/stencil resolve mode compatibility requirements are ignored.

A framebuffer is compatible with a render pass if it was created using the same render pass or a compatible render pass.

8.4. Framebuffers

Render passes operate in conjunction with framebuffers. Framebuffers represent a collection of specific memory attachments that a render pass instance uses.

Framebuffers are represented by VkFramebuffer handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkFramebuffer)
```

To create a framebuffer, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkCreateFramebuffer(
    VkDevice device, 
    const VkFramebufferCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator, 
    VkFramebuffer* pFramebuffer);
```

- `device` is the logical device that creates the framebuffer.
- `pCreateInfo` is a pointer to a VkFramebufferCreateInfo structure describing additional
information about framebuffer creation.

- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
- **pFramebuffer** is a pointer to a VkFramebuffer handle in which the resulting framebuffer object is returned.

### Valid Usage

- VUID-vkCreateFramebuffer-pCreateInfo-02777
  
  If `pCreateInfo->flags` does not include `VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT`, and `attachmentCount` is not 0, each element of `pCreateInfo->pAttachments` must have been created on `device`.

### Valid Usage (Implicit)

- VUID-vkCreateFramebuffer-device-parameter
  
  `device` must be a valid `VkDevice` handle.

- VUID-vkCreateFramebuffer-pCreateInfo-parameter
  
  `pCreateInfo` must be a valid pointer to a valid `VkFramebufferCreateInfo` structure.

- VUID-vkCreateFramebuffer-pAllocator-parameter
  
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure.

- VUID-vkCreateFramebuffer-pFramebuffer-parameter
  
  `pFramebuffer` must be a valid pointer to a `VkFramebuffer` handle.

### Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

The `VkFramebufferCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkFramebufferCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkFramebufferCreateFlags flags;
    VkRenderPass renderPass;
    uint32_t attachmentCount;
    const VkImageView* pAttachments;
} VkFramebufferCreateInfo;
```
uint32_t width;
uint32_t height;
uint32_t layers;
} VkFramebufferCreateInfo;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is a bitmask of `VkFramebufferCreateFlagBits`
- **renderPass** is a render pass defining what render passes the framebuffer will be compatible with. See [Render Pass Compatibility](#) for details.
- **attachmentCount** is the number of attachments.
- **pAttachments** is a pointer to an array of `VkImageView` handles, each of which will be used as the corresponding attachment in a render pass instance. If **flags** includes `VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT`, this parameter is ignored.
- **width**, **height** and **layers** define the dimensions of the framebuffer. If the render pass uses multiview, then **layers must** be one and each attachment requires a number of layers that is greater than the maximum bit index set in the view mask in the subpasses in which it is used.

It is legal for a subpass to use no color or depth/stencil attachments, either because it has no attachment references or because all of them are `VK_ATTACHMENT_UNUSED`. This kind of subpass can use shader side effects such as image stores and atomics to produce an output. In this case, the subpass continues to use the **width**, **height**, and **layers** of the framebuffer to define the dimensions of the rendering area, and the **rasterizationSamples** from each pipeline's `VkPipelineMultisampleStateCreateInfo` to define the number of samples used in rasterization; however, if `VkPhysicalDeviceFeatures::variableMultisampleRate` is `VK_FALSE`, then all pipelines to be bound with the subpass **must** have the same value for `VkPipelineMultisampleStateCreateInfo::rasterizationSamples`. In all such cases, **rasterizationSamples must** be a bit value that is set in `VkPhysicalDeviceLimits::framebufferNoAttachmentsSampleCounts`.

### Valid Usage

- **VUID-VkFramebufferCreateInfo-attachmentCount-00876**
  attachmentCount **must** be equal to the attachment count specified in **renderPass**

- **VUID-VkFramebufferCreateInfo-flags-02778**
  If **flags** does not include `VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT` and attachmentCount is not 0, **pAttachments** **must** be a valid pointer to an array of attachmentCount valid `VkImageView` handles

- **VUID-VkFramebufferCreateInfo-pAttachments-00877**
  If **flags** does not include `VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT`, each element of **pAttachments** that is used as a color attachment or resolve attachment by **renderPass** **must** have been created with a usage value including `VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT`

- **VUID-VkFramebufferCreateInfo-pAttachments-02633**
  If **flags** does not include `VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT`, each element of **pAttachments** that is used as a depth/stencil attachment by **renderPass** **must** have been
created with a usage value including VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT

- **VUID-VkFramebufferCreateInfo-pAttachments-02634**
  If flags does not include VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of pAttachments that is used as a depth/stencil resolve attachment by renderPass must have been created with a usage value including VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT

- **VUID-VkFramebufferCreateInfo-pAttachments-00879**
  If renderpass is not VK_NULL_HANDLE, flags does not include VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of pAttachments that is used as an input attachment by renderPass must have been created with a usage value including VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT

- **VUID-VkFramebufferCreateInfo-pAttachments-02552**
  Each element of pAttachments that is used as a fragment density map attachment by renderPass must not have been created with a flags value including VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT

- **VUID-VkFramebufferCreateInfo-renderPass-02553**
  If renderPass has a fragment density map attachment and the fragmentDensityMapNonSubsampledImages feature is not enabled, each element of pAttachments must have been created with a flags value including VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT unless that element is the fragment density map attachment

- **VUID-VkFramebufferCreateInfo-renderPass-06502**
  If renderPass was created with fragment density map offsets other than (0,0), each element of pAttachments must have been created with a flags value including VK_IMAGE_CREATE_FRAGMENT_DENSITY_MAP_OFFSET_BIT_QCOM

- **VUID-VkFramebufferCreateInfo-pAttachments-00880**
  If flags does not include VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of pAttachments must have been created with a VkFormat value that matches the VkFormat specified by the corresponding VkAttachmentDescription in renderPass

- **VUID-VkFramebufferCreateInfo-pAttachments-00881**
  If flags does not include VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of pAttachments must have been created with a samples value that matches the samples value specified by the corresponding VkAttachmentDescription in renderPass

- **VUID-VkFramebufferCreateInfo-flags-04533**
  If flags does not include VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of pAttachments that is used as an input, color, resolve, or depth/stencil attachment by renderPass must have been created with a VkImageCreateInfo::extent.width greater than or equal to width

- **VUID-VkFramebufferCreateInfo-flags-04534**
  If flags does not include VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of pAttachments that is used as an input, color, resolve, or depth/stencil attachment by renderPass must have been created with a VkImageCreateInfo::extent.height greater than or equal to height

- **VUID-VkFramebufferCreateInfo-flags-04535**
  If flags does not include VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of
pAttachments that is used as an input, color, resolve, or depth/stencil attachment by renderPass must have been created with a VkImageViewCreateInfo::subresourceRange.layerCount greater than or equal to layers

• VUID-VkFramebufferCreateInfo-renderPass-04536
  If renderPass was specified with non-zero view masks, each element of pAttachments that is used as an input, color, resolve, or depth/stencil attachment by renderPass must have a layerCount greater than the index of the most significant bit set in any of those view masks

• VUID-VkFramebufferCreateInfo-renderPass-02746
  If renderPass was specified with non-zero view masks, each element of pAttachments that is referenced by fragmentDensityMapAttachment must have a layerCount equal to 1 or greater than the index of the most significant bit set in any of those view masks

• VUID-VkFramebufferCreateInfo-renderPass-02747
  If renderPass was specified with non-zero view masks, each element of pAttachments that is referenced by fragmentDensityMapAttachment must have a layerCount equal to 1

• VUID-VkFramebufferCreateInfo-pAttachments-02555
  If flags does not include VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, an element of pAttachments that is referenced by fragmentDensityMapAttachment must have a width at least as large as
  \[ \left\lceil \frac{\text{width}}{\text{maxFragmentDensityTexelSize.width}} \right\rceil \]

• VUID-VkFramebufferCreateInfo-pAttachments-02556
  If flags does not include VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, an element of pAttachments that is referenced by fragmentDensityMapAttachment must have a height at least as large as
  \[ \left\lceil \frac{\text{height}}{\text{maxFragmentDensityTexelSize.height}} \right\rceil \]

• VUID-VkFramebufferCreateInfo-flags-04537
  If flags does not include VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, and renderPass was specified with non-zero view masks, each element of pAttachments that is used as a fragment shading rate attachment by renderPass must have a layerCount that is either 1, or greater than the index of the most significant bit set in any of those view masks

• VUID-VkFramebufferCreateInfo-flags-04538
  If flags does not include VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, and renderPass was not specified with non-zero view masks, each element of pAttachments that is used as a fragment shading rate attachment by renderPass must have a layerCount that is either 1, or greater than layers

• VUID-VkFramebufferCreateInfo-renderPass-08921
  If renderPass was specified with non-zero view masks, each element of pAttachments that is used as a fragment shading rate attachment must have a layerCount equal to 1 or greater than the index of the most significant bit set in any of those view masks

• VUID-VkFramebufferCreateInfo-flags-04539
  If flags does not include VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, an element of pAttachments that is used as a fragment shading rate attachment must have a width at least as large as
  \[ \left\lceil \frac{\text{width}}{\text{texelWidth}} \right\rceil \]

• VUID-VkFramebufferCreateInfo-flags-04540
  where texelWidth is the largest value of shadingRateAttachmentTexelSize.width in a VkFragmentShadingRateAttachmentInfoKHR which references that attachment
If flags does not include `VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT`, an element of pAttachments that is used as a fragment shading rate attachment must have a height at least as large as \( \lceil \text{height} / \text{texelHeight} \rceil \), where \( \text{texelHeight} \) is the largest value of `shadingRateAttachmentTexelSize.height` in a `VkFragmentShadingRateAttachmentInfoKHR` which references that attachment.

- **VUID-VkFramebufferCreateInfo-pAttachments-00883**
  If flags does not include `VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT`, each element of pAttachments must only specify a single mip level.

- **VUID-VkFramebufferCreateInfo-pAttachments-00884**
  If flags does not include `VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT`, each element of pAttachments must have been created with the identity swizzle.

- **VUID-VkFramebufferCreateInfo-width-00885**
  width must be greater than 0.

- **VUID-VkFramebufferCreateInfo-width-00886**
  width must be less than or equal to `maxFramebufferWidth`.

- **VUID-VkFramebufferCreateInfo-height-00887**
  height must be greater than 0.

- **VUID-VkFramebufferCreateInfo-height-00888**
  height must be less than or equal to `maxFramebufferHeight`.

- **VUID-VkFramebufferCreateInfo-layers-00889**
  layers must be greater than 0.

- **VUID-VkFramebufferCreateInfo-layers-00890**
  layers must be less than or equal to `maxFramebufferLayers`.

- **VUID-VkFramebufferCreateInfo-renderPass-02531**
  If `renderPass` was specified with non-zero view masks, layers must be 1.

- **VUID-VkFramebufferCreateInfo-flags-03189**
  If the imagelessFramebuffer feature is not enabled, flags must not include `VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT`.

- **VUID-VkFramebufferCreateInfo-flags-03190**
  If flags includes `VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT`, the pNext chain must include a `VkFramebufferAttachmentsCreateInfo` structure.

- **VUID-VkFramebufferCreateInfo-flags-03191**
  If flags includes `VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT`, the `attachmentImageInfoCount` member of a `VkFramebufferAttachmentsCreateInfo` structure in the pNext chain must be equal to either zero or `attachmentCount`.

- **VUID-VkFramebufferCreateInfo-flags-04541**
  If flags includes `VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT`, the width member of any element of the pAttachmentImageInfos member of a `VkFramebufferAttachmentsCreateInfo` structure.
structure in the pNext chain that is used as an input, color, resolve or depth/stencil attachment in renderPass must be greater than or equal to width

- VUID-VkFramebufferCreateInfo-flags-04542
  If flags includes VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, the height member of any element of the pAttachmentImageInfos member of a VkFramebufferAttachmentsCreateInfo structure in the pNext chain that is used as an input, color, resolve or depth/stencil attachment in renderPass must be greater than or equal to height

- VUID-VkFramebufferCreateInfo-flags-03196
  If flags includes VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, the width member of any element of the pAttachmentImageInfos member of a VkFramebufferAttachmentsCreateInfo structure in the pNext chain that is referenced by VkRenderPassFragmentDensityMapCreateInfoEXT::fragmentDensityMapAttachment in renderPass must be greater than or equal to \( \lceil \frac{width}{\text{texelWidth}} \rceil \)

- VUID-VkFramebufferCreateInfo-flags-03197
  If flags includes VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, the height member of any element of the pAttachmentImageInfos member of a VkFramebufferAttachmentsCreateInfo structure included in the pNext chain that is referenced by VkRenderPassFragmentDensityMapCreateInfoEXT::fragmentDensityMapAttachment in renderPass must be greater than or equal to \( \lceil \frac{height}{\text{texelHeight}} \rceil \)

- VUID-VkFramebufferCreateInfo-flags-04543
  If flags includes VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, the width member of any element of the pAttachmentImageInfos member of a VkFramebufferAttachmentsCreateInfo structure in the pNext chain that is used as a fragment shading rate attachment must be greater than or equal to \( \lceil \frac{width}{\text{texelWidth}} \rceil \)

- VUID-VkFramebufferCreateInfo-flags-04544
  If flags includes VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, the height member of any element of the pAttachmentImageInfos member of a VkFramebufferAttachmentsCreateInfo structure in the pNext chain that is used as a fragment shading rate attachment must be greater than or equal to \( \lceil \frac{height}{\text{texelHeight}} \rceil \)

- VUID-VkFramebufferCreateInfo-flags-04545
  If flags includes VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, the layerCount member of any element of the pAttachmentImageInfos member of a VkFramebufferAttachmentsCreateInfo structure in the pNext chain that is used as a fragment shading rate attachment must be either 1, or greater than or equal to layers

- VUID-VkFramebufferCreateInfo-flags-04587
  If flags includes VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT and renderPass was specified with non-zero view masks, each element of pAttachments that is used as a fragment shading rate attachment by renderPass must have a layerCount that is either 1, or greater than the index of the most significant bit set in any of those view masks

- VUID-VkFramebufferCreateInfo-renderPass-03198
  If multiview is enabled for renderPass and flags includes
VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, the layerCount member of any element of the pAttachmentImageInfos member of a VkFramebufferAttachmentsCreateInfo structure included in the pNext chain used as an input, color, resolve, or depth/stencil attachment in renderPass must be greater than the maximum bit index set in the view mask in the subpasses in which it is used in renderPass

- VUID-VkFramebufferCreateInfo-renderPass-04546
  If multiview is not enabled for renderPass and flags includes VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, the layerCount member of any element of the pAttachmentImageInfos member of a VkFramebufferAttachmentsCreateInfo structure included in the pNext chain used as an input, color, resolve, or depth/stencil attachment in renderPass must be greater than the maximum bit index set in the view mask in the subpasses in which it is used in renderPass

- VUID-VkFramebufferCreateInfo-flags-03201
  If flags includes VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, the usage member of any element of the pAttachmentImageInfos member of a VkFramebufferAttachmentsCreateInfo structure included in the pNext chain that refers to an attachment used as a color attachment or resolve attachment by renderPass must include VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT

- VUID-VkFramebufferCreateInfo-flags-03202
  If flags includes VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, the usage member of any element of the pAttachmentImageInfos member of a VkFramebufferAttachmentsCreateInfo structure included in the pNext chain that refers to an attachment used as a depth/stencil attachment by renderPass must include VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT

- VUID-VkFramebufferCreateInfo-flags-03203
  If flags includes VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, the usage member of any element of the pAttachmentImageInfos member of a VkFramebufferAttachmentsCreateInfo structure included in the pNext chain that refers to an attachment used as a depth/stencil resolve attachment by renderPass must include VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT

- VUID-VkFramebufferCreateInfo-flags-03204
  If flags includes VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, the usage member of any element of the pAttachmentImageInfos member of a VkFramebufferAttachmentsCreateInfo structure included in the pNext chain that refers to an attachment used as an input attachment by renderPass must include VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT

- VUID-VkFramebufferCreateInfo-flags-03205
  If flags includes VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, at least one element of the pViewFormats member of any element of the pAttachmentImageInfos member of a VkFramebufferAttachmentsCreateInfo structure included in the pNext chain must be equal to the corresponding value of VkAttachmentDescription::format used to create renderPass

- VUID-VkFramebufferCreateInfo-flags-04113
  If flags does not include VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of pAttachments must have been created with VkImageViewCreateInfo::viewType not equal to VK_IMAGE_VIEW_TYPE_3D

- VUID-VkFramebufferCreateInfo-flags-04548
  If flags does not include VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of
that is used as a fragment shading rate attachment by renderPass must have been created with a usage value including VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

- VUID-VkFramebufferCreateInfo-flags-04549
  If flags includes VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, the usage member of any element of the pAttachmentImageInfos member of a VkFramebufferAttachmentsCreateInfo structure included in the pNext chain that refers to an attachment used as a fragment shading rate attachment by renderPass must include VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

- VUID-VkFramebufferCreateInfo-samples-06881
  If multisampled-render-to-single-sampled is enabled for any subpass, all color, depth/stencil and input attachments used in that subpass which have VkAttachmentDescription::samples or VkAttachmentDescription2::samples equal to VK_SAMPLE_COUNT_1_BIT must have been created with VK_IMAGE_CREATE_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_BIT_EXT in their VkImageCreateInfo::flags

- VUID-VkFramebufferCreateInfo-samples-07009
  If multisampled-render-to-single-sampled is enabled for any subpass, all color, depth/stencil and input attachments used in that subpass which have VkAttachmentDescription::samples or VkAttachmentDescription2::samples equal to VK_SAMPLE_COUNT_1_BIT must have a format that supports the sample count specified in VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples

Valid Usage (Implicit)

- VUID-VkFramebufferCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_FRAMEBUFFER_CREATE_INFO

- VUID-VkFramebufferCreateInfo-pNext-pNext
  pNext must be NULL or a pointer to a valid instance of VkFramebufferAttachmentsCreateInfo

- VUID-VkFramebufferCreateInfo-sType-unique
  The sType value of each struct in the pNext chain must be unique

- VUID-VkFramebufferCreateInfo-flags-parameter
  flags must be a valid combination of VkFramebufferCreateFlagBits values

- VUID-VkFramebufferCreateInfo-renderPass-parameter
  renderPass must be a valid VkRenderPass handle

- VUID-VkFramebufferCreateInfo-commonparent
  Both of renderPass, and the elements of pAttachments that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice

The VkFramebufferAttachmentsCreateInfo structure is defined as:

// Provided by VK_VERSION_1_2
typedef struct VkFramebufferAttachmentsCreateInfo {
    VkStructureType sType;
    const void* pNext;
    uint32_t attachmentImageInfoCount;
    const VkFramebufferAttachmentImageInfo* pAttachmentImageInfos;
} VkFramebufferAttachmentsCreateInfo;

or the equivalent

// Provided by VK_KHR_imageless_framebuffer
typedef VkFramebufferAttachmentsCreateInfo VkFramebufferAttachmentsCreateInfoKHR;

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- attachmentImageInfoCount is the number of attachments being described.
- pAttachmentImageInfos is a pointer to an array of VkFramebufferAttachmentImageInfo structures, each structure describing a number of parameters of the corresponding attachment in a render pass instance.

Valid Usage (Implicit)

- VUID-VkFramebufferAttachmentsCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_FRAMEBUFFER_ATTACHMENTS_CREATE_INFO
- VUID-VkFramebufferAttachmentsCreateInfo-pAttachmentImageInfos-parameter
  If attachmentImageInfoCount is not 0, pAttachmentImageInfos must be a valid pointer to an array of attachmentImageInfoCount valid VkFramebufferAttachmentImageInfo structures

The VkFramebufferAttachmentImageInfo structure is defined as:

// Provided by VK_VERSION_1_2
typedef struct VkFramebufferAttachmentImageInfo {
    VkStructureType sType;
    const void* pNext;
    VkImageCreateFlags flags;
    VkImageUsageFlags usage;
    uint32_t width;
    uint32_t height;
    uint32_t layerCount;
    uint32_t viewFormatCount;
    const VkFormat* pViewFormats;
} VkFramebufferAttachmentImageInfo;

or the equivalent
typedef VkFramebufferAttachmentImageInfo VkFramebufferAttachmentImageInfoKHR;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkImageCreateFlagBits`, matching the value of `VkImageCreateInfo::flags` used to create an image that will be used with this framebuffer.
- `usage` is a bitmask of `VkImageUsageFlagBits`, matching the value of `VkImageCreateInfo::usage` used to create an image used with this framebuffer.
- `width` is the width of the image view used for rendering.
- `height` is the height of the image view used for rendering.
- `layerCount` is the number of array layers of the image view used for rendering.
- `viewFormatCount` is the number of entries in the `pViewFormats` array, matching the value of `VkImageFormatListCreateInfo::viewFormatCount` used to create an image used with this framebuffer.
- `pViewFormats` is a pointer to an array of `VkFormat` values specifying all of the formats which can be used when creating views of the image, matching the value of `VkImageFormatListCreateInfo::pViewFormats` used to create an image used with this framebuffer.

Images that can be used with the framebuffer when beginning a render pass, as specified by `VkRenderPassAttachmentBeginInfo`, must be created with parameters that are identical to those specified here.

---

### Valid Usage (Implicit)

- `VUID-VkFramebufferAttachmentImageInfo-sType-sType` sType must be `VK_STRUCTURE_TYPE_FRAMEBUFFER_ATTACHMENT_IMAGE_INFO`
- `VUID-VkFramebufferAttachmentImageInfo-pNext-pNext` pNext must be `NULL`
- `VUID-VkFramebufferAttachmentImageInfo-flags-parameter` flags must be a valid combination of `VkImageCreateFlagBits` values
- `VUID-VkFramebufferAttachmentImageInfo-usage-parameter` usage must be a valid combination of `VkImageUsageFlagBits` values
- `VUID-VkFramebufferAttachmentImageInfo-usage-requiredbitmask` usage must not be `0`
- `VUID-VkFramebufferAttachmentImageInfo-pViewFormats-parameter` If `viewFormatCount` is not `0`, `pViewFormats` must be a valid pointer to an array of `viewFormatCount` valid `VkFormat` values

Bits which can be set in `VkFramebufferCreateInfo::flags`, specifying options for framebuffers, are:
typedef enum VkFramebufferCreateFlagBits {
    // Provided by VK_VERSION_1_2
    VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT = 0x00000001,
    // Provided by VK_KHR_imageless_framebuffer
    VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT_KHR = VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT
} VkFramebufferCreateFlagBits;

- **VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT** specifies that image views are not specified, and only attachment compatibility information will be provided via a `VkFramebufferAttachmentImageInfo` structure.

```c
typedef VkFlags VkFramebufferCreateFlags;
```

`VkFramebufferCreateFlags` is a bitmask type for setting a mask of zero or more `VkFramebufferCreateFlagBits`.

To destroy a framebuffer, call:

```c
void vkDestroyFramebuffer(
    VkDevice device,
    VkFramebuffer framebuffer,
    const VkAllocationCallbacks* pAllocator);
```

- **device** is the logical device that destroys the framebuffer.
- **framebuffer** is the handle of the framebuffer to destroy.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.

### Valid Usage

- **VUID-vkDestroyFramebuffer-framebuffer-00892**
  All submitted commands that refer to `framebuffer` must have completed execution

- **VUID-vkDestroyFramebuffer-framebuffer-00893**
  If `VkAllocationCallbacks` were provided when `framebuffer` was created, a compatible set of callbacks must be provided here

- **VUID-vkDestroyFramebuffer-framebuffer-00894**
  If no `VkAllocationCallbacks` were provided when `framebuffer` was created, `pAllocator` must be `NULL`
Valid Usage (Implicit)

- VUID-vkDestroyFramebuffer-device-parameter
  device must be a valid VkDevice handle

- VUID-vkDestroyFramebuffer-framebuffer-parameter
  If framebuffer is not VK_NULL_HANDLE, framebuffer must be a valid VkFramebuffer handle

- VUID-vkDestroyFramebuffer-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkDestroyFramebuffer-framebuffer-parent
  If framebuffer is a valid handle, it must have been created, allocated, or retrieved from device

Host Synchronization

- Host access to framebuffer must be externally synchronized

8.5. Render Pass Load Operations

Render pass load operations define the initial values of an attachment during a render pass instance.

Load operations for attachments with a depth/stencil format execute in the VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT pipeline stage. Load operations for attachments with a color format execute in the VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT pipeline stage. The load operation for each sample in an attachment happens-before any recorded command which accesses the sample in that render pass instance via that attachment or an alias.

Note

Because load operations always happen first, external synchronization with attachment access only needs to synchronize the load operations with previous commands; not the operations within the render pass instance. This does not apply when using VK_ATTACHMENT_LOAD_OP_NONE_EXT.

Load operations only update values within the defined render area for the render pass instance. However, any writes performed by a load operation (as defined by its access masks) to a given attachment may read and write back any memory locations within the image subresource bound for that attachment. For depth/stencil images, writes to one aspect may also result in read-modify-write operations for the other aspect. If the subresource is in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT layout, implementations must not access pixels outside of the render area.

Note
As entire subresources could be accessed by load operations, applications cannot safely access values outside of the render area during a render pass instance when a load operation that modifies values is used.

Load operations that can be used for a render pass are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkAttachmentLoadOp {
    VK_ATTACHMENT_LOAD_OP_LOAD = 0,
    VK_ATTACHMENT_LOAD_OP_CLEAR = 1,
    VK_ATTACHMENT_LOAD_OP_DONT_CARE = 2,
    // Provided by VK_EXT_load_store_op_none
    VK_ATTACHMENT_LOAD_OP_NONE_EXT = 1000400000,
} VkAttachmentLoadOp;
```

- **VK_ATTACHMENT_LOAD_OP_LOAD** specifies that the previous contents of the image within the render area will be preserved as the initial values. For attachments with a depth/stencil format, this uses the access type `VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_READ_BIT`. For attachments with a color format, this uses the access type `VK_ACCESS_COLOR_ATTACHMENT_READ_BIT`.

- **VK_ATTACHMENT_LOAD_OP_CLEAR** specifies that the contents within the render area will be cleared to a uniform value, which is specified when a render pass instance is begun. For attachments with a depth/stencil format, this uses the access type `VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT`. For attachments with a color format, this uses the access type `VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT`.

- **VK_ATTACHMENT_LOAD_OP_DONT_CARE** specifies that the previous contents within the area need not be preserved; the contents of the attachment will be undefined inside the render area. For attachments with a depth/stencil format, this uses the access type `VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT`. For attachments with a color format, this uses the access type `VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT`.

- **VK_ATTACHMENT_LOAD_OP_NONE_EXT** specifies that the previous contents of the image will be undefined inside the render pass. No access type is used as the image is not accessed.

During a render pass instance, input and color attachments with color formats that have a component size of 8, 16, or 32 bits must be represented in the attachment's format throughout the instance. Attachments with other floating- or fixed-point color formats, or with depth components may be represented in a format with a precision higher than the attachment format, but must be represented with the same range. When such a component is loaded via the `loadOp`, it will be converted into an implementation-dependent format used by the render pass. Such components must be converted from the render pass format, to the format of the attachment, before they are resolved or stored at the end of a render pass instance via `storeOp`. Conversions occur as described in Numeric Representation and Computation and Fixed-Point Data Conversions.

### 8.6. Render Pass Store Operations

Render pass store operations define how values written to an attachment during a render pass instance are stored to memory.
Store operations for attachments with a depth/stencil format execute in the `VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT` pipeline stage. Store operations for attachments with a color format execute in the `VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT` pipeline stage. The store operation for each sample in an attachment happens-after any recorded command which accesses the sample via that attachment or an alias.

**Note**

Because store operations always happen after other accesses in a render pass instance, external synchronization with attachment access in an earlier render pass only needs to synchronize with the store operations; not the operations within the render pass instance. This does not apply when using `VK_ATTACHMENT_STORE_OP_NONE`.

Store operations only update values within the defined render area for the render pass instance. However, any writes performed by a store operation (as defined by its access masks) to a given attachment may read and write back any memory locations within the image subresource bound for that attachment. For depth/stencil images writes to one aspect may also result in read-modify-write operations for the other aspect. If the subresource is in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` layout, implementations must not access pixels outside of the render area.

**Note**

As entire subresources could be accessed by store operations, applications cannot safely access values outside of the render area via aliased resources during a render pass instance when a store operation that modifies values is used.

Possible values of `VkAttachmentDescription::storeOp` and `stencilStoreOp`, specifying how the contents of the attachment are treated, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkAttachmentStoreOp {
    VK_ATTACHMENT_STORE_OP_STORE = 0,
    VK_ATTACHMENT_STORE_OP_DONT_CARE = 1,
    // Provided by VK_VERSION_1_3
    VK_ATTACHMENT_STORE_OP_NONE = 100030100,
    // Provided by VK_KHR_dynamic_rendering
    VK_ATTACHMENT_STORE_OP_NONE_KHR = VK_ATTACHMENT_STORE_OP_NONE,
    // Provided by VK_QCOM_render_pass_store_ops
    VK_ATTACHMENT_STORE_OP_NONE_QCOM = VK_ATTACHMENT_STORE_OP_NONE,
    // Provided by VK_EXT_load_store_op_none
    VK_ATTACHMENT_STORE_OP_NONE_EXT = VK_ATTACHMENT_STORE_OP_NONE,
} VkAttachmentStoreOp;
```

- `VK_ATTACHMENT_STORE_OP_STORE` specifies the contents generated during the render pass and within the render area are written to memory. For attachments with a depth/stencil format, this uses the access type `VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT`. For attachments with a color format, this uses the access type `VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT`.  

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• **VK_ATTACHMENT_STORE_OP_DONT_CARE** specifies the contents within the render area are not needed after rendering, and **may** be discarded; the contents of the attachment will be undefined inside the render area. For attachments with a depth/stencil format, this uses the access type **VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT**. For attachments with a color format, this uses the access type **VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT**.

• **VK_ATTACHMENT_STORE_OP_NONE** specifies the contents within the render area are not accessed by the store operation as long as no values are written to the attachment during the render pass. If values are written during the render pass, this behaves identically to **VK_ATTACHMENT_STORE_OP_DONT_CARE** and with matching access semantics.

**Note**

**VK_ATTACHMENT_STORE_OP_DONT_CARE** can cause contents generated during previous render passes to be discarded before reaching memory, even if no write to the attachment occurs during the current render pass.

### 8.7. Render Pass Multisample Resolve Operations

Render pass multisample resolve operations combine sample values from a single pixel in a multisample attachment and store the result to the corresponding pixel in a single sample attachment.

Multisample resolve operations for attachments execute in the **VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT** pipeline stage. A final resolve operation for all pixels in the render area happens-after any recorded command which writes a pixel via the multisample attachment to be resolved or an explicit alias of it in the subpass that it is specified. Any single sample attachment specified for use in a multisample resolve operation **may** have its contents modified at any point once rendering begins for the render pass instance. Reads from the multisample attachment can be synchronized with **VK_ACCESS_COLOR_ATTACHMENT_READ_BIT**. Access to the single sample attachment can be synchronized with **VK_ACCESS_COLOR_ATTACHMENT_READ_BIT** and **VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT**. These pipeline stage and access types are used whether the attachments are color or depth/stencil attachments.

When using render pass objects, a subpass dependency specified with the above pipeline stages and access flags will ensure synchronization with multisample resolve operations for any attachments that were last accessed by that subpass. This allows later subpasses to read resolved values as input attachments.

Resolve operations only update values within the defined render area for the render pass instance. However, any writes performed by a resolve operation (as defined by its access masks) to a given attachment **may** read and write back any memory locations within the image subresource bound for that attachment. For depth/stencil images writes to one aspect **may** also result in read-modify-write operations for the other aspect. If the subresource is in the **VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT** layout, implementations **must** not access pixels outside of the render area.

**Note**

As entire subresources could be accessed by multisample resolve operations,
applications cannot safely access values outside of the render area via aliased resources during a render pass instance when a multisample resolve operation is performed.

Multisample values in a multisample attachment are combined according to the resolve mode used:

```c
// Provided by VK_VERSION_1_2
typedef enum VkResolveModeFlagBits {
    VK_RESOLVE_MODE_NONE = 0,
    VK_RESOLVE_MODE_SAMPLE_ZERO_BIT = 0x00000001,
    VK_RESOLVE_MODE_AVERAGE_BIT = 0x00000002,
    VK_RESOLVE_MODE_MIN_BIT = 0x00000004,
    VK_RESOLVE_MODE_MAX_BIT = 0x00000008,
    // Provided by VK_KHR_depth_stencil_resolve
    VK_RESOLVE_MODE_NONE_KHR = VK_RESOLVE_MODE_NONE,
    // Provided by VK_KHR_depth_stencil_resolve
    VK_RESOLVE_MODE_SAMPLE_ZERO_BIT_KHR = VK_RESOLVE_MODE_SAMPLE_ZERO_BIT,
    // Provided by VK_KHR_depth_stencil_resolve
    VK_RESOLVE_MODE_AVERAGE_BIT_KHR = VK_RESOLVE_MODE_AVERAGE_BIT,
    // Provided by VK_KHR_depth_stencil_resolve
    VK_RESOLVE_MODE_MIN_BIT_KHR = VK_RESOLVE_MODE_MIN_BIT,
    // Provided by VK_KHR_depth_stencil_resolve
    VK_RESOLVE_MODE_MAX_BIT_KHR = VK_RESOLVE_MODE_MAX_BIT,
} VkResolveModeFlagBits;
```

or the equivalent

```c
// Provided by VK_KHR_depth_stencil_resolve
typedef VkResolveModeFlagBits VkResolveModeFlagBitsKHR;
```

- **VK_RESOLVE_MODE_NONE** indicates that no resolve operation is done.
- **VK_RESOLVE_MODE_SAMPLE_ZERO_BIT** indicates that result of the resolve operation is equal to the value of sample 0.
- **VK_RESOLVE_MODE_AVERAGE_BIT** indicates that result of the resolve operation is the average of the sample values.
- **VK_RESOLVE_MODE_MIN_BIT** indicates that result of the resolve operation is the minimum of the sample values.
- **VK_RESOLVE_MODE_MAX_BIT** indicates that result of the resolve operation is the maximum of the sample values.

When no resolve mode is specified, **VK_RESOLVE_MODE_AVERAGE_BIT** is used.

```c
// Provided by VK_VERSION_1_2
typedef VkFlags VkResolveModeFlags;
```
or the equivalent

```c
// Provided by VK_KHR_depth_stencil_resolve
typedef VkResolveModeFlags VkResolveModeFlagsKHR;
```

`VkResolveModeFlags` is a bitmask type for setting a mask of zero or more `VkResolveModeFlagBits`.

### 8.8. Render Pass Commands

An application records the commands for a render pass instance one subpass at a time, by beginning a render pass instance, iterating over the subpasses to record commands for that subpass, and then ending the render pass instance.

To begin a render pass instance, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdBeginRenderPass(
    VkCommandBuffer commandBuffer,
    const VkRenderPassBeginInfo* pRenderPassBegin,
    VkSubpassContents contents);
```

- `commandBuffer` is the command buffer in which to record the command.
- `pRenderPassBegin` is a pointer to a `VkRenderPassBeginInfo` structure specifying the render pass to begin an instance of, and the framebuffer the instance uses.
- `contents` is a `VkSubpassContents` value specifying how the commands in the first subpass will be provided.

After beginning a render pass instance, the command buffer is ready to record the commands for the first subpass of that render pass.

**Valid Usage**

- **VUID-vkCmdBeginRenderPass-initialLayout-00895**
  If any of the `initialLayout` or `finalLayout` member of the `VkAttachmentDescription` structures or the `layout` member of the `VkAttachmentReference` structures specified when creating the render pass specified in the `renderPass` member of `pRenderPassBegin` is `VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL` then the corresponding attachment image view of the framebuffer specified in the `framebuffer` member of `pRenderPassBegin` must have been created with a `usage` value including `VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT`.

- **VUID-vkCmdBeginRenderPass-initialLayout-01758**
  If any of the `initialLayout` or `finalLayout` member of the `VkAttachmentDescription` structures or the `layout` member of the `VkAttachmentReference` structures specified when creating the render pass specified in the `renderPass` member of `pRenderPassBegin` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`, `VK_IMAGE_LAYOUT_DEPTH_WRITE_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, `VK_IMAGE_LAYOUT_DEPTH_WRITE_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, `VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL`, then the corresponding attachment image view of the framebuffer specified in the `framebuffer` member of `pRenderPassBegin` must have been created with a `usage` value including `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT`.

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VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL, or
VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL then the corresponding attachment image view of the framebuffer specified in the framebuffer member of pRenderPassBegin must have been created with a usage value including VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT

- **VUID-vkCmdBeginRenderPass-initialLayout-02842**
  If any of the initialLayout or finalLayout member of the VkAttachmentDescription structures or the layout member of the VkAttachmentReference structures specified when creating the render pass specified in the renderPass member of pRenderPassBegin is VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL, or VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL, VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL, or VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL then the corresponding attachment image view of the framebuffer specified in the framebuffer member of pRenderPassBegin must have been created with a usage value including VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT

- **VUID-vkCmdBeginRenderPass-stencilInitialLayout-02843**
  If any of the stencilInitialLayout or stencilFinalLayout member of the VkAttachmentDescriptionStencillayout structures or the stencilLayout member of the VkAttachmentReferenceStencillayout structures specified when creating the render pass specified in the renderPass member of pRenderPassBegin is VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL, or VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL then the corresponding attachment image view of the framebuffer specified in the framebuffer member of pRenderPassBegin must have been created with a usage value including VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT

- **VUID-vkCmdBeginRenderPass-initialLayout-00897**
  If any of the initialLayout or finalLayout member of the VkAttachmentDescription structures or the layout member of the VkAttachmentReference structures specified when creating the render pass specified in the renderPass member of pRenderPassBegin is VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL then the corresponding attachment image view of the framebuffer specified in the framebuffer member of pRenderPassBegin must have been created with a usage value including VK_IMAGE_USAGE_SAMPLED_BIT or VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT

- **VUID-vkCmdBeginRenderPass-initialLayout-00898**
  If any of the initialLayout or finalLayout member of the VkAttachmentDescription structures or the layout member of the VkAttachmentReference structures specified when creating the render pass specified in the renderPass member of pRenderPassBegin is VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL then the corresponding attachment image view of the framebuffer specified in the framebuffer member of pRenderPassBegin must have been created with a usage value including VK_IMAGE_USAGE_TRANSFER_SRC_BIT

- **VUID-vkCmdBeginRenderPass-initialLayout-00899**
  If any of the initialLayout or finalLayout member of the VkAttachmentDescription structures or the layout member of the VkAttachmentReference structures specified when creating the render pass specified in the renderPass member of pRenderPassBegin is VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL then the corresponding attachment image view of the framebuffer specified in the framebuffer member of pRenderPassBegin must have been created with a usage value including VK_IMAGE_USAGE_TRANSFER_DST_BIT
created with a usage value including VK_IMAGE_USAGE_TRANSFER_DST_BIT

- VUID-vkCmdBeginRenderPass-initialLayout-00900
  If the initialLayout member of any of the VkAttachmentDescription structures specified when creating the render pass specified in the renderPass member of pRenderPassBegin is not VK_IMAGE_LAYOUT_UNDEFINED, then each such initialLayout must be equal to the current layout of the corresponding attachment image subresource of the framebuffer specified in the framebuffer member of pRenderPassBegin.

- VUID-vkCmdBeginRenderPass-srcStageMask-06451
  The srcStageMask members of any element of the pDependencies member of VkRenderPassCreateInfo used to create renderPass must be supported by the capabilities of the queue family identified by the queueFamilyIndex member of the VkCommandPoolCreateInfo used to create the command pool which commandBuffer was allocated from.

- VUID-vkCmdBeginRenderPass-dstStageMask-06452
  The dstStageMask members of any element of the pDependencies member of VkRenderPassCreateInfo used to create renderPass must be supported by the capabilities of the queue family identified by the queueFamilyIndex member of the VkCommandPoolCreateInfo used to create the command pool which commandBuffer was allocated from.

- VUID-vkCmdBeginRenderPass-framebuffer-02532
  For any attachment in framebuffer that is used by renderPass and is bound to memory locations that are also bound to another attachment used by renderPass, and if at least one of those uses causes either attachment to be written to, both attachments must have had the VK_ATTACHMENT_DESCRIPTION_MAY_ALIAS_BIT set.

- VUID-vkCmdBeginRenderPass-framebuffer-09045
  If any attachments specified in framebuffer are used by renderPass and are bound to overlapping memory locations, there must be only one that is used as a color attachment, depth/stencil, or resolve attachment in any subpass.

- VUID-vkCmdBeginRenderPass-initialLayout-07000
  If any of the initialLayout or finalLayout member of the VkAttachmentDescription structures or the layout member of the VkAttachmentReference structures specified when creating the render pass specified in the renderPass member of pRenderPassBegin is VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT then the corresponding attachment image view of the framebuffer specified in the framebuffer member of pRenderPassBegin must have been created with a usage value including either the VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT or VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT and either the VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT or VK_IMAGE_USAGE_SAMPLED_BIT usage bits.

- VUID-vkCmdBeginRenderPass-initialLayout-07001
  If any of the initialLayout or finalLayout member of the VkAttachmentDescription structures or the layout member of the VkAttachmentReference structures specified when creating the render pass specified in the renderPass member of pRenderPassBegin is VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT then the corresponding attachment image view of the framebuffer specified in the framebuffer member of pRenderPassBegin must have been created with a usage value the VK_IMAGE_USAGE_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT usage bit.
Valid Usage (Implicit)

- VUID-vkCmdBeginRenderPass-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdBeginRenderPass-pRenderPassBegin-parameter
  pRenderPassBegin must be a valid pointer to a valid VkRenderPassBeginInfo structure

- VUID-vkCmdBeginRenderPass-contents-parameter
  contents must be a valid VkSubpassContents value

- VUID-vkCmdBeginRenderPass-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdBeginRenderPass-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdBeginRenderPass-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdBeginRenderPass-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdBeginRenderPass-bufferlevel
  commandBuffer must be a primary VkCommandBuffer

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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Alternatively to begin a render pass, call:

```c
// Provided by VK_VERSION_1_2
void vkCmdBeginRenderPass2(
    VkCommandBuffer       commandBuffer,
    const VkRenderPassBeginInfo* pRenderPassBegin,
);```

576
const VkSubpassBeginInfo* pSubpassBeginInfo);

or the equivalent command

// Provided by VK_KHR_create_renderpass2
void vkCmdBeginRenderPass2KHR(
  VkCommandBuffer commandBuffer,
  const VkRenderPassBeginInfo* pRenderPassBegin,
  const VkSubpassBeginInfo* pSubpassBeginInfo);

- `commandBuffer` is the command buffer in which to record the command.
- `pRenderPassBegin` is a pointer to a `VkRenderPassBeginInfo` structure specifying the render pass to begin an instance of, and the framebuffer the instance uses.
- `pSubpassBeginInfo` is a pointer to a `VkSubpassBeginInfo` structure containing information about the subpass which is about to begin rendering.

After beginning a render pass instance, the command buffer is ready to record the commands for the first subpass of that render pass.

Valid Usage

- VUID-vkCmdBeginRenderPass2-framebuffer-02779
  Both the `framebuffer` and `renderPass` members of `pRenderPassBegin` must have been created on the same `VkDevice` that `commandBuffer` was allocated on.

- VUID-vkCmdBeginRenderPass2-initialLayout-03094
  If any of the `initialLayout` or `finalLayout` member of the `VkAttachmentDescription` structures or the `layout` member of the `VkAttachmentReference` structures specified when creating the render pass specified in the `renderPass` member of `pRenderPassBegin` is `VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL` then the corresponding attachment image view of the framebuffer specified in the `framebuffer` member of `pRenderPassBegin` must have been created with a usage value including `VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT`.

- VUID-vkCmdBeginRenderPass2-initialLayout-02844
  If any of the `initialLayout` or `finalLayout` member of the `VkAttachmentDescription` structures or the `layout` member of the `VkAttachmentReference` structures specified when creating the render pass specified in the `renderPass` member of `pRenderPassBegin` is
    - `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`,
    - `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`,
    - `VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL`,
    - or
    - `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL` then the corresponding attachment image view of the framebuffer specified in the `framebuffer` member of `pRenderPassBegin` must have been created with a usage value including `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT`.

- VUID-vkCmdBeginRenderPass2-initialLayout-02844
  If any of the `initialLayout` or `finalLayout` member of the `VkAttachmentDescription` structures or the `layout` member of the `VkAttachmentReference` structures specified when
creating the render pass specified in the renderPass member of pRenderPassBegin is VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL, or VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL, VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL, or VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL then the corresponding attachment image view of the framebuffer specified in the framebuffer member of pRenderPassBegin must have been created with a usage value including VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT

• VUID-vkCmdBeginRenderPass2-stencilInitialLayout-02845
  If any of the stencilInitialLayout or stencilFinalLayout member of the VkAttachmentDescriptionStencilLayout structures or the stencilLayout member of the VkAttachmentReferenceStencilLayout structures specified when creating the render pass specified in the renderPass member of pRenderPassBegin is VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL, or VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL then the corresponding attachment image view of the framebuffer specified in the framebuffer member of pRenderPassBegin must have been created with a usage value including VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT

• VUID-vkCmdBeginRenderPass2-initialLayout-03097
  If any of the initialLayout or finalLayout member of the VkAttachmentDescription structures or the layout member of the VkAttachmentReference structures specified when creating the render pass specified in the renderPass member of pRenderPassBegin is VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL then the corresponding attachment image view of the framebuffer specified in the framebuffer member of pRenderPassBegin must have been created with a usage value including VK_IMAGE_USAGE_SAMPLED_BIT or VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT

• VUID-vkCmdBeginRenderPass2-initialLayout-03098
  If any of the initialLayout or finalLayout member of the VkAttachmentDescription structures or the layout member of the VkAttachmentReference structures specified when creating the render pass specified in the renderPass member of pRenderPassBegin is VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL then the corresponding attachment image view of the framebuffer specified in the framebuffer member of pRenderPassBegin must have been created with a usage value including VK_IMAGE_LAYOUT_TRANSFER_SRC_BIT

• VUID-vkCmdBeginRenderPass2-initialLayout-03099
  If any of the initialLayout or finalLayout member of the VkAttachmentDescription structures or the layout member of the VkAttachmentReference structures specified when creating the render pass specified in the renderPass member of pRenderPassBegin is VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL then the corresponding attachment image view of the framebuffer specified in the framebuffer member of pRenderPassBegin must have been created with a usage value including VK_IMAGE_USAGE_TRANSFER_DST_BIT

• VUID-vkCmdBeginRenderPass2-initialLayout-03100
  If the initialLayout member of any of the VkAttachmentDescription structures specified when creating the render pass specified in the renderPass member of pRenderPassBegin is not VK_IMAGE_LAYOUT_UNDEFINED, then each such initialLayout must be equal to the current layout of the corresponding attachment image subresource of the framebuffer specified in the framebuffer member of pRenderPassBegin
The `srcStageMask` members of any element of the `pDependencies` member of `VkRenderPassCreateInfo` used to create `renderPass` must be supported by the capabilities of the queue family identified by the `queueFamilyIndex` member of the `VkCommandPoolCreateInfo` used to create the command pool which `commandBuffer` was allocated from.

The `dstStageMask` members of any element of the `pDependencies` member of `VkRenderPassCreateInfo` used to create `renderPass` must be supported by the capabilities of the queue family identified by the `queueFamilyIndex` member of the `VkCommandPoolCreateInfo` used to create the command pool which `commandBuffer` was allocated from.

For any attachment in `framebuffer` that is used by `renderPass` and is bound to memory locations that are also bound to another attachment used by `renderPass`, and if at least one of those uses causes either attachment to be written to, both attachments must have had the `VK_ATTACHMENT_DESCRIPTION_MAY_ALIAS_BIT` set.

If any attachments specified in `framebuffer` are used by `renderPass` and are bound to overlapping memory locations, there must be only one that is used as a color attachment, depth/stencil, or resolve attachment in any subpass.

If any of the `initialLayout` or `finalLayout` member of the `VkAttachmentDescription` structures or the `layout` member of the `VkAttachmentReference` structures specified when creating the render pass specified in the `renderPass` member of `pRenderPassBegin` is `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` then the corresponding attachment image view of the framebuffer specified in the `framebuffer` member of `pRenderPassBegin` must have been created with a `usage` value including either the `VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT` or `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT` and either the `VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT` or `VK_IMAGE_USAGE_SAMPLED_BIT` usage bits.

If any of the `initialLayout` or `finalLayout` member of the `VkAttachmentDescription` structures or the `layout` member of the `VkAttachmentReference` structures specified when creating the render pass specified in the `renderPass` member of `pRenderPassBegin` is `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` then the corresponding attachment image view of the framebuffer specified in the `framebuffer` member of `pRenderPassBegin` must have been created with a `usage` value the `VK_IMAGE_USAGE_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` usage bit.

Valid Usage (Implicit)

- `commandBuffer` must be a valid `VkCommandBuffer` handle
- `pRenderPassBegin`
pRenderPassBegin must be a valid pointer to a valid VkRenderPassBeginInfo structure

- VUID-vkCmdBeginRenderPass2-pSubpassBeginInfo-parameter
  pSubpassBeginInfo must be a valid pointer to a valid VkSubpassBeginInfo structure

- VUID-vkCmdBeginRenderPass2-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdBeginRenderPass2-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdBeginRenderPass2-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdBeginRenderPass2-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdBeginRenderPass2-bufferlevel
  commandBuffer must be a primary VkCommandBuffer

**Host Synchronization**

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

**Command Properties**

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The VkRenderPassBeginInfo structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkRenderPassBeginInfo {
  VkStructureType sType;
  const void* pNext;
  VkRenderPass renderPass;
  VkFramebuffer framebuffer;
  VkRect2D renderArea;
  uint32_t clearValueCount;
  const VkClearValue* pClearValues;
} VkRenderPassBeginInfo;
```
• **sType** is a *VkStructureType* value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **renderPass** is the render pass to begin an instance of.

• **framebuffer** is the framebuffer containing the attachments that are used with the render pass.

• **renderArea** is the render area that is affected by the render pass instance, and is described in more detail below.

• **clearValueCount** is the number of elements in *pClearValues*.

• **pClearValues** is a pointer to an array of **clearValueCount** *VkClearValue* structures containing clear values for each attachment, if the attachment uses a **loadOp** value of 

  ```
  VK_ATTACHMENT_LOAD_OP_CLEAR
  ```

  or if the attachment has a depth/stencil format and uses a **stencilLoadOp** value of 

  ```
  VK_ATTACHMENT_LOAD_OP_CLEAR
  ```

  The array is indexed by attachment number. Only elements corresponding to cleared attachments are used. Other elements of *pClearValues* are ignored.

*renderArea* is the render area that is affected by the render pass instance. The effects of attachment load, store and multisample resolve operations are restricted to the pixels whose x and y coordinates fall within the render area on all attachments. The render area extends to all layers of *framebuffer*. The application must ensure (using scissor if necessary) that all rendering is contained within the render area. The render area, after any transform specified by *VkRenderPassTransformBeginInfoQCOM::transform* is applied, must be contained within the framebuffer dimensions.

If **render pass transform** is enabled, then **renderArea** must equal the framebuffer pre-transformed dimensions. After **renderArea** has been transformed by *VkRenderPassTransformBeginInfoQCOM::transform*, the resulting render area must be contained within the framebuffer dimensions.

If multiview is enabled in **renderPass**, and **multiviewPerViewRenderAreas** feature is enabled, and there is an instance of *VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM* included in the **pNext** chain with **perViewRenderAreaCount** not equal to 0, then the elements of *VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM::pPerViewRenderAreas* override **renderArea** and define a render area for each view. In this case, **renderArea** must be set to an area at least as large as the union of all the per-view render areas.

If the **subpassShading** feature is enabled, then **renderArea** must equal the framebuffer dimensions.

**Note**

There may be a performance cost for using a render area smaller than the framebuffer, unless it matches the render area granularity for the render pass.

### Valid Usage

- **VUID-VkRenderPassBeginInfo-clearValueCount-00902**
  
  **clearValueCount** must be greater than the largest attachment index in **renderPass** specifying a **loadOp** (or **stencilLoadOp**, if the attachment has a depth/stencil format) of 

  ```
  VK_ATTACHMENT_LOAD_OP_CLEAR
  ```
If `clearValueCount` is not 0, `pClearValues` must be a valid pointer to an array of `clearValueCount` `VkClearValue` unions.

`renderPass` must be compatible with the `renderPass` member of the `VkFramebufferCreateInfo` structure specified when creating `framebuffer`.

If `VkDeviceGroupRenderPassBeginInfo::deviceRenderAreaCount` is 0, `renderArea.extent.width` must be greater than 0.

If `VkDeviceGroupRenderPassBeginInfo::deviceRenderAreaCount` is 0, `renderArea.extent.height` must be greater than 0.

If the `pNext` chain does not contain `VkDeviceGroupRenderPassBeginInfo` or its `deviceRenderAreaCount` member is equal to 0, `renderArea.offset.x` must be greater than or equal to 0.

If the `pNext` chain does not contain `VkDeviceGroupRenderPassBeginInfo` or its `deviceRenderAreaCount` member is equal to 0, `renderArea.offset.y` must be greater than or equal to 0.

If the `pNext` chain does not contain `VkDeviceGroupRenderPassBeginInfo` or its `deviceRenderAreaCount` member is equal to 0, `renderArea.offset.x + renderArea.extent.width` must be less than or equal to `VkFramebufferCreateInfo::width` the `framebuffer` was created with.

If the `pNext` chain does not contain `VkDeviceGroupRenderPassBeginInfo` or its `deviceRenderAreaCount` member is equal to 0, `renderArea.offset.y + renderArea.extent.height` must be less than or equal to `VkFramebufferCreateInfo::height` the `framebuffer` was created with.

If the `pNext` chain contains `VkDeviceGroupRenderPassBeginInfo`, `offset.x + extent.width` of each element of `pDeviceRenderAreas` must be less than or equal to `VkFramebufferCreateInfo::width` the `framebuffer` was created with.

If the `pNext` chain contains `VkDeviceGroupRenderPassBeginInfo`, `offset.y + extent.height` of each element of `pDeviceRenderAreas` must be less than or equal to `VkFramebufferCreateInfo::height` the `framebuffer` was created with.

If `framebuffer` was created with a `VkFramebufferCreateInfo::flags` value that did not include `VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT`, and the `pNext` chain includes a `VkRenderPassAttachmentBeginInfo` structure, its `attachmentCount` must be zero.
If framebuffer was created with a VkFramebufferCreateInfo::flags value that included VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, the attachmentCount of a VkRenderPassAttachmentBeginInfo structure included in the pNext chain must be equal to the value of VkFramebufferAttachmentsCreateInfo::attachmentImageInfoCount used to create framebuffer

- VUID-VkRenderPassBeginInfo-framebuffer-02780
  If framebuffer was created with a VkFramebufferCreateInfo::flags value that included VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of the pAttachments member of a VkRenderPassAttachmentBeginInfo structure included in the pNext chain must have been created on the same VkDevice as framebuffer and renderPass

- VUID-VkRenderPassBeginInfo-framebuffer-03209
  If framebuffer was created with a VkFramebufferCreateInfo::flags value that included VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of the pAttachments member of a VkRenderPassAttachmentBeginInfo structure included in the pNext chain must be a VkImageView of an image created with a value of VkImageCreateInfo::flags equal to the flags member of the corresponding element of VkFramebufferAttachmentsCreateInfo::pAttachmentImageInfos used to create framebuffer

- VUID-VkRenderPassBeginInfo-framebuffer-04627
  If framebuffer was created with a VkFramebufferCreateInfo::flags value that included VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of the pAttachments member of a VkRenderPassAttachmentBeginInfo structure included in the pNext chain must be a VkImageView with an inherited usage equal to the usage member of the corresponding element of VkFramebufferAttachmentsCreateInfo::pAttachmentImageInfos used to create framebuffer

- VUID-VkRenderPassBeginInfo-framebuffer-03211
  If framebuffer was created with a VkFramebufferCreateInfo::flags value that included VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of the pAttachments member of a VkRenderPassAttachmentBeginInfo structure included in the pNext chain must be a VkImageView with a width equal to the width member of the corresponding element of VkFramebufferAttachmentsCreateInfo::pAttachmentImageInfos used to create framebuffer

- VUID-VkRenderPassBeginInfo-framebuffer-03212
  If framebuffer was created with a VkFramebufferCreateInfo::flags value that included VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of the pAttachments member of a VkRenderPassAttachmentBeginInfo structure included in the pNext chain must be a VkImageView with a height equal to the height member of the corresponding element of VkFramebufferAttachmentsCreateInfo::pAttachmentImageInfos used to create framebuffer

- VUID-VkRenderPassBeginInfo-framebuffer-03213
  If framebuffer was created with a VkFramebufferCreateInfo::flags value that included VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of the pAttachments member of a VkRenderPassAttachmentBeginInfo structure included in the pNext chain must be a VkImageView of an image created with a value of VkImageViewCreateInfo::subresourceRange.layerCount equal to the layerCount member of the corresponding element of VkFramebufferAttachmentsCreateInfo::pAttachmentImageInfos used to create framebuffer

- VUID-VkRenderPassBeginInfo-framebuffer-03214
If framebuffer was created with a VkFramebufferCreateInfo::flags value that included VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of the pAttachments member of a VkRenderPassAttachmentBeginInfo structure included in the pNext chain must be a VkImageView of an image created with a value of VkImageFormatListCreateInfo::viewFormatCount equal to the viewFormatCount member of the corresponding element of VkFramebufferAttachmentsCreateInfo::pAttachmentImageInfos used to create framebuffer.

- VUID-VkRenderPassBeginInfo-framebuffer-03215
  If framebuffer was created with a VkFramebufferCreateInfo::flags value that included VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of the pAttachments member of a VkRenderPassAttachmentBeginInfo structure included in the pNext chain must be a VkImageView of an image created with a set of elements in VkImageFormatListCreateInfo::pViewFormats equal to the set of elements in the pViewFormats member of the corresponding element of VkFramebufferAttachmentsCreateInfo::pAttachmentImageInfos used to create framebuffer.

- VUID-VkRenderPassBeginInfo-framebuffer-03216
  If framebuffer was created with a VkFramebufferCreateInfo::flags value that included VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of the pAttachments member of a VkRenderPassAttachmentBeginInfo structure included in the pNext chain must be a VkImageView of an image created with a value of VkImageViewCreateInfo::format equal to the corresponding value of VkAttachmentDescription::format in renderPass.

- VUID-VkRenderPassBeginInfo-framebuffer-09047
  If framebuffer was created with a VkFramebufferCreateInfo::flags value that included VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT, each element of the pAttachments member of a VkRenderPassAttachmentBeginInfo structure included in the pNext chain must be a VkImageView of an image created with a value of VkImageCreateInfo::samples equal to the corresponding value of VkAttachmentDescription::samples in renderPass, or VK_SAMPLE_COUNT_1_BIT if renderPass was created with VkMultisampledRenderToSingleSampledInfoEXT structure in the pNext chain with multisampledRenderToSingleSampledEnable equal to VK_TRUE.

- VUID-VkRenderPassBeginInfo-pNext-02869
  If the pNext chain includes VkRenderPassTransformBeginInfoQCOM, renderArea.offset must equal (0,0).

- VUID-VkRenderPassBeginInfo-pNext-02870
  If the pNext chain includes VkRenderPassTransformBeginInfoQCOM, renderArea.extent transformed by VkRenderPassTransformBeginInfoQCOM::transform must equal the framebuffer dimensions.

- VUID-VkRenderPassBeginInfo-perViewRenderAreaCount-07859
  If the perViewRenderAreaCount member of a VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM structure included in the pNext chain is not 0, then the multiviewPerViewRenderAreas feature must be enabled.

- VUID-VkRenderPassBeginInfo-perViewRenderAreaCount-07860
  If the perViewRenderAreaCount member of a VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM structure included in the pNext chain is not 0, then renderArea must specify a render area that includes the union of all per view render areas.
Valid Usage (Implicit)

- **VUID-VkRenderPassBeginInfo-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_RENDER_PASS_BEGIN_INFO`.

- **VUID-VkRenderPassBeginInfo-pNext-pNext**
  
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkDeviceGroupRenderPassBeginInfo`, `VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM`, `VkRenderPassAttachmentBeginInfo`, `VkRenderPassSampleLocationsBeginInfoEXT`, or `VkRenderPassTransformBeginInfoQCOM`.

- **VUID-VkRenderPassBeginInfo-sType-unique**
  
  The `sType` value of each struct in the `pNext` chain must be unique.

- **VUID-VkRenderPassBeginInfo-renderPass-parameter**
  
  `renderPass` must be a valid `VkRenderPass` handle.

- **VUID-VkRenderPassBeginInfo-framebuffer-parameter**
  
  `framebuffer` must be a valid `VkFramebuffer` handle.

- **VUID-VkRenderPassBeginInfo-commonparent**
  
  Both of `framebuffer`, and `renderPass` must have been created, allocated, or retrieved from the same `VkDevice`.

The image layout of the depth aspect of a depth/stencil attachment referring to an image created with `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` is dependent on the last sample locations used to render to the image subresource, thus preserving the contents of such depth/stencil attachments across subpass boundaries requires the application to specify these sample locations whenever a layout transition of the attachment may occur. This information can be provided by adding a `VkRenderPassSampleLocationsBeginInfoEXT` structure to the `pNext` chain of `VkRenderPassBeginInfo`.

The `VkRenderPassSampleLocationsBeginInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_sample_locations
typedef struct VkRenderPassSampleLocationsBeginInfoEXT {
    VkStructureType sType;
    const void* pNext;
    uint32_t attachmentInitialSampleLocationsCount;
    const VkAttachmentSampleLocationsEXT* pAttachmentInitialSampleLocations;
    uint32_t postSubpassSampleLocationsCount;
    const VkSubpassSampleLocationsEXT* pPostSubpassSampleLocations;
} VkRenderPassSampleLocationsBeginInfoEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.

- **pNext** is `NULL` or a pointer to a structure extending this structure.

- **attachmentInitialSampleLocationsCount** is the number of elements in the `pAttachmentInitialSampleLocations` array.
• **pAttachmentInitialSampleLocations** is a pointer to an array of `attachmentInitialSampleLocationsCount` `VkAttachmentSampleLocationsEXT` structures specifying the attachment indices and their corresponding sample location state. Each element of **pAttachmentInitialSampleLocations** can specify the sample location state to use in the automatic layout transition performed to transition a depth/stencil attachment from the initial layout of the attachment to the image layout specified for the attachment in the first subpass using it.

• **postSubpassSampleLocationsCount** is the number of elements in the **pPostSubpassSampleLocations** array.

• **pPostSubpassSampleLocations** is a pointer to an array of `postSubpassSampleLocationsCount` `VkSubpassSampleLocationsEXT` structures specifying the subpass indices and their corresponding sample location state. Each element of **pPostSubpassSampleLocations** can specify the sample location state to use in the automatic layout transition performed to transition the depth/stencil attachment used by the specified subpass to the image layout specified in a dependent subpass or to the final layout of the attachment in case the specified subpass is the last subpass using that attachment. In addition, if `VkPhysicalDeviceSampleLocationsPropertiesEXT::variableSampleLocations` is **VK_FALSE**, each element of **pPostSubpassSampleLocations** must specify the sample location state that matches the sample locations used by all pipelines that will be bound to a command buffer during the specified subpass. If `variableSampleLocations` is **VK_TRUE**, the sample locations used for rasterization do not depend on **pPostSubpassSampleLocations**.

---

**Valid Usage (Implicit)**

- **VUID-VkRenderPassSampleLocationsBeginInfoEXT-sType-sType**
  - **sType** must be **VK_STRUCTURE_TYPE_RENDER_PASS_SAMPLE_LOCATIONS_BEGIN_INFO_EXT**

- **VUID-VkRenderPassSampleLocationsBeginInfoEXT-pAttachmentInitialSampleLocations-parameter**
  - If `attachmentInitialSampleLocationsCount` is not 0, **pAttachmentInitialSampleLocations** must be a valid pointer to an array of `attachmentInitialSampleLocationsCount` valid `VkAttachmentSampleLocationsEXT` structures

- **VUID-VkRenderPassSampleLocationsBeginInfoEXT-pPostSubpassSampleLocations-parameter**
  - If `postSubpassSampleLocationsCount` is not 0, **pPostSubpassSampleLocations** must be a valid pointer to an array of `postSubpassSampleLocationsCount` valid `VkSubpassSampleLocationsEXT` structures

---

The **VkAttachmentSampleLocationsEXT** structure is defined as:

```c
// Provided by VK_EXT_sample_locations
typedef structVkAttachmentSampleLocationsEXT {
   uint32_t attachmentIndex;
   VkSampleLocationsInfoEXT sampleLocationsInfo;
} VkAttachmentSampleLocationsEXT;
```
• `attachmentIndex` is the index of the attachment for which the sample locations state is provided.
• `sampleLocationsInfo` is the sample locations state to use for the layout transition of the given attachment from the initial layout of the attachment to the image layout specified for the attachment in the first subpass using it.

If the image referenced by the framebuffer attachment at index `attachmentIndex` was not created with `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` then the values specified in `sampleLocationsInfo` are ignored.

### Valid Usage

- VUID-VkAttachmentSampleLocationsEXT-attachmentIndex-01531
  
  `attachmentIndex` must be less than the `attachmentCount` specified in `VkRenderPassCreateInfo` the render pass specified by `VkRenderPassBeginInfo::renderPass` was created with

### Valid Usage (Implicit)

- VUID-VkAttachmentSampleLocationsEXT-sampleLocationsInfo-parameter
  
  `sampleLocationsInfo` must be a valid `VkSampleLocationsInfoEXT` structure

The `VkSubpassSampleLocationsEXT` structure is defined as:

```c
// Provided by VK_EXT_sample_locations
typedef struct VkSubpassSampleLocationsEXT {
  uint32_t subpassIndex;
  VkSampleLocationsInfoEXT sampleLocationsInfo;
} VkSubpassSampleLocationsEXT;
```

• `subpassIndex` is the index of the subpass for which the sample locations state is provided.
• `sampleLocationsInfo` is the sample locations state to use for the layout transition of the depth/stencil attachment away from the image layout the attachment is used with in the subpass specified in `subpassIndex`.

If the image referenced by the depth/stencil attachment used in the subpass identified by `subpassIndex` was not created with `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` or if the subpass does not use a depth/stencil attachment, and `VkPhysicalDeviceSampleLocationsPropertiesEXT::variableSampleLocations` is `VK_TRUE` then the values specified in `sampleLocationsInfo` are ignored.

### Valid Usage

- VUID-VkSubpassSampleLocationsEXT-subpassIndex-01532
  
  `subpassIndex` must be less than the `subpassCount` specified in `VkRenderPassCreateInfo` the
To begin a render pass instance with render pass transform enabled, add the VkRenderPassTransformBeginInfoQCOM to the pNext chain of VkRenderPassBeginInfo structure passed to the vkCmdBeginRenderPass command specifying the render pass transform.

The VkRenderPassTransformBeginInfoQCOM structure is defined as:

```c
// Provided by VK_QCOM_render_pass_transform
typedef struct VkRenderPassTransformBeginInfoQCOM {
    VkStructureType sType;
    void* pNext;
    VkSurfaceTransformFlagBitsKHR transform;
} VkRenderPassTransformBeginInfoQCOM;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `transform` is a VkSurfaceTransformFlagBitsKHR value describing the transform to be applied to rasterization.

Valid Usage

- VUID-VkRenderPassTransformBeginInfoQCOM-transform-02871
  `transform` must be VK_SURFACE_TRANSFORM_IDENTITY_BIT_KHR, VK_SURFACE_TRANSFORM_ROTATE_90_BIT_KHR, VK_SURFACE_TRANSFORM_ROTATE_180_BIT_KHR, or VK_SURFACE_TRANSFORM_ROTATE_270_BIT_KHR.
- VUID-VkRenderPassTransformBeginInfoQCOM-flags-02872
  The renderpass must have been created with VkRenderPassCreateInfo::flags containing VK_RENDER_PASS_CREATE_TRANSFORM_BIT_QCOM.

Valid Usage (Implicit)

- VUID-VkRenderPassTransformBeginInfoQCOM-sType-sType
  `sType` must be VK_STRUCTURE_TYPE_RENDER_PASS_TRANSFORM_BEGIN_INFO_QCOM.
typedef struct VkSubpassBeginInfo {
    VkStructureType sType;
    const void* pNext;
    VkSubpassContents contents;
} VkSubpassBeginInfo;

or the equivalent

typedef VkSubpassBeginInfo VkSubpassBeginInfoKHR;

- \textit{sType} is a \textbf{VkStructureType} value identifying this structure.
- \textit{pNext} is NULL or a pointer to a structure extending this structure.
- \textit{contents} is a \textbf{VkSubpassContents} value specifying how the commands in the next subpass will be provided.

\section*{Valid Usage (Implicit)}

- VUID-VkSubpassBeginInfo-sType-sType
  \textit{sType} must be \texttt{VK_STRUCTURE_TYPE_SUBPASS_BEGIN_INFO}
- VUID-VkSubpassBeginInfo-pNext-pNext
  \textit{pNext} must be NULL
- VUID-VkSubpassBeginInfo-contents-parameter
  \textit{contents} must be a valid \textbf{VkSubpassContents} value

Possible values of \texttt{vkCmdBeginRenderPass::contents}, specifying how the commands in the first subpass will be provided, are:

\begin{verbatim}
// Provided by VK_VERSION_1_0
typedef enum VkSubpassContents {
    VK_SUBPASS_CONTENTS_INLINE = 0,
    VK_SUBPASS_CONTENTS_SECONDARY_COMMAND_BUFFERS = 1,
} VkSubpassContents;
\end{verbatim}

- \texttt{VK_SUBPASS_CONTENTS_INLINE} specifies that the contents of the subpass will be recorded inline in the primary command buffer, and secondary command buffers must not be executed within the subpass.
- \texttt{VK_SUBPASS_CONTENTS_SECONDARY_COMMAND_BUFFERS} specifies that the contents are recorded in secondary command buffers that will be called from the primary command buffer, and \texttt{vkCmdExecuteCommands} is the only valid command in the command buffer until \texttt{vkCmdNextSubpass} or \texttt{vkCmdEndRenderPass}. 
If the `pNext` chain of `VkRenderPassBeginInfo` or `VkRenderingInfo` includes a `VkDeviceGroupRenderPassBeginInfo` structure, then that structure includes a device mask and set of render areas for the render pass instance.

The `VkDeviceGroupRenderPassBeginInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkDeviceGroupRenderPassBeginInfo {
    VkStructureType sType;
    const void* pNext;
    uint32_t deviceMask;
    uint32_t deviceRenderAreaCount;
    const VkRect2D* pDeviceRenderAreas;
} VkDeviceGroupRenderPassBeginInfo;
```

or the equivalent

```c
// Provided by VK_KHR_device_group
typedef VkDeviceGroupRenderPassBeginInfo VkDeviceGroupRenderPassBeginInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `deviceMask` is the device mask for the render pass instance.
- `deviceRenderAreaCount` is the number of elements in the `pDeviceRenderAreas` array.
- `pDeviceRenderAreas` is a pointer to an array of `VkRect2D` structures defining the render area for each physical device.

The `deviceMask` serves several purposes. It is an upper bound on the set of physical devices that can be used during the render pass instance, and the initial device mask when the render pass instance begins. In addition, commands transitioning to the next subpass in a render pass instance and commands ending the render pass instance, and, accordingly render pass `load`, `store`, and `multisample resolve` operations and subpass dependencies corresponding to the render pass instance, are executed on the physical devices included in the device mask provided here.

If `deviceRenderAreaCount` is not zero, then the elements of `pDeviceRenderAreas` override the value of `VkRenderPassBeginInfo::renderArea`, and provide a render area specific to each physical device. These render areas serve the same purpose as `VkRenderPassBeginInfo::renderArea`, including controlling the region of attachments that are cleared by `VK_ATTACHMENT_LOAD_OP_CLEAR` and that are resolved into resolve attachments.

If this structure is not present, the render pass instance’s device mask is the value of `VkDeviceGroupCommandBufferBeginInfo::deviceMask`. If this structure is not present or if `deviceRenderAreaCount` is zero, `VkRenderPassBeginInfo::renderArea` is used for all physical devices.
Valid Usage

- **VUID-VkDeviceGroupRenderPassBeginInfo-deviceMask-00905**
  deviceMask must be a valid device mask value

- **VUID-VkDeviceGroupRenderPassBeginInfo-deviceMask-00906**
  deviceMask must not be zero

- **VUID-VkDeviceGroupRenderPassBeginInfo-deviceMask-00907**
  deviceMask must be a subset of the command buffer’s initial device mask

- **VUID-VkDeviceGroupRenderPassBeginInfo-deviceRenderAreaCount-00908**
  deviceRenderAreaCount must either be zero or equal to the number of physical devices in the logical device

- **VUID-VkDeviceGroupRenderPassBeginInfo-offset-06166**
  The offset.x member of any element of pDeviceRenderAreas must be greater than or equal to 0

- **VUID-VkDeviceGroupRenderPassBeginInfo-offset-06167**
  The offset.y member of any element of pDeviceRenderAreas must be greater than or equal to 0

- **VUID-VkDeviceGroupRenderPassBeginInfo-offset-06168**
  The sum of the offset.x and extent.width members of any element of pDeviceRenderAreas must be less than or equal to maxFramebufferWidth

- **VUID-VkDeviceGroupRenderPassBeginInfo-offset-06169**
  The sum of the offset.y and extent.height members of any element of pDeviceRenderAreas must be less than or equal to maxFramebufferHeight

- **VUID-VkDeviceGroupRenderPassBeginInfo-extent-08998**
  The extent.width member of any element of pDeviceRenderAreas must be greater than 0

- **VUID-VkDeviceGroupRenderPassBeginInfo-extent-08999**
  The extent.height member of any element of pDeviceRenderAreas must be greater than 0

Valid Usage (Implicit)

- **VUID-VkDeviceGroupRenderPassBeginInfo-sType-sType**
  sType must be VK_STRUCTURE_TYPE_DEVICE_GROUP_RENDER_PASS_BEGIN_INFO

- **VUID-VkDeviceGroupRenderPassBeginInfo-pDeviceRenderAreas-parameter**
  If deviceRenderAreaCount is not 0, pDeviceRenderAreas must be a valid pointer to an array of deviceRenderAreaCount VkRect2D structures

The VkRenderPassAttachmentBeginInfo structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkRenderPassAttachmentBeginInfo {
    VkStructureType sType;
```
The `VkRenderPassAttachmentBeginInfo` structure is defined as follows:

```c
const void* pNext;
uint32_t attachmentCount;
const VkImageView* pAttachments;
} VkRenderPassAttachmentBeginInfo;
```

or the equivalent

```c
// Provided by VK_KHR_imageless_framebuffer
typedef VkRenderPassAttachmentBeginInfo VkRenderPassAttachmentBeginInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `attachmentCount` is the number of attachments.
- `pAttachments` is a pointer to an array of `VkImageView` handles, each of which will be used as the corresponding attachment in the render pass instance.

### Valid Usage

- **VUID-VkRenderPassAttachmentBeginInfo-pAttachments-03218**
  Each element of `pAttachments` must only specify a single mip level

- **VUID-VkRenderPassAttachmentBeginInfo-pAttachments-03219**
  Each element of `pAttachments` must have been created with the identity swizzle

- **VUID-VkRenderPassAttachmentBeginInfo-pAttachments-04114**
  Each element of `pAttachments` must have been created with `VkImageViewCreateInfo`'s `viewType` not equal to `VK_IMAGE_VIEW_TYPE_3D`

- **VUID-VkRenderPassAttachmentBeginInfo-pAttachments-07010**
  If `multisampled-render-to-single-sampled` is enabled for any subpass, all element of `pAttachments` which have a sample count equal to `VK_SAMPLE_COUNT_1_BIT` must have a format that supports the sample count specified in `VkMultisampledRenderToSingleSampledInfoEXT`'s `rasterizationSamples`

### Valid Usage (Implicit)

- **VUID-VkRenderPassAttachmentBeginInfo-sType-sType**
  `sType` must be `VK_STRUCTURE>Type_RENDER_PASS_ATTACHMENT_BEGIN_INFO`

- **VUID-VkRenderPassAttachmentBeginInfo-pAttachments-parameter**
  If `attachmentCount` is not 0, `pAttachments` must be a valid pointer to an array of `attachmentCount` valid `VkImageView` handles

If a render pass instance enables multiview and if the `<features-multiview-per-view-render-areas,multiviewPerViewRenderAreas>>` feature is enabled, the `VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM` structure can be included in the `pNext` chain.
of VkRenderPassBeginInfo or VkRenderingInfo

The VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM structure is defined as:

```c
// Provided by VK_QCOM_multiview_per_view_render_areas
typedef struct VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM {
    VkStructureType sType;
    const void* pNext;
    uint32_t perViewRenderAreaCount;
    const VkRect2D* pPerViewRenderAreas;
} VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- perViewRenderAreaCount is the number of elements in the pPerViewRenderAreas array.
- pPerViewRenderAreas is a pointer to an array of VkRect2D structures defining the render area for each view.

If perViewRenderAreaCount is not zero, then the elements of pPerViewRenderAreas override the value of VkRenderPassBeginInfo::renderArea or VkRenderingInfo::renderArea and define per-view render areas for the individual views of a multiview render pass. The render area for the view with view index i is specified by pPerViewRenderAreas[i].

The per-view render areas define per-view regions of attachments that are loaded, stored, and resolved according to the loadOp, storeOp, and resolveMode values of the render pass instance. When per-view render areas are defined, the value of VkRenderPassBeginInfo::renderArea or VkRenderingInfo::renderArea must be set to a render area that includes the union of all per-view render areas, may be used by the implementation for optimizations, but does not affect loads, stores, or resolves.

If this structure is present and if perViewRenderAreaCount is not zero, then perViewRenderAreaCount must be at least one greater than the most significant bit set in any element of VkRenderPassMultiviewCreateInfo::pViewMasks or VkRenderingInfo::viewMask.

If this structure is not present or if perViewRenderAreaCount is zero, VkRenderPassBeginInfo::renderArea or VkRenderingInfo::renderArea is used for all views.

**Valid Usage**

- VUID-VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM-offset-07861
  The offset.x member of any element of pPerViewRenderAreas must be greater than or equal to 0.
- VUID-VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM-offset-07862
  The offset.y member of any element of pPerViewRenderAreas must be greater than or equal to 0.
- VUID-VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM-offset-07863
The sum of the `offset.x` and `extent.width` members of any element of `pPerViewRenderAreas` must be less than or equal to `maxFramebufferWidth`.

- VUID-VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM-offset-07864
  The sum of the `offset.y` and `extent.height` members of any element of `pPerViewRenderAreas` must be less than or equal to `maxFramebufferHeight`.

- VUID-VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM-pNext-07865
  If this structure is in the `pNext` chain of `VkRenderPassBeginInfo` and if the render pass object included an element in `VkRenderPassMultiviewCreateInfo::pViewMasks` that set bit `n`, then `perViewRenderAreaCount` must be at least equal to `n+1`.

- VUID-VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM-pNext-07866
  If this structure is in the `pNext` chain of `VkRenderingInfo` and if `VkRenderingInfo::viewMask` set bit `n`, then `perViewRenderAreaCount` must be at least equal to `n+1`.

Valid Usage (Implicit)

- VUID-VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_MULTIVIEW_PER_VIEW_RENDERAREAS_RENDER_PASS_BEGIN_INFO_QCOM`.

- VUID-VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM-pPerViewRenderAreas-parameter
  If `perViewRenderAreaCount` is not `0`, `pPerViewRenderAreas` must be a valid pointer to an array of `perViewRenderAreaCount` `VkRect2D` structures.

To query the render area granularity, call:

```cpp
// Provided by VK_VERSION_1_0
void vkGetRenderAreaGranularity(
    VkDevice device,
    VkRenderPass renderPass,
    VkExtent2D* pGranularity);
```

- `device` is the logical device that owns the render pass.
- `renderPass` is a handle to a render pass.
- `pGranularity` is a pointer to a `VkExtent2D` structure in which the granularity is returned.

The conditions leading to an optimal `renderArea` are:

- the `offset.x` member in `renderArea` is a multiple of the `width` member of the returned `VkExtent2D` (the horizontal granularity).
- the `offset.y` member in `renderArea` is a multiple of the `height` member of the returned `VkExtent2D` (the vertical granularity).
- either the `extent.width` member in `renderArea` is a multiple of the horizontal granularity or `offset.x+extent.width` is equal to the `width` of the `framebuffer` in the `VkRenderPassBeginInfo`.
• either the `extent.height` member in `renderArea` is a multiple of the vertical granularity or `offset.y+extent.height` is equal to the `height` of the framebuffer in the `VkRenderPassBeginInfo`.

Subpass dependencies are not affected by the render area, and apply to the entire image subresources attached to the framebuffer as specified in the description of automatic layout transitions. Similarly, pipeline barriers are valid even if their effect extends outside the render area.

### Valid Usage (Implicit)

- VUID-vkGetRenderAreaGranularity-device-parameter
  - `device` must be a valid `VkDevice` handle
- VUID-vkGetRenderAreaGranularity-renderPass-parameter
  - `renderPass` must be a valid `VkRenderPass` handle
- VUID-vkGetRenderAreaGranularity-pGranularity-parameter
  - `pGranularity` must be a valid pointer to a `VkExtent2D` structure
- VUID-vkGetRenderAreaGranularity-renderPass-parent
  - `renderPass` must have been created, allocated, or retrieved from `device`

To transition to the next subpass in the render pass instance after recording the commands for a subpass, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdNextSubpass(
    VkCommandBuffer commandBuffer,
    VkSubpassContents contents);
```

- `commandBuffer` is the command buffer in which to record the command.
- `contents` specifies how the commands in the next subpass will be provided, in the same fashion as the corresponding parameter of `vkCmdBeginRenderPass`.

The subpass index for a render pass begins at zero when `vkCmdBeginRenderPass` is recorded, and increments each time `vkCmdNextSubpass` is recorded.

After transitioning to the next subpass, the application can record the commands for that subpass.

### Valid Usage

- VUID-vkCmdNextSubpass-None-00909
  - The current subpass index must be less than the number of subpasses in the render pass minus one
- VUID-vkCmdNextSubpass-None-02349
  - This command must not be recorded when transform feedback is active
Valid Usage (Implicit)

- VUID-vkCmdNextSubpass-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdNextSubpass-contents-parameter
  contents must be a valid VkSubpassContents value

- VUID-vkCmdNextSubpass-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdNextSubpass-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdNextSubpass-renderpass
  This command must only be called inside of a render pass instance

- VUID-vkCmdNextSubpass-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdNextSubpass-bufferlevel
  commandBuffer must be a primary VkCommandBuffer

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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To transition to the next subpass in the render pass instance after recording the commands for a subpass, call:

```c
// Provided by VK_VERSION_1_2
def void vkCmdNextSubpass2(
    VkCommandBuffer commandBuffer,
    const VkSubpassBeginInfo* pSubpassBeginInfo,
    const VkSubpassEndInfo* pSubpassEndInfo);
```
or the equivalent command

```c
// Provided by VK_KHR_create_renderpass2
void vkCmdNextSubpass2KHR(
    VkCommandBuffer commandBuffer,
    const VkSubpassBeginInfo* pSubpassBeginInfo,
    const VkSubpassEndInfo* pSubpassEndInfo);
```

- `commandBuffer` is the command buffer in which to record the command.
- `pSubpassBeginInfo` is a pointer to a `VkSubpassBeginInfo` structure containing information about the subpass which is about to begin rendering.
- `pSubpassEndInfo` is a pointer to a `VkSubpassEndInfo` structure containing information about how the previous subpass will be ended.

`vkCmdNextSubpass2` is semantically identical to `vkCmdNextSubpass`, except that it is extensible, and that `contents` is provided as part of an extensible structure instead of as a flat parameter.

Valid Usage

- VUID-vkCmdNextSubpass2-None-03102
  The current subpass index **must** be less than the number of subpasses in the render pass minus one

- VUID-vkCmdNextSubpass2-None-02350
  This command **must** not be recorded when transform feedback is active

Valid Usage (Implicit)

- VUID-vkCmdNextSubpass2-commandBuffer-parameter
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- VUID-vkCmdNextSubpass2-pSubpassBeginInfo-parameter
  `pSubpassBeginInfo` **must** be a valid pointer to a valid `VkSubpassBeginInfo` structure

- VUID-vkCmdNextSubpass2-pSubpassEndInfo-parameter
  `pSubpassEndInfo` **must** be a valid pointer to a valid `VkSubpassEndInfo` structure

- VUID-vkCmdNextSubpass2-commandBuffer-recording
  `commandBuffer` **must** be in the recording state

- VUID-vkCmdNextSubpass2-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics operations

- VUID-vkCmdNextSubpass2-renderpass
  This command **must** only be called inside of a render pass instance

- VUID-vkCmdNextSubpass2-videocoding
  This command **must** only be called outside of a video coding scope
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

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To record a command to end a render pass instance after recording the commands for the last subpass, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdEndRenderPass(
    VkCommandBuffer commandBuffer);
```

- `commandBuffer` is the command buffer in which to end the current render pass instance.

Ending a render pass instance performs any multisample resolve operations on the final subpass.

Valid Usage

- VUID-vkCmdEndRenderPass-None-00910
  The current subpass index **must** be equal to the number of subpasses in the render pass minus one
- VUID-vkCmdEndRenderPass-None-02351
  This command **must** not be recorded when transform feedback is active
- VUID-vkCmdEndRenderPass-None-06170
  The current render pass instance **must** not have been begun with `vkCmdBeginRendering`
- VUID-vkCmdEndRenderPass-None-07004
  If `vkCmdBeginQuery*` was called within a subpass of the render pass, the corresponding `vkCmdEndQuery*` **must** have been called subsequently within the same subpass
Valid Usage (Implicit)

- VUID-vkCmdEndRenderPass-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdEndRenderPass-commandBuffer-recording
  `commandBuffer` must be in the recording state
- VUID-vkCmdEndRenderPass-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations
- VUID-vkCmdEndRenderPass-renderpass
  This command must only be called inside of a render pass instance
- VUID-vkCmdEndRenderPass-videoencoding
  This command must only be called outside of a video coding scope
- VUID-vkCmdEndRenderPass-bufferlevel
  `commandBuffer` must be a primary `VkCommandBuffer`

Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the ` VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
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</tr>
</tbody>
</table>

To record a command to end a render pass instance after recording the commands for the last subpass, call:

```c
// Provided by VK_VERSION_1_2
void vkCmdEndRenderPass2(
    VkCommandBuffer commandBuffer,
    const VkSubpassEndInfo* pSubpassEndInfo);
```
```c
void vkCmdEndRenderPass2KHR(
    VkCommandBuffer commandBuffer,
    const VkSubpassEndInfo* pSubpassEndInfo);
```

- `commandBuffer` is the command buffer in which to end the current render pass instance.
- `pSubpassEndInfo` is a pointer to a `VkSubpassEndInfo` structure containing information about how the last subpass will be ended.

`vkCmdEndRenderPass2` is semantically identical to `vkCmdEndRenderPass`, except that it is extensible.

### Valid Usage

- **VUID-vkCmdEndRenderPass2-None-03103**
  The current subpass index **must** be equal to the number of subpasses in the render pass minus one

- **VUID-vkCmdEndRenderPass2-None-02352**
  This command **must** not be recorded when transform feedback is active

- **VUID-vkCmdEndRenderPass2-None-06171**
  The current render pass instance **must** not have been begun with `vkCmdBeginRendering`

- **VUID-vkCmdEndRenderPass2-None-07005**
  If `vkCmdBeginQuery*` was called within a subpass of the render pass, the corresponding `vkCmdEndQuery*` **must** have been called subsequently within the same subpass

### Valid Usage (Implicit)

- **VUID-vkCmdEndRenderPass2-commandBuffer-parameter**
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- **VUID-vkCmdEndRenderPass2-pSubpassEndInfo-parameter**
  `pSubpassEndInfo` **must** be a valid pointer to a valid `VkSubpassEndInfo` structure

- **VUID-vkCmdEndRenderPass2-commandBuffer-recording**
  `commandBuffer` **must** be in the recording state

- **VUID-vkCmdEndRenderPass2-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics operations

- **VUID-vkCmdEndRenderPass2-renderpass**
  This command **must** only be called inside of a render pass instance

- **VUID-vkCmdEndRenderPass2-videocoding**
  This command **must** only be called outside of a video coding scope

- **VUID-vkCmdEndRenderPass2-bufferlevel**
  `commandBuffer` **must** be a primary `VkCommandBuffer`
**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

**Command Properties**

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<td>Action State Synchronization</td>
</tr>
</tbody>
</table>

The `VkSubpassEndInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkSubpassEndInfo {
    VkStructureType sType;
    const void* pNext;
} VkSubpassEndInfo;
```

or the equivalent

```c
// Provided by VK_KHR_create_renderpass2
typedef VkSubpassEndInfo VkSubpassEndInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.

**Valid Usage (Implicit)**

- VUID-VkSubpassEndInfo-sType-sType
  `sType must be VK_STRUCTURE_TYPE_SUBPASS_END_INFO`
- VUID-VkSubpassEndInfo-pNext-pNext
  `pNext must be NULL or a pointer to a valid instance of VkSubpassFragmentDensityMapOffsetEndInfoQCOM`
- VUID-VkSubpassEndInfo-sType-unique
  The `sType` value of each struct in the `pNext` chain must be unique

If the `VkSubpassEndInfo::pNext` chain includes a `VkSubpassFragmentDensityMapOffsetEndInfoQCOM`
structure, then that structure includes an array of fragment density map offsets per layer for the render pass.

The `VkSubpassFragmentDensityMapOffsetEndInfoQCOM` structure is defined as:

```c
// Provided by VK_QCOM_fragment_density_map_offset
typedef struct VkSubpassFragmentDensityMapOffsetEndInfoQCOM {
    VkStructureType sType;
    const void* pNext;
    uint32_t fragmentDensityOffsetCount;
    const VkOffset2D* pFragmentDensityOffsets;
} VkSubpassFragmentDensityMapOffsetEndInfoQCOM;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `fragmentDensityOffsetCount` is the number of offsets being specified.
- `pFragmentDensityOffsets` is a pointer to an array of `VkOffset2D` structs, each of which describes the offset per layer.

The array elements are given per layer as defined by Fetch Density Value, where index = layer. Each (x,y) offset is in framebuffer pixels and shifts the fetch of the fragment density map by that amount. Offsets can be positive or negative.

Offset values specified for any subpass that is not the last subpass in the render pass are ignored. If the `VkSubpassEndInfo::pNext` chain for the last subpass of a render pass does not include `VkSubpassFragmentDensityMapOffsetEndInfoQCOM`, or if `fragmentDensityOffsetCount` is zero, then the offset (0,0) is used for Fetch Density Value.

### Valid Usage

- VUID-VkSubpassFragmentDensityMapOffsetEndInfoQCOM-fragmentDensityMapOffsets-06503
  If the `fragmentDensityMapOffsets` feature is not enabled or fragment density map is not enabled in the render pass, `fragmentDensityOffsetCount` must equal 0

- VUID-VkSubpassFragmentDensityMapOffsetEndInfoQCOM-fragmentDensityMapAttachment-06504
  If `VkSubpassDescription::fragmentDensityMapAttachment` is not is not `VK_ATTACHMENT_UNUSED` and was not created with `VK_IMAGE_CREATE_FRAGMENT_DENSITY_MAP_OFFSET_BIT_QCOM`, `fragmentDensityOffsetCount` must equal 0

- VUID-VkSubpassFragmentDensityMapOffsetEndInfoQCOM-pDepthStencilAttachment-06505
  If `VkSubpassDescription::pDepthStencilAttachment` is not is not `VK_ATTACHMENT_UNUSED` and was not created with `VK_IMAGE_CREATE_FRAGMENT_DENSITY_MAP_OFFSET_BIT_QCOM`, `fragmentDensityOffsetCount` must equal 0

- VUID-VkSubpassFragmentDensityMapOffsetEndInfoQCOM-pInputAttachments-06506
If any element of VkSubpassDescription::pInputAttachments is not VK_ATTACHMENT_UNUSED and was not created with VK_IMAGE_CREATE_FRAGMENT_DENSITY_MAP_OFFSET_BIT_QCOM, fragmentDensityOffsetCount must equal 0

- VUID-VkSubpassFragmentDensityMapOffsetEndInfoQCOM-pColorAttachments-06507
  If any element of VkSubpassDescription::pColorAttachments is not VK_ATTACHMENT_UNUSED and was not created with VK_IMAGE_CREATE_FRAGMENT_DENSITY_MAP_OFFSET_BIT_QCOM, fragmentDensityOffsetCount must equal 0

- VUID-VkSubpassFragmentDensityMapOffsetEndInfoQCOM-pResolveAttachments-06508
  If any element of VkSubpassDescription::pResolveAttachments is not VK_ATTACHMENT_UNUSED and was not created with VK_IMAGE_CREATE_FRAGMENT_DENSITY_MAP_OFFSET_BIT_QCOM, fragmentDensityOffsetCount must equal 0

- VUID-VkSubpassFragmentDensityMapOffsetEndInfoQCOM-pPreserveAttachments-06509
  If any element of VkSubpassDescription::pPreserveAttachments is not VK_ATTACHMENT_UNUSED and was not created with VK_IMAGE_CREATE_FRAGMENT_DENSITY_MAP_OFFSET_BIT_QCOM, fragmentDensityOffsetCount must equal 0

- VUID-VkSubpassFragmentDensityMapOffsetEndInfoQCOM-fragmentDensityOffsetCount-06510
  If fragmentDensityOffsetCount is not 0 and multiview is enabled for the render pass, fragmentDensityOffsetCount must equal the layerCount that was specified in creating the fragment density map attachment view

- VUID-VkSubpassFragmentDensityMapOffsetEndInfoQCOM-fragmentDensityOffsetCount-06511
  If fragmentDensityOffsetCount is not 0 and multiview is not enabled for the render pass, fragmentDensityOffsetCount must equal 1

- VUID-VkSubpassFragmentDensityMapOffsetEndInfoQCOM-x-06512
  The x component of each element of pFragmentDensityOffsets must be an integer multiple of fragmentDensityOffsetGranularity.width

- VUID-VkSubpassFragmentDensityMapOffsetEndInfoQCOM-y-06513
  The y component of each element of pFragmentDensityOffsets must be an integer multiple of fragmentDensityOffsetGranularity.height

**Valid Usage (Implicit)**

- VUID-VkSubpassFragmentDensityMapOffsetEndInfoQCOM-sType-sType
  sType must be VK_STRUCTURE_TYPE_SUBPASS_FRAGMENT_DENSITY_MAP_OFFSET_END_INFO_QCOM

- VUID-VkSubpassFragmentDensityMapOffsetEndInfoQCOM-pFragmentDensityOffsets-parameter
  If fragmentDensityOffsetCount is not 0, pFragmentDensityOffsets must be a valid pointer to an array of fragmentDensityOffsetCount VkOffset2D structures
8.9. Render Pass Creation Feedback

A `VkRenderPassCreationControlEXT` structure can be included in the `pNext` chain of `VkRenderPassCreateInfo2` or `pNext` chain of `VkSubpassDescription2`. The `VkRenderPassCreationControlEXT` structure is defined as:

```c
// Provided by VK_EXT_subpass_merge_feedback
typedef struct VkRenderPassCreationControlEXT {
    VkStructureType sType;
    const void* pNext;
    VkBool32 disallowMerging;
} VkRenderPassCreationControlEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `disallowMerging` is a boolean value indicating whether subpass merging will be disabled.

If a `VkRenderPassCreationControlEXT` structure is included in the `pNext` chain of `VkRenderPassCreateInfo2` and its value of `disallowMerging` is `VK_TRUE`, the implementation will disable subpass merging for the entire render pass. If a `VkRenderPassCreationControlEXT` structure is included in the `pNext` chain of `VkSubpassDescription2` and its value of `disallowMerging` is `VK_TRUE`, the implementation will disable merging the described subpass with previous subpasses in the render pass.

**Valid Usage (Implicit)**

- `VUID-VkRenderPassCreationControlEXT-sType-sType` sType must be `VK_STRUCTURE_TYPE_RENDER_PASS_CREATION_CONTROL_EXT`

To obtain feedback about the creation of a render pass, include a `VkRenderPassCreationFeedbackCreateInfoEXT` structure in the `pNext` chain of `VkRenderPassCreateInfo2`. The `VkRenderPassCreationFeedbackCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_subpass_merge_feedback
typedef struct VkRenderPassCreationFeedbackCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkRenderPassCreationFeedbackCreateInfoEXT* pRenderPassFeedback;
} VkRenderPassCreationFeedbackCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `pRenderPassFeedback` is a pointer to a `VkRenderPassCreationFeedbackCreateInfoEXT` structure in which feedback is returned.
Valid Usage (Implicit)

- **VUID-VkRenderPassCreationFeedbackCreateInfoEXT-sType-sType**
  
  The *sType* must be `VK_STRUCTURE_TYPE_RENDER_PASS_CREATION_FEEDBACK_CREATE_INFO_EXT`.

- **VUID-VkRenderPassCreationFeedbackCreateInfoEXT-pRenderPassFeedback-parameter**
  
  The *pRenderPassFeedback* must be a valid pointer to a `VkRenderPassCreationFeedbackInfoEXT` structure.

The `VkRenderPassCreationFeedbackInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_subpass_merge_feedback
typedef struct VkRenderPassCreationFeedbackInfoEXT {
    uint32_t postMergeSubpassCount;
} VkRenderPassCreationFeedbackInfoEXT;
```

- **postMergeSubpassCount** is the subpass count after merge.

Feedback about the creation of a subpass can be obtained by including a `VkRenderPassSubpassFeedbackCreateInfoEXT` structure in the *pNext* chain of `VkSubpassDescription2`. The `VkRenderPassSubpassFeedbackCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_subpass_merge_feedback
typedef struct VkRenderPassSubpassFeedbackCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkRenderPassSubpassFeedbackInfoEXT* pSubpassFeedback;
} VkRenderPassSubpassFeedbackCreateInfoEXT;
```

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **pSubpassFeedback** is a pointer to a `VkRenderPassSubpassFeedbackInfoEXT` structure in which feedback is returned.

Valid Usage (Implicit)

- **VUID-VkRenderPassSubpassFeedbackCreateInfoEXT-sType-sType**
  
  The *sType* must be `VK_STRUCTURE_TYPE_RENDER_PASS_SUBPASS_FEEDBACK_CREATE_INFO_EXT`.

- **VUID-VkRenderPassSubpassFeedbackCreateInfoEXT-pSubpassFeedback-parameter**
  
  The *pSubpassFeedback* must be a valid pointer to a `VkRenderPassSubpassFeedbackInfoEXT` structure.

The `VkRenderPassSubpassFeedbackInfoEXT` structure is defined as:
```c
// Provided by VK_EXT_subpass_merge_feedback
typedef struct VkRenderPassSubpassFeedbackInfoEXT {
    VkSubpassMergeStatusEXT subpassMergeStatus;
    char description[VK_MAX_DESCRIPTION_SIZE];
    uint32_t postMergeIndex;
} VkRenderPassSubpassFeedbackInfoEXT;
```

- **subpassMergeStatus** is a `VkSubpassMergeStatusEXT` value specifying information about whether the subpass is merged with previous subpass and the reason why it is not merged.
- **description** is an array of `VK_MAX_DESCRIPTION_SIZE` `char` containing a null-terminated UTF-8 string which provides additional details.
- **postMergeIndex** is the subpass index after the subpass merging.

Possible values of `VkRenderPassSubpassFeedbackInfoEXT::subpassMergeStatus` are:

```c
// Provided by VK_EXT_subpass_merge_feedback
typedef enum VkSubpassMergeStatusEXT {
    VK_SUBPASS_MERGE_STATUS_MERGED_EXT = 0,
    VK_SUBPASS_MERGE_STATUS_DISALLOWED_EXT = 1,
    VK_SUBPASS_MERGE_STATUS_NOT_MERGED_SIDE_EFFECTS_EXT = 2,
    VK_SUBPASS_MERGE_STATUS_NOT_MERGED_SAMPLES_MISMATCH_EXT = 3,
    VK_SUBPASS_MERGE_STATUS_NOT_MERGED_VIEWS_MISMATCH_EXT = 4,
    VK_SUBPASS_MERGE_STATUS_NOT_MERGED_ALIASING_EXT = 5,
    VK_SUBPASS_MERGE_STATUS_NOT_MERGED_DEPENDENCIES_EXT = 6,
    VK_SUBPASS_MERGE_STATUS_NOT_MERGED_INCOMPATIBLE_INPUT_ATTACHMENT_EXT = 7,
    VK_SUBPASS_MERGE_STATUS_NOT_MERGED_TOO_MANY_ATTACHMENTS_EXT = 8,
    VK_SUBPASS_MERGE_STATUS_NOT_MERGED_INSUFFICIENT_STORAGE_EXT = 9,
    VK_SUBPASS_MERGE_STATUS_NOT_MERGED_DEPTH_STENCIL_COUNT_EXT = 10,
    VK_SUBPASS_MERGE_STATUS_NOT_MERGED_RESOLVE_ATTACHMENT_REUSE_EXT = 11,
    VK_SUBPASS_MERGE_STATUS_NOT_MERGED_SINGLE_SUBPASS_EXT = 12,
    VK_SUBPASS_MERGE_STATUS_NOT_MERGED_UNSPECIFIED_EXT = 13,
} VkSubpassMergeStatusEXT;
```

- **VK_SUBPASS_MERGE_STATUS_MERGED_EXT** specifies the subpass is merged with a previous subpass.
- **VK_SUBPASS_MERGE_STATUS_DISALLOWED_EXT** specifies the subpass is disallowed to merge with previous subpass. If the render pass does not allow subpass merging, then all subpass statuses are set to this value. If a subpass description does not allow subpass merging, then only that subpass’s status is set to this value.
- **VK_SUBPASS_MERGE_STATUS_NOT_MERGED_SIDE_EFFECTS_EXT** specifies the subpass is not merged because it contains side effects.
- **VK_SUBPASS_MERGE_STATUS_NOT_MERGED_SAMPLES_MISMATCH_EXT** specifies the subpass is not merged because sample count is not compatible with previous subpass.
- **VK_SUBPASS_MERGE_STATUS_NOT_MERGED_VIEWS_MISMATCH_EXT** specifies the subpass is not merged because view masks do not match with previous subpass.
- **VK_SUBPASS_MERGE_STATUS_NOT_MERGED_ALIASING_EXT** specifies the subpass is not merged because of
8.10. Common Render Pass Data Races (Informative)

Due to the complexity of how rendering is performed, there are several ways an application can accidentally introduce a data race, usually by doing something that may seem benign but actually cannot be supported. This section indicates a number of the more common cases as guidelines to help avoid them.

8.10.1. Sampling from a read-only attachment

Vulkan includes read-only layouts for depth/stencil images, that allow the images to be both read during a render pass for the purposes of depth/stencil tests, and read as a non-attachment.

However, because `VK_ATTACHMENT_STORE_OP_STORE` and `VK_ATTACHMENT_STORE_OP_DONT_CARE` may perform write operations, even if no recorded command writes to an attachment, reading from an image while also using it as an attachment with these store operations can result in a data race. If the reads from the non-attachment are performed in a fragment shader where the accessed samples match those covered by the fragment shader, no data race will occur as store operations are guaranteed to operate after fragment shader execution for the set of samples the fragment covers. Notably, input attachments can also be used for this case. Reading other samples or in any other shader stage can result in unexpected behavior due to the potential for a data race, and validation errors should be generated for doing so. In practice, many applications have shipped reading samples outside of the covered fragment without any observable issue, but there is no guarantee that this will always work, and it is not advisable to rely on this in new or re-worked code bases. As `VK_ATTACHMENT_STORE_OP_NONE` is guaranteed to perform no writes, applications wishing to read an image as both an attachment and a non-attachment should make use of this.
8.10.2. Non-overlapping access between resources

When relying on non-overlapping accesses between attachments and other resources, it is important to note that load and store operations have fairly wide alignment requirements - potentially affecting entire subresources and adjacent depth/stencil aspects. This makes it invalid to access a non-attachment subresource that is simultaneously being used as an attachment where either access performs a write operation.

The only exception to this is if a subresource is in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, in which case the overlap is defined to occur at a per-pixel granularity, and applications can read data from pixels outside the render area without introducing a data race.

8.10.3. Depth/stencil and input attachments

When rendering to only the depth OR stencil aspect of an image, an input attachment accessing the other aspect will not cause a data race only under very specific conditions. To avoid a data race, the aspect not being written must be in a read-only layout, and writes to it must be disabled in the draw state. For example, to read from stencil while writing depth, the attachment must be in `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL` (or equivalent), and the stencil write mask must be set to 0. Similarly to read from depth while writing stencil, the attachment must be in `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL` (or equivalent), and depth write enable must be set to `VK_FALSE`.

8.10.4. Synchronization Options

There are several synchronization options available to synchronize between accesses to resources within a render pass. Some of the options are outlined below:

- A `VkSubpassDependency` in a render pass object can synchronize attachment writes and multisample resolve operations from a prior subpass for subsequent input attachment reads.
- A `vkCmdPipelineBarrier` inside a subpass can synchronize prior attachment writes in the subpass with subsequent input attachment reads.
- A `vkCmdPipelineBarrier` inside a subpass can synchronize prior attachment writes in the subpass with subsequent non-attachment reads if the attachment is in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout.
- If a subresource is used as a color and input attachment, and the pipeline performing the read was created with `VK_PIPELINE_COLOR_BLEND_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_BIT_EXT`
- If a subresource is used as a depth and input attachment, and the pipeline performing the read was created with `VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT`
- If a subresource is used as a stencil and input attachment, and the pipeline performing the read was created with `VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT`
• If a subresource is used as two separate non-attachment resources, writes to a pixel or individual sample in a fragment shader can be synchronized with access to the same pixel or sample in another fragment shader by using one of the fragment interlock execution modes.
Chapter 9. Shaders

A shader specifies programmable operations that execute for each vertex, control point, tessellated vertex, primitive, fragment, or workgroup in the corresponding stage(s) of the graphics and compute pipelines.

Graphics pipelines include vertex shader execution as a result of primitive assembly, followed, if enabled, by tessellation control and evaluation shaders operating on patches, geometry shaders, if enabled, operating on primitives, and fragment shaders, if present, operating on fragments generated by Rasterization. In this specification, vertex, tessellation control, tessellation evaluation and geometry shaders are collectively referred to as pre-rasterization shader stages and occur in the logical pipeline before rasterization. The fragment shader occurs logically after rasterization.

Only the compute shader stage is included in a compute pipeline. Compute shaders operate on compute invocations in a workgroup.

Shaders can read from input variables, and read from and write to output variables. Input and output variables can be used to transfer data between shader stages, or to allow the shader to interact with values that exist in the execution environment. Similarly, the execution environment provides constants describing capabilities.

Shader variables are associated with execution environment-provided inputs and outputs using built-in decorations in the shader. The available decorations for each stage are documented in the following subsections.

9.1. Shader Objects

Shaders may be compiled and linked into pipeline objects as described in Pipelines chapter, or if the shaderObject feature is enabled they may be compiled into individual per-stage shader objects which can be bound on a command buffer independently from one another. Unlike pipelines, shader objects are not intrinsically tied to any specific set of state. Instead, state is specified dynamically in the command buffer.

Each shader object represents a single compiled shader stage, which may optionally be linked with one or more other stages.

Shader objects are represented by VkShaderEXT handles:

```cpp
// Provided by VK_EXT_shader_object
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkShaderEXT)
```

9.1.1. Shader Object Creation

Shader objects may be created from shader code provided as SPIR-V, or in an opaque, implementation-defined binary format specific to the physical device.

To create one or more shader objects, call:
Provided by VK_EXT_shader_object

```
VkResult vkCreateShadersEXT(
    VkDevice device, 
    uint32_t createInfoCount, 
    const VkShaderCreateInfoEXT* pCreateInfos, 
    const VkAllocationCallbacks* pAllocator, 
    VkShaderEXT* pShaders);
```

- **device** is the logical device that creates the shader objects.
- **createInfoCount** is the length of the **pCreateInfos** and **pShaders** arrays.
- **pCreateInfos** is a pointer to an array of **VkShaderCreateInfoEXT** structures.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
- **pShaders** is a pointer to an array of **VkShaderEXT** handles in which the resulting shader objects are returned.

When this function returns, whether or not it succeeds, it is guaranteed that every element of **pShaders** will have been overwritten by either **VK_NULL_HANDLE** or a valid **VkShaderEXT** handle.

This means that whenever shader creation fails, the application can determine which shader the returned error pertains to by locating the first **VK_NULL_HANDLE** element in **pShaders**. It also means that an application can reliably clean up from a failed call by iterating over the **pShaders** array and destroying every element that is not **VK_NULL_HANDLE**.

### Valid Usage

- **VUID-vkCreateShadersEXT-None-08400**
  The **shaderObject** feature must be enabled

- **VUID-vkCreateShadersEXT-pCreateInfos-08401**
  If **createInfoCount** is 1, there must be no element of **pCreateInfos** whose **flags** member includes **VK_SHADER_CREATE_LINK_STAGE_BIT_EXT**

- **VUID-vkCreateShadersEXT-pCreateInfos-08402**
  If the **flags** member of any element of **pCreateInfos** includes **VK_SHADER_CREATE_LINK_STAGE_BIT_EXT**, the **flags** member of all other elements of **pCreateInfos** whose **stage** is **VK_SHADER_STAGE_VERTEX_BIT**, **VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT**, **VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT**, **VK_SHADER_STAGE_GEOMETRY_BIT**, or **VK_SHADER_STAGE_FRAGMENT_BIT** must also include **VK_SHADER_CREATE_LINK_STAGE_BIT_EXT**

- **VUID-vkCreateShadersEXT-pCreateInfos-08403**
  If the **flags** member of any element of **pCreateInfos** includes **VK_SHADER_CREATE_LINK_STAGE_BIT_EXT**, the **flags** member of all other elements of **pCreateInfos** whose **stage** is **VK_SHADER_STAGE_TASK_BIT_EXT** or **VK_SHADER_STAGE_MESH_BIT_EXT** must also include **VK_SHADER>Create_LINK_STAGE_BIT_EXT**

- **VUID-vkCreateShadersEXT-pCreateInfos-08404**
  If the **flags** member of any element of **pCreateInfos** whose **stage** is
VK_SHADER_STAGE_TASK_BIT_EXT or VK_SHADER_STAGE_MESH_BIT_EXT includes VK_SHADER_CREATE_LINK_STAGE_BIT_EXT, there must be no member of pCreateInfos whose stage is VK_SHADER_STAGE_VERTEX_BIT and whose flags member includes VK_SHADER_CREATE_LINK_STAGE_BIT_EXT

- VUID-vkCreateShadersEXT-pCreateInfos-08405
  If there is any element of pCreateInfos whose stage is VK_SHADER_STAGE_MESH_BIT_EXT and whose flags member includes both VK_SHADER_CREATE_LINK_STAGE_BIT_EXT and VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT, there must be no element of pCreateInfos whose stage is VK_SHADER_STAGE_TASK_BIT_EXT and whose flags member includes VK_SHADER_CREATE_LINK_STAGE_BIT_EXT

- VUID-vkCreateShadersEXT-pCreateInfos-08409
  For each element of pCreateInfos whose flags member includes VK_SHADER_CREATE_LINK_STAGE_BIT_EXT, if there is any other element of pCreateInfos whose stage is logically later than the stage of the former and whose flags member also includes VK_SHADER_CREATE_LINK_STAGE_BIT_EXT, the nextStage of the former must be equal to the stage of the element with the logically earliest stage following the stage of the former whose flags member also includes VK_SHADER_CREATE_LINK_STAGE_BIT_EXT

- VUID-vkCreateShadersEXT-pCreateInfos-08410
  The stage member of each element of pCreateInfos whose flags member includes VK_SHADER_CREATE_LINK_STAGE_BIT_EXT must be unique

- VUID-vkCreateShadersEXT-pCreateInfos-08411
  The codeType member of all elements of pCreateInfos whose flags member includes VK_SHADER_CREATE_LINK_STAGE_BIT_EXT must be the same

- VUID-vkCreateShadersEXT-pCreateInfos-08867
  If pCreateInfos contains elements with both VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT and VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT, both elements’ flags include VK_SHADER_CREATE_LINK_STAGE_BIT_EXT, both elements’ codeType is VK_SHADER_CODE_TYPE_SPIRV_EXT, and the VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT stage’s pCode contains an OpExecutionMode instruction specifying the type of subdivision, it must match the subdivision type specified in the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT stage

- VUID-vkCreateShadersEXT-pCreateInfos-08868
  If pCreateInfos contains elements with both VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT and VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT, both elements’ flags include VK_SHADER_CREATE_LINK_STAGE_BIT_EXT, both elements’ codeType is VK_SHADER_CODE_TYPE_SPIRV_EXT, and the VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT stage’s pCode contains an OpExecutionMode instruction specifying the orientation of triangles, it must match the triangle orientation specified in the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT stage

- VUID-vkCreateShadersEXT-pCreateInfos-08869
  If pCreateInfos contains elements with both VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT and VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT, both elements’ flags include VK_SHADER_CREATE_LINK_STAGE_BIT_EXT, both elements’ codeType is VK_SHADER_CODE_TYPE_SPIRV_EXT, and the VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT stage’s pCode contains an OpExecutionMode instruction specifying PointMode, the
VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT stage must also contain an OpExecutionMode instruction specifying PointMode

- VUID-vkCreateShadersEXT-pCreateInfos-08870
  If pCreateInfos contains elements with both VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT and VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT, both elements' flags include VK_SHADER_CREATE_LINK_STAGE_BIT_EXT, both elements' codeType is VK_SHADER_CODE_TYPE_SPIRV_EXT, and the VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT stage's pCode contains an OpExecutionMode instruction specifying the spacing of segments on the edges of tessellated primitives, it must match the segment spacing specified in the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT stage.

- VUID-vkCreateShadersEXT-pCreateInfos-08871
  If pCreateInfos contains elements with both VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT and VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT, both elements' flags include VK_SHADER_CREATE_LINK_STAGE_BIT_EXT, both elements' codeType is VK_SHADER_CODE_TYPE_SPIRV_EXT, and the VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT stage's pCode contains an OpExecutionMode instruction specifying the output patch size, it must match the output patch size specified in the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT stage.

Valid Usage (Implicit)

- VUID-vkCreateShadersEXT-device-parameter
  device must be a valid VkDevice handle.

- VUID-vkCreateShadersEXT-pCreateInfos-parameter
  pCreateInfos must be a valid pointer to an array of createInfoCount valid VkShaderCreateInfoEXT structures.

- VUID-vkCreateShadersEXT-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure.

- VUID-vkCreateShadersEXT-pShaders-parameter
  pShaders must be a valid pointer to an array of createInfoCount VkShaderEXT handles.

- VUID-vkCreateShadersEXT-createInfoCount-arraylength
  createInfoCount must be greater than 0.

Return Codes

Success

- VK_SUCCESS

Failure

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_INITIALIZATION_FAILED
The **VkShaderCreateInfoEXT** structure is defined as:

```c
// Provided by VK_EXT_shader_object
typedef struct VkShaderCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkShaderCreateFlagsEXT flags;
    VkShaderStageFlagBits stage;
    VkShaderStageFlags nextStage;
    VkShaderCodeTypeEXT codeType;
    size_t codeSize;
    const void* pCode;
    const char* pName;
    uint32_t setLayoutCount;
    const VkDescriptorSetLayout* pSetLayouts;
    uint32_t pushConstantRangeCount;
    const VkPushConstantRange* pPushConstantRanges;
    const VkSpecializationInfo* pSpecializationInfo;
} VkShaderCreateInfoEXT;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **flags** is a bitmask of **VkShaderCreateFlagBitsEXT** describing additional parameters of the shader.
- **stage** is a **VkShaderStageFlagBits** value specifying a single shader stage.
- **nextStage** is a bitmask of **VkShaderStageFlagBits** specifying zero or stages which **may** be used as a logically next bound stage when drawing with the shader bound.
- **codeType** is a **VkShaderCodeTypeEXT** value specifying the type of the shader code pointed to be **pCode**.
- **codeSize** is the size in bytes of the shader code pointed to be **pCode**.
- **pName** is a pointer to a null-terminated UTF-8 string specifying the entry point name of the shader for this stage.
- **setLayoutCount** is the number of descriptor set layouts pointed to by **pSetLayouts**.
- **pSetLayouts** is a pointer to an array of **VkDescriptorSetLayout** objects used by the shader stage.
- **pushConstantRangeCount** is the number of push constant ranges pointed to by **pPushConstantRanges**.
- **pPushConstantRanges** is a pointer to an array of **VkPushConstantRange** structures used by the shader stage.
- **pSpecializationInfo** is a pointer to a **VkSpecializationInfo** structure, as described in
Specialization Constants, or NULL.

Valid Usage

- **VUID-VkShaderCreateInfoEXT-codeSize-08735**
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, `codeSize` **must** be a multiple of 4

- **VUID-VkShaderCreateInfoEXT-pCode-08736**
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, `pCode` **must** point to valid SPIR-V code, formatted and packed as described by the Khronos SPIR-V Specification

- **VUID-VkShaderCreateInfoEXT-pCode-08737**
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, `pCode` **must** adhere to the validation rules described by the Validation Rules within a Module section of the SPIR-V Environment appendix

- **VUID-VkShaderCreateInfoEXT-pCode-08738**
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, `pCode` **must** declare the Shader capability for SPIR-V code

- **VUID-VkShaderCreateInfoEXT-pCode-08739**
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, `pCode` **must** not declare any capability that is not supported by the API, as described by the Capabilities section of the SPIR-V Environment appendix

- **VUID-VkShaderCreateInfoEXT-pCode-08740**
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and `pCode` declares any of the SPIR-V extensions listed in the SPIR-V Environment appendix, one of the corresponding requirements **must** be satisfied

- **VUID-VkShaderCreateInfoEXT-pCode-08741**
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and `pCode` declares any of the SPIR-V extensions listed in the SPIR-V Environment appendix, one of the corresponding requirements **must** be satisfied

- **VUID-VkShaderCreateInfoEXT-flags-08412**
  If `stage` is not `VK_SHADER_STAGE_TASK_BIT_EXT`, `VK_SHADER_STAGE_MESH_BIT_EXT`, `VK_SHADER_STAGE_VERTEX_BIT`, `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`, `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`, `VK_SHADER_STAGE_GEOMETRY_BIT`, or `VK_SHADER_STAGE_FRAGMENT_BIT`, `flags` **must** not include `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT`

- **VUID-VkShaderCreateInfoEXT-flags-08486**
  If `stage` is not `VK_SHADER_STAGE_FRAGMENT_BIT`, `flags` **must** not include `VK_SHADER_CREATE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_EXT`

- **VUID-VkShaderCreateInfoEXT-flags-08487**
  If the `attachmentFragmentShadingRate` feature is not enabled, `flags` **must** not include
• VUID-VkShaderCreateInfoEXT-flags-08488
  If stage is not VK_SHADER_STAGE_FRAGMENT_BIT, flags must not include
  VK_SHADER_CREATE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_EXT

• VUID-VkShaderCreateInfoEXT-flags-08489
  If the fragmentDensityMap feature is not enabled, flags must not include
  VK_SHADER_CREATE_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT

• VUID-VkShaderCreateInfoEXT-flags-08992
  If flags includes VK_SHADER_CREATE_REQUIRE_FULL_SUBGROUPS_BIT_EXT, stage must be one of
  VK_SHADER_STAGE_MESH_BIT_EXT, VK_SHADER_STAGE_TASK_BIT_EXT, or
  VK_SHADER_STAGE_COMPUTE_BIT

• VUID-VkShaderCreateInfoEXT-flags-08485
  If stage is not VK_SHADER_STAGE_COMPUTE_BIT, flags must not include
  VK_SHADER_CREATE_DISPATCH_BASE_BIT_EXT

• VUID-VkShaderCreateInfoEXT-flags-08414
  If stage is not VK_SHADER_STAGE_MESH_BIT_EXT, flags must not include
  VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT

• VUID-VkShaderCreateInfoEXT-flags-08416
  If flags includes both VK_SHADER_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT_EXT and
  VK_SHADER_CREATE_REQUIRE_FULL_SUBGROUPS_BIT_EXT, the local workgroup size in the X
  dimension of the shader must be a multiple of maxSubgroupSize

• VUID-VkShaderCreateInfoEXT-flags-08417
  If flags includes VK_SHADER_CREATE_REQUIRE_FULL_SUBGROUPS_BIT_EXT but not
  VK_SHADER_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT_EXT and no
  VkShaderRequiredSubgroupSizeCreateInfoEXT structure is included in the pNext chain,
  the local workgroup size in the X dimension of the shader must be a multiple of
  subgroupSize

• VUID-VkShaderCreateInfoEXT-stage-08418
  stage must not be VK_SHADER_STAGE_ALL_GRAPHICS or VK_SHADER_STAGE_ALL

• VUID-VkShaderCreateInfoEXT-stage-08419
  If the tessellationShader feature is not enabled, stage must not be
  VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT or
  VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT

• VUID-VkShaderCreateInfoEXT-stage-08420
  If the geometryShader feature is not enabled, stage must not be
  VK_SHADER_STAGE_GEOMETRY_BIT

• VUID-VkShaderCreateInfoEXT-stage-08421
  If the taskShader feature is not enabled, stage must not be VK_SHADER_STAGE_TASK_BIT_EXT

• VUID-VkShaderCreateInfoEXT-stage-08422
  If the meshShader feature is not enabled, stage must not be VK_SHADER_STAGE_MESH_BIT_EXT

• VUID-VkShaderCreateInfoEXT-stage-08425
  stage must not be VK_SHADER_STAGE_SUBPASS_SHADING_BIT_HUAWEI
• VUID-VkShaderCreateInfoEXT-stage-08426
  stage must not be VK_SHADER_STAGE_CLUSTER_CULLING_BIT_HUAWEI

• VUID-VkShaderCreateInfoEXT-nextStage-08427
  If stage is VK_SHADER_STAGE_VERTEX_BIT, nextStage must not include any bits other than
  VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT, VK_SHADER_STAGE_GEOMETRY_BIT, and
  VK_SHADER_STAGE_FRAGMENT_BIT

• VUID-VkShaderCreateInfoEXT-nextStage-08428
  If the tessellationShader feature is not enabled, nextStage must not include
  VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT or
  VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT

• VUID-VkShaderCreateInfoEXT-nextStage-08429
  If the geometryShader feature is not enabled, nextStage must not include
  VK_SHADER_STAGE_GEOMETRY_BIT

• VUID-VkShaderCreateInfoEXT-nextStage-08430
  If stage is VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT, nextStage must not include any bits
  other than VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT

• VUID-VkShaderCreateInfoEXT-nextStage-08431
  If stage is VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT, nextStage must not include any
  bits other than VK_SHADER_STAGE_GEOMETRY_BIT and VK_SHADER_STAGE_FRAGMENT_BIT

• VUID-VkShaderCreateInfoEXT-nextStage-08433
  If stage is VK_SHADER_STAGE_GEOMETRY_BIT, nextStage must not include any bits other than
  VK_SHADER_STAGE_FRAGMENT_BIT

• VUID-VkShaderCreateInfoEXT-nextStage-08434
  If stage is VK_SHADER_STAGE_FRAGMENT_BIT or VK_SHADER_STAGE_COMPUTE_BIT, nextStage must
  be 0

• VUID-VkShaderCreateInfoEXT-nextStage-08435
  If stage is VK_SHADER_STAGE_TASK_BIT_EXT, nextStage must not include any bits other than
  VK_SHADER_STAGE_MESH_BIT_EXT

• VUID-VkShaderCreateInfoEXT-nextStage-08436
  If stage is VK_SHADER_STAGE_MESH_BIT_EXT, nextStage must not include any bits other than
  VK_SHADER_STAGE_FRAGMENT_BIT

• VUID-VkShaderCreateInfoEXT-pName-08440
  If codeType is VK_SHADER_CODE_TYPE_SPIRV_EXT, pName must be the name of an OpEntryPoint in
  pCode with an execution model that matches stage

• VUID-VkShaderCreateInfoEXT-pCode-08492
  If codeType is VK_SHADER_CODE_TYPE_BINARY_EXT, pCode must be aligned to 16 bytes

• VUID-VkShaderCreateInfoEXT-pCode-08493
  If codeType is VK_SHADER_CODE_TYPE_SPIRV_EXT, pCode must be aligned to 4 bytes

• VUID-VkShaderCreateInfoEXT-pCode-08448
  If codeType is VK_SHADER_CODE_TYPE_SPIRV_EXT, and the identified entry point includes any
  variable in its interface that is declared with the ClipDistance BuiltIn decoration, that
  variable must not have an array size greater than VkPhysicalDeviceLimits::maxClipDistances
• VUID-VkShaderCreateInfoEXT-pCode-08449
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and the identified entry point includes any variable in its interface that is declared with the `CullDistance` BuiltIn decoration, that variable must not have an array size greater than `VkPhysicalDeviceLimits::maxCullDistances`.

• VUID-VkShaderCreateInfoEXT-pCode-08450
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and the identified entry point includes any variables in its interface that are declared with the `ClipDistance` or `CullDistance` BuiltIn decoration, those variables must not have array sizes which sum to more than `VkPhysicalDeviceLimits::maxCombinedClipAndCullDistances`.

• VUID-VkShaderCreateInfoEXT-pCode-08451
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and the identified entry point includes any variable in its interface that is declared with the `SampleMask` BuiltIn decoration, that variable must not have an array size greater than `VkPhysicalDeviceLimits::maxSampleMaskWords`.

• VUID-VkShaderCreateInfoEXT-pCode-08452
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and `stage` is `VK_SHADER_STAGE_VERTEX_BIT`, the identified entry point must not include any input variable in its interface that is decorated with `CullDistance`.

• VUID-VkShaderCreateInfoEXT-pCode-08453
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and `stage` is either `VK_SHADER_STAGE_TESSellation_CONTROL_BIT` or `VK_SHADER_STAGE_TESSellation_Evaluation_BIT`, and the identified entry point has an `OpExecutionMode` instruction specifying a patch size with `OutputVertices`, the patch size must be greater than 0 and less than or equal to `VkPhysicalDeviceLimits::maxTessellationPatchSize`.

• VUID-VkShaderCreateInfoEXT-pCode-08454
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and `stage` is `VK_SHADER_STAGE_GEOMETRY_BIT`, the identified entry point must have an `OpExecutionMode` instruction specifying a maximum output vertex count that is greater than 0 and less than or equal to `VkPhysicalDeviceLimits::maxGeometryOutputVertices`.

• VUID-VkShaderCreateInfoEXT-pCode-08455
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and `stage` is `VK_SHADER_STAGE_GEOMETRY_BIT`, the identified entry point must have an `OpExecutionMode` instruction specifying an invocation count that is greater than 0 and less than or equal to `VkPhysicalDeviceLimits::maxGeometryShaderInvocations`.

• VUID-VkShaderCreateInfoEXT-pCode-08456
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and `stage` is a pre-rasterization shader stage, and the identified entry point writes to `Layer` for any primitive, it must write the same value to `Layer` for all vertices of a given primitive.

• VUID-VkShaderCreateInfoEXT-pCode-08457
  If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and `stage` is a pre-rasterization shader stage, and the identified entry point writes to `ViewportIndex` for any primitive, it must write the same value to `ViewportIndex` for all vertices of a given primitive.
• **VUID-VkShaderCreateInfoEXT-pCode-08458**
If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and `stage` is `VK_SHADER_STAGE_FRAGMENT_BIT`, the identified entry point must not include any output variables in its interface decorated with `CullDistance`.

• **VUID-VkShaderCreateInfoEXT-pCode-08459**
If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and `stage` is `VK_SHADER_STAGE_FRAGMENT_BIT`, and the identified entry point writes to `FragDepth` in any execution path, all execution paths that are not exclusive to helper invocations must either discard the fragment, or write or initialize the value of `FragDepth`.

• **VUID-VkShaderCreateInfoEXT-pCode-08460**
If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, the shader code in `pCode` must be valid as described by the Khronos SPIR-V Specification after applying the specializations provided in `pSpecializationInfo`, if any, and then converting all specialization constants into fixed constants.

• **VUID-VkShaderCreateInfoEXT-codeType-08872**
If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and `stage` is `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`, `pCode` must contain an `OpExecutionMode` instruction specifying the type of subdivision.

• **VUID-VkShaderCreateInfoEXT-codeType-08873**
If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and `stage` is `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`, `pCode` must contain an `OpExecutionMode` instruction specifying the orientation of triangles generated by the tessellator.

• **VUID-VkShaderCreateInfoEXT-codeType-08874**
If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and `stage` is `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`, `pCode` must contain an `OpExecutionMode` instruction specifying the spacing of segments on the edges of tessellated primitives.

• **VUID-VkShaderCreateInfoEXT-codeType-08875**
If `codeType` is `VK_SHADER_CODE_TYPE_SPIRV_EXT`, and `stage` is `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`, `pCode` must contain an `OpExecutionMode` instruction specifying the output patch size.

---

**Valid Usage (Implicit)**

- **VUID-VkShaderCreateInfoEXT-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_SHADER_CREATE_INFO_EXT`.

- **VUID-VkShaderCreateInfoEXT-pNext-pNext**
  `pNext` must be `NULL` or a pointer to a valid instance of `VkPipelineShaderStageRequiredSubgroupSizeCreateInfo`.

- **VUID-VkShaderCreateInfoEXT-sType-unique**
  The `sType` value of each struct in the `pNext` chain must be unique.

- **VUID-VkShaderCreateInfoEXT-flags-parameter**
  `flags` must be a valid combination of `VkShaderCreateFlagBitsEXT` values.

- **VUID-VkShaderCreateInfoEXT-stage-parameter**


\textbf{stage must} be a valid \texttt{VkShaderStageFlagBits} value

- VUID-VkShaderCreateInfoEXT-nextStage-parameter
  \textbf{nextStage must} be a valid combination of \texttt{VkShaderStageFlagBits} values

- VUID-VkShaderCreateInfoEXT-codeType-parameter
  \textbf{codeType must} be a valid \texttt{VkShaderCodeTypeEXT} value

- VUID-VkShaderCreateInfoEXT-pCode-parameter
  \textbf{pCode must} be a valid pointer to an array of \texttt{codeSize} bytes

- VUID-VkShaderCreateInfoEXT-pName-parameter
  If \texttt{pName} is not NULL, \textbf{pName must} be a null-terminated UTF-8 string

- VUID-VkShaderCreateInfoEXT-pSetLayouts-parameter
  If \texttt{setLayoutCount} is not zero, and \texttt{pSetLayouts} is not NULL, \textbf{pSetLayouts must} be a valid pointer to an array of \texttt{setLayoutCount} valid \texttt{VkDescriptorSetLayout} handles

- VUID-VkShaderCreateInfoEXT-pPushConstantRanges-parameter
  If \texttt{pushConstantRangeCount} is not zero, and \texttt{pPushConstantRanges} is not NULL, \textbf{pPushConstantRanges must} be a valid pointer to an array of \texttt{pushConstantRangeCount} valid \texttt{VkPushConstantRange} structures

- VUID-VkShaderCreateInfoEXT-pSpecializationInfo-parameter
  If \texttt{pSpecializationInfo} is not NULL, \textbf{pSpecializationInfo must} be a valid pointer to a valid \texttt{VkSpecializationInfo} structure

- VUID-VkShaderCreateInfoEXT-codeSize-arraylength
  \textbf{codeSize must} be greater than zero

\begin{verbatim}
// Provided by VK_EXT_shader_object
typedef VkFlags VkShaderCreateFlagsEXT;

VkShaderCreateFlagsEXT is a bitmask type for setting a mask of zero or more
VkShaderCreateFlagBitsEXT.

Possible values of the flags member of VkShaderCreateInfoEXT specifying how a shader object is
created, are:

\begin{verbatim}
// Provided by VK_EXT_shader_object
typedef enum VkShaderCreateFlagBitsEXT {
    VK_SHADER_CREATE_LINK_STAGE_BIT_EXT = 0x00000001,
    // Provided by VK_EXT_shader_object with VK_EXT_subgroup_size_control or
    VK_VERSION_1_3
    VK_SHADER_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT_EXT = 0x00000002,
    // Provided by VK_EXT_shader_object with VK_EXT_subgroup_size_control or
    VK_VERSION_1_3
    VK_SHADER_CREATE_REQUIRE_FULL_SUBGROUPS_BIT_EXT = 0x00000004,
    // Provided by VK_EXT_shader_object with VK_EXT_mesh_shader or VK_NV_mesh_shader
    VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT = 0x00000008,
    // Provided by VK_EXT_shader_object with VK_KHR_device_group or VK_VERSION_1_1
    VK_SHADER_CREATE_DISPATCH_BASE_BIT_EXT = 0x00000010
} VkShaderCreateFlagBitsEXT;
\end{verbatim}
\end{verbatim}
• **VK_SHADER_CREATE_LINK_STAGE_BIT_EXT** specifies that a shader is linked to all other shaders created in the same `vkCreateShadersEXT` call whose `VkShaderCreateInfoEXT` structures’ flags include `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT`.

• **VK_SHADER_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT_EXT** specifies that the `SubgroupSize` may vary in a task, mesh, or compute shader.

• **VK_SHADER_CREATE_REQUIRE_FULL_SUBGROUPS_BIT_EXT** specifies that the subgroup sizes must be launched with all invocations active in a task, mesh, or compute shader.

• **VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT** specifies that a mesh shader must only be used without a task shader. Otherwise, the mesh shader must only be used with a task shader.

• **VK_SHADER_CREATE_DISPATCH_BASE_BIT_EXT** specifies that a compute shader can be used with `vkCmdDispatchBase` with a non-zero base workgroup.

• **VK_SHADER_CREATE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_EXT** specifies that a fragment shader can be used with a fragment shading rate attachment.

• **VK_SHADER_CREATE_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT** specifies that a fragment shader can be used with a fragment density map attachment.

---

**Note**

The behavior of `VK_SHADER_CREATE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_EXT` and `VK_SHADER_CREATE_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT` differs subtly from the behavior of `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR` and `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT` in that the shader bit allows, but does not require the shader to be used with that type of attachment. This means that the application need not create multiple shaders when it does not know in advance whether the shader will be used with or without the attachment type, or when it needs the same shader to be compatible with usage both with and without. This may come at some performance cost on some implementations, so applications should still only set bits that are actually necessary.

Shader objects can be created using different types of shader code. Possible values of `VkShaderCreateInfoEXT::codeType`, are:

---

```c
// Provided by VK_EXT_shader_object
typedef enum VkShaderCodeTypeEXT {
    VK_SHADER_CODE_TYPE_BINARY_EXT = 0,
    VK_SHADER_CODE_TYPE_SPIRV_EXT = 1,
} VkShaderCodeTypeEXT;
```
• **VK_SHADER_CODE_TYPE_BINARY_EXT** specifies shader code in an opaque, implementation-defined binary format specific to the physical device.

• **VK_SHADER_CODE_TYPE_SPIRV_EXT** specifies shader code in SPIR-V format.

### 9.1.2. Binary Shader Code

Binary shader code can be retrieved from a shader object using the command:

```c
// Provided by VK_EXT_shader_object
VkResult vkGetShaderBinaryDataEXT(
    VkDevice device,                        // Logical device that shader was created from.
    VkShaderEXT shader,                    // Shader object to retrieve binary shader code from.
    size_t*pDataSize,                      // Pointer to a size_t value related to the size of the binary shader code.
    void*pData);                           // Pointer to a buffer.
```

- `device` is the logical device that shader object was created from.
- `shader` is the shader object to retrieve binary shader code from.
- `pDataSize` is a pointer to a `size_t` value related to the size of the binary shader code, as described below.
- `pData` is either `NULL` or a pointer to a buffer.

If `pData` is `NULL`, then the size of the binary shader code is returned in `pDataSize`. Otherwise, `pDataSize` must point to a variable set by the user to the size of the buffer, in bytes, pointed to by `pData`, and on return the variable is overwritten with the amount of data actually written to `pData`. If `pDataSize` is less than the size of the binary shader code, nothing is written to `pData`, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`.

**Note**

The behavior of this command when `pDataSize` is too small differs from how some other getter-type commands work in Vulkan. Because shader binary data is only usable in its entirety, it would never be useful for the implementation to return partial data. Because of this, nothing is written to `pData` unless `pDataSize` is large enough to fit the data in its entirety.

Binary shader code retrieved using `vkGetShaderBinaryDataEXT` can be passed to a subsequent call to `vkCreateShadersEXT` on a compatible physical device by specifying `VK_SHADER_CODE_TYPE_BINARY_EXT` in the `codeType` member of `VkShaderCreateInfoEXT`.

The shader code returned by repeated calls to this function with the same `VkShaderEXT` is guaranteed to be invariant for the lifetime of the `VkShaderEXT` object.

### Valid Usage

- **VUID-vkGetShaderBinaryDataEXT-None-08461**
  The `shaderObject` feature must be enabled
If `pData` is not NULL, it must be aligned to 16 bytes

### Valid Usage (Implicit)

- **VUID-vkGetShaderBinaryDataEXT-device-parameter**
  
  `device` must be a valid `VkDevice` handle

- **VUID-vkGetShaderBinaryDataEXT-shader-parameter**
  
  `shader` must be a valid `VkShaderEXT` handle

- **VUID-vkGetShaderBinaryDataEXT-pDataSize-parameter**
  
  `pDataSize` must be a valid pointer to a `size_t` value

- **VUID-vkGetShaderBinaryDataEXT-pData-parameter**
  
  If the value referenced by `pDataSize` is not 0, and `pData` is not NULL, `pData` must be a valid pointer to an array of `pDataSize` bytes

- **VUID-vkGetShaderBinaryDataEXT-shader-parent**
  
  `shader` must have been created, allocated, or retrieved from `device`

### Return Codes

**Success**

- `VK_SUCCESS`
- `VK_INCOMPLETE`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

### 9.1.3. Binary Shader Compatibility

Binary shader compatibility means that binary shader code returned from a call to `vkGetShaderBinaryDataEXT` can be passed to a later call to `vkCreateShadersEXT`, potentially on a different logical and/or physical device, and that this will result in the successful creation of a shader object functionally equivalent to the shader object that the code was originally queried from.

Binary shader code queried from `vkGetShaderBinaryDataEXT` is not guaranteed to be compatible across all devices, but implementations are required to provide some compatibility guarantees. Applications may determine binary shader compatibility using either (or both) of two mechanisms.

Guaranteed compatibility of shader binaries is expressed through a combination of the `shaderBinaryUUID` and `shaderBinaryVersion` members of the `VkPhysicalDeviceShaderObjectPropertiesEXT` structure queried from a physical device. Binary shaders retrieved from a physical device with a certain `shaderBinaryUUID` are guaranteed to be
compatible with all other physical devices reporting the same `shaderBinaryUUID` and the same or higher `shaderBinaryVersion`.

Whenever a new version of an implementation incorporates any changes that affect the output of `vkGetShaderBinaryDataEXT`, the implementation should either increment `shaderBinaryVersion` if binary shader code retrieved from older versions remains compatible with the new implementation, or else replace `shaderBinaryUUID` with a new value if backward compatibility has been broken. Binary shader code queried from a device with a matching `shaderBinaryUUID` and lower `shaderBinaryVersion` relative to the device on which `vkCreateShadersEXT` is being called may be suboptimal for the new device in ways that do not change shader functionality, but it is still guaranteed to be usable to successfully create the shader object(s).

### Note

Implementations are encouraged to share `shaderBinaryUUID` between devices and driver versions to the maximum extent their hardware naturally allows, and are strongly discouraged from ever changing the `shaderBinaryUUID` for the same hardware except unless absolutely necessary.

In addition to the shader compatibility guarantees described above, it is valid for an application to call `vkCreateShadersEXT` with binary shader code created on a device with a different or unknown `shaderBinaryUUID` and/or higher `shaderBinaryVersion`. In this case, the implementation may use any unspecified means of its choosing to determine whether the provided binary shader code is usable. If it is, the `vkCreateShadersEXT` call must return `VK_SUCCESS`, and the created shader object is guaranteed to be valid. Otherwise, in the absence of some other error, the `vkCreateShadersEXT` call must return `VK_ERROR_INCOMPATIBLE_SHADER_BINARY_EXT` to indicate that the provided binary shader code is not compatible with the device.

### 9.1.4. Binding Shader Objects

Once shader objects have been created, they can be bound to the command buffer using the command:

```c
// Provided by VK_EXT_shader_object
void vkCmdBindShadersEXT(
    VkCommandBuffer commandBuffer,  // Provided by VK_EXT_shader_object
    uint32_t stageCount,            // Provided by VK_EXT_shader_object
    const VkShaderStageFlagBits* pStages,  // Provided by VK_EXT_shader_object
    const VkShaderEXT* pShaders);  // Provided by VK_EXT_shader_object
```

- `commandBuffer` is the command buffer that the shader object will be bound to.
- `stageCount` is the length of the `pStages` and `pShaders` arrays.
- `pStages` is a pointer to an array of `VkShaderStageFlagBits` values specifying one stage per array index that is affected by the corresponding value in the `pShaders` array.
- `pShaders` is a pointer to an array of `VkShaderEXT` handles and/or `VK_NULL_HANDLE` values describing the shader binding operations to be performed on each stage in `pStages`. 
When binding linked shaders, an application may bind them in any combination of one or more calls to `vkCmdBindShadersEXT` (i.e., shaders that were created linked together do not need to be bound in the same `vkCmdBindShadersEXT` call).

Any shader object bound to a particular stage may be unbound by setting its value in `pShaders` to `VK_NULL_HANDLE`. If `pShaders` is `NULL`, `vkCmdBindShadersEXT` behaves as if `pShaders` was an array of `stageCount` `VK_NULL_HANDLE` values (i.e., any shaders bound to the stages specified in `pStages` are unbound).

### Valid Usage

- **VUID-vkCmdBindShadersEXT-None-08462**
  The shaderObject feature must be enabled

- **VUID-vkCmdBindShadersEXT-pStages-08463**
  Every element of `pStages` must be unique

- **VUID-vkCmdBindShadersEXT-pStages-08464**
  `pStages` must not contain `VK_SHADER_STAGE_ALL_GRAPHICS` or `VK_SHADER_STAGE_ALL`

- **VUID-vkCmdBindShadersEXT-pStages-08465**
  `pStages` must not contain `VK_SHADER_STAGE_RAYGEN_BIT_KHR`, `VK_SHADER_STAGE_CLOSEST_HIT_BIT_KHR`, `VK_SHADER_STAGE_MISS_BIT_KHR`, `VK_SHADER_STAGE_INTERSECTION_BIT_KHR`, or `VK_SHADER_STAGE_CALLABLE_BIT_KHR`

- **VUID-vkCmdBindShadersEXT-pStages-08467**
  `pStages` must not contain `VK_SHADER_STAGE_SUBPASS_SHADING_BIT_HUAWEI`

- **VUID-vkCmdBindShadersEXT-pStages-08468**
  `pStages` must not contain `VK_SHADER_STAGE_CLUSTER_CULLING_BIT_HUAWEI`

- **VUID-vkCmdBindShadersEXT-pShaders-08469**
  For each element of `pStages`, if `pShaders` is not `NULL`, and the element of the `pShaders` array with the same index is not `VK_NULL_HANDLE`, it must have been created with a stage equal to the corresponding element of `pStages`

- **VUID-vkCmdBindShadersEXT-pShaders-08470**
  If `pStages` contains both `VK_SHADER_STAGE_TASK_BIT_EXT` and `VK_SHADER_STAGE_VERTEX_BIT`, and `pShaders` is not `NULL`, and the same index in `pShaders` as `VK_SHADER_STAGE_TASK_BIT_EXT` in `pStages` is not `VK_NULL_HANDLE`, the same index in `pShaders` as `VK_SHADER_STAGE_TASK_BIT_EXT` in `pStages` must be `VK_NULL_HANDLE`

- **VUID-vkCmdBindShadersEXT-pShaders-08471**
  If `pStages` contains both `VK_SHADER_STAGE_MESH_BIT_EXT` and `VK_SHADER_STAGE_VERTEX_BIT`, and `pShaders` is not `NULL`, and the same index in `pShaders` as `VK_SHADER_STAGE_MESH_BIT_EXT` in `pStages` is not `VK_NULL_HANDLE`, the same index in `pShaders` as `VK_SHADER_STAGE_MESH_BIT_EXT` in `pStages` must be `VK_NULL_HANDLE`

- **VUID-vkCmdBindShadersEXT-pShaders-08474**
  If the tessellationShader feature is not enabled, and `pStages` contains `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT` or `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`, and `pShaders` is not `NULL`, the same index or
indices in `pShaders` must be `VK_NULL_HANDLE`

- **VUID-vkCmdBindShadersEXT-pShaders-08475**
  If the `geometryShader` feature is not enabled, and `pStages` contains `VK_SHADER_STAGE_GEOMETRY_BIT`, and `pShaders` is not `NULL`, the same index in `pShaders` must be `VK_NULL_HANDLE`

- **VUID-vkCmdBindShadersEXT-pShaders-08490**
  If the `taskShader` feature is not enabled, and `pStages` contains `VK_SHADER_STAGE_TASK_BIT_EXT`, and `pShaders` is not `NULL`, the same index in `pShaders` must be `VK_NULL_HANDLE`

- **VUID-vkCmdBindShadersEXT-pShaders-08491**
  If the `meshShader` feature is not enabled, and `pStages` contains `VK_SHADER_STAGE_MESH_BIT_EXT`, and `pShaders` is not `NULL`, the same index in `pShaders` must be `VK_NULL_HANDLE`

- **VUID-vkCmdBindShadersEXT-pShaders-08476**
  If `pStages` contains `VK_SHADER_STAGE_COMPUTE_BIT`, the `VkCommandPool` that `commandBuffer` was allocated from must support compute operations

- **VUID-vkCmdBindShadersEXT-pShaders-08477**
  If `pStages` contains `VK_SHADER_STAGE_VERTEX_BIT`, `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`, `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`, `VK_SHADER_STAGE_GEOMETRY_BIT`, or `VK_SHADER_STAGE_FRAGMENT_BIT`, the `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations

- **VUID-vkCmdBindShadersEXT-pShaders-08478**
  If `pStages` contains `VK_SHADER_STAGE_MESH_BIT_EXT` or `VK_SHADER_STAGE_TASK_BIT_EXT`, the `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations

---

**Valid Usage (Implicit)**

- **VUID-vkCmdBindShadersEXT-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- **VUID-vkCmdBindShadersEXT-pStages-parameter**
  `pStages` must be a valid pointer to an array of `stageCount` valid `VkShaderStageFlagBits` values

- **VUID-vkCmdBindShadersEXT-pShaders-parameter**
  If `pShaders` is not `NULL`, `pShaders` must be a valid pointer to an array of `stageCount` valid or `VK_NULL_HANDLE` `VkShaderEXT` handles

- **VUID-vkCmdBindShadersEXT-commandBuffer-recording**
  `commandBuffer` must be in the recording state

- **VUID-vkCmdBindShadersEXT-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, or compute operations

- **VUID-vkCmdBindShadersEXT-videocoding**
  This command must only be called outside of a video coding scope
9.1.5. Setting State

Whenever shader objects are used to issue drawing commands, the appropriate dynamic state setting commands **must** have been called to set the relevant state in the command buffer prior to drawing:

- `vkCmdSetViewportWithCount`
- `vkCmdSetScissorWithCount`
- `vkCmdSetRasterizerDiscardEnable`

If a shader is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, the following commands **must** have been called in the command buffer prior to drawing:

- `vkCmdSetVertexInputEXT`
- `vkCmdSetPrimitiveTopology`
- `vkCmdSetPatchControlPointsEXT`, if `primitiveTopology` is `VK_PRIMITIVE_TOPOLOGY_PATCH_LIST`
- `vkCmdSetPrimitiveRestartEnable`

If a shader is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, the following command **must** have been called in the command buffer prior to drawing:

- `vkCmdSetTessellationDomainOriginEXT`

If `rasterizerDiscardEnable` is `VK_FALSE`, the following commands **must** have been called in the command buffer prior to drawing:

- `vkCmdSetViewportWithCount`
- `vkCmdSetScissorWithCount`
- `vkCmdSetRasterizerDiscardEnable`
command buffer prior to drawing:

- vkCmdSetRasterizationSamplesEXT
- vkCmdSetSampleMaskEXT
- vkCmdSetAlphaToCoverageEnableEXT
- vkCmdSetAlphaToOneEnableEXT, if the alphaToOne feature is enabled on the device
- vkCmdSetPolygonModeEXT
- vkCmdSetLineWidth, if polygonMode is VK_POLYGON_MODE_LINE, or if a shader is bound to the VK_SHADER_STAGE_VERTEX_BIT stage and primitiveTopology is a line topology, or if a shader which outputs line primitives is bound to the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT stage
- vkCmdSetCullMode
- vkCmdSetFrontFace, if cullMode is not VK_CULL_MODE_NONE, or if stencilTestEnable is VK_TRUE, or if the fragment shader uses a variable decorated with FrontFacing
- vkCmdSetDepthTestEnable
- vkCmdSetDepthWriteEnable
- vkCmdSetDepthCompareOp, if depthTestEnable is VK_TRUE
- vkCmdSetDepthBoundsTestEnable, if the depthBounds feature is enabled on the device
- vkCmdSetDepthBounds, if depthBoundsTestEnable is VK_TRUE
- vkCmdSetDepthBiasEnable
- vkCmdSetDepthBias or vkCmdSetDepthBias2EXT, if depthBiasEnable is VK_TRUE
- vkCmdSetDepthClampEnableEXT, if the depthClamp feature is enabled on the device
- vkCmdSetStencilTestEnable
- vkCmdSetStencilOp, if stencilTestEnable is VK_TRUE
- vkCmdSetStencilCompareMask, if stencilTestEnable is VK_TRUE
- vkCmdSetStencilWriteMask, if stencilTestEnable is VK_TRUE
- vkCmdSetStencilReference, if stencilTestEnable is VK_TRUE

If a shader is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and rasterizerDiscardEnable is VK_FALSE, the following commands must have been called in the command buffer prior to drawing:

- vkCmdSetLogicOpEnableEXT, if the logicOp feature is enabled on the device
- vkCmdSetLogicOpEXT, if logicOpEnable is VK_TRUE
- vkCmdSetColorBlendEnableEXT, with values set for every color attachment in the render pass instance active at draw time
- vkCmdSetColorBlendEquationEXT or vkCmdSetColorBlendAdvancedEXT, for every attachment whose index in pColorBlendEnables is a pointer to a value of VK_TRUE
- vkCmdSetBlendConstants, if any index in pColorBlendEnables is VK_TRUE, and the same index in pColorBlendEquations is a VkColorBlendEquationEXT structure with any VkBlendFactor member
with a value of VK_BLEND_FACTOR_CONSTANT_COLOR, VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR, VK_BLEND_FACTOR_CONSTANT_ALPHA, or VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA

- `vkCmdSetColorWriteMaskEXT`

If the `pipelineFragmentShadingRate` feature is enabled on the device, and a shader is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and `rasterizerDiscardEnable` is `VK_FALSE`, the following command **must** have been called in the command buffer prior to drawing:

- `vkCmdSetFragmentShadingRateKHR`

If the `geometryStreams` feature is enabled on the device, and a shader is bound to the `VK_SHADER_STAGE_GEOMETRY_BIT` stage, the following command **must** have been called in the command buffer prior to drawing:

- `vkCmdSetRasterizationStreamEXT`

If the `VK_EXT_discard_rectangles` extension is enabled on the device, and `rasterizerDiscardEnable` is `VK_FALSE`, the following commands **must** have been called in the command buffer prior to drawing:

- `vkCmdSetDiscardRectangleEnableEXT`
- `vkCmdSetDiscardRectangleModeEXT`, if `discardRectangleEnable` is `VK_TRUE`
- `vkCmdSetDiscardRectangleEXT`, if `discardRectangleEnable` is `VK_TRUE`

If the `VK_EXT_conservative_rasterization` extension is enabled on the device, and `rasterizerDiscardEnable` is `VK_FALSE`, the following commands **must** have been called in the command buffer prior to drawing:

- `vkCmdSetConservativeRasterizationModeEXT`
- `vkCmdSetExtraPrimitiveOverestimationSizeEXT`, if `conservativeRasterizationMode` is `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`

If the `depthClipEnable` feature is enabled on the device, the following command **must** have been called in the command buffer prior to drawing:

- `vkCmdSetDepthClipEnableEXT`

If the `VK_EXT_sample_locations` extension is enabled on the device, and `rasterizerDiscardEnable` is `VK_FALSE`, the following commands **must** have been called in the command buffer prior to drawing:

- `vkCmdSetSampleLocationsEnableEXT`
- `vkCmdSetSampleLocationsEXT`, if `sampleLocationsEnable` is `VK_TRUE`

If the `VK_EXT_provoking_vertex` extension is enabled on the device, and `rasterizerDiscardEnable` is `VK_FALSE`, and a shader is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, the following command **must** have been called in the command buffer prior to drawing:

- `vkCmdSetProvokingVertexModeEXT`

If the `VK_EXT_line_rasterization` extension is enabled on the device, and `rasterizerDiscardEnable` is
VK_FALSE, and if polygonMode is VK_POLYGON_MODE_LINE or a shader is bound to the VK_SHADER_STAGE_VERTEX_BIT stage and primitiveTopology is a line topology or a shader which outputs line primitives is bound to the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT stage, the following commands must have been called in the command buffer prior to drawing:

- vkCmdSetLineRasterizationModeEXT
- vkCmdSetLineStippleEnableEXT
- vkCmdSetLineStippleEXT, if stippledLineEnable is VK_TRUE

If the depthClipControl feature is enabled on the device, the following command must have been called in the command buffer prior to drawing:

- vkCmdSetDepthClipNegativeOneToOneEXT

If the colorWriteEnable feature is enabled on the device, a shader is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and rasterizerDiscardEnable is VK_FALSE, the following command must have been called in the command buffer prior to drawing:

- vkCmdSetColorWriteEnableEXT, with values set for every color attachment in the render pass instance active at draw time

If the attachmentFeedbackLoopDynamicState feature is enabled on the device, a shader is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and rasterizerDiscardEnable is VK_FALSE, the following command must have been called in the command buffer prior to drawing:

- vkCmdSetAttachmentFeedbackLoopEnableEXT, for each image aspect corresponding to an attachment type used by the render pass instance which can use feedback loops

If the VK_NV_clip_space_w_scaling extension is enabled on the device, the following commands must have been called in the command buffer prior to drawing:

- vkCmdSetViewportWScalingEnableNV
- vkCmdSetViewportWScalingNV, if viewportWScalingEnable is VK_TRUE

If the VK_NV_viewport_swizzle extension is enabled on the device, the following command must have been called in the command buffer prior to drawing:

- vkCmdSetViewportSwizzleNV

If the VK_NV_fragment_coverage_to_color extension is enabled on the device, and a shader is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and rasterizerDiscardEnable is VK_FALSE, the following commands must have been called in the command buffer prior to drawing:

- vkCmdSetCoverageToColorEnableNV
- vkCmdSetCoverageToColorLocationNV, if coverageToColorEnable is VK_TRUE

If the VK_NV_framebuffer_mixed_samples extension is enabled on the device, and rasterizerDiscardEnable is VK_FALSE, the following commands must have been called in the
command buffer prior to drawing:

- `vkCmdSetCoverageModulationModeNV`
- `vkCmdSetCoverageModulationTableEnableNV`, if `coverageModulationMode` is not `VK_COVERAGE_MODULATION_MODE_NONE_NV`
- `vkCmdSetCoverageModulationTableNV`, if `coverageModulationTableEnable` is `VK_TRUE`

If the `coverageReductionMode` feature is enabled on the device, and `rasterizerDiscardEnable` is `VK_FALSE`, the following command must have been called in the command buffer prior to drawing:

- `vkCmdSetCoverageReductionModeNV`

If the `representativeFragmentTest` feature is enabled on the device, and `rasterizerDiscardEnable` is `VK_FALSE`, the following command must have been called in the command buffer prior to drawing:

- `vkCmdSetRepresentativeFragmentTestEnableNV`

If the `shadingRateImage` feature is enabled on the device, and `rasterizerDiscardEnable` is `VK_FALSE`, the following commands must have been called in the command buffer prior to drawing:

- `vkCmdSetCoarseSampleOrderNV`
- `vkCmdSetShadingRateImageEnableNV`
- `vkCmdSetViewportShadingRatePaletteNV`, if `shadingRateImageEnable` is `VK_TRUE`

If the `exclusiveScissor` feature is enabled on the device, the following commands must have been called in the command buffer prior to drawing:

- `vkCmdSetExclusiveScissorEnableNV`
- `vkCmdSetExclusiveScissorNV`, if any value in `pExclusiveScissorEnables` is `VK_TRUE`

State can be set either at any time before or after shader objects are bound, but all required state must be set prior to issuing drawing commands.

### 9.1.6. Interaction with Pipelines

Calling `vkCmdBindShadersEXT` causes the pipeline bind points corresponding to each stage in `pStages` to be disturbed, meaning that any pipelines that had previously been bound to those pipeline bind points are no longer bound.

If `VK_PIPELINE_BIND_POINT_GRAPHICS` is disturbed (i.e., if `pStages` contains any graphics stage), any graphics pipeline state that the previously bound pipeline did not specify as dynamic becomes undefined, and must be set in the command buffer before issuing drawing commands using shader objects.

Calls to `vkCmdBindPipeline` likewise disturb the shader stage(s) corresponding to `pipelineBindPoint`, meaning that any shaders that had previously been bound to any of those stages are no longer bound, even if the pipeline was created without shaders for some of those stages.
9.1.7. Shader Object Destruction

To destroy a shader object, call:

```c
// Provided by VK_EXT_shader_object
define vkDestroyShaderEXT
void vkDestroyShaderEXT(
    VkDevice device,
    VkShaderEXT shader,
    const VkAllocationCallbacks* pAllocator);
```

- `device` is the logical device that destroys the shader object.
- `shader` is the handle of the shader object to destroy.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

Destroying a shader object used by one or more command buffers in the recording or executable state causes those command buffers to move into the invalid state.

**Valid Usage**

- VUID-vkDestroyShaderEXT-None-08481
  The shaderObject feature must be enabled

- VUID-vkDestroyShaderEXT-shader-08482
  All submitted commands that refer to shader must have completed execution

- VUID-vkDestroyShaderEXT-pAllocator-08483
  If VkAllocationCallbacks were provided when shader was created, a compatible set of callbacks must be provided here

- VUID-vkDestroyShaderEXT-pAllocator-08484
  If no VkAllocationCallbacks were provided when shader was created, pAllocator must be NULL

**Valid Usage (Implicit)**

- VUID-vkDestroyShaderEXT-device-parameter
  device must be a valid VkDevice handle

- VUID-vkDestroyShaderEXT-shader-parameter
  shader must be a valid VkShaderEXT handle

- VUID-vkDestroyShaderEXT-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkDestroyShaderEXT-shader-parent
  shader must have been created, allocated, or retrieved from device
9.2. Shader Modules

Shader modules contain shader code and one or more entry points. Shaders are selected from a shader module by specifying an entry point as part of pipeline creation. The stages of a pipeline can use shaders that come from different modules. The shader code defining a shader module must be in the SPIR-V format, as described by the Vulkan Environment for SPIR-V appendix.

Shader modules are represented by VkShaderModule handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkShaderModule)
```

To create a shader module, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkCreateShaderModule(  
  VkDevice device,  
  const VkShaderModuleCreateInfo* pCreateInfo,  
  const VkAllocationCallbacks* pAllocator,  
  VkShaderModule* pShaderModule);
```

- `device` is the logical device that creates the shader module.
- `pCreateInfo` is a pointer to a VkShaderModuleCreateInfo structure.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pShaderModule` is a pointer to a VkShaderModule handle in which the resulting shader module object is returned.

Once a shader module has been created, any entry points it contains can be used in pipeline shader stages as described in Compute Pipelines and Graphics Pipelines.

**Note**

If the maintenance5 feature is enabled, shader module creation can be omitted entirely. Instead, applications should provide the VkShaderModuleCreateInfo structure directly into pipeline creation by chaining it to VkPipelineShaderStageCreateInfo. This avoids the overhead of creating and managing an additional object.
Valid Usage

- VUID-vkCreateShaderModule-pCreateInfo-06904
  If pCreateInfo is not NULL, pCreateInfo->pNext must be NULL or a pointer to a VkShaderModuleValidationCacheCreateInfoEXT structure

Valid Usage (Implicit)

- VUID-vkCreateShaderModule-device-parameter
device must be a valid VkDevice handle
- VUID-vkCreateShaderModule-pCreateInfo-parameter
  pCreateInfo must be a valid pointer to a valid VkShaderModuleCreateInfo structure
- VUID-vkCreateShaderModule-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure
- VUID-vkCreateShaderModule-pShaderModule-parameter
  pShaderModule must be a valid pointer to a VkShaderModule handle

Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_INVALID_SHADER_NV

The VkShaderModuleCreateInfo structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkShaderModuleCreateInfo {
  VkStructureType sType;
  const void* pNext;
  VkShaderModuleCreateFlags flags;
  size_t codeSize;
  const uint32_t* pCode;
} VkShaderModuleCreateInfo;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
• **flags** is reserved for future use.

• **codeSize** is the size, in bytes, of the code pointed to by **pCode**.

• **pCode** is a pointer to code that is used to create the shader module. The type and format of the code is determined from the content of the memory addressed by **pCode**.

**Valid Usage**

• VUID-VkShaderModuleCreateInfo-codeSize-08735
  If pCode is a pointer to SPIR-V code, **codeSize** **must** be a multiple of 4

• VUID-VkShaderModuleCreateInfo-pCode-08736
  If pCode is a pointer to SPIR-V code, **pCode** **must** point to valid SPIR-V code, formatted and packed as described by the **Khronos SPIR-V Specification**

• VUID-VkShaderModuleCreateInfo-pCode-08737
  If pCode is a pointer to SPIR-V code, **pCode** **must** adhere to the validation rules described by the **Validation Rules within a Module** section of the **SPIR-V Environment** appendix

• VUID-VkShaderModuleCreateInfo-pCode-08738
  If pCode is a pointer to SPIR-V code, **pCode** **must** declare the **Shader** capability for SPIR-V code

• VUID-VkShaderModuleCreateInfo-pCode-08739
  If pCode is a pointer to SPIR-V code, **pCode** **must** not declare any capability that is not supported by the API, as described by the **Capabilities** section of the **SPIR-V Environment** appendix

• VUID-VkShaderModuleCreateInfo-pCode-08740
  If pCode is a pointer to SPIR-V code, and **pCode** declares any of the capabilities listed in the **SPIR-V Environment** appendix, one of the corresponding requirements **must** be satisfied

• VUID-VkShaderModuleCreateInfo-pCode-08741
  If pCode is a pointer to SPIR-V code, **pCode** **must** not declare any SPIR-V extension that is not supported by the API, as described by the **Extension** section of the **SPIR-V Environment** appendix

• VUID-VkShaderModuleCreateInfo-pCode-08742
  If pCode is a pointer to SPIR-V code, and **pCode** declares any of the SPIR-V extensions listed in the **SPIR-V Environment** appendix, one of the corresponding requirements **must** be satisfied

• VUID-VkShaderModuleCreateInfo-pCode-07912
  If the **VK_NV_gsl_shader** extension is not enabled, **pCode** **must** be a pointer to SPIR-V code

• VUID-VkShaderModuleCreateInfo-pCode-01379
  If **pCode** is a pointer to GLSL code, it **must** be valid GLSL code written to the **GL_KHR_vulkan_gls1** GLSL extension specification

• VUID-VkShaderModuleCreateInfo-codeSize-01085
  **codeSize** **must** be greater than 0
Valid Usage (Implicit)

- VUID-VkShaderModuleCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_SHADER_MODULE_CREATE_INFO

- VUID-VkShaderModuleCreateInfo-flags-zerobitmask
  flags must be 0

- VUID-VkShaderModuleCreateInfo-pCode-parameter
  pCode must be a valid pointer to an array of \( \frac{\text{codeSize}}{4} \) uint32_t values

// Provided by VK_VERSION_1_0
typedef VkFlags VkShaderModuleCreateFlags;

VkShaderModuleCreateFlags is a bitmask type for setting a mask, but is currently reserved for future use.

To use a VkValidationCacheEXT to cache shader validation results, add a VkShaderModuleValidationCacheCreateInfoEXT structure to the pNext chain of the VkShaderModuleCreateInfo structure, specifying the cache object to use.

The VkShaderModuleValidationCacheCreateInfoEXT struct is defined as:

// Provided by VK_EXT_validation_cache
typedef struct VkShaderModuleValidationCacheCreateInfoEXT {
  VkStructureType sType;
  const void* pNext;
  VkValidationCacheEXT validationCache;
} VkShaderModuleValidationCacheCreateInfoEXT;

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- validationCache is the validation cache object from which the results of prior validation attempts will be written, and to which new validation results for this VkShaderModule will be written (if not already present).

Valid Usage (Implicit)

- VUID-VkShaderModuleValidationCacheCreateInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_SHADER_MODULE_VALIDATION_CACHE_CREATE_INFO_EXT

- VUID-VkShaderModuleValidationCacheCreateInfoEXT-validationCache-parameter
  validationCache must be a valid VkValidationCacheEXT handle

To destroy a shader module, call:
```c
void vkDestroyShaderModule(
    VkDevice device,  
    VkShaderModule shaderModule,  
    const VkAllocationCallbacks* pAllocator);
```

- **device** is the logical device that destroys the shader module.
- **shaderModule** is the handle of the shader module to destroy.
- **pAllocator** controls host memory allocation as described in the *Memory Allocation* chapter.

A shader module **can** be destroyed while pipelines created using its shaders are still in use.

### Valid Usage

- **VUID-vkDestroyShaderModule-shaderModule-01092**
  If VkAllocationCallbacks were provided when shaderModule was created, a compatible set of callbacks **must** be provided here.

- **VUID-vkDestroyShaderModule-shaderModule-01093**
  If no VkAllocationCallbacks were provided when shaderModule was created, **pAllocator must be NULL**

### Valid Usage (Implicit)

- **VUID-vkDestroyShaderModule-device-parameter**
  *device must be a valid VkDevice handle*

- **VUID-vkDestroyShaderModule-shaderModule-parameter**
  If shaderModule is not VK_NULL_HANDLE, shaderModule **must be a valid VkShaderModule handle**

- **VUID-vkDestroyShaderModule-pAllocator-parameter**
  If pAllocator is not NULL, **pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure**

- **VUID-vkDestroyShaderModule-shaderModule-parent**
  If shaderModule is a valid handle, it **must have been created, allocated, or retrieved from device**

### Host Synchronization

- Host access to shaderModule **must be externally synchronized**
9.3. Shader Module Identifiers

Shader modules have unique identifiers associated with them. To query an implementation provided identifier, call:

```c
// Provided by VK_EXT_shader_module_identifier
void vkGetShaderModuleIdentifierEXT(
    VkDevice device,
    VkShaderModule shaderModule,
    VkShaderModuleIdentifierEXT* pIdentifier);
```

- `device` is the logical device that created the shader module.
- `shaderModule` is the handle of the shader module.
- `pIdentifier` is a pointer to the returned `VkShaderModuleIdentifierEXT`.

The identifier returned by the implementation must only depend on `shaderIdentifierAlgorithmUUID` and information provided in the `VkShaderModuleCreateInfo` which created `shaderModule`. The implementation may return equal identifiers for two different `VkShaderModuleCreateInfo` structures if the difference does not affect pipeline compilation. Identifiers are only meaningful on different `VkDevice` objects if the device the identifier was queried from had the same `shaderModuleIdentifierAlgorithmUUID` as the device consuming the identifier.

**Valid Usage**

- VUID-vkGetShaderModuleIdentifierEXT-shaderModuleIdentifier-06884
  shaderModuleIdentifier feature must be enabled

**Valid Usage (Implicit)**

- VUID-vkGetShaderModuleIdentifierEXT-device-parameter
  `device` must be a valid `VkDevice` handle
- VUID-vkGetShaderModuleIdentifierEXT-shaderModule-parameter
  `shaderModule` must be a valid `VkShaderModule` handle
- VUID-vkGetShaderModuleIdentifierEXT-pIdentifier-parameter
  `pIdentifier` must be a valid pointer to a `VkShaderModuleIdentifierEXT` structure
- VUID-vkGetShaderModuleIdentifierEXT-shaderModule-parent
  `shaderModule` must have been created, allocated, or retrieved from `device`

`VkShaderModuleCreateInfo` structures have unique identifiers associated with them. To query an implementation provided identifier, call:

```c
// Provided by VK_EXT_shader_module_identifier
void vkGetShaderModuleCreateInfoIdentifierEXT(
    VkDevice device,
    VkShaderModule shaderModule,
    VkShaderModuleCreateInfoIdentifierEXT* pIdentifier);
```
VkDevice device,  
const VkShaderModuleCreateInfo* pCreateInfo,  
VkShaderModuleIdentifierEXT* pIdentifier);

• device is the logical device that can create a VkShaderModule from pCreateInfo.
• pCreateInfo is a pointer to a VkShaderModuleCreateInfo structure.
• pIdentifier is a pointer to the returned VkShaderModuleIdentifierEXT.

The identifier returned by implementation must only depend on shaderIdentifierAlgorithmUUID and information provided in the VkShaderModuleCreateInfo. The implementation may return equal identifiers for two different VkShaderModuleCreateInfo structures if the difference does not affect pipeline compilation. Identifiers are only meaningful on different VkDevice objects if the device the identifier was queried from had the same shaderModuleIdentifierAlgorithmUUID as the device consuming the identifier.

The identifier returned by the implementation in vkGetShaderModuleCreateInfoIdentifierEXT must be equal to the identifier returned by vkGetShaderModuleIdentifierEXT given equivalent definitions of VkShaderModuleCreateInfo and any chained pNext structures.

Valid Usage

• VUID-vkGetShaderModuleCreateInfoIdentifierEXT-shaderModuleIdentifier-06885 shaderModuleIdentifier feature must be enabled

Valid Usage (Implicit)

• VUID-vkGetShaderModuleCreateInfoIdentifierEXT-device-parameter  
device must be a valid VkDevice handle
• VUID-vkGetShaderModuleCreateInfoIdentifierEXT-pCreateInfo-parameter  
pCreateInfo must be a valid pointer to a valid VkShaderModuleCreateInfo structure
• VUID-vkGetShaderModuleCreateInfoIdentifierEXT-pIdentifier-parameter  
pIdentifier must be a valid pointer to a VkShaderModuleIdentifierEXT structure

VkShaderModuleIdentifierEXT represents a shader module identifier returned by the implementation.

// Provided by VK_EXT_shader_module_identifier
typedef struct VkShaderModuleIdentifierEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t identifierSize;
    uint8_t identifier[VK_MAX_SHADER_MODULE_IDENTIFIER_SIZE_EXT];
} VkShaderModuleIdentifierEXT;
• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• identifierSize is the size, in bytes, of valid data returned in identifier.
• identifier is a buffer of opaque data specifying an identifier.

Any returned values beyond the first identifierSize bytes are undefined. Implementations must return an identifierSize greater than 0, and less-or-equal to VK_MAX_SHADER_MODULE_IDENTIFIER_SIZE_EXT.

Two identifiers are considered equal if identifierSize is equal and the first identifierSize bytes of identifier compare equal.

Implementations may return a different identifierSize for different modules. Implementations should ensure that identifierSize is large enough to uniquely define a shader module.

Valid Usage (Implicit)

- VUID-VkShaderModuleIdentifierEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_SHADER_MODULE_IDENTIFIER_EXT
- VUID-VkShaderModuleIdentifierEXT-pNext-pNext
  pNext must be NULL

VK_MAX_SHADER_MODULE_IDENTIFIER_SIZE_EXT is the length in bytes of a shader module identifier, as returned in VkShaderModuleIdentifierEXT::identifierSize.

#define VK_MAX_SHADER_MODULE_IDENTIFIER_SIZE_EXT 32

9.4. Binding Shaders

Before a shader can be used it must be first bound to the command buffer.

Calling vkCmdBindPipeline binds all stages corresponding to the VkPipelineBindPoint. Calling vkCmdBindShadersEXT binds all stages in pStages.

The following table describes the relationship between shader stages and pipeline bind points:
<table>
<thead>
<tr>
<th>Shader stage</th>
<th>Pipeline bind point</th>
<th>behavior controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_SHADER_STAGE_VERTEX_BIT</td>
<td>VK_PIPELINE_BIND_POINT_GRAPHICS</td>
<td>all drawing commands</td>
</tr>
<tr>
<td>VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_SHADER_STAGE_GEOMETRY_BIT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_SHADER_STAGE_FRAGMENT_BIT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_SHADER_STAGE_TASK_BIT_EXT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_SHADER_STAGE_MESH_BIT_EXT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_SHADER_STAGE_COMPUTE_BIT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_PIPELINE_BIND_POINT_GRAPHICS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_PIPELINE_BIND_POINT_COMPUTE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_SHADER_STAGE_ANY_HIT_BIT_KHR</td>
<td>VK_PIPELINE_BIND_POINT_RAY_TRACING_KHR</td>
<td>vkCmdTraceRaysKHR and vkCmdTraceRaysIndirectKHR</td>
</tr>
<tr>
<td>VK_SHADER_STAGE_CALLABLE_BIT_KHR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_SHADER_STAGE_CLOSEST_HIT_BIT_KHR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_SHADER_STAGE_INTERSECTION_BIT_KHR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_SHADER_STAGE_MISS_BIT_KHR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_SHADER_STAGE_RAYGEN_BIT_KHR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_SHADER_STAGE_SUBPASS_SHADING_BIT_HUAWEI</td>
<td>VK_PIPELINE_BIND_POINT_SUBPASS_SHADING_HUAWEI</td>
<td>vkCmdSubpassShadingHUAWEI</td>
</tr>
<tr>
<td>VK_SHADER_STAGE_CLUSTER_CULLING_BIT_HUAWEI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_SHADER_STAGE_COMPUTE_BIT</td>
<td>VK_PIPELINE_BIND_POINT_EXECUTION_GRAPH_AMDX</td>
<td>all execution graph commands</td>
</tr>
</tbody>
</table>

### 9.5. Shader Execution

At each stage of the pipeline, multiple invocations of a shader may execute simultaneously. Further, invocations of a single shader produced as the result of different commands may execute simultaneously. The relative execution order of invocations of the same shader type is undefined. Shader invocations may complete in a different order than that in which the primitives they originated from were drawn or dispatched by the application. However, fragment shader outputs
are written to attachments in rasterization order.

The relative execution order of invocations of different shader types is largely undefined. However, when invoking a shader whose inputs are generated from a previous pipeline stage, the shader invocations from the previous stage are guaranteed to have executed far enough to generate input values for all required inputs.

9.5.1. Shader Termination

A shader invocation that is terminated has finished executing instructions.

Executing OpReturn in the entry point, or executing OpTerminateInvocation in any function will terminate an invocation. Implementations may also terminate a shader invocation when OpKill is executed in any function; otherwise it becomes a helper invocation.

In addition to the above conditions, helper invocations are terminated when all non-helper invocations in the same derivative group either terminate or become helper invocations via OpDemoteToHelperInvocationEXT or OpKill.

A shader stage for a given command completes execution when all invocations for that stage have terminated.

9.6. Shader Memory Access Ordering

The order in which image or buffer memory is read or written by shaders is largely undefined. For some shader types (vertex, tessellation evaluation, and in some cases, fragment), even the number of shader invocations that may perform loads and stores is undefined.

In particular, the following rules apply:

- **Vertex** and **tessellation evaluation** shaders will be invoked at least once for each unique vertex, as defined in those sections.

- **Fragment** shaders will be invoked zero or more times, as defined in that section.

- The relative execution order of invocations of the same shader type is undefined. A store issued by a shader when working on primitive B might complete prior to a store for primitive A, even if primitive A is specified prior to primitive B. This applies even to fragment shaders; while fragment shader outputs are always written to the framebuffer in rasterization order, stores executed by fragment shader invocations are not.

- The relative execution order of invocations of different shader types is largely undefined.

  **Note**

  The above limitations on shader invocation order make some forms of synchronization between shader invocations within a single set of primitives unimplementable. For example, having one invocation poll memory written by another invocation assumes that the other invocation has been launched and will complete its writes in finite time.
The Memory Model appendix defines the terminology and rules for how to correctly communicate between shader invocations, such as when a write is Visible-To a read, and what constitutes a Data Race.

Applications must not cause a data race.

The SPIR-V SubgroupMemory, CrossWorkgroupMemory, and AtomicCounterMemory memory semantics are ignored. Sequentially consistent atomics and barriers are not supported and SequentiallyConsistent is treated as AcquireRelease. SequentiallyConsistent should not be used.

9.7. Shader Inputs and Outputs

Data is passed into and out of shaders using variables with input or output storage class, respectively. User-defined inputs and outputs are connected between stages by matching their Location decorations. Additionally, data can be provided by or communicated to special functions provided by the execution environment using BuiltIn decorations.

In many cases, the same BuiltIn decoration can be used in multiple shader stages with similar meaning. The specific behavior of variables decorated as BuiltIn is documented in the following sections.

9.8. Task Shaders

Task shaders operate in conjunction with the mesh shaders to produce a collection of primitives that will be processed by subsequent stages of the graphics pipeline. Its primary purpose is to create a variable amount of subsequent mesh shader invocations.

Task shaders are invoked via the execution of the programmable mesh shading pipeline.

The task shader has no fixed-function inputs other than variables identifying the specific workgroup and invocation. In the TaskNV Execution Model the number of mesh shader workgroups to create is specified via a TaskCountNV decorated output variable. In the TaskEXT Execution Model the number of mesh shader workgroups to create is specified via the OpEmitMeshTasksEXT instruction.

The task shader can write additional outputs to task memory, which can be read by all of the mesh shader workgroups it created.

9.8.1. Task Shader Execution

Task workloads are formed from groups of work items called workgroups and processed by the task shader in the current graphics pipeline. A workgroup is a collection of shader invocations that execute the same shader, potentially in parallel. Task shaders execute in global workgroups which are divided into a number of local workgroups with a size that can be set by assigning a value to the LocalSize or LocalSizeId execution mode or via an object decorated by the WorkgroupSize decoration. An invocation within a local workgroup can share data with other members of the local workgroup through shared variables and issue memory and control flow barriers to synchronize with other members of the local workgroup. If the subpass includes multiple views in its view mask, a Task shader using TaskEXT Execution Model may be invoked separately for each view.
9.9. Mesh Shaders

Mesh shaders operate in workgroups to produce a collection of primitives that will be processed by subsequent stages of the graphics pipeline. Each workgroup emits zero or more output primitives and the group of vertices and their associated data required for each output primitive.

Mesh shaders are invoked via the execution of the programmable mesh shading pipeline.

The only inputs available to the mesh shader are variables identifying the specific workgroup and invocation and, if applicable, any outputs written to task memory by the task shader that spawned the mesh shader’s workgroup. The mesh shader can operate without a task shader as well.

The invocations of the mesh shader workgroup write an output mesh, comprising a set of primitives with per-primitive attributes, a set of vertices with per-vertex attributes, and an array of indices identifying the mesh vertices that belong to each primitive. The primitives of this mesh are then processed by subsequent graphics pipeline stages, where the outputs of the mesh shader form an interface with the fragment shader.

9.9.1. Mesh Shader Execution

Mesh workloads are formed from groups of work items called workgroups and processed by the mesh shader in the current graphics pipeline. A workgroup is a collection of shader invocations that execute the same shader, potentially in parallel. Mesh shaders execute in global workgroups which are divided into a number of local workgroups with a size that can be set by assigning a value to the LocalSize or LocalSizeId execution mode or via an object decorated by the WorkgroupSize decoration. An invocation within a local workgroup can share data with other members of the local workgroup through shared variables and issue memory and control flow barriers to synchronize with other members of the local workgroup.

The global workgroups may be generated explicitly via the API, or implicitly through the task shader’s work creation mechanism. If the subpass includes multiple views in its view mask, a Mesh shader using MeshEXT Execution Model may be invoked separately for each view.

9.10. Cluster Culling Shaders

Cluster Culling shaders are invoked via the execution of the Programmable Cluster Culling Shading pipeline.

The only inputs available to the cluster culling shader are variables identifying the specific workgroup and invocation.

Cluster Culling shaders operate in workgroups to perform cluster-based culling and produce zero or more cluster drawing command that will be processed by subsequent stages of the graphics pipeline.

The Cluster Drawing Command(CDC) is very similar to the MDI command, invocations in workgroup can emit zero of more CDC to draw zero or more visible cluster.
9.10.1. Cluster Culling Shader Execution

Cluster Culling workloads are formed from groups of work items called workgroups and processed by the cluster culling shader in the current graphics pipeline. A workgroup is a collection of shader invocations that execute the same shader, potentially in parallel. Cluster Culling shaders execute in *global workgroups* which are divided into a number of *local workgroups* with a size that can be set by assigning a value to the `LocalSize` or `LocalSizeId` execution mode or via an object decorated by the `WorkgroupSize` decoration. An invocation within a local workgroup can share data with other members of the local workgroup through shared variables and issue memory and control flow barriers to synchronize with other members of the local workgroup.

9.11. Vertex Shaders

Each vertex shader invocation operates on one vertex and its associated vertex attribute data, and outputs one vertex and associated data. Graphics pipelines using primitive shading must include a vertex shader, and the vertex shader stage is always the first shader stage in the graphics pipeline.

9.11.1. Vertex Shader Execution

A vertex shader must be executed at least once for each vertex specified by a drawing command. If the subpass includes multiple views in its view mask, the shader may be invoked separately for each view. During execution, the shader is presented with the index of the vertex and instance for which it has been invoked. Input variables declared in the vertex shader are filled by the implementation with the values of vertex attributes associated with the invocation being executed.

If the same vertex is specified multiple times in a drawing command (e.g. by including the same index value multiple times in an index buffer) the implementation may reuse the results of vertex shading if it can statically determine that the vertex shader invocations will produce identical results.

*Note*

It is implementation-dependent when and if results of vertex shading are reused, and thus how many times the vertex shader will be executed. This is true also if the vertex shader contains stores or atomic operations (see `vertexPipelineStoresAndAtomics`).

9.12. Tessellation Control Shaders

The tessellation control shader is used to read an input patch provided by the application and to produce an output patch. Each tessellation control shader invocation operates on an input patch (after all control points in the patch are processed by a vertex shader) and its associated data, and outputs a single control point of the output patch and its associated data, and can also output additional per-patch data. The input patch is sized according to the `patchControlPoints` member of `VkPipelineTessellationStateCreateInfo`, as part of input assembly.

The input patch can also be dynamically sized with `patchControlPoints` parameter of `vkCmdSetPatchControlPointsEXT`. 
To **dynamically set** the number of control points per patch, call:

```c
// Provided by VK_EXT_extended_dynamic_state2, VK_EXT_shader_object
void vkCmdSetPatchControlPointsEXT(
    VkCommandBuffer commandBuffer,  
    uint32_t patchControlPoints);
```

- **commandBuffer** is the command buffer into which the command will be recorded.
- **patchControlPoints** specifies the number of control points per patch.

This command sets the number of control points per patch for subsequent drawing commands when drawing using **shader objects**, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT` set in `VkPipelineDynamicStateCreateInfo ::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineTessellationStateCreateInfo ::patchControlPoints` value used to create the currently active pipeline.

### Valid Usage

- **VUID-vkCmdSetPatchControlPointsEXT-None-08574**
  Either the `extendedDynamicState2PatchControlPoints` feature or the `shaderObject` feature or both **must** be enabled

- **VUID-vkCmdSetPatchControlPointsEXT-patchControlPoints-04874**
  `patchControlPoints` **must** be greater than zero and less than or equal to `VkPhysicalDeviceLimits ::maxTessellationPatchSize`

### Valid Usage (Implicit)

- **VUID-vkCmdSetPatchControlPointsEXT-commandBuffer-parameter**
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- **VUID-vkCmdSetPatchControlPointsEXT-commandBuffer-recording**
  `commandBuffer` **must** be in the **recording state**

- **VUID-vkCmdSetPatchControlPointsEXT-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics operations

- **VUID-vkCmdSetPatchControlPointsEXT-videocoding**
  This command **must** only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` **must** be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized
The size of the output patch is controlled by the `OpExecutionMode OutputVertices` specified in the tessellation control or tessellation evaluation shaders, which must be specified in at least one of the shaders. The size of the input and output patches must each be greater than zero and less than or equal to `VkPhysicalDeviceLimits::maxTessellationPatchSize`.

### 9.12.1. Tessellation Control Shader Execution

A tessellation control shader is invoked at least once for each output vertex in a patch. If the subpass includes multiple views in its view mask, the shader may be invoked separately for each view.

Inputs to the tessellation control shader are generated by the vertex shader. Each invocation of the tessellation control shader can read the attributes of any incoming vertices and their associated data. The invocations corresponding to a given patch execute logically in parallel, with undefined relative execution order. However, the `OpControlBarrier` instruction can be used to provide limited control of the execution order by synchronizing invocations within a patch, effectively dividing tessellation control shader execution into a set of phases. Tessellation control shaders will read undefined values if one invocation reads a per-vertex or per-patch output written by another invocation at any point during the same phase, or if two invocations attempt to write different values to the same per-patch output in a single phase.

### 9.13. Tessellation Evaluation Shaders

The Tessellation Evaluation Shader operates on an input patch of control points and their associated data, and a single input barycentric coordinate indicating the invocation's relative position within the subdivided patch, and outputs a single vertex and its associated data.

### 9.13.1. Tessellation Evaluation Shader Execution

A tessellation evaluation shader is invoked at least once for each unique vertex generated by the tessellator. If the subpass includes multiple views in its view mask, the shader may be invoked separately for each view.


The geometry shader operates on a group of vertices and their associated data assembled from a single input primitive, and emits zero or more output primitives and the group of vertices and their associated data required for each output primitive.

A geometry shader is invoked at least once for each primitive produced by the tessellation stages, or at least once for each primitive generated by primitive assembly when tessellation is not in use. A shader can request that the geometry shader runs multiple instances. A geometry shader is invoked at least once for each instance. If the subpass includes multiple views in its view mask, the shader may be invoked separately for each view.

9.15. Fragment Shaders

Fragment shaders are invoked as a fragment operation in a graphics pipeline. Each fragment shader invocation operates on a single fragment and its associated data. With few exceptions, fragment shaders do not have access to any data associated with other fragments and are considered to execute in isolation of fragment shader invocations associated with other fragments.

9.16. Compute Shaders

Compute shaders are invoked via vkCmdDispatch and vkCmdDispatchIndirect commands. In general, they have access to similar resources as shader stages executing as part of a graphics pipeline.

Compute workloads are formed from groups of work items called workgroups and processed by the compute shader in the current compute pipeline. A workgroup is a collection of shader invocations that execute the same shader, potentially in parallel. Compute shaders execute in global workgroups which are divided into a number of local workgroups with a size that can be set by assigning a value to the LocalSize or LocalSizeId execution mode or via an object decorated by the WorkgroupSize decoration. An invocation within a local workgroup can share data with other members of the local workgroup through shared variables and issue memory and control flow barriers to synchronize with other members of the local workgroup.

9.17. Ray Generation Shaders

A ray generation shader is similar to a compute shader. Its main purpose is to execute ray tracing queries using OpTraceRayKHR instructions and process the results.

9.17.1. Ray Generation Shader Execution

One ray generation shader is executed per ray tracing dispatch. Its location in the shader binding table (see Shader Binding Table for details) is passed directly into vkCmdTraceRaysKHR using the pRaygenShaderBindingTable parameter or vkCmdTraceRaysNV using the raygenShaderBindingTableBuffer and raygenShaderBindingOffset parameters.

9.18. Intersection Shaders

Intersection shaders enable the implementation of arbitrary, application defined geometric primitives. An intersection shader for a primitive is executed whenever its axis-aligned bounding box is hit by a ray.
Like other ray tracing shader domains, an intersection shader operates on a single ray at a time. It also operates on a single primitive at a time. It is therefore the purpose of an intersection shader to compute the ray-primitive intersections and report them. To report an intersection, the shader calls the OpReportIntersectionKHR instruction.

An intersection shader communicates with any-hit and closest shaders by generating attribute values that they can read. Intersection shaders cannot read or modify the ray payload.

### 9.18.1. Intersection Shader Execution

The order in which intersections are found along a ray, and therefore the order in which intersection shaders are executed, is unspecified.

The intersection shader of the closest AABB which intersects the ray is guaranteed to be executed at some point during traversal, unless the ray is forcibly terminated.

### 9.19. Any-Hit Shaders

The any-hit shader is executed after the intersection shader reports an intersection that lies within the current \([t_{\min}, t_{\max}]\) of the ray. The main use of any-hit shaders is to programmatically decide whether or not an intersection will be accepted. The intersection will be accepted unless the shader calls the OpIgnoreIntersectionKHR instruction. Any-hit shaders have read-only access to the attributes generated by the corresponding intersection shader, and can read or modify the ray payload.

#### 9.19.1. Any-Hit Shader Execution

The order in which intersections are found along a ray, and therefore the order in which any-hit shaders are executed, is unspecified.

The any-hit shader of the closest hit is guaranteed to be executed at some point during traversal, unless the ray is forcibly terminated.

### 9.20. Closest Hit Shaders

Closest hit shaders have read-only access to the attributes generated by the corresponding intersection shader, and can read or modify the ray payload. They also have access to a number of system-generated values. Closest hit shaders can call OpTraceRayKHR to recursively trace rays.

#### 9.20.1. Closest Hit Shader Execution

Exactly one closest hit shader is executed when traversal is finished and an intersection has been found and accepted.

### 9.21. Miss Shaders

Miss shaders can access the ray payload and can trace new rays through the OpTraceRayKHR instruction, but cannot access attributes since they are not associated with an intersection.
9.21.1. Miss Shader Execution

A miss shader is executed instead of a closest hit shader if no intersection was found during traversal.

9.22. Callable Shaders

Callable shaders can access a callable payload that works similarly to ray payloads to do subroutine work.

9.22.1. Callable Shader Execution

A callable shader is executed by calling `OpExecuteCallableKHR` from an allowed shader stage.

9.23. Interpolation decorations

Variables in the `Input` storage class in a fragment shader's interface are interpolated from the values specified by the primitive being rasterized.

**Note**

Interpolation decorations can be present on input and output variables in pre-rasterization shaders but have no effect on the interpolation performed.

An undecorated input variable will be interpolated with perspective-correct interpolation according to the primitive type being rasterized. Lines and polygons are interpolated in the same way as the primitive's clip coordinates. If the `NoPerspective` decoration is present, linear interpolation is instead used for lines and polygons. For points, as there is only a single vertex, input values are never interpolated and instead take the value written for the single vertex.

If the `Flat` decoration is present on an input variable, the value is not interpolated, and instead takes its value directly from the provoking vertex. Fragment shader inputs that are signed or unsigned integers, integer vectors, or any double-precision floating-point type must be decorated with `Flat`.

Interpolation of input variables is performed at an implementation-defined position within the fragment area being shaded. The position is further constrained as follows:

- If the `Centroid` decoration is used, the interpolation position used for the variable must also fall within the bounds of the primitive being rasterized.
- If the `Sample` decoration is used, the interpolation position used for the variable must be at the position of the sample being shaded by the current fragment shader invocation.
- If a sample count of 1 is used, the interpolation position must be at the center of the fragment area.

**Note**

As `Centroid` restricts the possible interpolation position to the covered area of the primitive, the position can be forced to vary between neighboring fragments when
it otherwise would not. Derivatives calculated based on these differing locations can produce inconsistent results compared to undecorated inputs. It is recommended that input variables used in derivative calculations are not decorated with `Centroid`.

If the `PerVertexKHR` decoration is present on an input variable, the value is not interpolated, and instead values from all input vertices are available in an array. Each index of the array corresponds to one of the vertices of the primitive that produced the fragment.

If the `CustomInterpAMD` decoration is present on an input variable, the value cannot be accessed directly; instead the extended instruction `InterpolateAtVertexAMD` must be used to obtain values from the input vertices.

### 9.24. Static Use

A SPIR-V module declares a global object in memory using the `OpVariable` instruction, which results in a pointer `x` to that object. A specific entry point in a SPIR-V module is said to *statically use* that object if that entry point's call tree contains a function containing a instruction with `x` as an `id` operand. A shader entry point also *statically uses* any variables explicitly declared in its interface.

### 9.25. Scope

A *scope* describes a set of shader invocations, where each such set is a *scope instance*. Each invocation belongs to one or more scope instances, but belongs to no more than one scope instance for each scope.

The operations available between invocations in a given scope instance vary, with smaller scopes generally able to perform more operations, and with greater efficiency.

#### 9.25.1. Cross Device

All invocations executed in a Vulkan instance fall into a single *cross device scope instance*.

Whilst the `CrossDevice` scope is defined in SPIR-V, it is disallowed in Vulkan. API synchronization commands can be used to communicate between devices.

#### 9.25.2. Device

All invocations executed on a single device form a *device scope instance*.

If the `vulkanMemoryModel` and `vulkanMemoryModelDeviceScope` features are enabled, this scope is represented in SPIR-V by the `Device Scope`, which can be used as a `Memory Scope` for barrier and atomic operations.

If both the `shaderDeviceClock` and `vulkanMemoryModelDeviceScope` features are enabled, using the `Device Scope` with the `OpReadClockKHR` instruction will read from a clock that is consistent across invocations in the same device scope instance.

There is no method to synchronize the execution of these invocations within SPIR-V, and this can...
only be done with API synchronization primitives.

Invocations executing on different devices in a device group operate in separate device scope instances.

**9.25.3. Queue Family**

Invocations executed by queues in a given queue family form a *queue family scope instance*.

This scope is identified in SPIR-V as the *QueueFamily Scope* if the `vulkanMemoryModel` feature is enabled, or if not, the *Device Scope*, which can be used as a *Memory Scope* for barrier and atomic operations.

If the `shaderDeviceClock` feature is enabled, but the `vulkanMemoryModelDeviceScope` feature is not enabled, using the *Device Scope* with the `OpReadClockKHR` instruction will read from a clock that is consistent across invocations in the same queue family scope instance.

There is no method to synchronize the execution of these invocations within SPIR-V, and this can only be done with API synchronization primitives.

Each invocation in a queue family scope instance must be in the same *device scope instance*.

**9.25.4. Command**

Any shader invocations executed as the result of a single command such as `vkCmdDispatch` or `vkCmdDraw` form a *command scope instance*. For indirect drawing commands with `drawCount` greater than one, invocations from separate draws are in separate command scope instances. For ray tracing shaders, an invocation group is an implementation-dependent subset of the set of shader invocations of a given shader stage which are produced by a single trace rays command.

There is no specific *Scope* for communication across invocations in a command scope instance. As this has a clear boundary at the API level, coordination here can be performed in the API, rather than in SPIR-V.

Each invocation in a command scope instance must be in the same *queue-family scope instance*.

For shaders without defined *workgroups*, this set of invocations forms an *invocation group* as defined in the SPIR-V specification.

**9.25.5. Primitive**

Any fragment shader invocations executed as the result of rasterization of a single primitive form a *primitive scope instance*.

There is no specific *Scope* for communication across invocations in a primitive scope instance.

Any generated *helper invocations* are included in this scope instance.

Each invocation in a primitive scope instance must be in the same *command scope instance*.

Any input variables decorated with *Flat* are uniform within a primitive scope instance.
9.25.6. Shader Call

Any shader-call-related invocations that are executed in one or more ray tracing execution models form a shader call scope instance.

The ShaderCallKHR Scope can be used as Memory Scope for barrier and atomic operations.

Each invocation in a shader call scope instance must be in the same queue family scope instance.

9.25.7. Workgroup

A local workgroup is a set of invocations that can synchronize and share data with each other using memory in the Workgroup storage class.

The Workgroup Scope can be used as both an Execution Scope and Memory Scope for barrier and atomic operations.

Each invocation in a local workgroup must be in the same command scope instance.

Only task, mesh, and compute shaders have defined workgroups - other shader types cannot use workgroup functionality. For shaders that have defined workgroups, this set of invocations forms an invocation group as defined in the SPIR-V specification.

When variables declared with the Workgroup storage class are explicitly laid out (hence they are also decorated with Block), the amount of storage consumed is the size of the largest Block variable, not counting any padding at the end. The amount of storage consumed by the non-Block variables declared with the Workgroup storage class is implementation-dependent. However, the amount of storage consumed may not exceed the largest block size that would be obtained if all active non-Block variables declared with Workgroup storage class were assigned offsets in an arbitrary order by successively taking the smallest valid offset according to the Standard Storage Buffer Layout rules, and with Boolean values considered as 32-bit integer values for the purpose of this calculation. (This is equivalent to using the GLSL std430 layout rules.)

9.25.8. Subgroup

A subgroup (see the subsection “Control Flow” of section 2 of the SPIR-V 1.3 Revision 1 specification) is a set of invocations that can synchronize and share data with each other efficiently.

The Subgroup Scope can be used as both an Execution Scope and Memory Scope for barrier and atomic operations. Other subgroup features allow the use of group operations with subgroup scope.

If the shaderSubgroupClock feature is enabled, using the Subgroup Scope with the OpReadClockKHR instruction will read from a clock that is consistent across invocations in the same subgroup.

For shaders that have defined workgroups, each invocation in a subgroup must be in the same local workgroup.

In other shader stages, each invocation in a subgroup must be in the same device scope instance.

Only shader stages that support subgroup operations have defined subgroups.
Note

In shaders, there are two kinds of uniformity that are of primary interest to applications: uniform within an invocation group (a.k.a. dynamically uniform), and uniform within a subgroup scope.

While one could make the assumption that being uniform in invocation group implies being uniform in subgroup scope, it is not necessarily the case for shader stages without defined workgroups.

For shader stages with defined workgroups however, the relationship between invocation group and subgroup scope is well defined as a subgroup is a subset of the workgroup, and the workgroup is the invocation group. If a value is uniform in invocation group, it is by definition also uniform in subgroup scope. This is important if writing code like:

```glsl
uniform texture2D Textures[];
uint dynamicallyUniformValue = gl_WorkGroupID.x;
vec4 value = texelFetch(Textures[dynamicallyUniformValue], coord, 0);

// subgroupUniformValue is guaranteed to be uniform within the subgroup.
// This value also happens to be dynamically uniform.
vec4 subgroupUniformValue = subgroupBroadcastFirst(dynamicallyUniformValue);
```

In shader stages without defined workgroups, this gets complicated. Due to scoping rules, there is no guarantee that a subgroup is a subset of the invocation group, which in turn defines the scope for dynamically uniform. In graphics, the invocation group is a single draw command, except for multi-draw situations, and indirect draws with drawCount > 1, where there are multiple invocation groups, one per `DrawIndex`.
Another problematic scenario is when a shader attempts to help the compiler notice that a value is uniform in subgroup scope to potentially improve performance.

```
vec4 value = texelFetch(Textures[notActuallyDynamicallyUniformAnymore], coord, 0);
```

For implementations where subgroups are packed across draws, the implementation must make sure to handle descriptor indexing correctly. From the specification's point of view, a dynamically uniform index does not require `NonUniform` decoration, and such an implementation will likely either promote descriptor indexing into `NonUniform` on its own, or handle non-uniformity implicitly.

### 9.25.9. Quad

A *quad scope instance* is formed of four shader invocations.

In a fragment shader, each invocation in a quad scope instance is formed of invocations in neighboring framebuffer locations \((x_i, y_i)\), where:

- \(i\) is the index of the invocation within the scope instance.
- \(w\) and \(h\) are the number of pixels the fragment covers in the x and y axes.
- \(w\) and \(h\) are identical for all participating invocations.
- \((x_0) = (x_1 - w) = (x_2) = (x_3 - w)\)
- \((y_0) = (y_1) = (y_2 - h) = (y_3 - h)\)
- Each invocation has the same layer and sample indices.

In a compute shader, if the `DerivativeGroupQuadsNV` execution mode is specified, each invocation in a
quad scope instance is formed of invocations with adjacent local invocation IDs \((x_i, y_i)\), where:

- \(i\) is the index of the invocation within the quad scope instance.
- \((x_0) = (x_1 - 1) = (x_2) = (x_3 - 1)\)
- \((y_0) = (y_1) = (y_2 - 1) = (y_3 - 1)\)
- \(x_0\) and \(y_0\) are integer multiples of 2.
- Each invocation has the same \(z\) coordinate.

In a compute shader, if the \texttt{DerivativeGroupLinearNV} execution mode is specified, each invocation in a quad scope instance is formed of invocations with adjacent local invocation indices \((l_i)\), where:

- \(i\) is the index of the invocation within the quad scope instance.
- \((l_0) = (l_1 - 1) = (l_2 - 2) = (l_3 - 3)\)
- \(l_0\) is an integer multiple of 4.

In all shaders, each invocation in a quad scope instance is formed of invocations in adjacent subgroup invocation indices \((s_i)\), where:

- \(i\) is the index of the invocation within the quad scope instance.
- \((s_0) = (s_1 - 1) = (s_2 - 2) = (s_3 - 3)\)
- \(s_0\) is an integer multiple of 4.

Each invocation in a quad scope instance must be in the same subgroup.

In a fragment shader, each invocation in a quad scope instance must be in the same primitive scope instance.

Fragment and compute shaders have defined quad scope instances. If the \texttt{quadOperationsInAllStages} limit is supported, any shader stages that support subgroup operations also have defined quad scope instances.

### 9.25.10. Fragment Interlock

A fragment interlock scope instance is formed of fragment shader invocations based on their framebuffer locations \((x, y, \text{layer}, \text{sample})\), executed by commands inside a single subpass.

The specific set of invocations included varies based on the execution mode as follows:

- If the \texttt{SampleInterlockOrderedEXT} or \texttt{SampleInterlockUnorderedEXT} execution modes are used, only invocations with identical framebuffer locations \((x, y, \text{layer}, \text{sample})\) are included.
- If the \texttt{PixelInterlockOrderedEXT} or \texttt{PixelInterlockUnorderedEXT} execution modes are used, fragments with different sample ids are also included.
- If the \texttt{ShadingRateInterlockOrderedEXT} or \texttt{ShadingRateInterlockUnorderedEXT} execution modes are used, fragments from neighbouring framebuffer locations are also included. The shading rate image or fragment shading rate determines these fragments.

Only fragment shaders with one of the above execution modes have defined fragment interlock
scope instances.

There is no specific Scope value for communication across invocations in a fragment interlock scope instance. However, this is implicitly used as a memory scope by OpBeginInvocationInterlockEXT and OpEndInvocationInterlockEXT.

Each invocation in a fragment interlock scope instance must be in the same queue family scope instance.

9.25.11. Invocation

The smallest scope is a single invocation; this is represented by the Invocation Scope in SPIR-V.

Fragment shader invocations must be in a primitive scope instance.

Invocations in fragment shaders that have a defined fragment interlock scope must be in a fragment interlock scope instance.

Invocations in shaders that have defined workgroups must be in a local workgroup.

Invocations in shaders that have a defined subgroup scope must be in a subgroup.

Invocations in shaders that have a defined quad scope must be in a quad scope instance.

All invocations in all stages must be in a command scope instance.


*Group operations* are executed by multiple invocations within a scope instance; with each invocation involved in calculating the result. This provides a mechanism for efficient communication between invocations in a particular scope instance.

Group operations all take a Scope defining the desired scope instance to operate within. Only the Subgroup scope can be used for these operations; the subgroupSupportedOperations limit defines which types of operation can be used.


Basic group operations include the use of OpGroupNonUniformElect, OpControlBarrier, OpMemoryBarrier, and atomic operations.

OpGroupNonUniformElect can be used to choose a single invocation to perform a task for the whole group. Only the invocation with the lowest id in the group will return true.

The Memory Model appendix defines the operation of barriers and atomics.

9.26.2. Vote Group Operations

The vote group operations allow invocations within a group to compare values across a group. The types of votes enabled are:
• Do all active group invocations agree that an expression is true?
• Do any active group invocations evaluate an expression to true?
• Do all active group invocations have the same value of an expression?

**Note**
These operations are useful in combination with control flow in that they allow for developers to check whether conditions match across the group and choose potentially faster code-paths in these cases.

### 9.26.3. Arithmetic Group Operations

The arithmetic group operations allow invocations to perform scans and reductions across a group. The operators supported are add, mul, min, max, and, or, xor.

For reductions, every invocation in a group will obtain the cumulative result of these operators applied to all values in the group. For exclusive scans, each invocation in a group will obtain the cumulative result of these operators applied to all values in invocations with a lower index in the group. Inclusive scans are identical to exclusive scans, except the cumulative result includes the operator applied to the value in the current invocation.

The order in which these operators are applied is implementation-dependent.


The ballot group operations allow invocations to perform more complex votes across the group. The ballot functionality allows all invocations within a group to provide a boolean value and get as a result what each invocation provided as their boolean value. The broadcast functionality allows values to be broadcast from an invocation to all other invocations within the group.

### 9.26.5. Shuffle Group Operations

The shuffle group operations allow invocations to read values from other invocations within a group.


The shuffle relative group operations allow invocations to read values from other invocations within the group relative to the current invocation in the group. The relative operations supported allow data to be shifted up and down through the invocations within a group.

### 9.26.7. Clustered Group Operations

The clustered group operations allow invocations to perform an operation among partitions of a group, such that the operation is only performed within the group invocations within a partition. The partitions for clustered group operations are consecutive power-of-two size groups of invocations and the cluster size **must** be known at pipeline creation time. The operations supported are add, mul, min, max, and, or, xor.
9.27. Quad Group Operations

Quad group operations (OpGroupNonUniformQuad*) are a specialized type of group operations that only operate on quad scope instances. Whilst these instructions do include a Scope parameter, this scope is always overridden; only the quad scope instance is included in its execution scope.

Fragment shaders that statically execute quad group operations must launch sufficient invocations to ensure their correct operation; additional helper invocations are launched for framebuffer locations not covered by rasterized fragments if necessary.

The index used to select participating invocations is i, as described for a quad scope instance, defined as the quad index in the SPIR-V specification.

For OpGroupNonUniformQuadBroadcast this value is equal to Index. For OpGroupNonUniformQuadSwap, it is equal to the implicit Index used by each participating invocation.

9.28. Derivative Operations

Derivative operations calculate the partial derivative for an expression P as a function of an invocation’s x and y coordinates.

Derivative operations operate on a set of invocations known as a derivative group as defined in the SPIR-V specification. A derivative group is equivalent to the quad scope instance for a compute shader invocation, or the primitive scope instance for a fragment shader invocation.

Derivatives are calculated assuming that P is piecewise linear and continuous within the derivative group. All dynamic instances of explicit derivative instructions (OpDPdx*, OpDPdy*, and OpFwidth*) must be executed in control flow that is uniform within a derivative group. For other derivative operations, results are undefined if a dynamic instance is executed in control flow that is not uniform within the derivative group.

Fragment shaders that statically execute derivative operations must launch sufficient invocations to ensure their correct operation; additional helper invocations are launched for framebuffer locations not covered by rasterized fragments if necessary.

Note

In a compute shader, it is the application’s responsibility to ensure that sufficient invocations are launched.

Derivative operations calculate their results as the difference between the result of P across invocations in the quad. For fine derivative operations (OpDPdxFine and OpDPdyFine), the values of DPdx(Pi) are calculated as

\[ DPdx(P_0) = DPdx(P_1) = P_1 - P_0 \]

\[ DPdx(P_2) = DPdx(P_3) = P_3 - P_2 \]
and the values of \( \text{DPdy}(P_i) \) are calculated as

\[
\begin{align*}
\text{DPdy}(P_0) &= \text{DPdy}(P_2) = P_2 - P_0 \\
\text{DPdy}(P_1) &= \text{DPdy}(P_3) = P_3 - P_1
\end{align*}
\]

where \( i \) is the index of each invocation as described in \textit{Quad}.

Coarse derivative operations (\texttt{OpDPdxCoarse} and \texttt{OpDPdyCoarse}), calculate their results in roughly the same manner, but \textbf{may} only calculate two values instead of four (one for each of \( \text{DPdx} \) and \( \text{DPdy} \)), reusing the same result no matter the originating invocation. If an implementation does this, it \textbf{should} use the fine derivative calculations described for \( P_0 \).

\textit{Note}

Derivative values are calculated between fragments rather than pixels. If the fragment shader invocations involved in the calculation cover multiple pixels, these operations cover a wider area, resulting in larger derivative values. This in turn will result in a coarser LOD being selected for image sampling operations using derivatives.

Applications may want to account for this when using multi-pixel fragments; if pixel derivatives are desired, applications should use explicit derivative operations and divide the results by the size of the fragment in each dimension as follows:

\[
\begin{align*}
\text{DPdx}(P_n)' &= \text{DPdx}(P_n) / w \\
\text{DPdy}(P_n)' &= \text{DPdy}(P_n) / h
\end{align*}
\]

where \( w \) and \( h \) are the size of the fragments in the quad, and \( \text{DPdx}(P_n)' \) and \( \text{DPdy}(P_n)' \) are the pixel derivatives.

The results for \texttt{OpDPdx} and \texttt{OpDPdy} \textbf{may} be calculated as either fine or coarse derivatives, with implementations favouring the most efficient approach. Implementations \textbf{must} choose coarse or fine consistently between the two.

Executing \texttt{OpFwidthFine}, \texttt{OpFwidthCoarse}, or \texttt{OpFwidth} is equivalent to executing the corresponding \texttt{OpDPdx*} and \texttt{OpDPdy*} instructions, taking the absolute value of the results, and summing them.

Executing an \texttt{OpImage*Sample*ImplicitLod} instruction is equivalent to executing \texttt{OpDPdx(Coordinate)} and \texttt{OpDPdy(Coordinate)}, and passing the results as the \texttt{Grad} operands \( dx \) and \( dy \).

\textit{Note}

It is expected that using the \texttt{ImplicitLod} variants of sampling functions will be substantially more efficient than using the \texttt{ExplicitLod} variants with explicitly
9.29. Helper Invocations

When performing derivative or quad group operations in a fragment shader, additional invocations may be spawned in order to ensure correct results. These additional invocations are known as helper invocations and can be identified by a non-zero value in the HelperInvocation built-in. Stores and atomics performed by helper invocations must not have any effect on memory except for the Function, Private and Output storage classes, and values returned by atomic instructions in helper invocations are undefined.

Note

While storage to Output storage class has an effect even in helper invocations, it does not mean that helper invocations have an effect on the framebuffer. Output variables in fragment shaders can be read from as well, and they behave more like Private variables for the duration of the shader invocation.

For group operations other than derivative and quad group operations, helper invocations may be treated as inactive even if they would be considered otherwise active.

Helper invocations may become permanently inactive if all invocations in a quad scope instance become helper invocations.

9.30. Cooperative Matrices

A cooperative matrix type is a SPIR-V type where the storage for and computations performed on the matrix are spread across the invocations in a scope instance. These types give the implementation freedom in how to optimize matrix multiplies.

SPIR-V defines the types and instructions, but does not specify rules about what sizes/combinations are valid, and it is expected that different implementations may support different sizes.

To enumerate the supported cooperative matrix types and operations, call:

```c
// Provided by VK_KHR_cooperative_matrix
VkResult vkGetPhysicalDeviceCooperativeMatrixPropertiesKHR(
    VkPhysicalDevice physicalDevice,
    uint32_t* pPropertyCount,
    VkCooperativeMatrixPropertiesKHR* pProperties);
```

- `physicalDevice` is the physical device.
- `pPropertyCount` is a pointer to an integer related to the number of cooperative matrix properties available or queried.
- `pProperties` is either NULL or a pointer to an array of `VkCooperativeMatrixPropertiesKHR` structures.
If `pProperties` is `NULL`, then the number of cooperative matrix properties available is returned in `pPropertyCount`. Otherwise, `pPropertyCount` **must** point to a variable set by the user to the number of elements in the `pProperties` array, and on return the variable is overwritten with the number of structures actually written to `pProperties`. If `pPropertyCount` is less than the number of cooperative matrix properties available, at most `pPropertyCount` structures will be written, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available cooperative matrix properties were returned.

### Valid Usage (Implicit)

- **VUID-vkGetPhysicalDeviceCooperativeMatrixPropertiesKHR-physicalDevice-parameter**
  - `physicalDevice` **must** be a valid `VkPhysicalDevice` handle

- **VUID-vkGetPhysicalDeviceCooperativeMatrixPropertiesKHR-pPropertyCount-parameter**
  - `pPropertyCount` **must** be a valid pointer to a `uint32_t` value

- **VUID-vkGetPhysicalDeviceCooperativeMatrixPropertiesKHR-pProperties-parameter**
  - If the value referenced by `pPropertyCount` is not 0, and `pProperties` is not `NULL`, `pProperties` **must** be a valid pointer to an array of `pPropertyCount` `VkCooperativeMatrixPropertiesKHR` structures

### Return Codes

**Success**
- `VK_SUCCESS`  
- `VK_INCOMPLETE`  

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`  
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

To enumerate the supported cooperative matrix types and operations, call:

```c
// Provided by VK_NV_cooperative_matrix
VkResult vkGetPhysicalDeviceCooperativeMatrixPropertiesNV(
    VkPhysicalDevice physicalDevice,
    uint32_t* pPropertyCount,
    VkCooperativeMatrixPropertiesNV* pProperties);
```

- `physicalDevice` is the physical device.

- `pPropertyCount` is a pointer to an integer related to the number of cooperative matrix properties available or queried.

- `pProperties` is either `NULL` or a pointer to an array of `VkCooperativeMatrixPropertiesNV` structures.
If `pProperties` is `NULL`, then the number of cooperative matrix properties available is returned in `pPropertyCount`. Otherwise, `pPropertyCount` must point to a variable set by the user to the number of elements in the `pProperties` array, and on return the variable is overwritten with the number of structures actually written to `pProperties`. If `pPropertyCount` is less than the number of cooperative matrix properties available, at most `pPropertyCount` structures will be written, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available cooperative matrix properties were returned.

**Valid Usage (Implicit)**

- `VUID-vkGetPhysicalDeviceCooperativeMatrixPropertiesNV-physicalDevice-parameter` `physicalDevice` must be a valid `VkPhysicalDevice` handle
- `VUID-vkGetPhysicalDeviceCooperativeMatrixPropertiesNV-pPropertyCount-parameter` `pPropertyCount` must be a valid pointer to a `uint32_t` value
- `VUID-vkGetPhysicalDeviceCooperativeMatrixPropertiesNV-pProperties-parameter` If the value referenced by `pPropertyCount` is not 0, and `pProperties` is not `NULL`, `pProperties` must be a valid pointer to an array of `pPropertyCount` `VkCooperativeMatrixPropertiesNV` structures

**Return Codes**

**Success**

- `VK_SUCCESS`
- `VK_INCOMPLETE`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

Each `VkCooperativeMatrixPropertiesKHR` or `VkCooperativeMatrixPropertiesNV` structure describes a single supported combination of types for a matrix multiply/add operation ( `OpCooperativeMatrixMulAddKHR` or `OpCooperativeMatrixMulAddNV` ). The multiply can be described in terms of the following variables and types (in SPIR-V pseudocode):

```spir-v
%A is of type `OpTypeCooperativeMatrixKHR` %AType %scope %MSize %KSize %MatrixAKHR
%B is of type `OpTypeCooperativeMatrixKHR` %BType %scope %KSize %NSize %MatrixBKHR
%C is of type `OpTypeCooperativeMatrixKHR` % CType %scope %MSize %NSize
%MatrixAccumulatorKHR
%Result is of type `OpTypeCooperativeMatrixKHR` %ResultType %scope %MSize %NSize
%MatrixAccumulatorKHR

%Result = %A * %B + %C // using `OpCooperativeMatrixMulAddKHR`
```
A matrix multiply with these dimensions is known as an \( M \times N \times K \) matrix multiply.

The `VkCooperativeMatrixPropertiesKHR` structure is defined as:

```c
// Provided by VK_KHR_cooperative_matrix
typedef struct VkCooperativeMatrixPropertiesKHR {
    VkStructureType sType;
    void* pNext;
    uint32_t MSize;
    uint32_t NSize;
    uint32_t KSize;
    VkComponentTypeKHR AType;
    VkComponentTypeKHR BType;
    VkComponentTypeKHR CType;
    VkComponentTypeKHR ResultType;
    VkBool32 saturatingAccumulation;
    VkScopeKHR scope;
} VkCooperativeMatrixPropertiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `MSize` is the number of rows in matrices \( A \), \( C \), and \( \text{Result} \).
- `KSize` is the number of columns in matrix \( A \) and rows in matrix \( B \).
- `NSize` is the number of columns in matrices \( B \), \( C \), \( \text{Result} \).
- `AType` is the component type of matrix \( A \), of type `VkComponentTypeKHR`.
- `BType` is the component type of matrix \( B \), of type `VkComponentTypeKHR`.
- ` CType` is the component type of matrix \( C \), of type `VkComponentTypeKHR`.
- `ResultType` is the component type of matrix \( \text{Result} \), of type `VkComponentTypeKHR`.
- `saturatingAccumulation` indicates whether the `SaturatingAccumulation` operand to `OpCooperativeMatrixMulAddKHR` must be present.
- `scope` is the scope of all the matrix types, of type `VkScopeKHR`.

If some types are preferred over other types (e.g. for performance), they **should** appear earlier in the list enumerated by `vkGetPhysicalDeviceCooperativeMatrixPropertiesKHR`.

At least one entry in the list **must** have power of two values for all of `MSize`, `KSize`, and `NSize`. 
Valid Usage (Implicit)

- **VUID-VkCooperativeMatrixPropertiesKHR-sType-sType**
  
  *sType must be* `VK_STRUCTURE_TYPE_COOPERATIVE_MATRIX_PROPERTIES_KHR`

- **VUID-VkCooperativeMatrixPropertiesKHR-pNext-pNext**
  
  *pNext must be* `NULL`

- **VUID-VkCooperativeMatrixPropertiesKHR-AType-parameter**
  
  *AType must be a valid* `VkComponentTypeKHR` value

- **VUID-VkCooperativeMatrixPropertiesKHR-BType-parameter**
  
  *BType must be a valid* `VkComponentTypeKHR` value

- **VUID-VkCooperativeMatrixPropertiesKHR-CType-parameter**
  
  *CType must be a valid* `VkComponentTypeKHR` value

- **VUID-VkCooperativeMatrixPropertiesKHR-ResultType-parameter**
  
  *ResultType must be a valid* `VkComponentTypeKHR` value

- **VUID-VkCooperativeMatrixPropertiesKHR-scope-parameter**
  
  *scope must be a valid* `VkScopeKHR` value

The **VkCooperativeMatrixPropertiesNV** structure is defined as:

```c
// Provided by VK_NV_cooperative_matrix
typedef struct VkCooperativeMatrixPropertiesNV {
    VkStructureType sType;
    void* pNext;
    uint32_t MSize;
    uint32_t NSize;
    uint32_t KSize;
    VkComponentTypeNV AType;
    VkComponentTypeNV BType;
    VkComponentTypeNV CType;
    VkComponentTypeNV DType;
    VkScopeNV scope;
} VkCooperativeMatrixPropertiesNV;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **MSize** is the number of rows in matrices A, C, and D.
- **KSize** is the number of columns in matrix A and rows in matrix B.
- **NSize** is the number of columns in matrices B, C, D.
- **AType** is the component type of matrix A, of type `VkComponentTypeNV`.
- **BType** is the component type of matrix B, of type `VkComponentTypeNV`.
- **CType** is the component type of matrix C, of type `VkComponentTypeNV`. 
• **DType** is the component type of matrix D, of type `VkComponentTypeNV`.

• **scope** is the scope of all the matrix types, of type `VkScopeNV`.

If some types are preferred over other types (e.g. for performance), they **should** appear earlier in the list enumerated by `vkGetPhysicalDeviceCooperativeMatrixPropertiesNV`.

At least one entry in the list **must** have power of two values for all of `MSize`, `KSize`, and `NSize`.

### Valid Usage (Implicit)

- **VUID-VkCooperativeMatrixPropertiesNV-sType-sType**
  * `sType` **must** be `VK_STRUCTURE_TYPE_COOPERATIVE_MATRIX_PROPERTIES_NV`

- **VUID-VkCooperativeMatrixPropertiesNV-pNext-pNext**
  * `pNext` **must** be `NULL`

- **VUID-VkCooperativeMatrixPropertiesNV-AType-parameter**
  * `AType` **must** be a valid `VkComponentTypeNV` value

- **VUID-VkCooperativeMatrixPropertiesNV-BType-parameter**
  * `BType` **must** be a valid `VkComponentTypeNV` value

- **VUID-VkCooperativeMatrixPropertiesNV-CType-parameter**
  * `CType` **must** be a valid `VkComponentTypeNV` value

- **VUID-VkCooperativeMatrixPropertiesNV-DType-parameter**
  * `DType` **must** be a valid `VkComponentTypeNV` value

- **VUID-VkCooperativeMatrixPropertiesNV-scope-parameter**
  * `scope` **must** be a valid `VkScopeNV` value

Possible values for `VkScopeKHR` include:

```c
// Provided by VK_KHR_cooperative_matrix
typedef enum VkScopeKHR {
    VK_SCOPE_DEVICE_KHR = 1,
    VK_SCOPE_WORKGROUP_KHR = 2,
    VK_SCOPE_SUBGROUP_KHR = 3,
    VK_SCOPE_QUEUE_FAMILY_KHR = 5,
    // Provided by VK_NV_cooperative_matrix
    VK_SCOPE_DEVICE_NV = VK_SCOPE_DEVICE_KHR,
    // Provided by VK_NV_cooperative_matrix
    VK_SCOPE_WORKGROUP_NV = VK_SCOPE_WORKGROUP_KHR,
    // Provided by VK_NV_cooperative_matrix
    VK_SCOPE_SUBGROUP_NV = VK_SCOPE_SUBGROUP_KHR,
    // Provided by VK_NV_cooperative_matrix
    VK_SCOPE_QUEUE_FAMILY_NV = VK_SCOPE_QUEUE_FAMILY_KHR,
} VkScopeKHR;
```

or the equivalent
typedef VkScopeKHR VkScopeNV;

- **VK_SCOPE_DEVICE_KHR** corresponds to SPIR-V Device scope.
- **VK_SCOPE_WORKGROUP_KHR** corresponds to SPIR-V Workgroup scope.
- **VK_SCOPE_SUBGROUP_KHR** corresponds to SPIR-V Subgroup scope.
- **VK_SCOPE_QUEUE_FAMILY_KHR** corresponds to SPIR-V QueueFamily scope.

All enum values match the corresponding SPIR-V value.

Possible values for **VkComponentTypeKHR** include:

```cpp
typedef enum VkComponentTypeKHR {
    VK_COMPONENT_TYPE_FLOAT16_KHR = 0,
    VK_COMPONENT_TYPE_FLOAT32_KHR = 1,
    VK_COMPONENT_TYPE_FLOAT64_KHR = 2,
    VK_COMPONENT_TYPE_SINT8_KHR = 3,
    VK_COMPONENT_TYPE_SINT16_KHR = 4,
    VK_COMPONENT_TYPE_SINT32_KHR = 5,
    VK_COMPONENT_TYPE_SINT64_KHR = 6,
    VK_COMPONENT_TYPE_UINT8_KHR = 7,
    VK_COMPONENT_TYPE_UINT16_KHR = 8,
    VK_COMPONENT_TYPE_UINT32_KHR = 9,
    VK_COMPONENT_TYPE_UINT64_KHR = 10,
    VK_COMPONENT_TYPE_FLOAT16_NV = VK_COMPONENT_TYPE_FLOAT16_KHR,
    VK_COMPONENT_TYPE_FLOAT32_NV = VK_COMPONENT_TYPE_FLOAT32_KHR,
    VK_COMPONENT_TYPE_FLOAT64_NV = VK_COMPONENT_TYPE_FLOAT64_KHR,
    VK_COMPONENT_TYPE_SINT8_NV = VK_COMPONENT_TYPE_SINT8_KHR,
    VK_COMPONENT_TYPE_SINT16_NV = VK_COMPONENT_TYPE_SINT16_KHR,
    VK_COMPONENT_TYPE_SINT32_NV = VK_COMPONENT_TYPE_SINT32_KHR,
    VK_COMPONENT_TYPE_SINT64_NV = VK_COMPONENT_TYPE_SINT64_KHR,
    VK_COMPONENT_TYPE_UINT8_NV = VK_COMPONENT_TYPE_UINT8_KHR,
    VK_COMPONENT_TYPE_UINT16_NV = VK_COMPONENT_TYPE_UINT16_KHR,
    VK_COMPONENT_TYPE_UINT32_NV = VK_COMPONENT_TYPE_UINT32_KHR,
    VK_COMPONENT_TYPE_UINT64_NV = VK_COMPONENT_TYPE_UINT64_KHR,
}
```
or the equivalent

```c
// Provided by VK_NV_cooperative_matrix
typedef VkComponentTypeKHR VkComponentTypeNV;
```

- `VK_COMPONENT_TYPE_FLOAT16_KHR` corresponds to SPIR-V `OpTypeFloat 16`.
- `VK_COMPONENT_TYPE_FLOAT32_KHR` corresponds to SPIR-V `OpTypeFloat 32`.
- `VK_COMPONENT_TYPE_FLOAT64_KHR` corresponds to SPIR-V `OpTypeFloat 64`.
- `VK_COMPONENT_TYPE_SINT8_KHR` corresponds to SPIR-V `OpTypeInt 8`.
- `VK_COMPONENT_TYPE_SINT16_KHR` corresponds to SPIR-V `OpTypeInt 16`.
- `VK_COMPONENT_TYPE_SINT32_KHR` corresponds to SPIR-V `OpTypeInt 32`.
- `VK_COMPONENT_TYPE_SINT64_KHR` corresponds to SPIR-V `OpTypeInt 64`.
- `VK_COMPONENT_TYPE_UINT8_KHR` corresponds to SPIR-V `OpTypeInt 8`.
- `VK_COMPONENT_TYPE_UINT16_KHR` corresponds to SPIR-V `OpTypeInt 16`.
- `VK_COMPONENT_TYPE_UINT32_KHR` corresponds to SPIR-V `OpTypeInt 32`.
- `VK_COMPONENT_TYPE_UINT64_KHR` corresponds to SPIR-V `OpTypeInt 64`.

### 9.31. Validation Cache

Validation cache objects allow the result of internal validation to be reused, both within a single application run and between multiple runs. Reuse within a single run is achieved by passing the same validation cache object when creating supported Vulkan objects. Reuse across runs of an application is achieved by retrieving validation cache contents in one run of an application, saving the contents, and using them to preinitialize a validation cache on a subsequent run. The contents of the validation cache objects are managed by the validation layers. Applications can manage the host memory consumed by a validation cache object and control the amount of data retrieved from a validation cache object.

Validation cache objects are represented by `VkValidationCacheEXT` handles:

```c
// Provided by VK_EXT_validation_cache
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkValidationCacheEXT)
```

To create validation cache objects, call:

```c
// Provided by VK_EXT_validation_cache
VkResult vkCreateValidationCacheEXT(
    VkDevice device,
    const VkValidationCacheCreateInfoEXT* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
);```
• **device** is the logical device that creates the validation cache object.
• **pCreateInfo** is a pointer to a `VkValidationCacheCreateInfoEXT` structure containing the initial parameters for the validation cache object.
• **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
• **pValidationCache** is a pointer to a `VkValidationCacheEXT` handle in which the resulting validation cache object is returned.

**Note**
Applications **can** track and manage the total host memory size of a validation cache object using the **pAllocator**. Applications **can** limit the amount of data retrieved from a validation cache object in `vkGetValidationCacheDataEXT`. Implementations **should** not internally limit the total number of entries added to a validation cache object or the total host memory consumed.

Once created, a validation cache **can** be passed to the `vkCreateShaderModule` command by adding this object to the `VkShaderModuleCreateInfo` structure's **pNext** chain. If a `VkShaderModuleValidationCacheCreateInfoEXT` object is included in the `VkShaderModuleCreateInfo::pNext` chain, and its `validationCache` field is not `VK_NULL_HANDLE`, the implementation will query it for possible reuse opportunities and update it with new content. The use of the validation cache object in these commands is internally synchronized, and the same validation cache object **can** be used in multiple threads simultaneously.

**Note**
Implementations **should** make every effort to limit any critical sections to the actual accesses to the cache, which is expected to be significantly shorter than the duration of the `vkCreateShaderModule` command.

### Valid Usage (Implicit)

- VUID-vkCreateValidationCacheEXT-device-parameter
  **device** **must** be a valid `VkDevice` handle

- VUID-vkCreateValidationCacheEXT-pCreateInfo-parameter
  **pCreateInfo** **must** be a valid pointer to a valid `VkValidationCacheCreateInfoEXT` structure

- VUID-vkCreateValidationCacheEXT-pAllocator-parameter
  If **pAllocator** is not **NULL**, **pAllocator** **must** be a valid pointer to a valid `VkAllocationCallbacks` structure

- VUID-vkCreateValidationCacheEXT-pValidationCache-parameter
  **pValidationCache** **must** be a valid pointer to a `VkValidationCacheEXT` handle
Return Codes

Success

- VK_SUCCESS

Failure

- VK_ERROR_OUT_OF_HOST_MEMORY

The `VkValidationCacheCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_validation_cache
typedef struct VkValidationCacheCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkValidationCacheCreateFlagsEXT flags;
    size_t initialDataSize;
    const void* pInitialData;
} VkValidationCacheCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is reserved for future use.
- `initialDataSize` is the number of bytes in `pInitialData`. If `initialDataSize` is zero, the validation cache will initially be empty.
- `pInitialData` is a pointer to previously retrieved validation cache data. If the validation cache data is incompatible (as defined below) with the device, the validation cache will be initially empty. If `initialDataSize` is zero, `pInitialData` is ignored.

Valid Usage

- VUID-VkValidationCacheCreateInfoEXT-initialDataSize-01534
  If `initialDataSize` is not 0, it **must** be equal to the size of `pInitialData`, as returned by `vkGetValidationCacheDataEXT` when `pInitialData` was originally retrieved

- VUID-VkValidationCacheCreateInfoEXT-initialDataSize-01535
  If `initialDataSize` is not 0, `pInitialData` **must** have been retrieved from a previous call to `vkGetValidationCacheDataEXT`

Valid Usage (Implicit)

- VUID-VkValidationCacheCreateInfoEXT-sType-sType
  `sType` **must** be `VK_STRUCTURE_TYPE_VALIDATION_CACHE_CREATE_INFO_EXT`

- VUID-VkValidationCacheCreateInfoEXT-pNext-pNext
  `pNext` **must** be `NULL`
• VUID-VkValidationCacheCreateInfoEXT-flags-zerobitmask
  flags must be 0

• VUID-VkValidationCacheCreateInfoEXT-pInitialData-parameter
  If initialDataSize is not 0, pInitialData must be a valid pointer to an array of initialDataSize bytes

```c
// Provided by VK_EXT_validation_cache
typedef VkFlags VkValidationCacheCreateFlagsEXT;
```

VkValidationCacheCreateFlagsEXT is a bitmask type for setting a mask, but is currently reserved for future use.

Validation cache objects can be merged using the command:

```c
// Provided by VK_EXT_validation_cache
VkResult vkMergeValidationCachesEXT(
  VkDevice device,
  VkValidationCacheEXT dstCache,
  uint32_t srcCacheCount,
  const VkValidationCacheEXT* pSrcCaches);
```

• device is the logical device that owns the validation cache objects.
• dstCache is the handle of the validation cache to merge results into.
• srcCacheCount is the length of the pSrcCaches array.
• pSrcCaches is a pointer to an array of validation cache handles, which will be merged into dstCache. The previous contents of dstCache are included after the merge.

Note
The details of the merge operation are implementation-dependent, but implementations should merge the contents of the specified validation caches and prune duplicate entries.

Valid Usage

• VUID-vkMergeValidationCachesEXT-dstCache-01536
  dstCache must not appear in the list of source caches

Valid Usage (Implicit)

• VUID-vkMergeValidationCachesEXT-device-parameter
  device must be a valid VkDevice handle
• VUID-vkMergeValidationCachesEXT-dstCache-parameter
  671
**Return Codes**

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

Data can be retrieved from a validation cache object using the command:

```c
// Provided by VK_EXT_validation_cache
VkResult vkGetValidationCacheDataEXT(
    VkDevice device,
    VkValidationCacheEXT validationCache,
    size_t* pDataSize,
    void* pData);
```

- `device` is the logical device that owns the validation cache.
- `validationCache` is the validation cache to retrieve data from.
- `pDataSize` is a pointer to a value related to the amount of data in the validation cache, as described below.
- `pData` is either `NULL` or a pointer to a buffer.

If `pData` is `NULL`, then the maximum size of the data that can be retrieved from the validation cache, in bytes, is returned in `pDataSize`. Otherwise, `pDataSize` must point to a variable set by the user to the size of the buffer, in bytes, pointed to by `pData`, and on return the variable is overwritten with
the amount of data actually written to pData. If pDataSize is less than the maximum size that can be retrieved by the validation cache, at most pDataSize bytes will be written to pData, and vkGetValidationCacheDataEXT will return VK_INCOMPLETE instead of VK_SUCCESS, to indicate that not all of the validation cache was returned.

Any data written to pData is valid and can be provided as the pInitialData member of the VkValidationCacheCreateInfoEXT structure passed to vkCreateValidationCacheEXT.

Two calls to vkGetValidationCacheDataEXT with the same parameters must retrieve the same data unless a command that modifies the contents of the cache is called between them.

Applications can store the data retrieved from the validation cache, and use these data, possibly in a future run of the application, to populate new validation cache objects. The results of validation, however, may depend on the vendor ID, device ID, driver version, and other details of the device. To enable applications to detect when previously retrieved data is incompatible with the device, the initial bytes written to pData must be a header consisting of the following members:

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>length in bytes of the entire validation cache header written as a stream of bytes, with the least significant byte first</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>a VkValidationCacheHeaderVersionEXT value written as a stream of bytes, with the least significant byte first</td>
</tr>
<tr>
<td>8</td>
<td>VK_UUID_SIZE</td>
<td>a layer commit ID expressed as a UUID, which uniquely identifies the version of the validation layers used to generate these validation results</td>
</tr>
</tbody>
</table>

The first four bytes encode the length of the entire validation cache header, in bytes. This value includes all fields in the header including the validation cache version field and the size of the length field.

The next four bytes encode the validation cache version, as described for VkValidationCacheHeaderVersionEXT. A consumer of the validation cache should use the cache version to interpret the remainder of the cache header.

If pDataSize is less than what is necessary to store this header, nothing will be written to pData and zero will be written to pDataSize.

Valid Usage (Implicit)

- VUID-vkGetValidationCacheDataEXT-device-parameter
device must be a valid VkDevice handle
- VUID-vkGetValidationCacheDataEXT-validationCache-parameter
validationCache must be a valid VkValidationCacheEXT handle
• VUID-vkGetValidationCacheDataEXT-pDataSize-parameter
pDataSize must be a valid pointer to a size_t value

• VUID-vkGetValidationCacheDataEXT-pData-parameter
If the value referenced by pDataSize is not 0, and pData is not NULL, pData must be a valid pointer to an array of pDataSize bytes

• VUID-vkGetValidationCacheDataEXT-validationCache-parent
validationCache must have been created, allocated, or retrieved from device

Return Codes

Success
• VK_SUCCESS
• VK_INCOMPLETE

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY

Possible values of the second group of four bytes in the header returned by vkGetValidationCacheDataEXT, encoding the validation cache version, are:

```
// Provided by VK_EXT_validation_cache
typedef enum VkValidationCacheHeaderVersionEXT {
    VK_VALIDATION_CACHE_HEADER_VERSION_ONE_EXT = 1,
} VkValidationCacheHeaderVersionEXT;
```

• VK_VALIDATION_CACHE_HEADER_VERSION_ONE_EXT specifies version one of the validation cache.

To destroy a validation cache, call:

```
// Provided by VK_EXT_validation_cache
void vkDestroyValidationCacheEXT(
    VkDevice device,                // device
    VkValidationCacheEXT validationCache, // validationCache
    const VkAllocationCallbacks* pAllocator); // pAllocator
```

• device is the logical device that destroys the validation cache object.
• validationCache is the handle of the validation cache to destroy.
• pAllocator controls host memory allocation as described in the Memory Allocation chapter.

Valid Usage

• VUID-vkDestroyValidationCacheEXT-validationCache-01537
If `VkAllocationCallbacks` were provided when `validationCache` was created, a compatible set of callbacks **must** be provided here

- VUID-vkDestroyValidationCacheEXT-validationCache-01538
  If no `VkAllocationCallbacks` were provided when `validationCache` was created, `pAllocator` **must** be `NULL`

### Valid Usage (Implicit)

- VUID-vkDestroyValidationCacheEXT-device-parameter
  `device` **must** be a valid `VkDevice` handle

- VUID-vkDestroyValidationCacheEXT-validationCache-parameter
  If `validationCache` is not `VK_NULL_HANDLE`, `validationCache` **must** be a valid `VkValidationCacheEXT` handle

- VUID-vkDestroyValidationCacheEXT-pAllocator-parameter
  If `pAllocator` is not `NULL`, `pAllocator` **must** be a valid pointer to a valid `VkAllocationCallbacks` structure

- VUID-vkDestroyValidationCacheEXT-validationCache-parent
  If `validationCache` is a valid handle, it **must** have been created, allocated, or retrieved from `device`

### Host Synchronization

- Host access to `validationCache` **must** be externally synchronized
Chapter 10. Pipelines

The following figure shows a block diagram of the Vulkan pipelines. Some Vulkan commands specify geometric objects to be drawn or computational work to be performed, while others specify state controlling how objects are handled by the various pipeline stages, or control data transfer between memory organized as images and buffers. Commands are effectively sent through a processing pipeline, either a graphics pipeline, a ray tracing pipeline, or a compute pipeline.

The graphics pipeline can be operated in two modes, as either primitive shading or mesh shading pipeline.

**Primitive Shading**

The first stage of the graphics pipeline (Input Assembler) assembles vertices to form geometric primitives such as points, lines, and triangles, based on a requested primitive topology. In the next stage (Vertex Shader) vertices can be transformed, computing positions and attributes for each vertex. If tessellation and/or geometry shaders are supported, they can then generate multiple primitives from a single input primitive, possibly changing the primitive topology or generating additional attribute data in the process.

**Cluster Culling Shading**

When using the Cluster Culling Shader, a compute-like shader will perform cluster-based culling, a set of new built-in output variables are used to express visible cluster, in addition, a new built-in function is used to emit these variables from the cluster culling shader to the Input Assembler(IA) stage, then IA can use these variables to fetches vertices of visible cluster and drive vertex shader to work.

**Mesh Shading**

When using the mesh shading pipeline input primitives are not assembled implicitly, but explicitly through the (Mesh Shader). The work on the mesh pipeline is initiated by the application drawing a set of mesh tasks.

If an optional (Task Shader) is active, each task triggers the execution of a task shader workgroup that will generate a new set of tasks upon completion. Each of these spawned tasks, or each of the original dispatched tasks if no task shader is present, triggers the execution of a mesh shader workgroup that produces an output mesh with a variable-sized number of primitives assembled from vertices stored in the output mesh.

**Common**

The final resulting primitives are clipped to a clip volume in preparation for the next stage, Rasterization. The rasterizer produces a series of fragments associated with a region of the framebuffer, from a two-dimensional description of a point, line segment, or triangle. These fragments are processed by fragment operations to determine whether generated values will be written to the framebuffer. Fragment shading determines the values to be written to the framebuffer attachments. Framebuffer operations then read and write the color and depth/stencil attachments of the framebuffer for a given subpass of a render pass instance. The attachments can...
be used as input attachments in the fragment shader in a later subpass of the same render pass.

The **compute pipeline** is a separate pipeline from the graphics pipeline, which operates on one-, two-, or three-dimensional workgroups which **can** read from and write to buffer and image memory.

This ordering is meant only as a tool for describing Vulkan, not as a strict rule of how Vulkan is implemented, and we present it only as a means to organize the various operations of the pipelines. Actual ordering guarantees between pipeline stages are explained in detail in the **synchronization chapter**.

![Figure 2. Block diagram of the Vulkan pipeline](image)

Each pipeline is controlled by a monolithic object created from a description of all of the shader stages and any relevant fixed-function stages. **Linking** the whole pipeline together allows the optimization of shaders based on their input/outputs and eliminates expensive draw time state validation.

A pipeline object is bound to the current state using `vkCmdBindPipeline`. Any pipeline object state that is specified as **dynamic** is not applied to the current state when the pipeline object is bound, but is instead set by dynamic state setting commands.

No state, including dynamic state, is inherited from one command buffer to another.

Compute, ray tracing, and graphics pipelines are each represented by `VkPipeline` handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkPipeline)
```
10.1. Compute Pipelines

Compute pipelines consist of a single static compute shader stage and the pipeline layout.

The compute pipeline represents a compute shader and is created by calling `vkCreateComputePipelines` with `module` and `pName` selecting an entry point from a shader module, where that entry point defines a valid compute shader, in the `VkPipelineShaderStageCreateInfo` structure contained within the `VkComputePipelineCreateInfo` structure.

To create compute pipelines, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkCreateComputePipelines(
    VkDevice device, VkPipelineCache pipelineCache,
    uint32_t createInfoCount, const VkComputePipelineCreateInfo* pCreateInfos,
    const VkAllocationCallbacks* pAllocator,
    VkPipeline* pPipelines);
```

- **device** is the logical device that creates the compute pipelines.
- **pipelineCache** is either `VK_NULL_HANDLE`, indicating that pipeline caching is disabled; or the handle of a valid pipeline cache object, in which case use of that cache is enabled for the duration of the command.
- **createInfoCount** is the length of the `pCreateInfos` and `pPipelines` arrays.
- **pCreateInfos** is a pointer to an array of `VkComputePipelineCreateInfo` structures.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
- **pPipelines** is a pointer to an array of `VkPipeline` handles in which the resulting compute pipeline objects are returned.

### Valid Usage

- **VUID-vkCreateComputePipelines-flags-00695**
  If the `flags` member of any element of `pCreateInfos` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, and the `basePipelineIndex` member of that same element is not `-1`, `basePipelineIndex` must be less than the index into `pCreateInfos` that corresponds to that element.

- **VUID-vkCreateComputePipelines-flags-00696**
  If the `flags` member of any element of `pCreateInfos` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, the base pipeline must have been created with the `VK_PIPELINE_CREATE_ALLOW_DERIVATIVES_BIT` flag set.

- **VUID-vkCreateComputePipelines-pipelineCache-02873**
  If `pipelineCache` was created with `VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT`, host access to `pipelineCache` must be externally synchronized.
Valid Usage (Implicit)

• VUID-vkCreateComputePipelines-device-parameter
device must be a valid VkDevice handle

• VUID-vkCreateComputePipelines-pipelineCache-parameter
If pipelineCache is not VK_NULL_HANDLE, pipelineCache must be a valid VkPipelineCache handle

• VUID-vkCreateComputePipelines-pCreateInfos-parameter
pCreateInfos must be a valid pointer to an array of createInfoCount valid VkComputePipelineCreateInfo structures

• VUID-vkCreateComputePipelines-pAllocator-parameter
If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

• VUID-vkCreateComputePipelines-pPipelines-parameter
pPipelines must be a valid pointer to an array of createInfoCount VkPipeline handles

• VUID-vkCreateComputePipelines-createInfoCount-arraylength
createInfoCount must be greater than 0

• VUID-vkCreateComputePipelines-pipelineCache-parent
If pipelineCache is a valid handle, it must have been created, allocated, or retrieved from device

Return Codes

Success
• VK_SUCCESS
• VK_PIPELINE_COMPILE_REQUIRED_EXT

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY
• VK_ERROR_INVALID_SHADER_NV

The VkComputePipelineCreateInfo structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkComputePipelineCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkPipelineCreateFlags flags;
    VkPipelineShaderStageCreateInfo stage;
    VkPipelineLayout layout;
    VkPipeline basePipelineHandle;
} VkComputePipelineCreateInfo;
```
int32_t basePipelineIndex;
}

VkComputePipelineCreateInfo

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is a bitmask of *VkPipelineCreateFlagBits* specifying how the pipeline will be generated.
- **stage** is a *VkPipelineShaderStageCreateInfo* structure describing the compute shader.
- **layout** is the description of binding locations used by both the pipeline and descriptor sets used with the pipeline.
- **basePipelineHandle** is a pipeline to derive from.
- **basePipelineIndex** is an index into the *pCreateInfos* parameter to use as a pipeline to derive from.

The parameters *basePipelineHandle* and *basePipelineIndex* are described in more detail in **Pipeline Derivatives**.

If a *VkPipelineCreateFlags2CreateInfoKHR* structure is present in the *pNext* chain, *VkPipelineCreateFlags2CreateInfoKHR::flags* from that structure is used instead of *flags* from this structure.

### Valid Usage

- **VUID-VkComputePipelineCreateInfo-flags-07984**
  If *flags* contains the *VK_PIPELINE_CREATE_DERIVATIVE_BIT* flag, and *basePipelineIndex* is -1, *basePipelineHandle* must be a valid compute *VkPipeline* handle.

- **VUID-VkComputePipelineCreateInfo-flags-07985**
  If *flags* contains the *VK_PIPELINE_CREATE_DERIVATIVE_BIT* flag, and *basePipelineHandle* is *VK_NULL_HANDLE*, *basePipelineIndex* must be a valid index into the calling command's *pCreateInfos* parameter.

- **VUID-VkComputePipelineCreateInfo-flags-07986**
  If *flags* contains the *VK_PIPELINE_CREATE_DERIVATIVE_BIT* flag, *basePipelineIndex* must be -1 or *basePipelineHandle* must be *VK_NULL_HANDLE*.

- **VUID-VkComputePipelineCreateInfo-layout-07987**
  If a push constant block is declared in a shader, a push constant range in *layout* must match both the shader stage and range.

- **VUID-VkComputePipelineCreateInfo-layout-07988**
  If a resource variables is declared in a shader, a descriptor slot in *layout* must match the shader stage.

- **VUID-VkComputePipelineCreateInfo-layout-07989**
  If a resource variables is declared in a shader, and the descriptor type is not *VK_DESCRIPTOR_TYPE_MUTABLE_EXT*, a descriptor slot in *layout* must match the descriptor type.

- **VUID-VkComputePipelineCreateInfo-layout-07981**
If a resource variables is declared in a shader as an array, a descriptor slot in layout must match the descriptor count

- VUID-VkComputePipelineCreateInfo-flags-03365
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR

- VUID-VkComputePipelineCreateInfo-flags-03366
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR

- VUID-VkComputePipelineCreateInfo-flags-03367
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR

- VUID-VkComputePipelineCreateInfo-flags-03368
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR

- VUID-VkComputePipelineCreateInfo-flags-03369
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR

- VUID-VkComputePipelineCreateInfo-flags-04945
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_ALLOW_MOTION_BIT_NV

- VUID-VkComputePipelineCreateInfo-flags-09007
  If flags includes VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV, then the VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV::deviceGeneratedComputePipelines feature must be enabled

- VUID-VkComputePipelineCreateInfo-flags-09008
  If flags includes VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV, then the pNext chain must include a pointer to a valid instance of VkComputePipelineIndirectBufferInfoNV specifying the address where the pipeline’s metadata will be saved

- VUID-VkComputePipelineCreateInfo-pipelineCreationCacheControl-02875
  If the pipelineCreationCacheControl feature is not enabled, flags must not include VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT or VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT

- VUID-VkComputePipelineCreateInfo-stage-00701
  The stage member of stage must be VK_SHADER_STAGE_COMPUTE_BIT

- VUID-VkComputePipelineCreateInfo-stage-00702
  The shader code for the entry point identified by stage and the rest of the state identified by this structure must adhere to the pipeline linking rules described in the Shader Interfaces chapter

- VUID-VkComputePipelineCreateInfo-layout-01687
  The number of resources in layout accessible to the compute shader stage must be less than or equal to VkPhysicalDeviceLimits::maxPerStageResources
If `shaderEnqueue` is not enabled, `flags` must not include `VK_PIPELINE_CREATE_LIBRARY_BIT_KHR`.

If `flags` does not include `VK_PIPELINE_CREATE_LIBRARY_BIT_KHR`, the shader specified by `stage` must not declare the `ShaderEnqueueAMDX` capability.

If `VkPipelineCreationFeedbackCreateInfo::pipelineStageCreationFeedbackCount` is not 0, it must be 1.

`flags` must not include `VK_PIPELINE_CREATE_RAY_TRACING_OPACITY_MICROMAP_BIT_EXT`.

`flags` must not include `VK_PIPELINE_CREATE_RAY_TRACING_DISPLACEMENT_MICROMAP_BIT_NV`.

Valid Usage (Implicit)

- `sType` must be `VK_STRUCTURE_TYPE_COMPUTE_PIPELINE_CREATE_INFO`
- Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkPipelineCompilerControlCreateInfoAMD`, `VkPipelineCreateFlags2CreateInfoKHR`, `VkPipelineCreationFeedbackCreateInfo`, `VkPipelineRobustnessCreateInfoEXT`, or `VkSubpassShadingPipelineCreateInfoHUAWEI`.
- The `sType` value of each struct in the `pNext` chain must be unique.
- `flags` must be a valid combination of `VkPipelineCreateFlagBits` values.
- `stage` must be a valid `VkPipelineShaderStageCreateInfo` structure.
- `layout` must be a valid `VkPipelineLayout` handle.
- Both of `basePipelineHandle`, and `layout` that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same `VkDevice`.

The `VkPipelineShaderStageCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPipelineShaderStageCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkPipelineShaderStageCreateFlags flags;
} VkPipelineShaderStageCreateInfo;
```
```c
VkShaderStageFlagBits stage;
VkShaderModule module;
const char* pName;
const VkSpecializationInfo* pSpecializationInfo;
}
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is a bitmask of `VkPipelineShaderStageCreateFlagBits` specifying how the pipeline shader stage will be generated.
- **stage** is a `VkShaderStageFlagBits` value specifying a single pipeline stage.
- **module** is optionally a `VkShaderModule` object containing the shader code for this stage.
- **pName** is a pointer to a null-terminated UTF-8 string specifying the entry point name of the shader for this stage.
- **pSpecializationInfo** is a pointer to a `VkSpecializationInfo` structure, as described in Specialization Constants, or `NULL`.

If `module` is not `VK_NULL_HANDLE`, the shader code used by the pipeline is defined by `module`. If `module` is `VK_NULL_HANDLE`, the shader code is defined by the chained `VkShaderModuleCreateInfo` if present.

If the `shaderModuleIdentifier` feature is enabled, applications can omit shader code for `stage` and instead provide a module identifier. This is done by including a `VkPipelineShaderStageModuleIdentifierCreateInfoEXT` struct with `identifierSize` not equal to 0 in the `pNext` chain. A shader stage created in this way is equivalent to one created using a shader module with the same identifier. The identifier allows an implementation to look up a pipeline without consuming a valid SPIR-V module. If a pipeline is not found, pipeline compilation is not possible and the implementation must fail as specified by `VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT`.

When an identifier is used in lieu of a shader module, implementations may fail pipeline compilation with `VK_PIPELINE_COMPILE_REQUIRED` for any reason.

**Note**

The rationale for the relaxed requirement on implementations to return a pipeline with `VkPipelineShaderStageModuleIdentifierCreateInfoEXT` is that layers or tools may intercept pipeline creation calls and require the full SPIR-V context to operate correctly. ICDs are not expected to fail pipeline compilation if the pipeline exists in a cache somewhere.

Applications can use identifiers when creating pipelines with `VK_PIPELINE_CREATE_LIBRARY_BIT_KHR`. When creating such pipelines, `VK_SUCCESS` may be returned, but subsequently fail when referencing the pipeline in a `VkPipelineLibraryCreateInfoKHR` struct. Applications must allow pipeline compilation to fail during link steps with `VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT` as it may not be possible to determine if a pipeline can be created from identifiers until the link step.
Valid Usage

• VUID-VkPipelineShaderStageCreateInfo-stage-00704
  If the geometryShader feature is not enabled, stage must not be VK_SHADER_STAGE_GEOMETRY_BIT

• VUID-VkPipelineShaderStageCreateInfo-stage-00705
  If the tessellationShader feature is not enabled, stage must not be VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT or VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT

• VUID-VkPipelineShaderStageCreateInfo-stage-02091
  If the meshShaders feature is not enabled, stage must not be VK_SHADER_STAGE_MESH_BIT_EXT

• VUID-VkPipelineShaderStageCreateInfo-stage-02092
  If the taskShaders feature is not enabled, stage must not be VK_SHADER_STAGE_TASK_BIT_EXT

• VUID-VkPipelineShaderStageCreateInfo-clustercullingShader-07813
  If the clustercullingShader feature is not enabled, stage must not be VK_SHADER_STAGE_CLUSTER_CULLING_BIT_HUAWEI

• VUID-VkPipelineShaderStageCreateInfo-stage-00706
  stage must not be VK_SHADER_STAGE_ALL_GRAPHICS, or VK_SHADER_STAGE_ALL

• VUID-VkPipelineShaderStageCreateInfo-pName-00707
  pName must be the name of an OpEntryPoint in module with an execution model that matches stage

• VUID-VkPipelineShaderStageCreateInfo-maxClipDistances-00708
  If the identified entry point includes any variable in its interface that is declared with the ClipDistance BuiltIn decoration, that variable must not have an array size greater than VkPhysicalDeviceLimits::maxClipDistances

• VUID-VkPipelineShaderStageCreateInfo-maxCullDistances-00709
  If the identified entry point includes any variable in its interface that is declared with the CullDistance BuiltIn decoration, that variable must not have an array size greater than VkPhysicalDeviceLimits::maxCullDistances

• VUID-VkPipelineShaderStageCreateInfo-maxCombinedClipAndCullDistances-00710
  If the identified entry point includes any variables in its interface that are declared with the ClipDistance or CullDistance BuiltIn decoration, those variables must not have array sizes which sum to more than VkPhysicalDeviceLimits::maxCombinedClipAndCullDistances

• VUID-VkPipelineShaderStageCreateInfo-maxSampleMaskWords-00711
  If the identified entry point includes any variable in its interface that is declared with the SampleMask BuiltIn decoration, that variable must not have an array size greater than VkPhysicalDeviceLimits::maxSampleMaskWords

• VUID-VkPipelineShaderStageCreateInfo-stage-00713
  If stage is VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT or VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT, and the identified entry point has an OpExecutionMode instruction specifying a patch size with OutputVertices, the patch size must be greater than 0 and less than or equal to VkPhysicalDeviceLimits::maxTessellationPatchSize
If `stage` is `VK_SHADER_STAGE_GEOMETRY_BIT`, the identified entry point must have an `OpExecutionMode` instruction specifying a maximum output vertex count that is greater than 0 and less than or equal to `VkPhysicalDeviceLimits::maxGeometryOutputVertices`.

If `stage` is `VK_SHADER_STAGE_GEOMETRY_BIT`, the identified entry point must have an `OpExecutionMode` instruction specifying an invocation count that is greater than 0 and less than or equal to `VkPhysicalDeviceLimits::maxGeometryShaderInvocations`.

If `stage` is either `VK_SHADER_STAGE_VERTEX_BIT`, `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`, `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`, or `VK_SHADER_STAGE_GEOMETRY_BIT`, and the identified entry point writes to `Layer` for any primitive, it must write the same value to `Layer` for all vertices of a given primitive.

If `stage` is either `VK_SHADER_STAGE_VERTEX_BIT`, `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`, `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`, or `VK_SHADER_STAGE_GEOMETRY_BIT`, and the identified entry point writes to `ViewportIndex` for any primitive, it must write the same value to `ViewportIndex` for all vertices of a given primitive.

If `stage` is `VK_SHADER_STAGE_FRAGMENT_BIT`, and the identified entry point writes to `FragDepth` in any execution path, all execution paths that are not exclusive to helper invocations must either discard the fragment, or write or initialize the value of `FragDepth`.

If `stage` is `VK_SHADER_STAGE_FRAGMENT_BIT`, and the identified entry point writes to `FragStencilRefEXT` in any execution path, all execution paths that are not exclusive to helper invocations must either discard the fragment, or write or initialize the value of `FragStencilRefEXT`.

If `flags` has the `VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT` flag set, the `subgroupSizeControl` feature must be enabled.

If `flags` has the `VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT` flag set, the `computeFullSubgroups` feature must be enabled.

If `flags` includes `VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT`, `stage` must be one of `VK_SHADER_STAGE_MESH_BIT_EXT`, `VK_SHADER_STAGE_TASK_BIT_EXT`, or `VK_SHADER_STAGE_COMPUTE_BIT`.

If a `VkPipelineShaderStageRequiredSubgroupSizeCreateInfo` structure is included in the `pNext` chain, `flags` must not have the `VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT` flag set.

If a `VkPipelineShaderStageRequiredSubgroupSizeCreateInfo` structure is included in the `pNext` chain, the `subgroupSizeControl` feature must be enabled, and `stage` must be a valid...
bit specified in requiredSubgroupSizeStages

- **VUID-VkPipelineShaderStageCreateInfo-pNext-02756**
  If a VkPipelineShaderStageRequiredSubgroupSizeCreateInfo structure is included in the pNext chain and stage is VK_SHADER_STAGE_COMPUTE_BIT, VK_SHADER_STAGE_MESH_BIT_EXT, or VK_SHADER_STAGE_TASK_BIT_EXT, the local workgroup size of the shader must be less than or equal to the product of VkPipelineShaderStageRequiredSubgroupSizeCreateInfo::requiredSubgroupSize and maxComputeWorkgroupSubgroups.

- **VUID-VkPipelineShaderStageCreateInfo-pNext-02757**
  If a VkPipelineShaderStageRequiredSubgroupSizeCreateInfo structure is included in the pNext chain, and flags has the VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT flag set, the local workgroup size in the X dimension of the pipeline must be a multiple of VkPipelineShaderStageRequiredSubgroupSizeCreateInfo::requiredSubgroupSize.

- **VUID-VkPipelineShaderStageCreateInfo-flags-02758**
  If flags has both the VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT and VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT flags set and no VkPipelineShaderStageRequiredSubgroupSizeCreateInfo structure is included in the pNext chain, the local workgroup size in the X dimension of the pipeline must be a multiple of maxSubgroupSize.

- **VUID-VkPipelineShaderStageCreateInfo-flags-02759**
  If flags has the VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT flag set and flags does not have the VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT flag set and no VkPipelineShaderStageRequiredSubgroupSizeCreateInfo structure is included in the pNext chain, the local workgroup size in the X dimension of the pipeline must be a multiple of subgroupSize.

- **VUID-VkPipelineShaderStageCreateInfo-module-08987**
  If module uses the OpTypeCooperativeMatrixKHR instruction with a Scope equal to Subgroup, then the local workgroup size in the X dimension of the pipeline must be a multiple of subgroupSize.

- **VUID-VkPipelineShaderStageCreateInfo-stage-06844**
  If a shader module identifier is specified for this stage, a VkShaderModuleCreateInfo structure must not be present in the pNext chain.

- **VUID-VkPipelineShaderStageCreateInfo-stage-06845**
  If a shader module identifier is not specified for this stage, module must be a valid VkShaderModule or there must be a valid VkShaderModuleCreateInfo structure in the pNext chain.

- **VUID-VkPipelineShaderStageCreateInfo-stage-08771**
  If a shader module identifier is not specified for this stage, and neither the maintenance5 nor graphicsPipelineLibrary feature are enabled, module must be a valid VkShaderModule.

- **VUID-VkPipelineShaderStageCreateInfo-stage-06848**
  If a shader module identifier is specified for this stage, module must be VK_NULL_HANDLE.

- **VUID-VkPipelineShaderStageCreateInfo-pSpecializationInfo-06849**
  If a shader module identifier is not specified, the shader code used by the pipeline must be valid as described by the Khronos SPIR-V Specification after applying the specializations provided in pSpecializationInfo, if any, and then converting all specialization constants into fixed constants.
Valid Usage (Implicit)

- **VUID-VkPipelineShaderStageCreateInfo-sType-sType**
  
  The `sType` member of any struct in the `pNext` chain must be `VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_CREATE_INFO`.

- **VUID-VkPipelineShaderStageCreateInfo-pNext-pNext**
  
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkDebugUtilsObjectNameInfoEXT`, `VkPipelineRobustnessCreateInfoEXT`, `VkPipelineShaderStageModuleIdentifierCreateInfoEXT`, `VkPipelineShaderStageNodeCreateInfoAMDX`, `VkPipelineShaderStageRequiredSubgroupSizeCreateInfo`, `VkShaderModuleCreateInfo`, or `VkShaderModuleValidationCacheCreateInfoEXT`.

- **VUID-VkPipelineShaderStageCreateInfo-sType-unique**
  
  The `sType` value of each struct in the `pNext` chain must be unique.

- **VUID-VkPipelineShaderStageCreateInfo-flags-parameter**
  
  The `flags` member of `VkPipelineShaderStageCreateInfo` specifying how a pipeline shader stage is created, are:

  Possible values of the `flags` member of `VkPipelineShaderStageCreateInfo` specifying how a pipeline shader stage is created, are:

  - **VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT**
    
    The value of `VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT` is `0x00000001`.

  - **VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT**
    
    The value of `VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT` is `0x00000002`.

  - **VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT_EXT**
    
    The value of `VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT_EXT` is `687`.

---

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkPipelineShaderStageCreateFlags;
```

`VkPipelineShaderStageCreateFlags` is a bitmask type for setting a mask of zero or more `VkPipelineShaderStageCreateFlagBits` values.

Possible values of the `flags` member of `VkPipelineShaderStageCreateInfo` specifying how a pipeline shader stage is created, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkPipelineShaderStageCreateFlagBits {
    // Provided by VK_VERSION_1_3
    VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT = 0x00000001,
    // Provided by VK_VERSION_1_3
    VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT = 0x00000002,
    // Provided by VK_EXT_subgroup_size_control
    VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT_EXT =
```
• **VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT** specifies that the `SubgroupSize` may vary in the shader stage.

• **VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT_EXT** specifies that the subgroup sizes must be launched with all invocations active in the task, mesh, or compute stage.

**Note**

If **VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT_EXT** and **VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT_EXT** are specified and `minSubgroupSize` does not equal `maxSubgroupSize` and no required subgroup size is specified, then the only way to guarantee that the ‘X’ dimension of the local workgroup size is a multiple of `SubgroupSize` is to make it a multiple of `maxSubgroupSize`. Under these conditions, you are guaranteed full subgroups but not any particular subgroup size.

Bits which can be set by commands and structures, specifying one or more shader stages, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkShaderStageFlagBits {
    VK_SHADER_STAGE_VERTEX_BIT = 0x00000001,
    VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT = 0x00000002,
    VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT = 0x00000004,
    VK_SHADER_STAGE_GEOMETRY_BIT = 0x00000008,
    VK_SHADER_STAGE_FRAGMENT_BIT = 0x00000010,
    VK_SHADER_STAGE_COMPUTE_BIT = 0x00000020,
    VK_SHADER_STAGE_ALL_GRAPHICS = 0x0000001F,
    VK_SHADER_STAGE_ALL = 0x7FFFFFFF,
    // Provided by VK_KHR_ray_tracing_pipeline
    VK_SHADER_STAGE_RAYGEN_BIT_KHR = 0x00000100,
    // Provided by VK_KHR_ray_tracing_pipeline
    VK_SHADER_STAGE_ANY_HIT_BIT_KHR = 0x00000200,
    // Provided by VK_KHR_ray_tracing_pipeline
    VK_SHADER_STAGE_CLOSEST_HIT_BIT_KHR = 0x00000400,
    // Provided by VK_KHR_ray_tracing_pipeline
    VK_SHADER_STAGE_MISS_BIT_KHR = 0x00000800,
    // Provided by VK_KHR_ray_tracing_pipeline
    VK_SHADER_STAGE_INTERSECTION_BIT_KHR = 0x00001000,
    // Provided by VK_KHR_ray_tracing_pipeline
    VK_SHADER_STAGE_CALLABLE_BIT_KHR = 0x00002000,
    // Provided by VK_EXT_mesh_shader
    VK_SHADER_STAGE_TASK_BIT_EXT = 0x00000040,
    // Provided by VK_EXT_mesh_shader
    VK_SHADER_STAGE_MESH_BIT_EXT = 0x00000080,
} VkShaderStageFlagBits;
```
• **VK_SHADER_STAGE_VERTEX_BIT** specifies the vertex stage.

• **VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT** specifies the tessellation control stage.

• **VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT** specifies the tessellation evaluation stage.

• **VK_SHADER_STAGE_GEOMETRY_BIT** specifies the geometry stage.

• **VK_SHADER_STAGE_FRAGMENT_BIT** specifies the fragment stage.

• **VK_SHADER_STAGE_COMPUTE_BIT** specifies the compute stage.

• **VK_SHADER_STAGE_ALL_GRAPHICS** is a combination of bits used as shorthand to specify all graphics stages defined above (excluding the compute stage).

• **VK_SHADER_STAGE_ALL** is a combination of bits used as shorthand to specify all shader stages supported by the device, including all additional stages which are introduced by extensions.

• **VK_SHADER_STAGE_TASK_BIT_EXT** specifies the task stage.

• **VK_SHADER_STAGE_MESH_BIT_EXT** specifies the mesh stage.

• **VK_SHADER_STAGE_CLUSTER_CULLING_BIT_HUAWEI** specifies the cluster culling stage.

• **VK_SHADER_STAGE_RAYGEN_BIT_KHR** specifies the ray generation stage.

• **VK_SHADER_STAGE_ANY_HIT_BIT_KHR** specifies the any-hit stage.

• **VK_SHADER_STAGE_CLOSEST_HIT_BIT_KHR** specifies the closest hit stage.

• **VK_SHADER_STAGE_MISS_BIT_KHR** specifies the miss stage.

• **VK_SHADER_STAGE_INTERSECTION_BIT_KHR** specifies the intersection stage.

• **VK_SHADER_STAGE_CALLABLE_BIT_KHR** specifies the callable stage.
**Note**

`VK_SHADER_STAGE_ALL_GRAPHICS` only includes the original five graphics stages included in Vulkan 1.0, and not any stages added by extensions. Thus, it may not have the desired effect in all cases.

```cpp
// Provided by VK_VERSION_1_0
typedef VkFlags VkShaderStageFlags;
```

`VkShaderStageFlags` is a bitmask type for setting a mask of zero or more `VkShaderStageFlagBits`.

The `VkPipelineShaderStageRequiredSubgroupSizeCreateInfo` structure is defined as:

```cpp
// Provided by VK_VERSION_1_3
typedef struct VkPipelineShaderStageRequiredSubgroupSizeCreateInfo {
    VkStructureType sType;
    void* pNext;
    uint32_t requiredSubgroupSize;
} VkPipelineShaderStageRequiredSubgroupSizeCreateInfo;
```

or the equivalent

```cpp
// Provided by VK_EXT_subgroup_size_control
typedef VkPipelineShaderStageRequiredSubgroupSizeCreateInfo
    VkPipelineShaderStageRequiredSubgroupSizeCreateInfoEXT;
```

or the equivalent

```cpp
// Provided by VK_EXT_shader_object
typedef VkPipelineShaderStageRequiredSubgroupSizeCreateInfo
    VkShaderRequiredSubgroupSizeCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `requiredSubgroupSize` is an unsigned integer value specifying the required subgroup size for the newly created pipeline shader stage.

If a `VkPipelineShaderStageRequiredSubgroupSizeCreateInfo` structure is included in the `pNext` chain of `VkPipelineShaderStageCreateInfo`, it specifies that the pipeline shader stage being compiled has a required subgroup size.

If a `VkShaderRequiredSubgroupSizeCreateInfoEXT` structure is included in the `pNext` chain of `VkShaderCreateInfoEXT`, it specifies that the shader being compiled has a required subgroup size.
Valid Usage

• VUID-VkPipelineShaderStageRequiredSubgroupSizeCreateInfo-requiredSubgroupSize-02760
  requiredSubgroupSize must be a power-of-two integer

• VUID-VkPipelineShaderStageRequiredSubgroupSizeCreateInfo-requiredSubgroupSize-02761
  requiredSubgroupSize must be greater or equal to minSubgroupSize

• VUID-VkPipelineShaderStageRequiredSubgroupSizeCreateInfo-requiredSubgroupSize-02762
  requiredSubgroupSize must be less than or equal to maxSubgroupSize

Valid Usage (Implicit)

• VUID-VkPipelineShaderStageRequiredSubgroupSizeCreateInfo-sType-sType
  sType must be
  VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_REQUIRED(Subgroup Size CREATE INFO

A subpass shading pipeline is a compute pipeline which must be called only in a subpass of a render pass with work dimensions specified by render area size. The subpass shading pipeline shader is a compute shader allowed to access input attachments specified in the calling subpass. To create a subpass shading pipeline, call `vkCreateComputePipelines` with `VkSubpassShadingPipelineCreateInfoHUAWEI` in the `pNext` chain of `VkComputePipelineCreateInfo`.

The `VkSubpassShadingPipelineCreateInfoHUAWEI` structure is defined as:

```c
// Provided by VK_HUAWEI_subpass_shading
typedef struct VkSubpassShadingPipelineCreateInfoHUAWEI {
    VkStructureType sType;
    void* pNext;
    VkRenderPass renderPass;
    uint32_t subpass;
} VkSubpassShadingPipelineCreateInfoHUAWEI;
```

• `sType` is a `VkStructureType` value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.
• `renderPass` is a handle to a render pass object describing the environment in which the pipeline will be used. The pipeline must only be used with a render pass instance compatible with the one provided. See Render Pass Compatibility for more information.
• `subpass` is the index of the subpass in the render pass where this pipeline will be used.
Valid Usage

- VUID-VkSubpassShadingPipelineCreateInfoHUAWEI-subpass-04946
  subpass must be created with VK_PIPELINE_BIND_POINT_SUBPASS_SHADING_HUAWEI bind point

Valid Usage (Implicit)

- VUID-VkSubpassShadingPipelineCreateInfoHUAWEI-sType-sType
  sType must be VK_STRUCTURE_TYPE_SUBPASS_SHADING_PIPELINE_CREATE_INFO_HUAWEI

A subpass shading pipeline's workgroup size is a 2D vector with number of power-of-two in width and height. The maximum number of width and height is implementation-dependent, and may vary for different formats and sample counts of attachments in a render pass.

To query the maximum workgroup size, call:

```c
// Provided by VK_HUAWEI_subpass_shading
VkResult vkGetDeviceSubpassShadingMaxWorkgroupSizeHUAWEI(
    VkDevice device,
    VkRenderPass renderpass,
    VkExtent2D* pMaxWorkgroupSize);
```

- `device` is a handle to a local device object that was used to create the given render pass.
- `renderPass` is a handle to a render pass object describing the environment in which the pipeline will be used. The pipeline must only be used with a render pass instance compatible with the one provided. See Render Pass Compatibility for more information.
- `pMaxWorkgroupSize` is a pointer to a VkExtent2D structure.

Valid Usage (Implicit)

- VUID-vkGetDeviceSubpassShadingMaxWorkgroupSizeHUAWEI-device-parameter
  device must be a valid VkDevice handle
- VUID-vkGetDeviceSubpassShadingMaxWorkgroupSizeHUAWEI-renderpass-parameter
  renderpass must be a valid VkRenderPass handle
- VUID-vkGetDeviceSubpassShadingMaxWorkgroupSizeHUAWEI-pMaxWorkgroupSize-parameter
  pMaxWorkgroupSize must be a valid pointer to a VkExtent2D structure
- VUID-vkGetDeviceSubpassShadingMaxWorkgroupSizeHUAWEI-renderpass-parent
  renderpass must have been created, allocated, or retrieved from device
Return Codes

Success
• VK_SUCCESS
• VK_INCOMPLETE

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY
• VK_ERROR_SURFACE_LOST_KHR

The `VkPipelineRobustnessCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_pipeline_robustness
typedef struct VkPipelineRobustnessCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkPipelineRobustnessBufferBehaviorEXT storageBuffers;
    VkPipelineRobustnessBufferBehaviorEXT uniformBuffers;
    VkPipelineRobustnessBufferBehaviorEXT vertexInputs;
    VkPipelineRobustnessImageBehaviorEXT images;
} VkPipelineRobustnessCreateInfoEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **storageBuffers** sets the behaviour of out of bounds accesses made to resources bound as:
  - `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER`
  - `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER`
  - `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC`

- **uniformBuffers** describes the behaviour of out of bounds accesses made to resources bound as:
  - `VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER`
  - `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER`
  - `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC`
  - `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK`

- **vertexInputs** describes the behaviour of out of bounds accesses made to vertex input attributes

- **images** describes the behaviour of out of bounds accesses made to resources bound as:
  - `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE`
  - `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE`

Resources bound as `VK_DESCRIPTOR_TYPE_MUTABLE_EXT` will have the robustness behavior that covers
its active descriptor type.

The scope of the effect of \texttt{VkPipelineRobustnessCreateInfoEXT} depends on which structure's \texttt{pNext} chain it is included in.

- \texttt{VkGraphicsPipelineCreateInfo}, \texttt{VkRayTracingPipelineCreateInfoKHR}, \texttt{VkComputePipelineCreateInfo}:
The robustness behavior described by \texttt{VkPipelineRobustnessCreateInfoEXT} applies to all accesses through this pipeline

- \texttt{VkPipelineShaderStageCreateInfo}:
The robustness behavior described by \texttt{VkPipelineRobustnessCreateInfoEXT} applies to all accesses emanating from the shader code of this shader stage

If \texttt{VkPipelineRobustnessCreateInfoEXT} is specified for both a pipeline and a pipeline stage, the \texttt{VkPipelineRobustnessCreateInfoEXT} specified for the pipeline stage will take precedence.

When \texttt{VkPipelineRobustnessCreateInfoEXT} is specified for a pipeline, it only affects the subset of the pipeline that is specified by the create info, as opposed to subsets linked from pipeline libraries. For \texttt{VkGraphicsPipelineCreateInfo}, that subset is specified by \texttt{VkGraphicsPipelineLibraryCreateInfoEXT::flags}. For \texttt{VkRayTracingPipelineCreateInfoKHR}, that subset is specified by the specific stages in \texttt{VkRayTracingPipelineCreateInfoKHR::pStages}.

### Valid Usage

- \texttt{VUID-VkPipelineRobustnessCreateInfoEXT-pipelineRobustness-06926}  
  If the \texttt{pipelineRobustness} feature is not enabled, \texttt{storageBuffers} must be \texttt{VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_DEVICE_DEFAULT_EXT}

- \texttt{VUID-VkPipelineRobustnessCreateInfoEXT-pipelineRobustness-06927}  
  If the \texttt{pipelineRobustness} feature is not enabled, \texttt{uniformBuffers} must be \texttt{VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_DEVICE_DEFAULT_EXT}

- \texttt{VUID-VkPipelineRobustnessCreateInfoEXT-pipelineRobustness-06928}  
  If the \texttt{pipelineRobustness} feature is not enabled, \texttt{vertexInputs} must be \texttt{VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_DEVICE_DEFAULT_EXT}

- \texttt{VUID-VkPipelineRobustnessCreateInfoEXT-pipelineRobustness-06929}  
  If the \texttt{pipelineRobustness} feature is not enabled, \texttt{images} must be \texttt{VK_PIPELINE_ROBUSTNESS_IMAGE_BEHAVIOR_DEVICE_DEFAULT_EXT}

- \texttt{VUID-VkPipelineRobustnessCreateInfoEXT-robustImageAccess-06930}  
  If the \texttt{robustImageAccess} feature is not supported, \texttt{images} must not be \texttt{VK_PIPELINE_ROBUSTNESS_IMAGE_BEHAVIOR_ROBUST_IMAGE_ACCESS_EXT}

- \texttt{VUID-VkPipelineRobustnessCreateInfoEXT-robustBufferAccess2-06931}  
  If the \texttt{robustBufferAccess2} feature is not supported, \texttt{storageBuffers} must not be \texttt{VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT}

- \texttt{VUID-VkPipelineRobustnessCreateInfoEXT-robustBufferAccess2-06932}  
  If the \texttt{robustBufferAccess2} feature is not supported, \texttt{uniformBuffers} must not be \texttt{VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT}

- \texttt{VUID-VkPipelineRobustnessCreateInfoEXT-robustBufferAccess2-06933}  
  If the \texttt{robustBufferAccess2} feature is not supported, \texttt{storageBuffers} must not be \texttt{VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT}
If the robustBufferAccess2 feature is not supported, vertexInputs must not be
VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT

- VUID-VkPipelineRobustnessCreateInfoEXT-robustImageAccess2-06934
If the robustImageAccess2 feature is not supported, images must not be
VK_PIPELINE_ROBUSTNESS_IMAGE_BEHAVIOR_ROBUST_IMAGE_ACCESS_2_EXT

Valid Usage (Implicit)

- VUID-VkPipelineRobustnessCreateInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PIPELINE_ROBUSTNESS_CREATE_INFO_EXT

- VUID-VkPipelineRobustnessCreateInfoEXT-storageBuffers-parameter
  storageBuffers must be a valid VkPipelineRobustnessBufferBehaviorEXT value

- VUID-VkPipelineRobustnessCreateInfoEXT-uniformBuffers-parameter
  uniformBuffers must be a valid VkPipelineRobustnessBufferBehaviorEXT value

- VUID-VkPipelineRobustnessCreateInfoEXT-vertexInputs-parameter
  vertexInputs must be a valid VkPipelineRobustnessBufferBehaviorEXT value

- VUID-VkPipelineRobustnessCreateInfoEXT-images-parameter
  images must be a valid VkPipelineRobustnessImageBehaviorEXT value

Possible values of the storageBuffers, uniformBuffers, and vertexInputs members of
VkPipelineRobustnessCreateInfoEXT are:

```c
// Provided by VK_EXT_pipeline_robustness
typedef enum VkPipelineRobustnessBufferBehaviorEXT {
    VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_DEVICE_DEFAULT_EXT = 0,
    VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_DISABLED_EXT = 1,
    VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT = 2,
    VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT = 3,
} VkPipelineRobustnessBufferBehaviorEXT;
```

- **VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_DEVICE_DEFAULT_EXT** specifies that this pipeline stage follows the behavior of robustness features that are enabled on the device that created this pipeline

- **VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_DISABLED_EXT** specifies that buffer accesses by this pipeline stage to the relevant resource types must not be out of bounds

- **VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT** specifies that out of bounds accesses by this pipeline stage to the relevant resource types behave as if the robustBufferAccess feature is enabled

- **VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT** specifies that out of bounds accesses by this pipeline stage to the relevant resource types behave as if the robustBufferAccess2 feature is enabled

Possible values of the images member of VkPipelineRobustnessCreateInfoEXT are:


```c
// Provided by VK_EXT_pipeline_robustness
typedef enum VkPipelineRobustnessImageBehaviorEXT {
    VK_PIPELINE_ROBUSTNESS_IMAGE_BEHAVIOR_DEVICE_DEFAULT_EXT = 0,
    VK_PIPELINE_ROBUSTNESS_IMAGE_BEHAVIOR_DISABLED_EXT = 1,
    VK_PIPELINE_ROBUSTNESS_IMAGE_BEHAVIOR_ROBUST_IMAGE_ACCESS_EXT = 2,
    VK_PIPELINE_ROBUSTNESS_IMAGE_BEHAVIOR_ROBUST_IMAGE_ACCESS_2_EXT = 3,
} VkPipelineRobustnessImageBehaviorEXT;
```

- **VK_PIPELINE_ROBUSTNESS_IMAGE_BEHAVIOR_DEVICE_DEFAULT_EXT** specifies that this pipeline stage follows the behavior of robustness features that are enabled on the device that created this pipeline.
- **VK_PIPELINE_ROBUSTNESS_IMAGE_BEHAVIOR_DISABLED_EXT** specifies that image accesses by this pipeline stage to the relevant resource types **must** not be out of bounds.
- **VK_PIPELINE_ROBUSTNESS_IMAGE_BEHAVIOR_ROBUST_IMAGE_ACCESS_EXT** specifies that out of bounds accesses by this pipeline stage to images behave as if the `robustImageAccess` feature is enabled.
- **VK_PIPELINE_ROBUSTNESS_IMAGE_BEHAVIOR_ROBUST_IMAGE_ACCESS_2_EXT** specifies that out of bounds accesses by this pipeline stage to images behave as if the `robustImageAccess2` feature is enabled.

An identifier can be provided instead of shader code in an attempt to compile pipelines without providing complete SPIR-V to the implementation.

The `VkPipelineShaderStageModuleIdentifierCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_shader_module_identifier
typedef struct VkPipelineShaderStageModuleIdentifierCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    uint32_t identifierSize;
    const uint8_t* pIdentifier;
} VkPipelineShaderStageModuleIdentifierCreateInfoEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **identifierSize** is the size, in bytes, of the buffer pointed to by `pIdentifier`.
- **pIdentifier** is a pointer to a buffer of opaque data specifying an identifier.

Any identifier can be used. If the pipeline being created with identifier requires compilation to complete the pipeline creation call, pipeline compilation **must** fail as defined by `VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT`.

`pIdentifier` and `identifierSize` can be obtained from an `VkShaderModuleIdentifierEXT` queried earlier.
Valid Usage

- VUID-VkPipelineShaderStageModuleIdentifierCreateInfoEXT-pNext-06850
  If this structure is included in a pNext chain and identifierSize is not equal to 0, the shaderModuleIdentifier feature must be enabled.

- VUID-VkPipelineShaderStageModuleIdentifierCreateInfoEXT-pNext-06851
  If this struct is included in a pNext chain of VkPipelineShaderStageCreateInfo and identifierSize is not equal to 0, the pipeline must be created with the VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT flag set.

- VUID-VkPipelineShaderStageModuleIdentifierCreateInfoEXT-identifierSize-06852
  identifierSize must be less-or-equal to VK_MAX_SHADER_MODULE_IDENTIFIER_SIZE_EXT.

Valid Usage (Implicit)

- VUID-VkPipelineShaderStageModuleIdentifierCreateInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_MODULE_IDENTIFIER_CREATE_INFO_EXT.

- VUID-VkPipelineShaderStageModuleIdentifierCreateInfoEXT-pIdentifier-parameter
  If identifierSize is not 0, pIdentifier must be a valid pointer to an array of identifierSize uint8_t values.

If a compute pipeline is going to be used in Device-Generated Commands by specifying its pipeline token with VkBindPipelineIndirectCommandCommandNV, then that pipeline's associated metadata must be saved at a specified buffer device address for later use in indirect command generation. The buffer device address must be specified at the time of compute pipeline creation with VkComputePipelineIndirectBufferInfoNV structure in the pNext chain of VkComputePipelineCreateInfo.

The VkComputePipelineIndirectBufferInfoNV structure is defined as:

```c
// Provided by VK_NV_device_generated_commands_compute
typedef struct VkComputePipelineIndirectBufferInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkDeviceAddress deviceAddress;
    VkDeviceSize size;
    VkDeviceAddress pipelineDeviceAddressCaptureReplay;
} VkComputePipelineIndirectBufferInfoNV;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- deviceAddress is the address where the pipeline’s metadata will be stored.
- size is the size of pipeline’s metadata that was queried using...
vkGetPipelineIndirectMemoryRequirementsNV.

- **pipelineDeviceAddressCaptureReplay** is the device address where pipeline’s metadata was originally saved and can now be used to re-populate deviceAddress for replay.

If **pipelineDeviceAddressCaptureReplay** is zero, no specific address is requested. If **pipelineDeviceAddressCaptureReplay** is not zero, then it **must** be an address retrieved from an identically created pipeline on the same implementation. The pipeline metadata **must** also be placed on an identically created buffer and at the same offset using the **vkCmdUpdatePipelineIndirectBufferNV** command.

### Valid Usage

- **VUID-VkComputePipelineIndirectBufferInfoNV-deviceGeneratedComputePipelines-09009**
  The **VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV**::deviceGeneratedComputePipelines feature **must** be enabled

- **VUID-VkComputePipelineIndirectBufferInfoNV-flags-09010**
  The pipeline creation flags in **VkComputePipelineCreateInfo**::flags **must** include **VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV**

- **VUID-VkComputePipelineIndirectBufferInfoNV-deviceAddress-09011**
  deviceAddress **must** be aligned to the **VkMemoryRequirements2**::alignment, as returned by **vkGetPipelineIndirectMemoryRequirementsNV**

- **VUID-VkComputePipelineIndirectBufferInfoNV-deviceAddress-09012**
  deviceAddress **must** have been allocated from a buffer that was created with usage **VK_BUFFER_USAGE_TRANSFER_DST_BIT** and **VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT**

- **VUID-VkComputePipelineIndirectBufferInfoNV-size-09013**
  size **must** be greater than or equal to the **VkMemoryRequirements2**::size, as returned by **vkGetPipelineIndirectMemoryRequirementsNV**

- **VUID-VkComputePipelineIndirectBufferInfoNV-pipelineDeviceAddressCaptureReplay-09014**
  If **pipelineDeviceAddressCaptureReplay** is non-zero then the **VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV**::deviceGeneratedComputeCaptureReplay feature **must** be enabled

- **VUID-VkComputePipelineIndirectBufferInfoNV-pipelineDeviceAddressCaptureReplay-09015**
  If **pipelineDeviceAddressCaptureReplay** is non-zero then that address **must** have been allocated with flag **VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT** set

- **VUID-VkComputePipelineIndirectBufferInfoNV-pipelineDeviceAddressCaptureReplay-09016**
  If **pipelineDeviceAddressCaptureReplay** is non-zero, the pipeline **must** have been recreated for replay

- **VUID-VkComputePipelineIndirectBufferInfoNV-pipelineDeviceAddressCaptureReplay-09017**
  **pipelineDeviceAddressCaptureReplay** **must** satisfy the alignment and size requirements similar to deviceAddress
Valid Usage (Implicit)

- VUID-VkComputePipelineIndirectBufferInfoNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_COMPUTE_PIPELINE_INDIRECT_BUFFER_INFO_NV

- VUID-VkComputePipelineIndirectBufferInfoNV-pNext-pNext
  pNext must be NULL

To save a compute pipeline's metadata at a device address call:

```c
void vkCmdUpdatePipelineIndirectBufferNV(
    VkCommandBuffer commandBuffer,
    VkPipelineBindPoint pipelineBindPoint,
    VkPipeline pipeline);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `pipelineBindPoint` is a `VkPipelineBindPoint` value specifying the type of pipeline whose metadata will be saved.
- `pipeline` is the pipeline whose metadata will be saved.

`vkCmdUpdatePipelineIndirectBufferNV` is only allowed outside of a render pass. This command is treated as a “transfer” operation for the purposes of synchronization barriers. The writes to the address must be synchronized using stages `VK_PIPELINE_STAGE_2_COPY_BIT` and `VK_PIPELINE_STAGE_COMMAND_PREPROCESS_BIT_NV` and with access masks `VK_ACCESS_MEMORY_WRITE_BIT` and `VK_ACCESS_COMMAND_PREPROCESS_READ_BIT_NV` respectively before using the results in preprocessing.

Valid Usage

- VUID-vkCmdUpdatePipelineIndirectBufferNV-pipelineBindPoint-09018
  pipelineBindPoint must be VK_PIPELINE_BIND_POINT_COMPUTE

- VUID-vkCmdUpdatePipelineIndirectBufferNV-pipeline-09019
  pipeline must have been created with VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV flag set

- VUID-vkCmdUpdatePipelineIndirectBufferNV-pipeline-09020
  pipeline must have been created with VkComputePipelineIndirectBufferInfoNV structure specifying a valid address where its metadata will be saved

- VUID-vkCmdUpdatePipelineIndirectBufferNV-deviceGeneratedComputePipelines-09021
  The `VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV`::deviceGeneratedComputePipelines feature must be enabled
Valid Usage (Implicit)

- VUID-vkCmdUpdatePipelineIndirectBufferNV-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdUpdatePipelineIndirectBufferNV-pipelineBindPoint-parameter
  pipelineBindPoint must be a valid VkPipelineBindPoint value

- VUID-vkCmdUpdatePipelineIndirectBufferNV-pipeline-parameter
  pipeline must be a valid VkPipeline handle

- VUID-vkCmdUpdatePipelineIndirectBufferNV-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdUpdatePipelineIndirectBufferNV-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support transfer, graphics, or compute operations

- VUID-vkCmdUpdatePipelineIndirectBufferNV-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdUpdatePipelineIndirectBufferNV-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdUpdatePipelineIndirectBufferNV-commonparent
  Both of commandBuffer, and pipeline must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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10.2. Graphics Pipelines

Graphics pipelines consist of multiple shader stages, multiple fixed-function pipeline stages, and a pipeline layout.
To create graphics pipelines, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkCreateGraphicsPipelines(
    VkDevice device,
    VkPipelineCache pipelineCache,
    uint32_t createInfoCount,
    const VkGraphicsPipelineCreateInfo* pCreateInfos,
    const VkAllocationCallbacks* pAllocator,
    VkPipeline* pPipelines);
```

- `device` is the logical device that creates the graphics pipelines.
- `pipelineCache` is either `VK_NULL_HANDLE`, indicating that pipeline caching is disabled; or the handle of a valid pipeline cache object, in which case use of that cache is enabled for the duration of the command.
- `createInfoCount` is the length of the `pCreateInfos` and `pPipelines` arrays.
- `pCreateInfos` is a pointer to an array of `VkGraphicsPipelineCreateInfo` structures.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pPipelines` is a pointer to an array of `VkPipeline` handles in which the resulting graphics pipeline objects are returned.

The `VkGraphicsPipelineCreateInfo` structure includes an array of `VkPipelineShaderStageCreateInfo` structures for each of the desired active shader stages, as well as creation information for all relevant fixed-function stages, and a pipeline layout.

### Valid Usage

- **VUID-vkCreateGraphicsPipelines-flags-00720**
  If the `flags` member of any element of `pCreateInfos` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, and the `basePipelineIndex` member of that same element is not `-1`, `basePipelineIndex` must be less than the index into `pCreateInfos` that corresponds to that element.

- **VUID-vkCreateGraphicsPipelines-flags-00721**
  If the `flags` member of any element of `pCreateInfos` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, the base pipeline must have been created with the `VK_PIPELINE_CREATE_ALLOW_DERIVATIVES_BIT` flag set.

- **VUID-vkCreateGraphicsPipelines-pipelineCache-02876**
  If `pipelineCache` was created with `VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT`, host access to `pipelineCache` must be externally synchronized.

### Note

An implicit cache may be provided by the implementation or a layer. For this reason, it is still valid to set
VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT on flags for any element of pCreateInfos while passing VK_NULL_HANDLE for pipelineCache.

Valid Usage (Implicit)

- VUID-vkCreateGraphicsPipelines-device-parameter
device must be a valid VkDevice handle

- VUID-vkCreateGraphicsPipelines-pipelineCache-parameter
If pipelineCache is not VK_NULL_HANDLE, pipelineCache must be a valid VkPipelineCache handle

- VUID-vkCreateGraphicsPipelines-pCreateInfos-parameter
pCreateInfos must be a valid pointer to an array of createInfoCount valid VkGraphicsPipelineCreateInfo structures

- VUID-vkCreateGraphicsPipelines-pAllocator-parameter
If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkCreateGraphicsPipelines-pPipelines-parameter
pPipelines must be a valid pointer to an array of createInfoCount VkPipeline handles

- VUID-vkCreateGraphicsPipelines-createInfoCount-arraylength
createInfoCount must be greater than 0

- VUID-vkCreateGraphicsPipelines-pipelineCache-parent
If pipelineCache is a valid handle, it must have been created, allocated, or retrieved from device

Return Codes

Success

- VK_SUCCESS
- VK_PIPELINE_COMPILE_REQUIRED_EXT

Failure

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_INVALID_SHADER_NV

The VkGraphicsPipelineCreateInfo structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkGraphicsPipelineCreateInfo {
    VkStructureType       sType;
    const void*           pNext;
    VkPipelineCreateFlags flags;
} VkGraphicsPipelineCreateInfo;
```
uint32_t stageCount;
const VkPipelineShaderStageCreateInfo* pStages;
const VkPipelineVertexInputStateCreateInfo* pVertexInputState;
const VkPipelineInputAssemblyStateCreateInfo* pInputAssemblyState;
const VkPipelineTessellationStateCreateInfo* pTessellationState;
const VkPipelineViewportStateCreateInfo* pViewportState;
const VkPipelineRasterizationStateCreateInfo* pRasterizationState;
const VkPipelineMultisampleStateCreateInfo* pMultisampleState;
const VkPipelineDepthStencilStateCreateInfo* pDepthStencilState;
const VkPipelineColorBlendStateCreateInfo* pColorBlendState;
const VkPipelineDynamicStateCreateInfo* pDynamicState;
VkPipelineLayout layout;
VkRenderPass renderPass;
uint32_t subpass;
VkPipeline basePipelineHandle;
int32_t basePipelineIndex;
} VkGraphicsPipelineCreateInfo;

• **sType** is a `VkStructureType` value identifying this structure.
• **pNext** is `NULL` or a pointer to a structure extending this structure.
• **flags** is a bitmask of `VkPipelineCreateFlagBits` specifying how the pipeline will be generated.
• **stageCount** is the number of entries in the **pStages** array.
• **pStages** is a pointer to an array of `stageCount` `VkPipelineShaderStageCreateInfo` structures describing the set of the shader stages to be included in the graphics pipeline.
• **pVertexInputState** is a pointer to a `VkPipelineVertexInputStateCreateInfo` structure. It is ignored if the pipeline includes a mesh shader stage. It **can** be `NULL` if the pipeline is created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state set.
• **pInputAssemblyState** is a pointer to a `VkPipelineInputAssemblyStateCreateInfo` structure which determines input assembly behavior for vertex shading, as described in Drawing Commands. If the `VK_EXT_extended_dynamic_state3` extension is enabled, it **can** be `NULL` if the pipeline is created with both `VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE`, and `VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY` dynamic states set and `dynamicPrimitiveTopologyUnrestricted` is `VK_TRUE`. It is ignored if the pipeline includes a mesh shader stage.
• **pTessellationState** is a pointer to a `VkPipelineTessellationStateCreateInfo` structure defining tessellation state used by tessellation shaders. It **can** be `NULL` if the pipeline is created with the `VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT` dynamic state set.
• **pViewportState** is a pointer to a `VkPipelineViewportStateCreateInfo` structure defining viewport state used when rasterization is enabled. If the `VK_EXT_extended_dynamic_state3` extension is enabled, it **can** be `NULL` if the pipeline is created with both `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT`, and `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic states set.
• **pRasterizationState** is a pointer to a `VkPipelineRasterizationStateCreateInfo` structure defining rasterization state. If the `VK_EXT_extended_dynamic_state3` extension is enabled, it **can** be `NULL` if the pipeline is created with all of `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT`, `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE`, and `VK_DYNAMIC_STATE_POLYGON_MODE_EXT`,...
VK_DYNAMIC_STATE_CULL_MODE, VK_DYNAMIC_STATE_FRONT_FACE, VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE, VK_DYNAMIC_STATE_DEPTH_BIAS, and VK_DYNAMIC_STATE_LINE_WIDTH dynamic states set.

- **pMultisampleState** is a pointer to a VkPipelineMultisampleStateCreateInfo structure defining multisample state used when rasterization is enabled. If the VK_EXT_extended_dynamic_state3 extension is enabled, it can be NULL if the pipeline is created with all of VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT, VK_DYNAMIC_STATE_SAMPLE_MASK_EXT, and VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic states set, and either alphaToOne is disabled on the device or VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT is set, in which case VkPipelineMultisampleStateCreateInfo::sampleShadingEnable is assumed to be VK_FALSE.

- **pDepthStencilState** is a pointer to a VkPipelineDepthStencilStateCreateInfo structure defining depth/stencil state used when rasterization is enabled for depth or stencil attachments accessed during rendering. If the VK_EXT_extended_dynamic_state3 extension is enabled, it can be NULL if the pipeline is created with all of VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE, VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE, VK_DYNAMIC_STATE_DEPTH_COMPARE_OP, VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE, VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE, VK_DYNAMIC_STATE_STENCIL_OP, and VK_DYNAMIC_STATE_DEPTH_BOUNDS dynamic states set.

- **pColorBlendState** is a pointer to a VkPipelineColorBlendStateCreateInfo structure defining color blend state used when rasterization is enabled for any color attachments accessed during rendering. If the VK_EXT_extended_dynamic_state3 extension is enabled, it can be NULL if the pipeline is created with all of VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT, VK_DYNAMIC_STATE_LOGIC_OP_EXT, VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT, VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT, VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT, and VK_DYNAMIC_STATE_BLEND_CONSTANTS dynamic states set.

- **pDynamicState** is a pointer to a VkPipelineDynamicStateCreateInfo structure defining which properties of the pipeline state object are dynamic and can be changed independently of the pipeline state. This can be NULL, which means no state in the pipeline is considered dynamic.

- **layout** is the description of binding locations used by both the pipeline and descriptor sets used with the pipeline.

- **renderPass** is a handle to a render pass object describing the environment in which the pipeline will be used. The pipeline must only be used with a render pass instance compatible with the one provided. See Render Pass Compatibility for more information.

- **subpass** is the index of the subpass in the render pass where this pipeline will be used.

- **basePipelineHandle** is a pipeline to derive from.

- **basePipelineIndex** is an index into the pCreateInfos parameter to use as a pipeline to derive from.

The parameters basePipelineHandle and basePipelineIndex are described in more detail in Pipeline Derivatives.

If any shader stage fails to compile, the compile log will be reported back to the application, and VK_ERROR_INVALID_SHADER_NV will be generated.

### Note

With VK_EXT_extended_dynamic_state3, it is possible that many of the
VkGraphicsPipelineCreateInfo members above can be NULL because all their state is dynamic and therefore ignored. This is optional so the application can still use a valid pointer if it needs to set the pNext or flags fields to specify state for other extensions.

The state required for a graphics pipeline is divided into vertex input state, pre-rasterization shader state, fragment shader state, and fragment output state.

**Vertex Input State**

Vertex input state is defined by:

- VkPipelineVertexInputStateCreateInfo
- VkPipelineInputAssemblyStateCreateInfo

If this pipeline specifies pre-rasterization state either directly or by including it as a pipeline library and its pStages includes a vertex shader, this state must be specified to create a complete graphics pipeline.

If a pipeline includes VK_GRAPHICS_PIPELINE_LIBRARY_VERTEX_INPUT_INTERFACE_BIT_EXT in VkGraphicsPipelineLibraryCreateInfoEXT::flags either explicitly or as a default, and either the conditions requiring this state for a complete graphics pipeline are met or this pipeline does not specify pre-rasterization state in any way, that pipeline must specify this state directly.

**Pre-Rasterization Shader State**

Pre-rasterization shader state is defined by:

- VkPipelineShaderStageCreateInfo entries for:
  - Vertex shaders
  - Tessellation control shaders
  - Tessellation evaluation shaders
  - Geometry shaders
  - Task shaders
  - Mesh shaders
- Within the VkPipelineLayout, all descriptor sets with pre-rasterization shader bindings if VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT was specified.
  - If VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT was not specified, the full pipeline layout must be specified.
- VkPipelineViewportStateCreateInfo
- VkPipelineRasterizationStateCreateInfo
- VkPipelineTessellationStateCreateInfo
- VkRenderPass and subpass parameter
- The viewMask parameter of VkPipelineRenderingCreateInfo (formats are ignored)
- VkPipelineDiscardRectangleStateCreateInfoEXT
This state **must** be specified to create a complete graphics pipeline.

If either the `pNext` chain includes a `VkGraphicsPipelineLibraryCreateInfoEXT` structure with `VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT` included in `flags`, or it is not specified and would default to include that value, this state **must** be specified in the pipeline.

**Fragment Shader State**

Fragment shader state is defined by:

- A `VkPipelineShaderStageCreateInfo` entry for the fragment shader
- Within the `VkPipelineLayout`, all descriptor sets with fragment shader bindings if `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT` was specified.
  - If `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT` was not specified, the full pipeline layout must be specified.
- `VkPipelineMultisampleStateCreateInfo` if sample shading is enabled or `renderpass` is not `VK_NULL_HANDLE`
- `VkPipelineDepthStencilStateCreateInfo`
- `VkRenderPass` and `subpass` parameter
- The `viewMask` parameter of `VkPipelineRenderingCreateInfo` (formats are ignored)
- `VkPipelineFragmentShadingRateStateCreateInfoKHR`
- `VkPipelineFragmentShadingRateEnumStateCreateInfoNV`
- `VkPipelineRepresentativeFragmentTestStateCreateInfoNV`
- Inclusion/omission of the `VK_PIPELINE_RASTERIZATION_STATE_CREATE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR` flag
- Inclusion/omission of the `VK_PIPELINE_RASTERIZATION_STATE_CREATE_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT` flag

If a pipeline specifies pre-rasterization state either directly or by including it as a pipeline library and `rasterizerDiscardEnable` is set to `VK_FALSE` or `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE` is used, this state **must** be specified to create a complete graphics pipeline.

If a pipeline includes `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT` in `VkGraphicsPipelineLibraryCreateInfoEXT::flags` either explicitly or as a default, and either the conditions requiring this state for a complete graphics pipeline are met or this pipeline does not specify pre-rasterization state in any way, that pipeline **must** specify this state directly.

**Fragment Output State**

Fragment output state is defined by:

- `VkPipelineColorBlendStateCreateInfo`
- `VkRenderPass` and `subpass` parameter
- `VkPipelineMultisampleStateCreateInfo`
If a pipeline specifies **pre-rasterization state** either directly or by including it as a pipeline library and `rasterizerDiscardEnable` is set to `VK_FALSE` or `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE` is used, this state **must** be specified to create a complete graphics pipeline.

If a pipeline includes `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT` in `VkGraphicsPipelineLibraryCreateInfoEXT::flags` either explicitly or as a default, and either the conditions requiring this state for a complete graphics pipeline are met or this pipeline does not specify **pre-rasterization state** in any way, that pipeline **must** specify this state directly.

**Dynamic State**

Dynamic state values set via `pDynamicState` **must** be ignored if the state they correspond to is not otherwise statically set by one of the state subsets used to create the pipeline. Additionally, setting dynamic state values **must** not modify whether state in a linked library is static or dynamic; this is set and unchangeable when the library is created. For example, if a pipeline only included **pre-rasterization shader state**, then any dynamic state value corresponding to depth or stencil testing has no effect. Any linked library that has dynamic state enabled that same dynamic state **must** also be enabled in all the other linked libraries to which that dynamic state applies.

**Complete Graphics Pipelines**

A complete graphics pipeline always includes **pre-rasterization shader state**, with other subsets included depending on that state as specified in the above sections.

**Graphics Pipeline Library Layouts**

If different subsets are linked together with pipeline layouts created with `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`, the final effective pipeline layout is effectively the union of the linked pipeline layouts. When binding descriptor sets for this pipeline, the pipeline layout used **must** be compatible with this union. This pipeline layout **can** be overridden when linking with `VK_PIPELINE_CREATE_LINK_TIME_OPTIMIZATION_BIT_EXT` by providing a `VkPipelineLayout` that is **compatible** with this union other than `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`, or when linking without `VK_PIPELINE_CREATE_LINK_TIME_OPTIMIZATION_BIT_EXT` by providing a `VkPipelineLayout` that is fully **compatible** with this union.

If a `VkPipelineCreateFlags2CreateInfoKHR` structure is present in the `pNext` chain, `VkPipelineCreateFlags2CreateInfoKHR::flags` from that structure is used instead of `flags` from this structure.

**Valid Usage**

- **VUID-VkGraphicsPipelineCreateInfo-flags-07984**
  If `flags` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, and `basePipelineIndex` is -1, `basePipelineHandle` **must** be a valid graphics `VkPipeline` handle
If `flags` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, `basePipelineHandle` is `VK_NULL_HANDLE`, `basePipelineIndex` must be a valid index into the calling command’s `pCreateInfos` parameter.

If `flags` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, `basePipelineIndex` must be `-1` or `basePipelineHandle` must be `VK_NULL_HANDLE`.

If a push constant block is declared in a shader, a push constant range in `layout` must match both the shader stage and range.

If a `resource variables` is declared in a shader, a descriptor slot in `layout` must match the shader stage.

If a `resource variables` is declared in a shader as an array, a descriptor slot in `layout` must match the descriptor count.

If the pipeline requires pre-rasterization shader state the geometric shader stages provided in `pStages` must be either from the mesh shading pipeline (`stage` is `VK_SHADER_STAGE_TASK_BIT_EXT` or `VK_SHADER_STAGE_MESH_BIT_EXT`) or from the primitive shading pipeline (`stage` is `VK_SHADER_STAGE_VERTEX_BIT`, `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`, `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`, or `VK_SHADER_STAGE_GEOMETRY_BIT`).

If the pipeline requires pre-rasterization shader state the `stage` member of one element of `pStages` must be either `VK_SHADER_STAGE_VERTEX_BIT` or `VK_SHADER_STAGE_MESH_BIT_EXT`.

The shader stages for `VK_SHADER_STAGE_TASK_BIT_EXT` or `VK_SHADER_STAGE_MESH_BIT_EXT` must use either the TaskNV and MeshNV Execution Model or the TaskEXT and MeshEXT Execution Model, but must not use both.

If the pipeline requires pre-rasterization shader state and `pStages` includes a tessellation control shader stage, it must include a tessellation evaluation shader stage.

If the pipeline requires pre-rasterization shader state and `pStages` includes a tessellation evaluation shader stage, it must include a tessellation control shader stage.

If the pipeline requires pre-rasterization shader state and `pStages` includes a tessellation control shader stage, and the `VK_EXT_extended_dynamic_state3` extension is not enabled or
the `VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT` dynamic state is not set, `pTessellationState` must be a valid pointer to a valid `VkPipelineTessellationStateCreateInfo` structure

- VUID-VkGraphicsPipelineCreateInfo-pTessellationState-09023
  If `pTessellationState` is not `NULL` it must be a pointer to a valid `VkPipelineTessellationStateCreateInfo` structure

- VUID-VkGraphicsPipelineCreateInfo-pStages-00732
  If the pipeline requires `pre-rasterization shader state` and `pStages` includes tessellation shader stages, the shader code of at least one stage must contain an `OpExecutionMode` instruction specifying the type of subdivision in the pipeline

- VUID-VkGraphicsPipelineCreateInfo-pStages-00733
  If the pipeline requires `pre-rasterization shader state` and `pStages` includes tessellation shader stages, and the shader code of both stages contain an `OpExecutionMode` instruction specifying the type of subdivision in the pipeline, they must both specify the same subdivision mode

- VUID-VkGraphicsPipelineCreateInfo-pStages-00734
  If the pipeline requires `pre-rasterization shader state` and `pStages` includes tessellation shader stages, the shader code of at least one stage must contain an `OpExecutionMode` instruction specifying the output patch size in the pipeline

- VUID-VkGraphicsPipelineCreateInfo-pStages-00735
  If the pipeline requires `pre-rasterization shader state` and `pStages` includes tessellation shader stages, and the shader code of both contain an `OpExecutionMode` instruction specifying the out patch size in the pipeline, they must both specify the same patch size

- VUID-VkGraphicsPipelineCreateInfo-pStages-08888
  If the pipeline is being created with `pre-rasterization shader state` and `vertex input state` and `pStages` includes tessellation shader stages, and either `VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY` dynamic state is not enabled or `dynamicPrimitiveTopologyUnrestricted` is `VK_FALSE`, the topology member of `pInputAssembly` must be `VK_PRIMITIVE_TOPOLOGY_PATCH_LIST`

- VUID-VkGraphicsPipelineCreateInfo-topology-08773
  If the pipeline is being created with `pre-rasterization shader state` and `vertex input state` and the `topology` member of `pInputAssembly` is `VK_PRIMITIVE_TOPOLOGY_POINT_LIST`, and either `VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY` dynamic state is not enabled or `dynamicPrimitiveTopologyUnrestricted` is `VK_FALSE`, then `pStages` must include tessellation shader stages

- VUID-VkGraphicsPipelineCreateInfo-TemplateTessellationEvaluation-07723
  If the pipeline is being created with a `TessellationEvaluation Execution Model`, no `Geometry Execution Model`, uses the `PointMode` Execution Mode, and `shaderTessellationAndGeometryPointSize` is enabled, a `PointSize` decorated variable must be written to if `maintenance5` is not enabled

- VUID-VkGraphicsPipelineCreateInfo-topology-08889
  If the pipeline is being created with `pre-rasterization shader state` and `vertex input state` and the `topology` member of `pInputAssembly` is `VK_PRIMITIVE_TOPOLOGY_PATCH_LIST`, and either `VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY` dynamic state is not enabled or `dynamicPrimitiveTopologyUnrestricted` is `VK_FALSE`, then `pStages` must include tessellation shader stages
VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state is not enabled or
dynamicPrimitiveTopologyUnrestricted is VK_FALSE, a PointSize decorated variable must be
written to if maintenance5 is not enabled

- VUID-VkGraphicsPipelineCreateInfo-maintenance5-08775
  If maintenance5 is enabled and a PointSize decorated variable is written to, all execution
  paths must write to a PointSize decorated variable

- VUID-VkGraphicsPipelineCreateInfo-TessellationEvaluation-07724
  If the pipeline is being created with a TessellationEvaluation Execution Model, no Geometry
  Execution Model, uses the PointMode Execution Mode, and shaderTessellationAndGeometryPointSize is not enabled, a PointSize decorated variable must not be written to

- VUID-VkGraphicsPipelineCreateInfo-shaderTessellationAndGeometryPointSize-08776
  If the pipeline is being created with a Geometry Execution Model, uses the OutputPoints
  Execution Mode, and shaderTessellationAndGeometryPointSize is enabled, a PointSize decorated variable must be written to for every vertex emitted if maintenance5 is not enabled

- VUID-VkGraphicsPipelineCreateInfo-Geometry-07726
  If the pipeline is being created with a Geometry Execution Model, uses the OutputPoints
  Execution Mode, and shaderTessellationAndGeometryPointSize is not enabled, a PointSize decorated variable must not be written to

- VUID-VkGraphicsPipelineCreateInfo-pStages-00738
  If the pipeline requires pre-rasterization shader state and pStages includes a geometry
  shader stage, and does not include any tessellation shader stages, its shader code must
  contain an OpExecutionMode instruction specifying an input primitive type that is
  compatible with the primitive topology specified in pInputAssembly

- VUID-VkGraphicsPipelineCreateInfo-pStages-00739
  If the pipeline requires pre-rasterization shader state and pStages includes a geometry
  shader stage, and also includes tessellation shader stages, its shader code must contain an
  OpExecutionMode instruction specifying an input primitive type that is compatible with the
  primitive topology that is output by the tessellation stages

- VUID-VkGraphicsPipelineCreateInfo-pStages-00740
  If the pipeline requires pre-rasterization shader state and fragment shader state,
  includes both a fragment shader and a geometry shader, and the fragment shader code
  reads from an input variable that is decorated with PrimitiveId, then the geometry shader
  code must write to a matching output variable, decorated with PrimitiveId, in all
  execution paths

- VUID-VkGraphicsPipelineCreateInfo-PrimitiveId-06264
  If the pipeline requires pre-rasterization shader state, it includes a mesh shader and the
  fragment shader code reads from an input variable that is decorated with PrimitiveId, then the mesh shader code must write to a matching output variable, decorated with PrimitiveId, in all execution paths

- VUID-VkGraphicsPipelineCreateInfo-renderPass-06038
  If renderPass is not VK_NULL_HANDLE and the pipeline is being created with fragment
  shader state the fragment shader must not read from any input attachment that is
defined as `VK_ATTACHMENT_UNUSED` in `subpass`

- VUID-VkGraphicsPipelineCreateInfo-pStages-00742  
  If the pipeline requires pre-rasterization shader state and multiple pre-rasterization shader stages are included in `pStages`, the shader code for the entry points identified by those `pStages` and the rest of the state identified by this structure must adhere to the pipeline linking rules described in the Shader Interfaces chapter

- VUID-VkGraphicsPipelineCreateInfo-None-04889  
  If the pipeline requires pre-rasterization shader state and fragment shader state, the fragment shader and last pre-rasterization shader stage and any relevant state must adhere to the pipeline linking rules described in the Shader Interfaces chapter

- VUID-VkGraphicsPipelineCreateInfo-renderPass-06041  
  If `renderPass` is not `VK_NULL_HANDLE`, and the pipeline is being created with fragment output interface state, then for each color attachment in the subpass, if the potential format features of the format of the corresponding attachment description do not contain `VK_FORMATFeatureCOLOR_ATTACHMENT_BLEND_BIT`, then the `blendEnable` member of the corresponding element of the `pAttachments` member of `pColorBlendState` must be `VK_FALSE`

- VUID-VkGraphicsPipelineCreateInfo-renderPass-07609  
  If `renderPass` is not `VK_NULL_HANDLE`, and the pipeline is being created with fragment output interface state, and the `pColorBlendState` pointer is not NULL, and the subpass uses color attachments, the `attachmentCount` member of `pColorBlendState` must be equal to the `colorAttachmentCount` used to create `subpass`

- VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-04130  
  If the pipeline requires pre-rasterization shader state, and `pViewportState->pViewports` is not dynamic, then `pViewportState->pViewports` must be a valid pointer to an array of `pViewportState->viewportCount` valid `VkViewport` structures

- VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-04131  
  If the pipeline requires pre-rasterization shader state, and `pViewportState->pScissors` is not dynamic, then `pViewportState->pScissors` must be a valid pointer to an array of `pViewportState->scissorCount` `VkRect2D` structures

- VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-00749  
  If the pipeline requires pre-rasterization shader state, and the `wideLines` feature is not enabled, and no element of the `pDynamicStates` member of `pDynamicState` is `VK_DYNAMIC_STATE_LINE_WIDTH`, the `lineWidth` member of `pRasterizationState` must be 1.0

- VUID-VkGraphicsPipelineCreateInfo-rasterizerDiscardEnable-09024  
  If the pipeline requires pre-rasterization shader state, and the `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE` dynamic state is enabled or the `rasterizerDiscardEnable` member of `pRasterizationState` is `VK_FALSE`, and either the `VK_EXT_extended_dynamic_state3` extension is not enabled, or either the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` or `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic states are not set, `pViewportState` must be a valid pointer to a valid `VkPipelineViewportStateCreateInfo` structure

- VUID-VkGraphicsPipelineCreateInfo-pViewportState-09025  
  If `pViewportState` is not NULL it must be a valid pointer to a valid `VkPipelineViewportStateCreateInfo` structure
If the pipeline requires pre-rasterization shader state, and the graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE} dynamic state enabled, \texttt{pViewportState} must be a valid pointer to a valid \texttt{VkPipelineViewportStateCreateInfo} structure.

If the pipeline requires fragment output interface state, and the \texttt{VK_EXT_extended_dynamic_state3} extension is not enabled or any of the \texttt{VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT}, \texttt{VK_DYNAMIC_STATE_SAMPLE_MASK_EXT}, or \texttt{VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT} dynamic states is not set, or \texttt{alphaToOne} is enabled on the device and \texttt{VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT} is not set, \texttt{pMultisampleState} must be a valid pointer to a valid \texttt{VkPipelineMultisampleStateCreateInfo} structure.

If \texttt{pMultisampleState} is not \texttt{NULL} it must be a valid pointer to a valid \texttt{VkPipelineMultisampleStateCreateInfo} structure.

If the pipeline is being created with fragment shader state, the \texttt{VkPipelineMultisampleStateCreateInfo::alphaToCoverageEnable} is not ignored and is \texttt{VK_TRUE}, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0.

If \texttt{renderPass} is not \texttt{VK_NULL_HANDLE}, the pipeline is being created with fragment shader state, and \texttt{subpass} uses a depth/stencil attachment, and the \texttt{VK_EXT_extended_dynamic_state3} extension is not enabled or any of the \texttt{VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE}, \texttt{VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE}, \texttt{VK_DYNAMIC_STATE_DEPTH_COMPARE_OP}, \texttt{VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE}, \texttt{VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE}, \texttt{VK_DYNAMIC_STATE_STENCIL_OP}, or \texttt{VK_DYNAMIC_STATE_DEPTH_BOUNDS} dynamic states are not set, \texttt{pDepthStencilState} must be a valid pointer to a valid \texttt{VkPipelineDepthStencilStateCreateInfo} structure.

If \texttt{pDepthStencilState} is not \texttt{NULL} it must be a valid pointer to a valid \texttt{VkPipelineDepthStencilStateCreateInfo} structure.

If \texttt{renderPass} is not \texttt{VK_NULL_HANDLE}, the pipeline is being created with fragment output interface state, and \texttt{subpass} uses color attachments, and \texttt{VK_EXT_extended_dynamic_state3} extension is not enabled, or any of the \texttt{VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT}, \texttt{VK_DYNAMIC_STATE_LOGIC_OP_EXT}, \texttt{VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT}, \texttt{VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT}, \texttt{VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT}, or \texttt{VK_DYNAMIC_STATE_BLEND_CONSTANTS} dynamic states are not set, \texttt{pColorBlendState} must be a valid pointer to a valid \texttt{VkPipelineColorBlendStateCreateInfo} structure.

If the pipeline requires pre-rasterization shader state, the \texttt{depthBiasClamp} feature is not enabled, no element of the \texttt{pDynamicStates} member of \texttt{pDynamicState} is \texttt{VK_DYNAMIC_STATE_DEPTH_BIAS}, and the \texttt{depthBiasEnable} member of \texttt{pRasterizationState} is
VK_TRUE, the depthBiasClamp member of pRasterizationState must be 0.0.

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-02510**
  If the pipeline requires fragment shader state, and the VK_EXT_depth_range_unrestricted extension is not enabled and no element of the pDynamicStates member of pDynamicState is VK_DYNAMIC_STATE_DEPTH_BOUNDS, and the depthBoundsTestEnable member of pDepthStencilState is VK_TRUE, the minDepthBounds and maxDepthBounds members of pDepthStencilState must be between 0.0 and 1.0, inclusive.

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-07610**
  If the pipeline requires fragment shader state or fragment output interface state, and rasterizationSamples and sampleLocationsInfo are not dynamic, andVkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable included in the pNext chain of pMultisampleState is VK_TRUE, sampleLocationsInfo.sampleLocationGridSize.width must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples.

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-07611**
  If the pipeline requires fragment shader state or fragment output interface state, and rasterizationSamples and sampleLocationsInfo are not dynamic, and VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable the included in the pNext chain of pMultisampleState is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT is used, sampleLocationsInfo.sampleLocationGridSize.height must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples.

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-07612**
  If the pipeline requires fragment shader state or fragment output interface state, and rasterizationSamples and sampleLocationsInfo are not dynamic, and VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable included in the pNext chain of pMultisampleState is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT is used, sampleLocationsInfo.sampleLocationsPerPixel must equal rasterizationSamples.

- **VUID-VkGraphicsPipelineCreateInfo-sampleLocationsEnable-01524**
  If the pipeline requires fragment shader state, and the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT structure included in the pNext chain of pMultisampleState is VK_TRUE, the fragment shader code must not statically use the extended instruction InterpolateAtSample.

- **VUID-VkGraphicsPipelineCreateInfo-multisampledRenderToSingleSampled-06853**
  If the pipeline requires fragment output interface state, and none of the VK_AMD_mixed_attachment_samples extension, the VK_NV_framebuffer_mixed_samples extension, or the multisampledRenderToSingleSampled feature are enabled, rasterizationSamples is not dynamic, and if subpass uses color and/or depth/stencil attachments, then the rasterizationSamples member of pMultisampleState must be the same as the sample count for those subpass attachments.
If the pipeline requires fragment output interface state, and the VK_AMD_mixed_attachment_samples extension is enabled, rasterizationSamples is not dynamic, and if subpass uses color and/or depth/stencil attachments, then the rasterizationSamples member of pMultisampleState must equal the maximum of the sample counts of those subpass attachments.

If renderPass is not VK_NULL_HANDLE, the VK_EXT_multisampled_render_to_single_sampled extension is enabled, rasterizationSamples is not dynamic, and subpass has a VkMultisampledRenderToSingleSampledInfoEXT structure included in the VkSubpassDescription2::pNext chain with multisampledRenderToSingleSampledEnable equal to VK_TRUE, then the rasterizationSamples member of pMultisampleState must be equal to VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples.

If the pipeline requires fragment output interface state, the VK_NV_framebuffer_mixed_samples extension is enabled, rasterizationSamples is not dynamic, and if subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled, then the rasterizationSamples member of pMultisampleState must be the same as the sample count of the depth/stencil attachment.

If the pipeline requires fragment output interface state, the VK_NV_framebuffer_mixed_samples extension is enabled, rasterizationSamples is not dynamic, and if subpass has any color attachments, then the rasterizationSamples member of pMultisampleState must be greater than or equal to the sample count for those subpass attachments.

If the pipeline requires fragment output interface state, the VK_NV_coverage_reduction_mode extension is enabled, and rasterizationSamples is not dynamic, the coverage reduction mode specified by VkPipelineCoverageReductionStateCreateInfoNV::coverageReductionMode, the rasterizationSamples member of pMultisampleState and the sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV.

If the pipeline requires fragment output interface state, rasterizationSamples is not dynamic, and subpass does not use any color and/or depth/stencil attachments, then the rasterizationSamples member of pMultisampleState must follow the rules for a zero-attachment subpass.

If renderPass is not VK_NULL_HANDLE, subpass must be a valid subpass within renderPass.

If renderPass is not VK_NULL_HANDLE, the pipeline is being created with prerasterization shader state, subpass viewMask is not 0, and multiviewTessellationShader is not enabled, then pStages must not include tessellation shaders.
If `renderPass` is not `VK_NULL_HANDLE`, the pipeline is being created with pre-rasterization shader state, `subpass` viewMask is not 0, and `multiviewGeometryShader` is not enabled, then `pStages` **must** not include a geometry shader.

- VUID-VkGraphicsPipelineCreateInfo-renderPass-06049
  If `renderPass` is not `VK_NULL_HANDLE`, the pipeline is being created with pre-rasterization shader state, and `subpass` viewMask is not 0, all of the shaders in the pipeline **must** not write to the `Layer` built-in output.

- VUID-VkGraphicsPipelineCreateInfo-renderPass-06050
  If `renderPass` is not `VK_NULL_HANDLE` and the pipeline is being created with pre-rasterization shader state, and `subpass` viewMask is not 0, then all of the shaders in the pipeline **must** not include variables decorated with the `Layer` built-in decoration in their interfaces.

- VUID-VkGraphicsPipelineCreateInfo-renderPass-07717
  If `renderPass` is not `VK_NULL_HANDLE` and the pipeline is being created with pre-rasterization shader state, and `subpass` viewMask is not 0, then all of the shaders in the pipeline **must** not include variables decorated with the `ViewMask` built-in decoration in their interfaces.

- VUID-VkGraphicsPipelineCreateInfo-renderPass-07064
  If `renderPass` is not `VK_NULL_HANDLE`, the pipeline is being created with pre-rasterization shader state, `subpass` viewMask is not 0, and `multiviewMeshShader` is not enabled, then `pStages` **must** not include a mesh shader.

- VUID-VkGraphicsPipelineCreateInfo-flags-00764
  `flags` **must** not contain the `VK_PIPELINE_CREATE_DISPATCH_BASE` flag.

- VUID-VkGraphicsPipelineCreateInfo-pStages-01565
  If the pipeline requires fragment shader state and an input attachment was referenced by an `aspectMask` at `renderPass` creation time, the fragment shader **must** only read from the aspects that were specified for that input attachment.

- VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-01688
  The number of resources in `layout` accessible to each shader stage that is used by the pipeline **must** be less than or equal to `VkPhysicalDeviceLimits::maxPerStageResources`.

- VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-01715
  If the pipeline requires pre-rasterization shader state, and no element of the `pDynamicStates` member of `pDynamicState` is `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV`, and the `viewportWScalingEnable` member of a `VkPipelineViewportWScalingStateCreateInfoNV` structure, included in the `pNext` chain of `pViewportState`, is `VK_TRUE`, the `pViewportWScalings` member of the `VkPipelineViewportWScalingStateCreateInfoNV` **must** be a pointer to an array of `VkPipelineViewportWScalingStateCreateInfoNV::_viewportCount` valid `VkViewportWScalingNV` structures.

- VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-04056
  If the pipeline requires pre-rasterization shader state, and no element of the `pDynamicStates` member of `pDynamicState` is `VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV`, and if `pViewportState->pNext` chain includes a `VkPipelineViewportExclusiveScissorStateCreateInfoNV` structure, and if its `exclusiveScissorCount` member is not 0, then its `pExclusiveScissors` member **must** be a
valid pointer to an array of exclusiveScissorCount VkRect2D structures

- VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-07854
  If VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV is included in the pDynamicStates array then the implementation must support at least specVersion 2 of the VK_NV_scissor_exclusive extension

- VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-04057
  If the pipeline requires pre-rasterization shader state, and no element of the pDynamicStates member of pDynamicState is VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV, and if pViewportState->pNext chain includes a VkPipelineViewportShadingRateImageStateCreateInfoNV structure, then its pShadingRatePalettes member must be a valid pointer to an array of viewportCount valid VkShadingRatePaletteNV structures

- VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-07855
  If VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT is included in the pDynamicStates array then the implementation must support at least specVersion 2 of the VK_EXT_discard_rectangles extension

- VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-07856
  If VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT is included in the pDynamicStates array then the implementation must support at least specVersion 2 of the VK_EXT_discard_rectangles extension

- VUID-VkGraphicsPipelineCreateInfo-pStages-02097
  If the pipeline requires vertex input state, and pVertexInputState is not dynamic, then pVertexInputState must be a valid pointer to a valid VkPipelineVertexInputStateCreateInfo structure

- VUID-VkGraphicsPipelineCreateInfo-Input-07904
  If the pipeline is being created with vertex input state and pVertexInputState is not dynamic, and VkVertexInputAttributeDescription::format has a 64-bit component, then the scalar width associated with all Input variables of the corresponding Location in the Vertex Execution Model OpEntryPoint must contain a location in VkVertexInputAttributeDescription::location

- VUID-VkGraphicsPipelineCreateInfo-Input-08733
  If the pipeline requires vertex input state and pVertexInputState is not dynamic, then the numeric type associated with all Input variables of the corresponding Location in the Vertex Execution Model OpEntryPoint must be the same as VkVertexInputAttributeDescription::format

- VUID-VkGraphicsPipelineCreateInfo-pVertexInputState-08929
  If the pipeline is being created with vertex input state and pVertexInputState is not dynamic, and VkVertexInputAttributeDescription::format has a 64-bit component, then the scalar width associated with all Input variables of the corresponding Location in the
**Vertex Execution Model OpEntryPoint must** be 64-bit

- **VUID-VkGraphicsPipelineCreateInfo-pVertexInputState-08930**
  If the pipeline is being created with *vertex input state* and *pVertexInputState* is not dynamic, and the scalar width associated with a *Location* decorated *Input* variable in the *Vertex Execution Model OpEntryPoint* is 64-bit, then the corresponding *VkVertexInputAttributeDescription::format* must have a 64-bit component.

- **VUID-VkGraphicsPipelineCreateInfo-pVertexInputState-09198**
  If the pipeline is being created with *vertex input state* and *pVertexInputState* is not dynamic, and *VkVertexInputAttributeDescription::format* has a 64-bit component, then all *Input* variables at the corresponding *Location* in the *Vertex Execution Model OpEntryPoint* must not use components that are not present in the format.

- **VUID-VkGraphicsPipelineCreateInfo-dynamicPrimitiveTopologyUnrestricted-09031**
  If the pipeline requires *vertex input state*, and the *VK_EXT_extended_dynamic_state3* extension is not enabled, or either *VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE*, or *VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY* dynamic states are not set, or *dynamicPrimitiveTopologyUnrestricted* is *VK_FALSE*, *pInputAssemblyState* must be a valid pointer to a valid *VkPipelineInputAssemblyStateCreateInfo* structure.

- **VUID-VkGraphicsPipelineCreateInfo-pInputAssemblyState-09032**
  If *pInputAssemblyState* is not NULL it must be a valid pointer to a valid *VkPipelineInputAssemblyStateCreateInfo* structure.

- **VUID-VkGraphicsPipelineCreateInfo-pStages-02317**
  If the pipeline requires *pre-rasterization shader state*, the *Xfb execution mode* can be specified by no more than one shader stage in *pStages*.

- **VUID-VkGraphicsPipelineCreateInfo-pStages-02318**
  If the pipeline requires *pre-rasterization shader state*, and any shader stage in *pStages* specifies *Xfb execution mode* it must be the last *pre-rasterization shader stage*.

- **VUID-VkGraphicsPipelineCreateInfo-rasterizationStream-02319**
  If the pipeline requires *pre-rasterization shader state*, and a *VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream* value other than zero is specified, all variables in the output interface of the entry point being compiled decorated with *Position, PointSize, ClipDistance*, or *CullDistance* must be decorated with identical *Stream* values that match the *rasterizationStream*.

- **VUID-VkGraphicsPipelineCreateInfo-rasterizationStream-02320**
  If the pipeline requires *pre-rasterization shader state*, and a *VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream* is zero, or not specified, all variables in the output interface of the entry point being compiled decorated with *Position, PointSize, ClipDistance*, or *CullDistance* must be decorated with a *Stream* value of zero, or must not specify the *Stream* decoration.

- **VUID-VkGraphicsPipelineCreateInfo-geometryStreams-02321**
  If the pipeline requires *pre-rasterization shader state*, and the last *pre-rasterization shader stage* is a geometry shader, and that geometry shader uses the *GeometryStreams* capability, then *VkPhysicalDeviceTransformFeedbackFeaturesEXT::geometryStreams* feature must be enabled.

- **VUID-VkGraphicsPipelineCreateInfo-None-02322**
If the pipeline requires pre-rasterization shader state, and there are any mesh shader stages in the pipeline there must not be any shader stage in the pipeline with a Xfb execution mode

- **VUID-VkGraphicsPipelineCreateInfo-lineRasterizationMode-02766**
  If the pipeline requires pre-rasterization shader state and at least one of fragment output interface state or fragment shader state, and pMultisampleState is not NULL, the lineRasterizationMode member of a VkPipelineRasterizationLineStateCreateInfoEXT structure included in the pNext chain of pRasterizationState is VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT or VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT, then the alphaToCoverageEnable, alphaToOneEnable, and sampleShadingEnable members of pMultisampleState must all be VK_FALSE

- **VUID-VkGraphicsPipelineCreateInfo-stippledLineEnable-02767**
  If the pipeline requires pre-rasterization shader state, the stippledLineEnable member of VkPipelineRasterizationLineStateCreateInfoEXT is VK_TRUE, and no element of the pDynamicStates member of pDynamicState is VK_DYNAMIC_STATE_LINE_STIPPLE_EXT, then the lineStippleFactor member of VkPipelineRasterizationLineStateCreateInfoEXT must be in the range [1, 256]

- **VUID-VkGraphicsPipelineCreateInfo-flags-03372**
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR

- **VUID-VkGraphicsPipelineCreateInfo-flags-03373**
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR

- **VUID-VkGraphicsPipelineCreateInfo-flags-03374**
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR

- **VUID-VkGraphicsPipelineCreateInfo-flags-03375**
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR

- **VUID-VkGraphicsPipelineCreateInfo-flags-03376**
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR

- **VUID-VkGraphicsPipelineCreateInfo-flags-03377**
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR

- **VUID-VkGraphicsPipelineCreateInfo-flags-03577**
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR

- **VUID-VkGraphicsPipelineCreateInfo-flags-04947**
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_ALLOW_MOTION_BIT_NV

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-03378**
  If the extendedDynamicState feature is not enabled, and the value of VkApplicationInfo::apiVersion used to create the VkInstance is less than Version 1.3 there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_CULL_MODE, VK_DYNAMIC_STATE_FRONT_FACE, VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY, VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT, or VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT,
VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE, VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE, VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE, VK_DYNAMIC_STATE_DEPTH_COMPARE_OP, VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE, VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE, or VK_DYNAMIC_STATE_STENCIL_OP

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-03379**
  If the pipeline requires pre-rasterization shader state, and VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT is included in the pDynamicStates array then viewportCount must be zero

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-03380**
  If the pipeline requires pre-rasterization shader state, and VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT is included in the pDynamicStates array then scissorCount must be zero

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-04132**
  If the pipeline requires pre-rasterization shader state, and VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT is included in the pDynamicStates array then VK_DYNAMIC_STATE_VIEWPORT must not be present

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-04133**
  If the pipeline requires pre-rasterization shader state, and VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT is included in the pDynamicStates array then VK_DYNAMIC_STATE_SCISSOR must not be present

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-07065**
  If the pipeline requires pre-rasterization shader state, and includes a mesh shader, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY, or VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-04868**
  If the extendedDynamicState2 feature is not enabled, and the value of VkApplicationInfo::apiVersion used to create the VkInstance is less than Version 1.3 there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE, VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE, or VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-04869**
  If the extendedDynamicState2LogicOp feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_LOGIC_OP_EXT

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-04870**
  If the extendedDynamicState2PatchControlPoints feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-07066**
  If the pipeline requires pre-rasterization shader state, and includes a mesh shader, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE, or VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT

- **VUID-VkGraphicsPipelineCreateInfo-flags-02877**
  If flags includes VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV, then the deviceGeneratedCommands feature must be enabled
If the pipeline requires pre-rasterization shader state and flags includes `VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV`, then all stages must not specify Xfb execution mode.

If the pipeline is not created with a complete set of state, or `VkPipelineLibraryCreateInfoKHR::libraryCount` is not 0, `VkGraphicsPipelineShaderGroupsCreateInfoNV::groupCount` and `VkGraphicsPipelineShaderGroupsCreateInfoNV::pipelineCount` must be 0.

If the pipeline is created with a complete set of state, and `VkPipelineLibraryCreateInfoKHR::libraryCount` is 0, and the pNext chain includes an instance of `VkGraphicsPipelineShaderGroupsCreateInfoNV`, `VkGraphicsPipelineShaderGroupsCreateInfoNV::groupCount` must be greater than 0.

If the pipelineCreationCacheControl feature is not enabled, flags must not include `VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT` or `VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT`.

If the pipelineProtectedAccess feature is not enabled, flags must not include `VK_PIPELINE_CREATE_NO_PROTECTED_ACCESS_BIT_EXT` or `VK_PIPELINE_CREATE_PROTECTED_ACCESS_ONLY_BIT_EXT`.

Flags must not include both `VK_PIPELINE_CREATE_NO_PROTECTED_ACCESS_BIT_EXT` and `VK_PIPELINE_CREATE_PROTECTED_ACCESS_ONLY_BIT_EXT`.

If the pipeline requires pre-rasterization shader state or fragment shader state and `VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR` is not included in pDynamicState->pDynamicStates, `VkPipelineFragmentShadingRateStateCreateInfoKHR::fragmentSize.width` must be greater than or equal to 1.

If the pipeline requires pre-rasterization shader state or fragment shader state and `VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR` is not included in pDynamicState->pDynamicStates, `VkPipelineFragmentShadingRateStateCreateInfoKHR::fragmentSize.height` must be greater than or equal to 1.

If the pipeline requires pre-rasterization shader state or fragment shader state and `VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR` is not included in pDynamicState->pDynamicStates, `VkPipelineFragmentShadingRateStateCreateInfoKHR::fragmentSize.width` must be a power-of-two value.

If the pipeline requires pre-rasterization shader state or fragment shader state and `VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR` is not included in pDynamicState->pDynamicStates, `VkPipelineFragmentShadingRateStateCreateInfoKHR::fragmentSize.width` must be a power-of-two value.
::fragmentSize.height must be a power-of-two value

- VUID-VkGraphicsPipelineCreateInfo-pDynamicState-04498
  If the pipeline requires pre-rasterization shader state or fragment shader state and 
  VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR is not included in pDynamicState- 
  >pDynamicStates, VkPipelineFragmentShadingRateStateCreateInfoKHR::fragmentSize.width 
  must be less than or equal to 4

- VUID-VkGraphicsPipelineCreateInfo-pDynamicState-04499
  If the pipeline requires pre-rasterization shader state or fragment shader state and 
  VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR is not included in pDynamicState- 
  >pDynamicStates, VkPipelineFragmentShadingRateStateCreateInfoKHR::fragmentSize.height must be less than or equal to 4

- VUID-VkGraphicsPipelineCreateInfo-pDynamicState-04500
  If the pipeline requires pre-rasterization shader state or fragment shader state and 
  VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR is not included in pDynamicState- 
  >pDynamicStates and the pipelineFragmentShadingRate feature is not enabled, 
  VkPipelineFragmentShadingRateStateCreateInfoKHR::fragmentSize.width and 
  VkPipelineFragmentShadingRateStateCreateInfoKHR::fragmentSize.height must both be equal to 1

- VUID-VkGraphicsPipelineCreateInfo-pDynamicState-06567
  If the pipeline requires pre-rasterization shader state or fragment shader state and 
  VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR is not included in pDynamicState- 
  >pDynamicStates, VkPipelineFragmentShadingRateStateCreateInfoKHR::combinerOps[0] must be a valid VkFragmentShadingRateCombinerOpKHR value

- VUID-VkGraphicsPipelineCreateInfo-pDynamicState-06568
  If the pipeline requires pre-rasterization shader state or fragment shader state and 
  VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR is not included in pDynamicState- 
  >pDynamicStates, VkPipelineFragmentShadingRateStateCreateInfoKHR::combinerOps[1] must be a valid VkFragmentShadingRateCombinerOpKHR value

- VUID-VkGraphicsPipelineCreateInfo-pDynamicState-04501
  If the pipeline requires pre-rasterization shader state or fragment shader state and 
  VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR is not included in pDynamicState- 
  >pDynamicStates and the primitiveFragmentShadingRate feature is not enabled, 
  VkPipelineFragmentShadingRateStateCreateInfoKHR::combinerOps[0] must be 
  VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR

- VUID-VkGraphicsPipelineCreateInfo-pDynamicState-04502
  If the pipeline requires pre-rasterization shader state or fragment shader state and 
  VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR is not included in pDynamicState- 
  >pDynamicStates and the attachmentFragmentShadingRate feature is not enabled, 
  VkPipelineFragmentShadingRateStateCreateInfoKHR::combinerOps[1] must be 
  VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR

- VUID-VkGraphicsPipelineCreateInfo-primitiveFragmentShadingRateWithMultipleViewports-04503
  If the pipeline requires pre-rasterization shader state and the 
  primitiveFragmentShadingRateWithMultipleViewports limit is not supported, 
  VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT is not included in pDynamicState->pDynamicStates,
and `VkPipelineViewportStateCreateInfo::viewportCount` is greater than 1, entry points specified in `pStages` **must** not write to the `PrimitiveShadingRateKHR` built-in.

- **VUID-VkGraphicsPipelineCreateInfo-primitiveFragmentShadingRateWithMultipleViewports-04504**
  If the pipeline requires pre-rasterization shader state and the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, and entry points specified in `pStages` write to the `ViewportIndex` built-in, they **must** not also write to the `PrimitiveShadingRateKHR` built-in.

- **VUID-VkGraphicsPipelineCreateInfo-primitiveFragmentShadingRateWithMultipleViewports-04505**
  If the pipeline requires pre-rasterization shader state and the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, and entry points specified in `pStages` write to the `ViewportMaskNV` built-in, they **must** not also write to the `PrimitiveShadingRateKHR` built-in.

- **VUID-VkGraphicsPipelineCreateInfo-fragmentShadingRateNonTrivialCombinerOps-04506**
  If the pipeline requires pre-rasterization shader state or fragment shader state, the `fragmentShadingRateNonTrivialCombinerOps` limit is not supported, and `VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR` is not included in `pDynamicState->pDynamicStates`, elements of `VkPipelineFragmentShadingRateStateCreateInfoKHR::combinerOps` **must** be `VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR` or `VK_FRAGMENT_SHADING_RATE_COMBINER_OP_REPLACE_KHR`.

- **VUID-VkGraphicsPipelineCreateInfo-None-06569**
  If the pipeline requires fragment shader state and `VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR` is not included in `pDynamicState->pDynamicStates`, `VkPipelineFragmentShadingRateEnumStateCreateInfoNV::shadingRateType` **must** be a valid `VkFragmentShadingRateTypeNV` value.

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicState-06570**
  If the pipeline requires fragment shader state and `VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR` is not included in `pDynamicState->pDynamicStates`, `VkPipelineFragmentShadingRateEnumStateCreateInfoNV::shadingRate` **must** be a valid `VkFragmentShadingRateNV` value.

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicState-06571**
  If the pipeline requires fragment shader state and `VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR` is not included in `pDynamicState->pDynamicStates`, `VkPipelineFragmentShadingRateEnumStateCreateInfoNV::combinerOps[0]` **must** be a valid `VkFragmentShadingRateCombinerOpKHR` value.

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicState-06572**
  If the pipeline requires fragment shader state and `VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR` is not included in `pDynamicState->pDynamicStates`, `VkPipelineFragmentShadingRateEnumStateCreateInfoNV::combinerOps[1]` **must** be a valid `VkFragmentShadingRateCombinerOpKHR` value.

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicState-04569**
  If the pipeline requires fragment shader state and `VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR` is not included in `pDynamicState->pDynamicStates`, and the `fragmentShadingRateEnums` feature is not enabled,
• VUID-VkGraphicsPipelineCreateInfo-pDynamicState-04570
If the pipeline requires fragment shader state and
VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR is not included in pDynamicState->pDynamicStates, and the pipelineFragmentShadingRate feature is not enabled,
VkPipelineFragmentShadingRateEnumStateCreateInfoNV::shadingRate must be equal to
VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_PIXEL_NV

• VUID-VkGraphicsPipelineCreateInfo-pDynamicState-04571
If the pipeline requires fragment shader state and
VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR is not included in pDynamicState->pDynamicStates, and the primitiveFragmentShadingRate feature is not enabled,
VkPipelineFragmentShadingRateEnumStateCreateInfoNV::combinerOps[0] must be
VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR

• VUID-VkGraphicsPipelineCreateInfo-pDynamicState-04572
If the pipeline requires fragment shader state and
VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR is not included in pDynamicState->pDynamicStates, and the attachmentFragmentShadingRate feature is not enabled,
VkPipelineFragmentShadingRateEnumStateCreateInfoNV::combinerOps[1] must be
VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR or
VK_FRAGMENT_SHADING_RATE_COMBINER_OP_REPLACE_KHR

• VUID-VkGraphicsPipelineCreateInfo-fragmentShadingRateNonTrivialCombinerOps-04573
If the pipeline requires fragment shader state, and the
fragmentShadingRateNonTrivialCombinerOps limit is not supported and
VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR is not included in pDynamicState->pDynamicStates, elements of VkPipelineFragmentShadingRateEnumStateCreateInfoNV::combinerOps must be
VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR or
VK_FRAGMENT_SHADING_RATE_COMBINER_OP_REPLACE_KHR

• VUID-VkGraphicsPipelineCreateInfo-None-04574
If the pipeline requires fragment shader state, and the
supersampleFragmentShadingRates feature is not enabled,
VkPipelineFragmentShadingRateEnumStateCreateInfoNV::shadingRate must not be equal to
VK_FRAGMENT_SHADING_RATE_2_INVOCATIONS_PER_PIXEL_NV,
VK_FRAGMENT_SHADING_RATE_4_INVOCATIONS_PER_PIXEL_NV,
VK_FRAGMENT_SHADING_RATE_8_INVOCATIONS_PER_PIXEL_NV,
VK_FRAGMENT_SHADING_RATE_16_INVOCATIONS_PER_PIXEL_NV

• VUID-VkGraphicsPipelineCreateInfo-None-04575
If the pipeline requires fragment shader state, and the
noInvocationFragmentShadingRates feature is not enabled,
VkPipelineFragmentShadingRateEnumStateCreateInfoNV::shadingRate must not be equal to
VK_FRAGMENT_SHADING_RATE_NO_INVOCATIONS_NV

• VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-03578
All elements of the pDynamicStates member of pDynamicState must not be
VK_DYNAMIC_STATE_RAY_TRACING_PIPELINE_STACK_SIZE_KHR

• VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-04807
If the pipeline requires pre-rasterization shader state and the vertexInputDynamicState feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_VERTEX_INPUT_EXT
If the pipeline requires pre-rasterization shader state, and includes a mesh shader, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_VERTEX_INPUT_EXT.

If the colorWriteEnable feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT.

If the pipeline requires fragment shader state, and the VK_QCOM_render_pass_shader_resolve extension is enabled, rasterizationSamples is not dynamic, and if subpass has any input attachments, and if the subpass description contains VK_SUBPASS_DESCRIPTION_FRAGMENT_REGION_BIT_QCOM, then the sample count of the input attachments must equal rasterizationSamples.

If the pipeline requires fragment shader state, and the VK_QCOM_render_pass_shader_resolve extension is enabled, and if the subpass description contains VK_SUBPASS_DESCRIPTION_FRAGMENT_REGION_BIT_QCOM, then sampleShadingEnable must be false.

If flags includes VK_SUBPASS_DESCRIPTION_SHADER_RESOLVE_BIT_QCOM, then the subpass must be the last subpass in a subpass dependency chain.

If flags includes VK_SUBPASS_DESCRIPTION_SHADER_RESOLVE_BIT_QCOM, and if pResolveAttachments is not NULL, then each resolve attachment must be VK_ATTACHMENT_UNUSED.

If the pipeline requires pre-rasterization shader state, fragment shader state, or fragment output interface state, renderPass must be VK_NULL_HANDLE or a valid render pass object.

If the dynamicRendering feature is not enabled and the pipeline requires pre-rasterization shader state, fragment shader state, or fragment output interface state, renderPass must not be VK_NULL_HANDLE.

If the multiview feature is not enabled, the pipeline requires pre-rasterization shader state, fragment shader state, or fragment output interface state, and renderPass is VK_NULL_HANDLE, VkPipelineRenderingCreateInfo::viewMask must be 0.

If the pipeline requires fragment output interface state, and renderPass is VK_NULL_HANDLE, the index of the most significant bit in VkPipelineRenderingCreateInfo::viewMask must be less than maxMultiviewViewCount.

If the pipeline requires fragment output interface state, and renderPass is VK_NULL_HANDLE, the index of the most significant bit in VkPipelineRenderingCreateInfo::viewMask must be less than maxMultiviewViewCount.
VK_NULL_HANDLE, and VkPipelineRenderingCreateInfo::colorAttachmentCount is not 0, VkPipelineRenderingCreateInfo::pColorAttachmentFormats must be a valid pointer to an array of colorAttachmentCount valid VkFormat values

• VUID-VkGraphicsPipelineCreateInfo-renderPass-06580
  If the pipeline requires fragment output interface state, and renderPass is VK_NULL_HANDLE, each element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats must be a valid VkFormat value

• VUID-VkGraphicsPipelineCreateInfo-renderPass-06582
  If the pipeline requires fragment output interface state, renderPass is VK_NULL_HANDLE, and any element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats is not VK_FORMAT_UNDEFINED, that format must be a format with potential format features that include VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT or VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV

• VUID-VkGraphicsPipelineCreateInfo-renderPass-06583
  If the pipeline requires fragment output interface state, and renderPass is VK_NULL_HANDLE, VkPipelineRenderingCreateInfo::depthAttachmentFormat must be a valid VkFormat value

• VUID-VkGraphicsPipelineCreateInfo-renderPass-06584
  If the pipeline requires fragment output interface state, and renderPass is VK_NULL_HANDLE, VkPipelineRenderingCreateInfo::stencilAttachmentFormat must be a valid VkFormat value

• VUID-VkGraphicsPipelineCreateInfo-renderPass-06585
  If the pipeline requires fragment output interface state, and renderPass is VK_NULL_HANDLE, VkPipelineRenderingCreateInfo::depthAttachmentFormat is not VK_FORMAT_UNDEFINED, it must be a format with potential format features that include VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT

• VUID-VkGraphicsPipelineCreateInfo-renderPass-06586
  If the pipeline requires fragment output interface state, renderPass is VK_NULL_HANDLE, and VkPipelineRenderingCreateInfo::stencilAttachmentFormat is not VK_FORMAT_UNDEFINED, it must be a format with potential format features that include VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT

• VUID-VkGraphicsPipelineCreateInfo-renderPass-06587
  If the pipeline requires fragment output interface state, renderPass is VK_NULL_HANDLE, and VkPipelineRenderingCreateInfo::depthAttachmentFormat is not VK_FORMAT_UNDEFINED, it must be a format that includes a depth component

• VUID-VkGraphicsPipelineCreateInfo-renderPass-06588
  If the pipeline requires fragment output interface state, renderPass is VK_NULL_HANDLE, and VkPipelineRenderingCreateInfo::stencilAttachmentFormat is not VK_FORMAT_UNDEFINED, it must be a format that includes a stencil component

• VUID-VkGraphicsPipelineCreateInfo-renderPass-06589
  If the pipeline requires fragment output interface state, renderPass is VK_NULL_HANDLE, VkPipelineRenderingCreateInfo::depthAttachmentFormat is not VK_FORMAT_UNDEFINED, and VkPipelineRenderingCreateInfo::stencilAttachmentFormat is not VK_FORMAT_UNDEFINED, depthAttachmentFormat must equal stencilAttachmentFormat
If `renderPass` is `VK_NULL_HANDLE`, the pipeline is being created with fragment shader state and fragment output interface state, and either of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` or `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` are not `VK_FORMAT_UNDEFINED`, and the `VK_EXT_extended_dynamic_state3` extension is not enabled or any of the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE`, `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE`, `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP`, `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE`, `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE`, or `VK_DYNAMIC_STATE_DEPTH_BOUNDS` dynamic states are not set, `pDepthStencilState` must be a valid pointer to a valid `VkPipelineDepthStencilStateCreateInfo` structure.

If `pDepthStencilState` is not `NULL` it must be a valid pointer to a valid `VkPipelineDepthStencilStateCreateInfo` structure.

If `renderPass` is `VK_NULL_HANDLE` and the pipeline is being created with fragment shader state but not fragment output interface state, and the `VK_EXT_extended_dynamic_state3` extension is not enabled, or any of the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE`, `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE`, `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP`, `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE`, `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE`, `VK_DYNAMIC_STATE_STENCIL_OP`, or `VK_DYNAMIC_STATE_DEPTH_BOUNDS` dynamic states are not set, `pDepthStencilState` must be a valid pointer to a valid `VkPipelineDepthStencilStateCreateInfo` structure.

If `pDepthStencilState` is not `NULL` it must be a valid pointer to a valid `VkPipelineDepthStencilStateCreateInfo` structure.

If `renderPass` is `VK_NULL_HANDLE` and the pipeline is being created with fragment output interface state, `pColorBlendState->attachmentCount` must be equal to `VkPipelineRenderingCreateInfo::colorAttachmentCount`.

If `renderPass` is `VK_NULL_HANDLE`, the pipeline is being created with pre-rasterization shader state, `VkPipelineRenderingCreateInfo::viewMask` is not `0`, and the `multiviewTessellationShader` feature is not enabled, then `pStages` must not include...
 tessellation shaders

• VUID-VkGraphicsPipelineCreateInfo-renderPass-06058
  If renderPass is VK_NULL_HANDLE, the pipeline is being created with pre-rasterization shader state, VkPipelineRenderingCreateInfo::viewMask is not 0, and the multiviewGeometryShader feature is not enabled, then pStages must not include a geometry shader

• VUID-VkGraphicsPipelineCreateInfo-renderPass-07718
  If renderPass is VK_NULL_HANDLE, the pipeline is being created with pre-rasterization shader state, and VkPipelineRenderingCreateInfo::viewMask is not 0, all of the shaders in the pipeline must not write to the Layer built-in output

• VUID-VkGraphicsPipelineCreateInfo-renderPass-06059
  If renderPass is VK_NULL_HANDLE, the pipeline is being created with pre-rasterization shader state, and VkPipelineRenderingCreateInfo::viewMask is not 0, all of the shaders in the pipeline must not include variables decorated with the Layer built-in decoration in their interfaces

• VUID-VkGraphicsPipelineCreateInfo-renderPass-07719
  If renderPass is VK_NULL_HANDLE, the pipeline is being created with pre-rasterization shader state, and VkPipelineRenderingCreateInfo::viewMask is not 0, all of the shaders in the pipeline must not include variables decorated with the ViewIndex built-in decoration in their interfaces

• VUID-VkGraphicsPipelineCreateInfo-renderPass-07720
  If renderPass is VK_NULL_HANDLE, the pipeline is being created with pre-rasterization shader state, and VkPipelineRenderingCreateInfo::viewMask is not 0, and multiviewMeshShader is not enabled, then pStages must not include a mesh shader

• VUID-VkGraphicsPipelineCreateInfo-renderPass-06061
  If the pipeline requires fragment shader state and renderPass is VK_NULL_HANDLE, fragment shaders in pStages must not include the InputAttachment capability

• VUID-VkGraphicsPipelineCreateInfo-renderPass-08710
  If the pipeline requires fragment shader state and renderPass is not VK_NULL_HANDLE, fragment shaders in pStages must not include any of the TileImageColorReadAccessEXT, TileImageDepthReadAccessEXT, or TileImageStencilReadAccessEXT capabilities

• VUID-VkGraphicsPipelineCreateInfo-renderPass-06062
  If the pipeline requires fragment output interface state and renderPass is VK_NULL_HANDLE, for each color attachment format defined by the pColorAttachmentFormats member of VkPipelineRenderingCreateInfo, if its potential format features do not contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT, then the blendEnable member of the corresponding element of the pAttachments member of pColorBlendState must be VK_FALSE

• VUID-VkGraphicsPipelineCreateInfo-renderPass-06063
  If the pipeline requires fragment output interface state and renderPass is VK_NULL_HANDLE, if the pNext chain includes VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV, the colorAttachmentCount member of that structure must be equal to the value of VkPipelineRenderingCreateInfo::colorAttachmentCount

• VUID-VkGraphicsPipelineCreateInfo-flags-06591
If `pStages` includes a fragment shader stage, and the fragment shader declares the `EarlyFragmentTests` execution mode, the `flags` member of `VkPipelineDepthStencilStateCreateInfo` must not include `VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT` or `VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT`.

- **VUID-VkGraphicsPipelineCreateInfo-flags-06482**
  If the pipeline requires fragment output interface state and the `flags` member of `VkPipelineColorBlendStateCreateInfo` includes `VK_PIPELINE_COLOR_BLEND_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_BIT_EXT`, `renderpass` must not be `VK_NULL_HANDLE`.

- **VUID-VkGraphicsPipelineCreateInfo-flags-06483**
  If the pipeline requires fragment output interface state and the `flags` member of `VkPipelineDepthStencilStateCreateInfo` includes `VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT` or `VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT`, `renderpass` must not be `VK_NULL_HANDLE`.

- **VUID-VkGraphicsPipelineCreateInfo-pColorAttachmentSamples-06592**
  If the fragment output interface state, elements of the `pColorAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` must be valid `VkSampleCountFlagBits` values.

- **VUID-VkGraphicsPipelineCreateInfo-depthStencilAttachmentSamples-06593**
  If the fragment output interface state and the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` is not 0, it must be a valid `VkSampleCountFlagBits` value.

- **VUID-VkGraphicsPipelineCreateInfo-flags-06484**
  If the pipeline requires fragment shader state and the `flags` member of `VkPipelineDepthStencilStateCreateInfo` includes `VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT`, `subpass` must have been created with `VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT`.

- **VUID-VkGraphicsPipelineCreateInfo-flags-06485**
  If the pipeline requires fragment shader state and the `flags` member of `VkPipelineDepthStencilStateCreateInfo` includes `VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT`, `subpass` must have been created with `VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT`.

- **VUID-VkGraphicsPipelineCreateInfo-flags-06486**
  If the pipeline requires fragment shader state and the `flags` member of `VkPipelineDepthStencilStateCreateInfo` includes `VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT`, `subpass` must have been created with `VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT`.
If \texttt{VkPipelineCreationFeedbackCreateInfo::pipelineStageCreationFeedbackCount} is not 0, it must be equal to stageCount.

If \texttt{renderPass} is \texttt{VK_NULL_HANDLE}, the pipeline is being created with pre-rasterization shader state or fragment shader state, and \texttt{VkMultiviewPerViewAttributesInfoNVX::perViewAttributesPositionXOnly} is \texttt{VK_TRUE} then \texttt{VkMultiviewPerViewAttributesInfoNVX::perViewAttributes} must also be \texttt{VK_TRUE}.

If \texttt{VkGraphicsPipelineLibraryCreateInfoEXT::flags} includes only one of \texttt{VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT} or \texttt{VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT}, and an element of \texttt{VkPipelineLibraryCreateInfoKHR::pLibraries} includes the other flag, the value of \texttt{VkMultiviewPerViewAttributesInfoNVX::perViewAttributes} specified in both this pipeline and the library must be equal.

If one element of \texttt{VkPipelineLibraryCreateInfoKHR::pLibraries} includes \texttt{VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT} and another element includes \texttt{VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT}, the value of \texttt{VkMultiviewPerViewAttributesInfoNVX::perViewAttributes} specified in both libraries must be equal.

If the pipeline requires pre-rasterization shader state or fragment shader state, \texttt{pStages} must be a valid pointer to an array of stageCount valid \texttt{VkPipelineShaderStageCreateInfo} structures.

If the \texttt{VK_EXT_extended_dynamic_state3} extension is not enabled, or any of the \texttt{VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT}, \texttt{VK_DYNAMIC_STATE_SAMPLE_MASK_EXT}, or \texttt{VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT} dynamic states are not set, or \texttt{alphaToOne} is enabled on the device and \texttt{VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT} is not set, then \texttt{pMultisampleState} must be a valid pointer to a valid \texttt{VkPipelineMultisampleStateCreateInfo} structure.
If \( pRasterizationState \) is not \( \text{NULL} \) it \textbf{must} be a valid pointer to a valid \texttt{VkPipelineRasterizationStateCreateInfo} structure.

If the pipeline requires fragment shader state or pre-rasterization shader state, \texttt{layout} \textbf{must} be a valid \texttt{VkPipelineLayout} handle.

If \( \text{pre-rasterization shader state, fragment shader state, or fragment output state} \), and \( \text{renderPass} \) is not \( \text{VK_NULL_HANDLE} \), \( \text{renderPass} \) \textbf{must} be a valid \texttt{VkRenderPass} handle.

If the pipeline requires \( \text{pre-rasterization shader state or fragment shader state} \), \( \text{stageCount} \) \textbf{must} be greater than \( 0 \).

If the \texttt{graphicsPipelineLibrary} feature is not enabled, \texttt{flags} \textbf{must} not include \( \texttt{VK_PIPELINE_CREATE_LIBRARY_BIT_KHR} \).

If the pipeline defines, or includes as libraries, all the state subsets required for a complete graphics pipeline, \texttt{flags} \textbf{must} not include \( \texttt{VK_PIPELINE_CREATE_LIBRARY_BIT_KHR} \).

If \texttt{flags} includes \( \texttt{VK_PIPELINE_CREATE_LINK_TIME_OPTIMIZATION_BIT_EXT} \), pipeline libraries included via \texttt{VkPipelineLibraryCreateInfoKHR} \textbf{must} have been created with \( \texttt{VK_PIPELINE_CREATE_RETAIN_LINK_TIME_OPTIMIZATION_INFO_BIT_EXT} \).

If \texttt{flags} includes \( \texttt{VK_PIPELINE_CREATE_RETAIN_LINK_TIME_OPTIMIZATION_INFO_BIT_EXT} \), \texttt{flags} \textbf{must} also include \( \texttt{VK_PIPELINE_CREATE_LIBRARY_BIT_KHR} \).

If \texttt{flags} includes \( \texttt{VK_PIPELINE_CREATE_RETAIN_LINK_TIME_OPTIMIZATION_INFO_BIT_EXT} \), pipeline libraries included via \texttt{VkPipelineLibraryCreateInfoKHR} \textbf{must} have been created with \( \texttt{VK_PIPELINE_CREATE_RETAIN_LINK_TIME_OPTIMIZATION_INFO_BIT_EXT} \).

Any pipeline libraries included via \texttt{VkPipelineLibraryCreateInfoKHR::pLibraries} \textbf{must} not include any state subset already defined by this structure or defined by any other pipeline library in \texttt{VkPipelineLibraryCreateInfoKHR::pLibraries}.

If \texttt{VkGraphicsPipelineLibraryCreateInfoEXT::flags} includes only one of \( \texttt{VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT} \) or \( \texttt{VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT} \), and an element of \texttt{VkPipelineLibraryCreateInfoKHR::pLibraries} includes the other flag, and \texttt{layout} was not created with \( \texttt{VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT} \), then the \texttt{layout} used by this pipeline and the library \textbf{must} be \textit{identically defined}.

If one element of \texttt{VkPipelineLibraryCreateInfoKHR::pLibraries} includes \( \texttt{VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT} \) and another element
includes `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT`, and the layout specified by either library was not created with `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`, then the layout used by each library must be identically defined.

- **VUID-VkGraphicsPipelineCreateInfo-flags-06614**
  If `VkGraphicsPipelineLibraryCreateInfoEXT::flags` includes only one of `VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT` or `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT`, an element of `VkPipelineLibraryCreateInfoKHR::pLibraries` includes the other subset, and layout was created with `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`, then the layout used by each library must also have been created with `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`.

- **VUID-VkGraphicsPipelineCreateInfo-pLibraries-06615**
  If one element of `VkPipelineLibraryCreateInfoKHR::pLibraries` includes `VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT` and another element includes `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT`, and the layout specified by either library was created with `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`, then the layout used by both libraries must have been created with `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`.

- **VUID-VkGraphicsPipelineCreateInfo-flags-06616**
  If `VkGraphicsPipelineLibraryCreateInfoEXT::flags` includes only one of `VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT` or `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT`, an element of `VkPipelineLibraryCreateInfoKHR::pLibraries` includes the other subset, and layout was created with `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`, elements of the `pSetLayouts` array which layout was created with that are not `VK_NULL_HANDLE` must be identically defined to the element at the same index of `pSetLayouts` used to create the library's layout.

- **VUID-VkGraphicsPipelineCreateInfo-pLibraries-06617**
  If one element of `VkPipelineLibraryCreateInfoKHR::pLibraries` includes `VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT` and another element includes `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT`, and the layout specified by either library was created with `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`, elements of the `pSetLayouts` array which either layout was created with that are not `VK_NULL_HANDLE` must be identically defined to the element at the same index of `pSetLayouts` used to create the other library's layout.

- **VUID-VkGraphicsPipelineCreateInfo-flags-06618**
  If `VkGraphicsPipelineLibraryCreateInfoEXT::flags` includes only one of `VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT` or `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT`, and an element of `VkPipelineLibraryCreateInfoKHR::pLibraries` includes the other flag, any descriptor set layout \( N \) specified by layout in both this pipeline and the library which include bindings accessed by shader stages in each must be identically defined.

- **VUID-VkGraphicsPipelineCreateInfo-pLibraries-06619**
  If one element of `VkPipelineLibraryCreateInfoKHR::pLibraries` includes...
VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT and another element includes VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, any descriptor set layout \( N \) specified by layout in both libraries which include bindings accessed by shader stages in each **must be identically defined**

- **VUID-VkGraphicsPipelineCreateInfo-flags-06620**
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes only one of VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT or VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, and an element of VkPipelineLibraryCreateInfoKHR::pLibraries includes the other flag, push constants specified in layout in both this pipeline and the library which are available to shader stages in each **must be identically defined**

- **VUID-VkGraphicsPipelineCreateInfo-pLibraries-06621**
  If one element of VkPipelineLibraryCreateInfoKHR::pLibraries includes VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT and another element includes VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, push constants specified in layout in both this pipeline and the library which are available to shader stages in each **must be identically defined**

- **VUID-VkGraphicsPipelineCreateInfo-flags-06679**
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes only one of VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT or VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, an element of VkPipelineLibraryCreateInfoKHR::pLibraries includes the other subset, and any element of the pSetLayouts array which layout was created with was VK_NULL_HANDLE, then the corresponding element of the pSetLayouts array used to create the library's layout **must not be** VK_NULL_HANDLE

- **VUID-VkGraphicsPipelineCreateInfo-flags-06680**
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes only one of VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT or VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, an element of VkPipelineLibraryCreateInfoKHR::pLibraries includes the other subset, and any element of the pSetLayouts array used to create each library's layout was VK_NULL_HANDLE, then the corresponding element of the pSetLayouts array used to create this pipeline's layout **must not be** VK_NULL_HANDLE

- **VUID-VkGraphicsPipelineCreateInfo-flags-06681**
  If one element of VkPipelineLibraryCreateInfoKHR::pLibraries includes VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT and another element includes VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, and any element of the pSetLayouts array used to create each library's layout was VK_NULL_HANDLE, then the corresponding element of the pSetLayouts array used to create the other library's layout **must not be** VK_NULL_HANDLE

- **VUID-VkGraphicsPipelineCreateInfo-flags-06756**
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes only one of VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT or VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, an element of VkPipelineLibraryCreateInfoKHR::pLibraries includes the other subset, and any element
of the pSetLayouts array which layout was created with was VK_NULL_HANDLE, then the corresponding element of the pSetLayouts array used to create the library's layout must not have shader bindings for shaders in the other subset

- VUID-VkGraphicsPipelineCreateInfo-flags-06757
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes only one of
  VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT or
  VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, an element of
  VkPipelineLibraryCreateInfoKHR::pLibraries includes the other subset, and any element of the pSetLayouts array used to create the library's layout was VK_NULL_HANDLE, then the corresponding element of the pSetLayouts array used to create this pipeline's layout must not have shader bindings for shaders in the other subset

- VUID-VkGraphicsPipelineCreateInfo-pLibraries-06758
  If one element of VkPipelineLibraryCreateInfoKHR::pLibraries includes
  VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT and another element includes VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, and any element of the pSetLayouts array used to create each library's layout was VK_NULL_HANDLE, then the corresponding element of the pSetLayouts array used to create the other library's layout must not have shader bindings for shaders in the other subset

- VUID-VkGraphicsPipelineCreateInfo-flags-06682
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes both
  VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT and
  VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, layout must have been created with no elements of the pSetLayouts array set to VK_NULL_HANDLE

- VUID-VkGraphicsPipelineCreateInfo-flags-06683
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes at least one of and no more than two of
  VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT, or
  VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, or
  VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT, and an element of
  VkPipelineLibraryCreateInfoKHR::pLibraries includes one of the other flags, the value of subpass must be equal to that used to create the library

- VUID-VkGraphicsPipelineCreateInfo-pLibraries-06623
  If one element of VkPipelineLibraryCreateInfoKHR::pLibraries includes at least one of and no more than two of
  VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT, or
  VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, or
  VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT, and another element of
  VkPipelineLibraryCreateInfoKHR::pLibraries includes one of the other flags, the value of subpass used to create each library must be identical

- VUID-VkGraphicsPipelineCreateInfo-renderpass-06624
  If renderpass is not VK_NULL_HANDLE, VkGraphicsPipelineLibraryCreateInfoEXT::flags
includes at least one of and no more than two of
VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT,
VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, or
VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT, and an element of
VkPipelineLibraryCreateInfoKHR::pLibraries includes one of the other flags, renderPass
must be compatible with that used to create the library

• VUID-VkGraphicsPipelineCreateInfo-renderpass-06625
If renderpass is VK_NULL_HANDLE, VkGraphicsPipelineLibraryCreateInfoEXT::flags
includes at least one of and no more than two of
VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT,
VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, or
VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT, and an element of
VkPipelineLibraryCreateInfoKHR::pLibraries includes one of the other flags, the value of
renderPass used to create that library must also be VK_NULL_HANDLE

• VUID-VkGraphicsPipelineCreateInfo-flags-06626
If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes at least one of and no more
than two of VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT,
VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, or
VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT, an element of
VkPipelineLibraryCreateInfoKHR::pLibraries includes one of the other flags, and
renderPass is VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::viewMask
used by this pipeline and that specified by the library must be identical

• VUID-VkGraphicsPipelineCreateInfo-pLibraries-06627
If one element of VkPipelineLibraryCreateInfoKHR::pLibraries includes at least one of
and no more than two of
VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT,
VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, or
VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT, another element of
VkPipelineLibraryCreateInfoKHR::pLibraries includes one of the other flags, and
renderPass was VK_NULL_HANDLE for both libraries, the value of
VkPipelineRenderingCreateInfo::viewMask set by each library must be identical

• VUID-VkGraphicsPipelineCreateInfo-pLibraries-06628
If one element of VkPipelineLibraryCreateInfoKHR::pLibraries includes at least one of
and no more than two of
VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT,
VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, or
VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT, and another element of
VkPipelineLibraryCreateInfoKHR::pLibraries includes one of the other flags, the
renderPass objects used to create each library must be compatible or all equal to
VK_NULL_HANDLE

• VUID-VkGraphicsPipelineCreateInfo-pMultisampleState-06629
If the pipeline requires fragment shader state pMultisampleState must be NULL or a valid
pointer to a valid VkPipelineMultisampleStateCreateInfo structure

• VUID-VkGraphicsPipelineCreateInfo-renderpass-06631
If the pipeline requires fragment shader state and renderpass is not VK_NULL_HANDLE,
then **pMultisampleState must not be NULL**

- **VUID-VkGraphicsPipelineCreateInfo-Input-06632**
  If the pipeline requires fragment shader state with a fragment shader that either enables sample shading or decorates any variable in the Input storage class with Sample, then **pMultisampleState must not be NULL**

- **VUID-VkGraphicsPipelineCreateInfo-flags-06633**
  If `VkGraphicsPipelineLibraryCreateInfoEXT::flags` includes `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT` with a `pMultisampleState` that was not NULL, and an element of `VkPipelineLibraryCreateInfoKHR::plibraries` was created with `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT`, **pMultisampleState must be identically defined** to that used to create the library

- **VUID-VkGraphicsPipelineCreateInfo-plibraries-06634**
  If an element of `VkPipelineLibraryCreateInfoKHR::plibraries` was created with `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT` with a `pMultisampleState` that was not NULL, and if `VkGraphicsPipelineLibraryCreateInfoEXT::flags` includes `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT`, **pMultisampleState must be identically defined** to that used to create the library

- **VUID-VkGraphicsPipelineCreateInfo-plibraries-06635**
  If one element of `VkPipelineLibraryCreateInfoKHR::plibraries` was created with `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT` and a value of `pMultisampleState->sampleShading` equal `VK_TRUE`, and if a different element of `VkPipelineLibraryCreateInfoKHR::plibraries` was created with `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT`, the **pMultisampleState used to create each library must be identically defined**

- **VUID-VkGraphicsPipelineCreateInfo-flags-06636**
  If `VkGraphicsPipelineLibraryCreateInfoEXT::flags` includes only one of `VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT` or `VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT`, and an element of `VkPipelineLibraryCreateInfoKHR::plibraries` includes the other flag, values specified in `VkPipelineFragmentShadingRateStateCreateInfoKHR` for both this pipeline and that library **must be identical**

- **VUID-VkGraphicsPipelineCreateInfo-plibraries-06639**
  If one element of `VkPipelineLibraryCreateInfoKHR::plibraries` includes
VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT and another element includes VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, values specified in VkPipelineFragmentShadingRateStateCreateInfoKHR for both this pipeline and that library must be identical

- **VUID-VkGraphicsPipelineCreateInfo-flags-06640**
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT or VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, pStages must be a valid pointer to an array of stageCount valid VkPipelineShaderStageCreateInfo structures

- **VUID-VkGraphicsPipelineCreateInfo-flags-09041**
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT, and the VK_EXT_extended_dynamic_state3 extension is not enabled, or any of the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT, VK_DYNAMIC_STATE_SAMPLE_MASK_EXT, or VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic states are not set, or alphaToOne is enabled on the device and VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT is not set, pMultisampleState must be a valid pointer to a valid VkPipelineMultisampleStateCreateInfo structure

- **VUID-VkGraphicsPipelineCreateInfo-flags-09042**
  If pRasterizationState is not NULL it must be a valid pointer to a valid VkPipelineRasterizationStateCreateInfo structure

- **VUID-VkGraphicsPipelineCreateInfo-flags-06642**
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT, and the layout must be a valid VkPipelineLayout handle

- **VUID-VkGraphicsPipelineCreateInfo-flags-06643**
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT, or VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT, and renderPass is not VK_NULL_HANDLE, renderPass must be a valid VkRenderPass handle

- **VUID-VkGraphicsPipelineCreateInfo-flags-06644**
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT or VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, stageCount must be greater than 0

- **VUID-VkGraphicsPipelineCreateInfo-flags-06645**
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags is non-zero, if flags includes VK_PIPELINE_CREATE_CAPTURE_INTERNAL_REPRESENTATIONS_BIT_KHR, any libraries must have also been created with VK_PIPELINE_CREATE_CAPTURE_INTERNAL_REPRESENTATIONS_BIT_KHR

- **VUID-VkGraphicsPipelineCreateInfo-pLibraries-06646**
  If VkPipelineLibraryCreateInfoKHR::pLibraries includes more than one library, and any library was created with VK_PIPELINE_CREATE_CAPTURE_INTERNAL_REPRESENTATIONS_BIT_KHR, all libraries must have also been created with VK_PIPELINE_CREATE_CAPTURE_INTERNAL_REPRESENTATIONS_BIT_KHR
If `VkPipelineLibraryCreateInfoKHR::pLibraries` includes at least one library, `VkGraphicsPipelineLibraryCreateInfoEXT::flags` is non-zero, and any library was created with `VK_PIPELINE_CREATE_CAPTURE_INTERNAL_REPRESENTATIONS_BIT_KHR`, `flags` must include `VK_PIPELINE_CREATE_CAPTURE_INTERNAL_REPRESENTATIONS_BIT_KHR`.

If the pipeline includes a complete set of state, `VkPipelineLayout` must be a valid pipeline layout.

If the pipeline includes a complete set of state specified entirely by libraries, and each library was created with a `VkPipelineLayout` created without `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`, then `layout` must be compatible with the layouts in those libraries.

If `flags` includes `VK_PIPELINE_CREATE_LINK_TIME_OPTIMIZATION_BIT_EXT`, the pipeline includes a complete set of state specified entirely by libraries, and each library was created with a `VkPipelineLayout` created without `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`, then `layout` must be compatible with the union of the libraries’ pipeline layouts other than the inclusion/exclusion of `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`.

If `flags` does not include `VK_PIPELINE_CREATE_LINK_TIME_OPTIMIZATION_BIT_EXT`, the pipeline includes a complete set of state specified entirely by libraries, and each library was created with a `VkPipelineLayout` created without `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`, then `layout` must be compatible with the union of the libraries' pipeline layouts.

If `conservativePointAndLineRasterization` is not supported; the pipeline is being created with vertex input state and pre-rasterization shader state; the pipeline does not include a geometry shader; and the value of `VkPipelineInputAssemblyStateCreateInfo::topology` is `VK_PRIMITIVE_TOPOLOGY_POINT_LIST`, `VK_PRIMITIVE_TOPOLOGY_LINE_LIST`, or `VK_PRIMITIVE_TOPOLOGY_LINE_STRIP`, and either `VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY` dynamic state is not enabled or `dynamicPrimitiveTopologyUnrestricted` is `VK_FALSE`, then `VkPipelineRasterizationConservativeStateCreateInfoEXT::conservativeRasterizationMode` must be `VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT`.

If `conservativePointAndLineRasterization` is not supported, the pipeline requires pre-rasterization shader state, and the pipeline includes a geometry shader with either the `OutputPoints` or `OutputLineStrip` execution modes, `VkPipelineRasterizationConservativeStateCreateInfoEXT::conservativeRasterizationMode` must be `VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT`.

If `conservativePointAndLineRasterization` is not supported, the pipeline requires pre-rasterization shader state, and the pipeline includes a mesh shader with either the `OutputPoints` or `OutputLinesNV` execution modes,
VkPipelineRasterizationConservativeStateCreateInfoEXT::conservativeRasterizationMode must be VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT

- VUID-VkGraphicsPipelineCreateInfo-pStages-06894
  If the pipeline requires pre-rasterization shader state but not fragment shader state, elements of pStages must not have stage set to VK_SHADER_STAGE_FRAGMENT_BIT

- VUID-VkGraphicsPipelineCreateInfo-pStages-06895
  If the pipeline requires fragment shader state but not pre-rasterization shader state, elements of pStages must not have stage set to a shader stage which participates in pre-rasterization

- VUID-VkGraphicsPipelineCreateInfo-pStages-06896
  If the pipeline requires pre-rasterization shader state, all elements of pStages must have a stage set to a shader stage which participates in fragment shader state or pre-rasterization shader state

- VUID-VkGraphicsPipelineCreateInfo-stage-06897
  If the pipeline requires fragment shader state and/or pre-rasterization shader state, any value of stage must not be set in more than one element of pStages

- VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3TessellationDomainOrigin-07370
  If the extendedDynamicState3TessellationDomainOrigin feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT

- VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3DepthClampEnable-07371
  If the extendedDynamicState3DepthClampEnable feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT

- VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3PolygonMode-07372
  If the extendedDynamicState3PolygonMode feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_POLYGON_MODE_EXT

- VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3RasterizationSamples-07373
  If the extendedDynamicState3RasterizationSamples feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT

- VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3SampleMask-07374
  If the extendedDynamicState3SampleMask feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_SAMPLE_MASK_EXT

- VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3AlphaToCoverageEnable-07375
  If the extendedDynamicState3AlphaToCoverageEnable feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT

- VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3AlphaToOneEnable-07376
  If the extendedDynamicState3AlphaToOneEnable feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT
• VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3LogicOpEnable-07377
  If the extendedDynamicState3LogicOpEnable feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT

• VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3ColorBlendEnable-07378
  If the extendedDynamicState3ColorBlendEnable feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT

• VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3ColorWriteMask-07380
  If the extendedDynamicState3ColorWriteMask feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT

• VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3RasterizationStream-07381
  If the extendedDynamicState3RasterizationStream feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT

• VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3ConservativeRasterizationMode-07382
  If the extendedDynamicState3ConservativeRasterizationMode feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT

• VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3ExtraPrimitiveOverestimationSize-07383
  If the extendedDynamicState3ExtraPrimitiveOverestimationSize feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT

• VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3DepthClipEnable-07384
  If the extendedDynamicState3DepthClipEnable feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT

• VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3SampleLocationsEnable-07385
  If the extendedDynamicState3SampleLocationsEnable feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT

• VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3ColorBlendAdvanced-07386
  If the extendedDynamicState3ColorBlendAdvanced feature is not enabled, there must be no element of the pDynamicStates member of pDynamicState set to VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT


If the `extendedDynamicState3ProvokingVertexMode` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT`.

If the `extendedDynamicState3LineRasterizationMode` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT`.

If the `extendedDynamicState3LineStippleEnable` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT`.

If the `extendedDynamicState3DepthClipNegativeOneToOne` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT`.

If the `extendedDynamicState3ViewportWScalingEnable` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV`.

If the `extendedDynamicState3ViewportSwizzle` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV`.

If the `extendedDynamicState3CoverageToColorEnable` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV`.

If the `extendedDynamicState3CoverageToColorLocation` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV`.

If the `extendedDynamicState3CoverageModulationMode` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV`.

If the `extendedDynamicState3CoverageModulationTableEnable` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV`.
If the `extendedDynamicState3CoverageModulationTableEnable` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV

- **VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3CoverageModulationTable-07397**
  If the `extendedDynamicState3CoverageModulationTable` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV

- **VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3CoverageReductionMode-07398**
  If the `extendedDynamicState3CoverageReductionMode` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV

- **VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3RepresentativeFragmentTestEnable-07399**
  If the `extendedDynamicState3RepresentativeFragmentTestEnable` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV

- **VUID-VkGraphicsPipelineCreateInfo-extendedDynamicState3ShadingRateImageEnable-07400**
  If the `extendedDynamicState3ShadingRateImageEnable` feature is not enabled, there **must** be no element of the `pDynamicStates` member of `pDynamicState` set to `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV

- **VUID-VkGraphicsPipelineCreateInfo-flags-07401**
  `flags` **must** not include `VK_PIPELINE_CREATE_RAY_TRACING_OPACITY_MICROMAP_BIT_EXT

- **VUID-VkGraphicsPipelineCreateInfo-flags-07997**
  `flags` **must** not include `VK_PIPELINE_CREATE_RAY_TRACING_DISPLACEMENT_MICROMAP_BIT_NV

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-07730**
  If the pipeline requires pre-rasterization shader state, and no element of the `pDynamicStates` member of `pDynamicState` is `VK_DYNAMIC_STATE_VIEWPORT` or `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT`, and if `multiviewPerViewViewports` is enabled, then the index of the most significant bit in each element of `VkRenderPassMultiviewCreateInfo::pViewMasks` **must** be less than `pViewportState::viewportCount

- **VUID-VkGraphicsPipelineCreateInfo-pDynamicStates-07731**
  If the pipeline requires pre-rasterization shader state, and no element of the `pDynamicStates` member of `pDynamicState` is `VK_DYNAMIC_STATE_SCISSOR` or `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT`, and if `multiviewPerViewViewports` is enabled, then the index of the most significant bit in each element of `VkRenderPassMultiviewCreateInfo::pViewMasks` **must** be less than `pViewportState::scissorCount

- **VUID-VkGraphicsPipelineCreateInfo-pStages-08711**
  If `pStages` includes a fragment shader stage, `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` is not set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`, and the fragment shader declares
the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable member of VkPipelineDepthStencilStateCreateInfo must be VK_FALSE

• VUID-VkGraphicsPipelineCreateInfo-pStages-08712
  If pStages includes a fragment shader stage, VK_DYNAMIC_STATE_STENCIL_WRITE_MASK is not set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpStencilAttachmentReadEXT, the value of VkStencilOpState::writeMask for both front and back in VkPipelineDepthStencilStateCreateInfo must be 0

• VUID-VkGraphicsPipelineCreateInfo-renderPass-08744
  If renderPass is VK_NULL_HANDLE, the pipeline requires fragment output state or fragment shader state, the pipeline enables sample shading, rasterizationSamples is not dynamic, and the pNext chain includes a VkPipelineRenderingCreateInfo structure, rasterizationSamples must be a bit value that is set in imageCreateSampleCounts (as defined in Image Creation Limits) for every element of depthAttachmentFormat, stencilAttachmentFormat and the pColorAttachmentFormats array which is not VK_FORMAT_UNDEFINED

• VUID-VkGraphicsPipelineCreateInfo-flags-08897
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes VK_GRAPHICS_PIPELINE_LIBRARY_VERTEX_INPUT_INTERFACE_BIT_EXT, pre-rasterization shader state is specified either in a library or by the inclusion of VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT, and that state includes a vertex shader stage in pStages, the pipeline must define vertex input state

• VUID-VkGraphicsPipelineCreateInfo-flags-08898
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes VK_GRAPHICS_PIPELINE_LIBRARY_VERTEX_INPUT_INTERFACE_BIT_EXT, and pre-rasterization shader state is not specified, the pipeline must define vertex input state

• VUID-VkGraphicsPipelineCreateInfo-flags-08899
  If flags does not include VK_PIPELINE_CREATE_LIBRARY_BIT_KHR, pre-rasterization shader state is specified either in a library or by the inclusion of VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT, and that state includes a vertex shader stage in pStages, the pipeline must either define pre-rasterization shader state or include that state in a linked pipeline library

• VUID-VkGraphicsPipelineCreateInfo-flags-08900
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT the pipeline must define pre-rasterization shader state

• VUID-VkGraphicsPipelineCreateInfo-flags-08901
  If flags does not include VK_PIPELINE_CREATE_LIBRARY_BIT_KHR, the pipeline must either define pre-rasterization shader state or include that state in a linked pipeline library

• VUID-VkGraphicsPipelineCreateInfo-flags-08903
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, pre-rasterization shader state is specified either in a library or by the inclusion of VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT, and that state either includes VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE or has pRasterizationState-
rasterizerDiscardEnable set to VK_FALSE, the pipeline must define fragment shader state

• VUID-VkGraphicsPipelineCreateInfo-flags-08904
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, and pre-rasterization shader state is not specified, the pipeline must define fragment shader state

• VUID-VkGraphicsPipelineCreateInfo-flags-08906
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, pre-rasterization shader state is specified either in a library or by the inclusion of VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT, and that state either includes VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE or has pRasterizationState->rasterizerDiscardEnable set to VK_FALSE, the pipeline must define fragment output interface state

• VUID-VkGraphicsPipelineCreateInfo-flags-08907
  If VkGraphicsPipelineLibraryCreateInfoEXT::flags includes VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT, pre-rasterization shader state is not specified, the pipeline must define fragment output interface state

• VUID-VkGraphicsPipelineCreateInfo-None-09043
  If pDynamicState->pDynamicStates does not include VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT, and the format of any color attachment is VK_FORMAT_E5B9G9R9_UFLOAT_PACK32, the colorWriteMask member of the corresponding element of pColorBlendState->pAttachments must either include all of VK_COLOR_COMPONENT_R_BIT, VK_COLOR_COMPONENT_G_BIT, and VK_COLOR_COMPONENT_B_BIT, or none of them

Valid Usage (Implicit)

• VUID-VkGraphicsPipelineCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_CREATE_INFO

• VUID-VkGraphicsPipelineCreateInfo-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkAttachmentSampleCountInfoAMD, VkGraphicsPipelineLibraryCreateInfoEXT, VkGraphicsPipelineShaderGroupsCreateInfoNV, VkMultiviewPerViewAttributesInfoNVX, VkPipelineCompilerControlCreateInfoAMD, VkPipelineCreateFlags2CreateInfoKHR, VkPipelineCreationFeedbackCreateInfo, VkPipelineDiscardRectangleStateCreateInfoEXT, VkPipelineFragmentShadingRateEnumStateCreateInfoNV, VkPipelineFragmentShadingRateStateCreateInfoKHR, VkPipelineLibraryCreateInfoKHR, VkPipelineRenderingCreateInfo, VkPipelineRepresentativeFragmentTestStateCreateInfoNV, or VkPipelineRobustnessCreateInfoEXT

• VUID-VkGraphicsPipelineCreateInfo-sType-unique
  The sType value of each struct in the pNext chain must be unique

• VUID-VkGraphicsPipelineCreateInfo-flags-parameter
  flags must be a valid combination of VkPipelineCreateFlagBits values
If \( \text{pDynamicState} \) is not NULL, \( \text{pDynamicState} \) must be a valid pointer to a valid \text{VkPipelineDynamicStateCreateInfo} structure.

Each of \text{basePipelineHandle}, \text{layout}, \text{and renderPass} that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same \text{VkDevice}.

The \text{VkPipelineRenderingCreateInfo} structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPipelineRenderingCreateInfo {
    VkStructureType sType;
    const void* pNext;
    uint32_t viewMask;
    uint32_t colorAttachmentCount;
    const VkFormat* pColorAttachmentFormats;
    VkFormat depthAttachmentFormat;
    VkFormat stencilAttachmentFormat;
} VkPipelineRenderingCreateInfo;
```

or the equivalent:

```c
// Provided by VK_KHR_dynamic_rendering
typedef VkPipelineRenderingCreateInfo VkPipelineRenderingCreateInfoKHR;
```

- \text{sType} is a \text{VkStructureType} value identifying this structure.
- \text{pNext} is NULL or a pointer to a structure extending this structure.
- \text{viewMask} is the viewMask used for rendering.
- \text{colorAttachmentCount} is the number of entries in \text{pColorAttachmentFormats}.
- \text{pColorAttachmentFormats} is a pointer to an array of \text{VkFormat} values defining the format of color attachments used in this pipeline.
- \text{depthAttachmentFormat} is a \text{VkFormat} value defining the format of the depth attachment used in this pipeline.
- \text{stencilAttachmentFormat} is a \text{VkFormat} value defining the format of the stencil attachment used in this pipeline.

When a pipeline is created without a \text{VkRenderPass}, if the \text{pNext} chain of \text{VkGraphicsPipelineCreateInfo} includes this structure, it specifies the view mask and format of attachments used for rendering. If this structure is not specified, and the pipeline does not include a \text{VkRenderPass}, \text{viewMask} and \text{colorAttachmentCount} are 0, and \text{depthAttachmentFormat} and \text{stencilAttachmentFormat} are \text{VK_FORMAT_UNDEFINED}. If a graphics pipeline is created with a valid \text{VkRenderPass}, parameters of this structure are ignored.

If \text{depthAttachmentFormat}, \text{stencilAttachmentFormat}, or any element of \text{pColorAttachmentFormats} is
it indicates that the corresponding attachment is unused within the render pass. Valid formats indicate that an attachment can be used - but it is still valid to set the attachment to NULL when beginning rendering.

Valid Usage (Implicit)

- VUID-VkPipelineRenderingCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_PIPELINE_RENDERING_CREATE_INFO

The VkPipelineCreateFlags2CreateInfoKHR structure is defined as:

```c
// Provided by VK_KHR_maintenance5
typedef struct VkPipelineCreateFlags2CreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkPipelineCreateFlags2KHR flags;
} VkPipelineCreateFlags2CreateInfoKHR;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `flags` is a bitmask of VkPipelineCreateFlagBits2KHR specifying how a pipeline will be generated.

If this structure is included in the `pNext` chain of a pipeline creation structure, `flags` is used instead of the corresponding `flags` value passed in that creation structure, allowing additional creation flags to be specified.

Valid Usage (Implicit)

- VUID-VkPipelineCreateFlags2CreateInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_PIPELINE_CREATE_FLAGS_2_CREATE_INFO_KHR

- VUID-VkPipelineCreateFlags2CreateInfoKHR-flags-parameter
  flags must be a valid combination of VkPipelineCreateFlagBits2KHR values

- VUID-VkPipelineCreateFlags2CreateInfoKHR-flags-requiredbitmask
  flags must not be 0

Bits which can be set in VkPipelineCreateFlags2CreateInfoKHR::flags, specifying how a pipeline is created, are:

```c
// Provided by VK_KHR_maintenance5
// Flag bits for VkPipelineCreateFlagBits2KHR
typedef VkFlags64 VkPipelineCreateFlagBits2KHR;
static const VkPipelineCreateFlagBits2KHR VK_PIPELINE_CREATE_2_DISABLE_OPTIMIZATION_BIT_KHR = 0x00000001ULL;
static const VkPipelineCreateFlagBits2KHR
```
VK_PIPELINE_CREATE_2_ALLOW_DERIVATIVES_BIT_KHR = 0x00000002ULL;
static const VkPipelineCreateFlagBits2KHR VK_PIPELINE_CREATE_2_DERIVATIVE_BIT_KHR = 0x00000004ULL;
// Provided by VK_KHR_maintenance5 with VK_VERSION_1_1 or VK_KHR_device_group
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_VIEW_INDEX_FROM_DEVICE_INDEX_BIT_KHR = 0x00000008ULL;
// Provided by VK_KHR_maintenance5 with VK_VERSION_1_1 or VK_KHR_device_group
static const VkPipelineCreateFlagBits2KHR VK_PIPELINE_CREATE_2_DISPATCH_BASE_BIT_KHR = 0x00000010ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_pipeline_executable_properties
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_CAPTURE_STATISTICS_BIT_KHR = 0x00000040ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_pipeline_executable_properties
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_CAPTURE_INTERNAL_REPRESENTATIONS_BIT_KHR = 0x00000080ULL;
// Provided by VK_KHR_maintenance5 with VK_VERSION_1_3 or VK_EXT_pipeline_creation_cache_control
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT_KHR = 0x00000100ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_ray_tracing_pipeline
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR = 0x00001000ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_ray_tracing_pipeline
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_RAY_TRACING_SKIP_AABBS_BIT_KHR = 0x00002000ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_ray_tracing_pipeline
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR = 0x00004000ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_ray_tracing_pipeline
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR = 0x00008000ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_ray_tracing_pipeline
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR = 0x00010000ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_ray_tracing_pipeline
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_LIBRARY_BIT_KHR = 0x00000800ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_pipeline_library
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR = 0x00001000ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_device_group
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_RAY_TRACING_SKIP_AABBS_BIT_KHR = 0x00002000ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_device_group
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR = 0x00004000ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_device_group
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR = 0x00008000ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_device_group
static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR = 0x00010000ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_device_group

static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_DISABLE_OPTIMIZATION_BIT_KHR = 0x00020000ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_ray_tracing_pipeline

static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_ALLOW_DERIVATIVES_BIT_KHR = 0x00040000ULL;
// Provided by VK_KHR_maintenance5 with VK_NV_device_generated_commands

static const VkPipelineCreateFlagBits2KHR
VK_PIPELINE_CREATE_2_DERIVATIVE_BIT_KHR = 0x40000000ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_dynamic_rendering and VK_KHR_fragment_shading_rate

• VK_PIPELINE_CREATE_2_DISABLE_OPTIMIZATION_BIT_KHR specifies that the created pipeline will not be optimized. Using this flag may reduce the time taken to create the pipeline.

• VK_PIPELINE_CREATE_2_ALLOW_DERIVATIVES_BIT_KHR specifies that the pipeline to be created is allowed to be the parent of a pipeline that will be created in a subsequent pipeline creation call.

• VK_PIPELINE_CREATE_2_DERIVATIVE_BIT_KHR specifies that the pipeline to be created will be a child
of a previously created parent pipeline.

- **VK_PIPELINE_CREATE_2_VIEW_INDEX_FROM_DEVICE_INDEX_BIT_KHR** specifies that any shader input variables decorated as `ViewIndex` will be assigned values as if they were decorated as `DeviceIndex`.

- **VK_PIPELINE_CREATE_2_DISPATCH_BASE_BIT_KHR** specifies that a compute pipeline can be used with `vkCmdDispatchBase` with a non-zero base workgroup.

- **VK_PIPELINE_CREATE_2_DEFER_COMPILE_BIT_NV** specifies that a pipeline is created with all shaders in the deferred state. Before using the pipeline the application must call `vkCompileDeferredNV` exactly once on each shader in the pipeline before using the pipeline.

- **VK_PIPELINE_CREATE_2_CAPTURE_STATISTICS_BIT_KHR** specifies that the shader compiler should capture statistics for the pipeline executables produced by the compile process which can later be retrieved by calling `vkGetPipelineExecutableStatisticsKHR`. Enabling this flag must not affect the final compiled pipeline but may disable pipeline caching or otherwise affect pipeline creation time.

- **VK_PIPELINE_CREATE_2_CAPTURE_INTERNAL_REPRESENTATIONS_BIT_KHR** specifies that the shader compiler should capture the internal representations of pipeline executables produced by the compile process which can later be retrieved by calling `vkGetPipelineExecutableInternalRepresentationsKHR`. Enabling this flag must not affect the final compiled pipeline but may disable pipeline caching or otherwise affect pipeline creation time. When capturing IR from pipelines created with pipeline libraries, there is no guarantee that IR from libraries can be retrieved from the linked pipeline. Applications should retrieve IR from each library, and any linked pipelines, separately.

- **VK_PIPELINE_CREATE_2_LIBRARY_BIT_KHR** specifies that the pipeline cannot be used directly, and instead defines a pipeline library that can be combined with other pipelines using the `VkPipelineLibraryCreateInfoKHR` structure. This is available in ray tracing and graphics pipelines.

- **VK_PIPELINE_CREATE_2_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR** specifies that an any-hit shader will always be present when an any-hit shader would be executed. A NULL any-hit shader is an any-hit shader which is effectively `VK_SHADER_UNUSED_KHR`, such as from a shader group consisting entirely of zeros.

- **VK_PIPELINE_CREATE_2_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR** specifies that a closest hit shader will always be present when a closest hit shader would be executed. A NULL closest hit shader is a closest hit shader which is effectively `VK_SHADER_UNUSED_KHR`, such as from a shader group consisting entirely of zeros.

- **VK_PIPELINE_CREATE_2_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR** specifies that a miss shader will always be present when a miss shader would be executed. A NULL miss shader is a miss shader which is effectively `VK_SHADER_UNUSED_KHR`, such as from a shader group consisting entirely of zeros.

- **VK_PIPELINE_CREATE_2_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR** specifies that an intersection shader will always be present when an intersection shader would be executed. A NULL intersection shader is an intersection shader which is effectively `VK_SHADER_UNUSED_KHR`, such as from a shader group consisting entirely of zeros.

- **VK_PIPELINE_CREATE_2_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR** specifies that triangle primitives will
be skipped during traversal using `OpTraceRayKHR`.

- `VK_PIPELINE_CREATE_2_RAY_TRACING_SKIP_AABBS_BIT_KHR` specifies that AABB primitives will be skipped during traversal using `OpTraceRayKHR`.

- `VK_PIPELINE_CREATE_2_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR` specifies that the shader group handles can be saved and reused on a subsequent run (e.g. for trace capture and replay).

- `VK_PIPELINE_CREATE_2_INDIRECT_BINDABLE_BIT_NV` specifies that the pipeline can be used in combination with `Device-Generated Commands`.

- `VK_PIPELINE_CREATE_2_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT_KHR` specifies that pipeline creation will fail if a compile is required for creation of a valid `VkPipeline` object; `VK_PIPELINE_COMPILE_REQUIRED` will be returned by pipeline creation, and the `VkPipeline` will be set to `VK_NULL_HANDLE`.

- When creating multiple pipelines, `VK_PIPELINE_CREATE_2_EARLY_RETURN_ON_FAILURE_BIT_KHR` specifies that control will be returned to the application if any individual pipeline returns a result which is not `VK_SUCCESS` rather than continuing to create additional pipelines.

- `VK_PIPELINE_CREATE_2_RAY_TRACING_ALLOW_MOTION_BIT_NV` specifies that the pipeline is allowed to use `OpTraceRayMotionNV`.

- `VK_PIPELINE_CREATE_2_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR` specifies that the pipeline will be used with a fragment shading rate attachment.

- `VK_PIPELINE_CREATE_2_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT` specifies that the pipeline will be used with a fragment density map attachment.

- `VK_PIPELINE_CREATE_2_LINK_TIME_OPTIMIZATION_BIT_EXT` specifies that pipeline libraries being linked into this library should have link time optimizations applied. If this bit is omitted, implementations should instead perform linking as rapidly as possible.

- `VK_PIPELINE_CREATE_2_RETAIN_LINK_TIME_OPTIMIZATION_INFO_BIT_EXT` specifies that pipeline libraries should retain any information necessary to later perform an optimal link with `VK_PIPELINE_CREATE_2_LINK_TIME_OPTIMIZATION_BIT_EXT`.

- `VK_PIPELINE_CREATE_2_DESCRIPTOR_BUFFER_BIT_EXT` specifies that a pipeline will be used with descriptor buffers, rather than descriptor sets.

- `VK_PIPELINE_CREATE_2_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` specifies that the pipeline may be used with an attachment feedback loop including color attachments.

- `VK_PIPELINE_CREATE_2_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` specifies that the pipeline may be used with an attachment feedback loop including depth-stencil attachments.

- `VK_PIPELINE_CREATE_2_RAY_TRACING_OPACITY_MICROMAP_BIT_EXT` specifies that the pipeline can be used with acceleration structures which reference an opacity micromap array.

- `VK_PIPELINE_CREATE_2_RAY_TRACING_DISPLACEMENT_MICROMAP_BIT_NV` specifies that the pipeline can be used with acceleration structures which reference a displacement micromap array.

- `VK_PIPELINE_CREATE_2_NO_PROTECTED_ACCESS_BIT_EXT` specifies that the pipeline must not be bound to a protected command buffer.

- `VK_PIPELINE_CREATE_2_PROTECTED_ACCESS_ONLY_BIT_EXT` specifies that the pipeline must not be bound to an unprotected command buffer.
It is valid to set both `VK_PIPELINE_CREATE_2_ALLOW_DERIVATIVES_BIT_KHR` and `VK_PIPELINE_CREATE_2_DERIVATIVE_BIT_KHR`. This allows a pipeline to be both a parent and possibly a child in a pipeline hierarchy. See Pipeline Derivatives for more information.

When an implementation is looking up a pipeline in a pipeline cache, if that pipeline is being created using linked libraries, implementations should always return an equivalent pipeline created with `VK_PIPELINE_CREATE_2_LINK_TIME_OPTIMIZATION_BIT_EXT` if available, whether or not that bit was specified.

**Note**

Using `VK_PIPELINE_CREATE_2_LINK_TIME_OPTIMIZATION_BIT_EXT` (or not) when linking pipeline libraries is intended as a performance tradeoff between host and device. If the bit is omitted, linking should be faster and produce a pipeline more rapidly, but performance of the pipeline on the target device may be reduced. If the bit is included, linking may be slower but should produce a pipeline with device performance comparable to a monolithically created pipeline. Using both options can allow latency-sensitive applications to generate a suboptimal but usable pipeline quickly, and then perform an optimal link in the background, substituting the result for the suboptimally linked pipeline as soon as it is available.

```c
// Provided by VK_KHR_maintenance5
typedef VkFlags64 VkPipelineCreateFlags2KHR;
```

`VkPipelineCreateFlags2KHR` is a bitmask type for setting a mask of zero or more `VkPipelineCreateFlagBits2KHR`.

Bits which can be set in

- `VkGraphicsPipelineCreateInfo::flags`
- `VkComputePipelineCreateInfo::flags`
- `VkRayTracingPipelineCreateInfoKHR::flags`
- `VkRayTracingPipelineCreateInfoNV::flags`

specify how a pipeline is created, and are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkPipelineCreateFlagBits {
    VK_PIPELINE_CREATE_DISABLE_OPTIMIZATION_BIT = 0x00000001,
    VK_PIPELINE_CREATE_ALLOW_DERIVATIVES_BIT = 0x00000002,
    VK_PIPELINE_CREATE_DERIVATIVE_BIT = 0x00000004,
    // Provided by VK_VERSION_1_1
    VK_PIPELINE_CREATE_VIEW_INDEX_FROM_DEVICE_INDEX_BIT = 0x00000008,
    // Provided by VK_VERSION_1_1
    VK_PIPELINE_CREATE_DISPATCH_BASE_BIT = 0x00000010,
    // Provided by VK_VERSION_1_3
    VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT = 0x00000100,
};
```
// Provided by VK_VERSION_1_3
VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT = 0x00000200,
// Provided by VK_KHR_dynamic_rendering with VK_KHR_fragment_shading_rate
VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR = 0x00000000,
// Provided by VK_KHR_dynamic_rendering with VK_EXT_fragment_density_map
VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT = 0x00400000,
// Provided by VK_KHR_ray_tracing_pipeline
VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR = 0x00004000,
// Provided by VK_KHR_ray_tracing_pipeline
VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR = 0x00008000,
// Provided by VK_KHR_ray_tracing_pipeline
VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR = 0x00010000,
// Provided by VK_KHR_ray_tracing_pipeline
VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR = 0x00020000,
// Provided by VK_KHR_ray_tracing_pipeline
VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR = 0x00001000,
// Provided by VK_KHR_ray_tracing_pipeline
VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR = 0x00002000,
// Provided by VK_KHR_ray_tracing_pipeline
VK_PIPELINE_CREATE_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR = 0x00080000,
// Provided by VK_NV_ray_tracing
VK_PIPELINE_CREATE_DEFER_COMPILE_BIT_NV = 0x00000020,
// Provided by VK_KHR_pipeline_executable_properties
VK_PIPELINE_CREATE_CAPTURE_STATISTICS_BIT_KHR = 0x00000040,
// Provided by VK_KHR_pipeline_executable_properties
VK_PIPELINE_CREATE_CAPTURE_INTERNAL_REPRESENTATIONS_BIT_KHR = 0x00000080,
// Provided by VK_NV_device_generated_commands
VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV = 0x00040000,
// Provided by VK_KHR_pipeline_library
VK_PIPELINE_CREATE_LIBRARY_BIT_KHR = 0x00000800,
// Provided by VK_EXT_descriptor_buffer
VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT = 0x20000000,
// Provided by VK_EXT_graphics_pipeline_library
VK_PIPELINE_CREATE_RETAIN_LINK_TIME_OPTIMIZATION_INFO_BIT_EXT = 0x00800000,
// Provided by VK_EXT_graphics_pipeline_library
VK_PIPELINE_CREATE_LINK_TIME_OPTIMIZATION_BIT_EXT = 0x00000400,
// Provided by VK_NV_ray_tracing_motion_blur
VK_PIPELINE_CREATE_RAY_TRACING_ALLOW_MOTION_BIT_NV = 0x00100000,
// Provided by VK_EXT_attachment_feedback_loop_layout
VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT = 0x02000000,
// Provided by VK_EXT_attachment_feedback_loop_layout
VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT = 0x04000000,
// Provided by VK_EXT_opacity_micromap
VK_PIPELINE_CREATE_RAY_TRACING_OPACITY_MICROMAP_BIT_EXT = 0x01000000,
#endif
// Provided by VK_ENABLE_BETA_EXTENSIONS
VK_PIPELINE_CREATE_RAY_TRACING_DISPLACEMENT_MICROMAP_BIT_NV = 0x10000000,
#endif
// Provided by VK_EXT_pipeline_protected_access
// Provided by VK_NV_pipeline_protected_access
VK_PIPELINE_CREATE_NO_PROTECTED_ACCESS_BIT_EXT = 0x08000000,
// Provided by VK_EXT_pipeline_protected_access
VK_PIPELINE_CREATE_PROTECTED_ACCESS_ONLY_BIT_EXT = 0x40000000,
// Provided by VK_VERSION_1_1
VK_PIPELINE_CREATE_DISPATCH_BASE = VK_PIPELINE_CREATE_DISPATCH_BASE_BIT,
// Provided by VK_KHR_dynamic_rendering with VK_KHR_fragment_shading_rate
VK_PIPELINE_RASTERIZATION_STATE_CREATE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR = VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR,
// Provided by VK_KHR_dynamic_rendering with VK_EXT_fragment_density_map
VK_PIPELINE_RASTERIZATION_STATE_CREATE_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT = VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT,
// Provided by VK_KHR_device_group
VK_PIPELINE_CREATE_VIEW_INDEX_FROM_DEVICE_INDEX_BIT_KHR = VK_PIPELINE_CREATE_VIEW_INDEX_FROM_DEVICE_INDEX_BIT,
// Provided by VK_KHR_device_group
VK_PIPELINE_CREATE_DISPATCH_BASE_KHR = VK_PIPELINE_CREATE_DISPATCH_BASE,
// Provided by VK_EXT_pipeline_creation_cache_control
VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT_EXT = VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT,
// Provided by VK_EXT_pipeline_creation_cache_control
VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT_EXT = VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT

VkPipelineCreateFlagBits

- **VK_PIPELINE_CREATE_DISABLE_OPTIMIZATION_BIT** specifies that the created pipeline will not be optimized. Using this flag **may** reduce the time taken to create the pipeline.

- **VK_PIPELINE_CREATE_ALLOW_DERIVATIVES_BIT** specifies that the pipeline to be created is allowed to be the parent of a pipeline that will be created in a subsequent pipeline creation call.

- **VK_PIPELINE_CREATE_DERIVATIVE_BIT** specifies that the pipeline to be created will be a child of a previously created parent pipeline.

- **VK_PIPELINE_CREATE_VIEW_INDEX_FROM_DEVICE_INDEX_BIT** specifies that any shader input variables decorated as `ViewIndex` will be assigned values as if they were decorated as `DeviceIndex`.

- **VK_PIPELINE_CREATE_DISPATCH_BASE** specifies that a compute pipeline **can** be used with `vkCmdDispatchBase` with a non-zero base workgroup.

- **VK_PIPELINE_CREATE_DEFER_COMPILE_BIT_NV** specifies that a pipeline is created with all shaders in the deferred state. Before using the pipeline the application **must** call `vkCompileDeferredNV` exactly once on each shader in the pipeline before using the pipeline.

- **VK_PIPELINE_CREATE_CAPTURE_STATISTICS_BIT_KHR** specifies that the shader compiler should capture statistics for the pipeline executables produced by the compile process which **can** later be retrieved by calling `vkGetPipelineExecutableStatisticsKHR`. Enabling this flag **must** not affect the final compiled pipeline but **may** disable pipeline caching or otherwise affect pipeline creation time.

- **VK_PIPELINE_CREATE_CAPTURE_INTERNAL_REPRESENTATIONS_BIT_KHR** specifies that the shader compiler should capture the internal representations of pipeline executables produced by the compile process which **can** later be retrieved by calling `vkGetPipelineExecutableInternalRepresentationsKHR`. Enabling this flag **must** not affect the
final compiled pipeline but **may** disable pipeline caching or otherwise affect pipeline creation time. When capturing IR from pipelines created with pipeline libraries, there is no guarantee that IR from libraries **can** be retrieved from the linked pipeline. Applications **should** retrieve IR from each library, and any linked pipelines, separately.

- **VK_PIPELINE_CREATE_LIBRARY_BIT_KHR** specifies that the pipeline **cannot** be used directly, and instead defines a **pipeline library** that **can** be combined with other pipelines using the `VkPipelineLibraryCreateInfoKHR` structure. This is available in ray tracing and graphics pipelines.

- **VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR** specifies that an any-hit shader will always be present when an any-hit shader would be executed. A NULL any-hit shader is an any-hit shader which is effectively **VK_SHADER_UNUSED_KHR**, such as from a shader group consisting entirely of zeros.

- **VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR** specifies that a closest hit shader will always be present when a closest hit shader would be executed. A NULL closest hit shader is a closest hit shader which is effectively **VK_SHADER_UNUSED_KHR**, such as from a shader group consisting entirely of zeros.

- **VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR** specifies that a miss shader will always be present when a miss shader would be executed. A NULL miss shader is a miss shader which is effectively **VK_SHADER_UNUSED_KHR**, such as from a shader group consisting entirely of zeros.

- **VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR** specifies that an intersection shader will always be present when an intersection shader would be executed. A NULL intersection shader is an intersection shader which is effectively **VK_SHADER_UNUSED_KHR**, such as from a shader group consisting entirely of zeros.

- **VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR** specifies that triangle primitives will be skipped during traversal using `OpTraceRayKHR`.

- **VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR** specifies that AABB primitives will be skipped during traversal using `OpTraceRayKHR`.

- **VK_PIPELINE_CREATE_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR** specifies that the shader group handles **can** be saved and reused on a subsequent run (e.g. for trace capture and replay).

- **VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV** specifies that the pipeline can be used in combination with Device-Generated Commands.

- **VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT** specifies that pipeline creation will fail if a compile is required for creation of a valid `VkPipeline` object; **VK_PIPELINE_COMPILE_REQUIRED** will be returned by pipeline creation, and the `VkPipeline` will be set to **VK_NULL_HANDLE**.

- When creating multiple pipelines, **VK_PIPELINE_CREATE_EARLY_RETURN_ON.FAILURE_BIT** specifies that control will be returned to the application if any individual pipeline returns a result which is not **VK_SUCCESS** rather than continuing to create additional pipelines.

- **VK_PIPELINE_CREATE_RAY_TRACING_ALLOW_MOTION_BIT_NV** specifies that the pipeline is allowed to use `OpTraceRayMotionNV`.

- **VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR** specifies that the
pipeline will be used with a fragment shading rate attachment and dynamic rendering.

- **VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT** specifies that the pipeline will be used with a fragment density map attachment and dynamic rendering.

- **VK_PIPELINE_CREATE_LINK_TIME_OPTIMIZATION_BIT_EXT** specifies that pipeline libraries being linked into this library should have link time optimizations applied. If this bit is omitted, implementations should instead perform linking as rapidly as possible.

- **VK_PIPELINE_CREATE_RETAIN_LINK_TIME_OPTIMIZATION_INFO_BIT_EXT** specifies that pipeline libraries should retain any information necessary to later perform an optimal link with **VK_PIPELINE_CREATE_LINK_TIME_OPTIMIZATION_BIT_EXT**.

- **VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT** specifies that a pipeline will be used with descriptor buffers, rather than descriptor sets.

- **VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT** specifies that the pipeline may be used with an attachment feedback loop including color attachments. It is ignored if **VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT** is set in **pDynamicStates**.

- **VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT** specifies that the pipeline may be used with an attachment feedback loop including depth-stencil attachments. It is ignored if **VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT** is set in **pDynamicStates**.

- **VK_PIPELINE_CREATE_RAY_TRACING_OPACITY_MICROMAP_BIT_EXT** specifies that the pipeline can be used with acceleration structures which reference an opacity micromap array.

- **VK_PIPELINE_CREATE_RAY_TRACING_DISPLACEMENT_MICROMAP_BIT_NV** specifies that the pipeline can be used with acceleration structures which reference a displacement micromap array.

- **VK_PIPELINE_CREATE_NO_PROTECTED_ACCESS_BIT_EXT** specifies that the pipeline must not be bound to a protected command buffer.

- **VK_PIPELINE_CREATE_PROTECTED_ACCESS_ONLY_BIT_EXT** specifies that the pipeline must not be bound to an unprotected command buffer.

It is valid to set both **VK_PIPELINE_CREATE_ALLOW_DERIVATIVES_BIT** and **VK_PIPELINE_CREATE_DERIVATIVE_BIT**. This allows a pipeline to be both a parent and possibly a child in a pipeline hierarchy. See [Pipeline Derivatives](#) for more information.

When an implementation is looking up a pipeline in a pipeline cache, if that pipeline is being created using linked libraries, implementations should always return an equivalent pipeline created with **VK_PIPELINE_CREATE_LINK_TIME_OPTIMIZATION_BIT_EXT** if available, whether or not that bit was specified.

**Note**

Using **VK_PIPELINE_CREATE_LINK_TIME_OPTIMIZATION_BIT_EXT** (or not) when linking pipeline libraries is intended as a performance tradeoff between host and device. If the bit is omitted, linking should be faster and produce a pipeline more rapidly, but performance of the pipeline on the target device may be reduced. If the bit is included, linking may be slower but should produce a pipeline with device performance comparable to a monolithically created pipeline. Using both options can allow latency-sensitive applications to generate a suboptimal but usable pipeline quickly, and then perform an optimal link in the background, substituting
the result for the suboptimally linked pipeline as soon as it is available.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkPipelineCreateFlags;
```

**VkPipelineCreateFlags** is a bitmask type for setting a mask of zero or more **VkPipelineCreateFlagBits**.

The **VkGraphicsPipelineLibraryCreateInfoEXT** structure is defined as:

```c
// Provided by VK_EXT_graphics_pipeline_library
typedef struct VkGraphicsPipelineLibraryCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkGraphicsPipelineLibraryFlagsEXT flags;
} VkGraphicsPipelineLibraryCreateInfoEXT;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **flags** is a bitmask of **VkGraphicsPipelineLibraryFlagBitsEXT** specifying the subsets of the graphics pipeline that are being compiled.

If a **VkGraphicsPipelineLibraryCreateInfoEXT** structure is included in the **pNext** chain of **VkGraphicsPipelineCreateInfo**, it specifies the subsets of the graphics pipeline being created, excluding any subsets from linked pipeline libraries. If the pipeline is created with pipeline libraries, state from those libraries is aggregated with said subset.

If this structure is omitted, and either **VkGraphicsPipelineCreateInfo::flags** includes **VK_PIPELINE_CREATE_LIBRARY_BIT_KHR** or the **VkGraphicsPipelineCreateInfo::pNext** chain includes a **VkPipelineLibraryCreateInfoKHR** structure with a **libraryCount** greater than 0, it is as if **flags** is 0. Otherwise if this structure is omitted, it is as if **flags** includes all possible subsets of the graphics pipeline (i.e. a complete graphics pipeline).

### Valid Usage (Implicit)

- VUID-VkGraphicsPipelineLibraryCreateInfoEXT-sType-sType
  **sType** must be **VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_LIBRARY_CREATE_INFO_EXT**

- VUID-VkGraphicsPipelineLibraryCreateInfoEXT-flags-parameter
  **flags** must be a valid combination of **VkGraphicsPipelineLibraryFlagBitsEXT** values

- VUID-VkGraphicsPipelineLibraryCreateInfoEXT-flags-requiredbitmask
  **flags** must not be 0
typedef VkFlags VkGraphicsPipelineLibraryFlagsEXT;

VkGraphicsPipelineLibraryFlagsEXT is a bitmask type for setting a mask of zero or more VkGraphicsPipelineLibraryFlagBitsEXT.

Possible values of the flags member of VkGraphicsPipelineLibraryCreateInfoEXT, specifying the subsets of a graphics pipeline to compile are:

```c
// Provided by VK_EXT_graphics_pipeline_library
typedef enum VkGraphicsPipelineLibraryFlagBitsEXT {
    VK_GRAPHICS_PIPELINE_LIBRARY_VERTEX_INPUT_INTERFACE_BIT_EXT = 0x00000001,
    VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT = 0x00000002,
    VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT = 0x00000004,
    VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT = 0x00000008,
} VkGraphicsPipelineLibraryFlagBitsEXT;
```

- **VK_GRAPHICS_PIPELINE_LIBRARY_VERTEX_INPUT_INTERFACE_BIT_EXT** specifies that a pipeline will include vertex input interface state.
- **VK_GRAPHICS_PIPELINE_LIBRARY_PRE_RASTERIZATION_SHADERS_BIT_EXT** specifies that a pipeline will include pre-rasterization shader state.
- **VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_SHADER_BIT_EXT** specifies that a pipeline will include fragment shader state.
- **VK_GRAPHICS_PIPELINE_LIBRARY_FRAGMENT_OUTPUT_INTERFACE_BIT_EXT** specifies that a pipeline will include fragment output interface state.

The VkPipelineDynamicStateCreateInfo structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPipelineDynamicStateCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkPipelineDynamicStateCreateFlags flags;
    uint32_t dynamicStateCount;
    const VkDynamicState* pDynamicStates;
} VkPipelineDynamicStateCreateInfo;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **dynamicStateCount** is the number of elements in the pDynamicStates array.
- **pDynamicStates** is a pointer to an array of VkDynamicState values specifying which pieces of pipeline state will use the values from dynamic state commands rather than from pipeline state creation information.
Valid Usage

- VUID-VkPipelineDynamicStateCreateInfo-pDynamicStates-01442
  Each element of pDynamicStates must be unique

Valid Usage (Implicit)

- VUID-VkPipelineDynamicStateCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_PIPELINE_DYNAMIC_STATE_CREATE_INFO
- VUID-VkPipelineDynamicStateCreateInfo-pNext-pNext
  pNext must be NULL
- VUID-VkPipelineDynamicStateCreateInfo-flags-zerobitmask
  flags must be 0
- VUID-VkPipelineDynamicStateCreateInfo-pDynamicStates-parameter
  If dynamicStateCount is not 0, pDynamicStates must be a valid pointer to an array of
dynamicStateCount valid VkDynamicState values

// Provided by VK_VERSION_1_0
typedef VkFlags VkPipelineDynamicStateCreateFlags;

VkPipelineDynamicStateCreateFlags is a bitmask type for setting a mask, but is currently reserved for
future use.

The source of different pieces of dynamic state is specified by the
VkPipelineDynamicStateCreateInfo::pDynamicStates property of the currently active pipeline, each
of whose elements must be one of the values:

// Provided by VK_VERSION_1_0
typedef enum VkDynamicState {
    VK_DYNAMIC_STATE_VIEWPORT = 0,
    VK_DYNAMIC_STATE_SCISSOR = 1,
    VK_DYNAMIC_STATE_LINE_WIDTH = 2,
    VK_DYNAMIC_STATE_DEPTH_BIAS = 3,
    VK_DYNAMIC_STATE_BLEND_CONSTANTS = 4,
    VK_DYNAMIC_STATE_DEPTH_BOUNDS = 5,
    VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK = 6,
    VK_DYNAMIC_STATE_STENCIL_WRITE_MASK = 7,
    VK_DYNAMIC_STATE_STENCIL_REFERENCE = 8,
    // Provided by VK_VERSION_1_3
    VK_DYNAMIC_STATE_CULL_MODE = 1000267000,
    // Provided by VK_VERSION_1_3
    VK_DYNAMIC_STATE_FRONT_FACE = 1000267001,
    // Provided by VK_VERSION_1_3
    VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY = 1000267002,
};
VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT = 1000267003,
VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT = 1000267004,
VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE = 1000267005,
VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE = 1000267006,
VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE = 1000267007,
VK_DYNAMIC_STATE_DEPTH_COMPARE_OP = 1000267008,
VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE = 1000267009,
VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE = 1000267010,
VK_DYNAMIC_STATE_STENCIL_OP = 1000267011,
RK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE = 1000377001,
VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE = 1000377002,
VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE = 1000377004,
VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV = 1000087000,
VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT = 1000099000,
VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT = 1000099001,
VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT = 1000099002,
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT = 1000143000,
VK_DYNAMIC_STATE_RAY_TRACING_PIPELINE_STACK_SIZE_KHR = 1000347000,
VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV = 1000164004,
VK_DYNAMIC_STATE_VIEWPORT_COARSE_SAMPLE_ORDER_NV = 1000164006,
VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV = 1000205000,
VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV = 1000205001,
VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR = 1000226000,
VK_DYNAMIC_STATE_LINE_STIPPLE_EXT = 1000259000,
VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT = 1000377000,
// Provided by VK_EXT_extended_dynamic_state2
VK_DYNAMIC_STATE_LOGIC_OP_EXT = 1000377003,
// Provided by VK_EXT_color_write_enable
VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT = 1000381000,
// Provided by VK_EXT_color_write_enable
VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT = 1000455002,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT = 1000455003,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_POLYGON_MODE_EXT = 1000455004,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT = 1000455005,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_SAMPLE_MASK_EXT = 1000455006,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT = 1000455007,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT = 1000455008,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT = 1000455009,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT = 1000455010,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT = 1000455011,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT = 1000455012,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT = 1000455013,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT = 1000455014,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT = 1000455015,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT = 1000455016,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT = 1000455017,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT = 1000455018,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT = 1000455019,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT = 1000455020,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT = 1000455021,
// Provided by VK_EXT_extended_dynamic_state3
VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT = 1000455022
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_clip_space_w_scaling
VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV = 1000455023,
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_viewport_swizzle
VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV = 1000455024,
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_fragment_coverage_to_color
VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV = 1000455025,
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_fragment_coverage_to_color
VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV = 1000455026,
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_framebuffer_mixed_samples
VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV = 1000455027,
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_framebuffer_mixed_samples
VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV = 1000455028,
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_framebuffer_mixed_samples
VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV = 1000455029,
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_shading_rate_image
VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV = 1000455030,
// Provided by VK_EXT_extended_dynamic_state3 with
VK_NV_representative_fragment_test
VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV = 1000455031,
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_coverage_reduction_mode
VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV = 1000455032,
// Provided by VK_EXT_attachment_feedback_loop_dynamic_state
VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT = 1000524000,
// Provided by VK_EXT_extended_dynamic_state
VK_DYNAMIC_STATE_CULL_MODE_EXT = VK_DYNAMIC_STATE_CULL_MODE,
// Provided by VK_EXT_extended_dynamic_state
VK_DYNAMIC_STATE_FRONT_FACE_EXT = VK_DYNAMIC_STATE_FRONT_FACE,
// Provided by VK_EXT_extended_dynamic_state
VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY_EXT = VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY,
// Provided by VK_EXT_extended_dynamic_state
VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT_EXT = VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT,
// Provided by VK_EXT_extended_dynamic_state
VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT_EXT = VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT,
// Provided by VK_EXT_extended_dynamic_state
VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT = VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE,
// Provided by VK_EXT_extended_dynamic_state
VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE_EXT = VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE,
// Provided by VK_EXT_extended_dynamic_state
VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE_EXT = VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE,
// Provided by VK_EXT_extended_dynamic_state
VK_DYNAMIC_STATE_DEPTH_COMPARE_OP_EXT = VK_DYNAMIC_STATE_DEPTH_COMPARE_OP,
// Provided by VK_EXT_extended_dynamic_state
VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE_EXT = VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE,
// Provided by VK_EXT_extended_dynamic_state
VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE_EXT = VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE,
// Provided by VK_EXT_extended_dynamic_state
VK_DYNAMIC_STATE_STENCIL_OP_EXT = VK_DYNAMIC_STATE_STENCIL_OP,
// Provided by VK_EXT_extended_dynamic_state2
VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE_EXT = VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE,
// Provided by VK_EXT_extended_dynamic_state2
VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE_EXT = VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE,
VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE_EXT = 
VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE,
} VkDynamicState;

- **VK_DYNAMIC_STATE_VIEWPORT** specifies that the `pViewports` state in `VkPipelineViewportStateCreateInfo` will be ignored and **must** be set dynamically with `vkCmdSetViewport` before any drawing commands. The number of viewports used by a pipeline is still specified by the `viewportCount` member of `VkPipelineViewportStateCreateInfo`.

- **VK_DYNAMIC_STATE_SCISSOR** specifies that the `pScissors` state in `VkPipelineViewportStateCreateInfo` will be ignored and **must** be set dynamically with `vkCmdSetScissor` before any drawing commands. The number of scissor rectangles used by a pipeline is still specified by the `scissorCount` member of `VkPipelineViewportStateCreateInfo`.

- **VK_DYNAMIC_STATE_LINE_WIDTH** specifies that the `lineWidth` state in `VkPipelineRasterizationStateCreateInfo` will be ignored and **must** be set dynamically with `vkCmdSetLineWidth` before any drawing commands that generate line primitives for the rasterizer.

- **VK_DYNAMIC_STATE_DEPTH_BIAS** specifies that any instance of `VkDepthBiasRepresentationInfoEXT` included in the `pNext` chain of `VkPipelineRasterizationStateCreateInfo` as well as the `depthBiasConstantFactor`, `depthBiasClamp` and `depthBiasSlopeFactor` states in `VkPipelineRasterizationStateCreateInfo` will be ignored and **must** be set dynamically with either `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` before any draws are performed with depth bias enabled.

- **VK_DYNAMIC_STATE_BLEND_CONSTANTS** specifies that the `blendConstants` state in `VkPipelineColorBlendStateCreateInfo` will be ignored and **must** be set dynamically with `vkCmdSetBlendConstants` before any draws are performed with a pipeline state with `VkPipelineColorBlendAttachmentState` member `blendEnable` set to `VK_TRUE` and any of the blend functions using a constant blend color.

- **VK_DYNAMIC_STATE_DEPTH_BOUNDS** specifies that the `minDepthBounds` and `maxDepthBounds` states of `VkPipelineDepthStencilStateCreateInfo` will be ignored and **must** be set dynamically with `vkCmdSetDepthBounds` before any draws are performed with a pipeline state with `VkPipelineDepthStencilStateCreateInfo` member `depthBoundsTestEnable` set to `VK_TRUE`.

- **VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK** specifies that the `compareMask` state in `VkPipelineDepthStencilStateCreateInfo` for both `front` and `back` will be ignored and **must** be set dynamically with `vkCmdSetStencilCompareMask` before any draws are performed with a pipeline state with `VkPipelineDepthStencilStateCreateInfo` member `stencilTestEnable` set to `VK_TRUE`.

- **VK_DYNAMIC_STATE_STENCIL_WRITE_MASK** specifies that the `writeMask` state in `VkPipelineDepthStencilStateCreateInfo` for both `front` and `back` will be ignored and **must** be set dynamically with `vkCmdSetStencilWriteMask` before any draws are performed with a pipeline state with `VkPipelineDepthStencilStateCreateInfo` member `stencilTestEnable` set to `VK_TRUE`.

- **VK_DYNAMIC_STATE_STENCIL_REFERENCE** specifies that the `reference` state in `VkPipelineDepthStencilStateCreateInfo` for both `front` and `back` will be ignored and **must** be set dynamically with `vkCmdSetStencilReference` before any draws are performed with a pipeline state with `VkPipelineDepthStencilStateCreateInfo` member `stencilTestEnable` set to `VK_TRUE`.


• **VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV** specifies that the pViewportWScalings state in VkPipelineViewportWScalingStateCreateInfoNV will be ignored and must be set dynamically with vkCmdSetViewportWScalingNV before any draws are performed with a pipeline state with VkPipelineViewportWScalingStateCreateInfoNV member viewportScalingEnable set to VK_TRUE.

• **VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT** specifies that the pDiscardRectangles state in VkPipelineDiscardRectangleStateCreateInfoEXT will be ignored and must be set dynamically with vkCmdSetDiscardRectangleNV before any draws are performed with a pipeline state with VkPipelineDiscardRectangleStateCreateInfoEXT.

• **VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT** specifies that the presence of the VkPipelineDiscardRectangleStateCreateInfoEXT structure in the VkGraphicsPipelineCreateInfo chain with a discardRectangleCount greater than zero does not implicitly enable discard rectangles and they must be enabled dynamically with vkCmdSetDiscardRectangleEnableEXT before any draw commands. This is available on implementations that support at least specVersion 2 of the VK_EXT_discard_rectangles extension.

• **VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT** specifies that the discardRectangleMode state in VkPipelineDiscardRectangleStateCreateInfoEXT will be ignored and must be set dynamically with vkCmdSetDiscardRectangleModeEXT before any draw commands. This is available on implementations that support at least specVersion 2 of the VK_EXT_discard_rectangles extension.

• **VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT** specifies that the sampleLocationsInfo state in VkPipelineSampleLocationsStateCreateInfoEXT will be ignored and must be set dynamically with vkCmdSetSampleLocationsEXT before any draw or clear commands. Enabling custom sample locations is still indicated by the sampleLocationsEnable member of VkPipelineSampleLocationsStateCreateInfoEXT.

• **VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV** specifies that the pExclusiveScissors state in VkPipelineViewportExclusiveScissorStateCreateInfoNV will be ignored and must be set dynamically with vkCmdSetExclusiveScissorNV before any drawing commands.

• **VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV** specifies that the exclusive scissors must be explicitly enabled with vkCmdSetExclusiveScissorEnableNV and the exclusiveScissorCount value in VkPipelineViewportExclusiveScissorStateCreateInfoNV will not implicitly enable them. This is available on implementations that support at least specVersion 2 of the VK_NV_scissor_exclusive extension.

• **VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV** specifies that the pShadingRatePalettes state in VkPipelineViewportShadingRateImageStateCreateInfoNV will be ignored and must be set dynamically with vkCmdSetViewportShadingRatePaletteNV before any drawing commands.

• **VK_DYNAMIC_STATE_VIEWPORT_COARSE_SAMPLE_ORDER_NV** specifies that the coarse sample order state in VkPipelineViewportCoarseSampleOrderStateCreateInfoNV will be ignored and must be set dynamically with vkCmdSetCoarseSampleOrderNV before any drawing commands.

• **VK_DYNAMIC_STATE_LINE_STIPPLE_EXT** specifies that the lineStippleFactor and lineStipplePattern state in VkPipelineRasterizationLineStateCreateInfoEXT will be ignored and must be set dynamically with vkCmdSetLineStippleEXT before any draws are performed with a pipeline state with VkPipelineRasterizationLineStateCreateInfoEXT member stippledLineEnable set to VK_TRUE.

• **VK_DYNAMIC_STATE_CULL_MODE** specifies that the cullMode state in VkPipelineRasterizationStateCreateInfo will be ignored and must be set dynamically with vkCmdSetCullMode before any drawing commands.
• **VK_DYNAMIC_STATE_FRONT_FACE** specifies that the `frontFace` state in `VkPipelineRasterizationStateCreateInfo` will be ignored and must be set dynamically with `vkCmdSetFrontFace` before any drawing commands.

• **VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY** specifies that the `topology` state in ` VkPipelineInputAssemblyStateCreateInfo` only specifies the topology class, and the specific topology order and adjacency must be set dynamically with `vkCmdSetPrimitiveTopology` before any drawing commands.

• **VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT** specifies that the `viewportCount` and `pViewports` state in `VkPipelineViewportStateCreateInfo` will be ignored and must be set dynamically with `vkCmdSetViewportWithCount` before any draw call.

• **VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT** specifies that the `scissorCount` and `pScissors` state in `VkPipelineViewportStateCreateInfo` will be ignored and must be set dynamically with `vkCmdSetScissorWithCount` before any draw call.

• **VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE** specifies that the `stride` state in `VkVertexInputBindingDescription` will be ignored and must be set dynamically with `vkCmdBindVertexBuffers2` before any draw call.

• **VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE** specifies that the `depthTestEnable` state in `VkPipelineDepthStencilStateCreateInfo` will be ignored and must be set dynamically with `vkCmdSetDepthTestEnable` before any draw call.

• **VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE** specifies that the `depthWriteEnable` state in `VkPipelineDepthStencilStateCreateInfo` will be ignored and must be set dynamically with `vkCmdSetDepthWriteEnable` before any draw call.

• **VK_DYNAMIC_STATE_DEPTH_COMPARE_OP** specifies that the `depthCompareOp` state in `VkPipelineDepthStencilStateCreateInfo` will be ignored and must be set dynamically with `vkCmdSetDepthCompareOp` before any draw call.

• **VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE** specifies that the `depthBoundsTestEnable` state in `VkPipelineDepthStencilStateCreateInfo` will be ignored and must be set dynamically with `vkCmdSetDepthBoundsTestEnable` before any draw call.

• **VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE** specifies that the `stencilTestEnable` state in `VkPipelineDepthStencilStateCreateInfo` will be ignored and must be set dynamically with `vkCmdSetStencilTestEnable` before any draw call.

• **VK_DYNAMIC_STATE_STENCIL_OP** specifies that the `failOp`, `passOp`, `depthFailOp`, and `compareOp` states in `VkPipelineDepthStencilStateCreateInfo` for both `front` and `back` will be ignored and must be set dynamically with `vkCmdSetStencilOp` before any draws are performed with a pipeline state with `VkPipelineDepthStencilStateCreateInfo` member `stencilTestEnable` set to `VK_TRUE`.

• **VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT** specifies that the `patchControlPoints` state in `VkPipelineTessellationStateCreateInfo` will be ignored and must be set dynamically with `vkCmdSetPatchControlPointsEXT` before any drawing commands.

• **VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE** specifies that the `rasterizerDiscardEnable` state in `VkPipelineRasterizationStateCreateInfo` will be ignored and must be set dynamically with `vkCmdSetRasterizerDiscardEnable` before any drawing commands.

• **VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE** specifies that the `depthBiasEnable` state in `VkPipelineRasterizationStateCreateInfo` will be ignored and must be set dynamically with
vkCmdSetDepthBiasEnable before any drawing commands.

- **VK_DYNAMIC_STATE_LOGIC_OP_EXT** specifies that the logicOp state in VkPipelineColorBlendStateCreateInfo will be ignored and **must** be set dynamically with vkCmdSetLogicOpEXT before any drawing commands.

- **VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE** specifies that the primitiveRestartEnable state in VkPipelineInputAssemblyStateCreateInfo will be ignored and **must** be set dynamically with vkCmdSetPrimitiveRestartEnable before any drawing commands.

- **VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR** specifies that state in VkPipelineFragmentShadingRateStateCreateInfoKHR and VkPipelineFragmentShadingRateEnumStateCreateInfoNV will be ignored and **must** be set dynamically with vkCmdSetFragmentShadingRateKHR or vkCmdSetFragmentShadingRateEnumNV before any drawing commands.

- **VK_DYNAMIC_STATE_RAY_TRACING_PIPELINE_STACK_SIZE_KHR** specifies that the default stack size computation for the pipeline will be ignored and **must** be set dynamically with vkCmdSetRayTracingPipelineStackSizeKHR before any ray tracing calls are performed.

- **VK_DYNAMIC_STATE_VERTEX_INPUT_EXT** specifies that the pVertexInputState state will be ignored and **must** be set dynamically with vkCmdSetVertexInputEXT before any drawing commands.

- **VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT** specifies that the pColorWriteEnables state in VkPipelineColorWriteCreateInfoEXT will be ignored and **must** be set dynamically with vkCmdSetColorWriteEnableEXT before any draw call.

- **VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT** specifies that the domainOrigin state in VkPipelineTessellationDomainOriginStateCreateInfo will be ignored and **must** be set dynamically with vkCmdSetTessellationDomainOriginEXT before any draw call.

- **VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT** specifies that the depthClampEnable state in VkPipelineRasterizationStateCreateInfo will be ignored and **must** be set dynamically with vkCmdSetDepthClampEnableEXT before any draw call.

- **VK_DYNAMIC_STATE_POLYGON_MODE_EXT** specifies that the polygonMode state in VkPipelineRasterizationStateCreateInfo will be ignored and **must** be set dynamically with vkCmdSetPolygonModeEXT before any draw call.

- **VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT** specifies that the rasterizationSamples state in VkPipelineMultisampleStateCreateInfo will be ignored and **must** be set dynamically with vkCmdSetRasterizationSamplesEXT before any draw call.

- **VK_DYNAMIC_STATE_SAMPLE_MASK_EXT** specifies that the pSampleMask state in VkPipelineMultisampleStateCreateInfo will be ignored and **must** be set dynamically with vkCmdSetSampleMaskEXT before any draw call.

- **VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT** specifies that the alphaToCoverageEnable state in VkPipelineMultisampleStateCreateInfo will be ignored and **must** be set dynamically with vkCmdSetAlphaToCoverageEnableEXT before any draw call.

- **VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT** specifies that the alphaToOneEnable state in VkPipelineMultisampleStateCreateInfo will be ignored and **must** be set dynamically with vkCmdSetAlphaToOneEnableEXT before any draw call.

- **VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT** specifies that the logicOpEnable state in VkPipelineColorBlendStateCreateInfo will be ignored and **must** be set dynamically with vkCmdSetLogicOpEXT before any drawing commands.
VkPipelineColorBlendStateCreateInfo will be ignored and **must** be set dynamically with vkCmdSetLogicOpEnableEXT before any draw call.

- **VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT** specifies that the **blendEnable** state in VkPipelineColorBlendAttachmentState will be ignored and **must** be set dynamically with vkCmdSetColorBlendEnableEXT before any draw call.

- **VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT** specifies that the **srcColorBlendFactor**, **dstColorBlendFactor**, **colorBlendOp**, **srcAlphaBlendFactor**, **dstAlphaBlendFactor**, and **alphaBlendOp** states in VkPipelineColorBlendAttachmentState will be ignored and **must** be set dynamically with vkCmdSetColorBlendEquationEXT before any draw call.

- **VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT** specifies that the **colorWriteMask** state in VkPipelineColorBlendAttachmentState will be ignored and **must** be set dynamically with vkCmdSetColorWriteMaskEXT before any draw call.

- **VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT** specifies that the **rasterizationStream** state in VkPipelineRasterizationStateStreamCreateInfoEXT will be ignored and **must** be set dynamically with vkCmdSetRasterizationStreamEXT before any draw call.

- **VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT** specifies that the **conservativeRasterizationMode** state in VkPipelineRasterizationConservativeStateCreateInfoEXT will be ignored and **must** be set dynamically with vkCmdSetConservativeRasterizationModeEXT before any draw call.

- **VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT** specifies that the **extraPrimitiveOverestimationSize** state in VkPipelineRasterizationConservativeStateCreateInfoEXT will be ignored and **must** be set dynamically with vkCmdSetExtraPrimitiveOverestimationSizeEXT before any draw call.

- **VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT** specifies that the **depthClipEnable** state in VkPipelineRasterizationDepthClipStateCreateInfoEXT will be ignored and **must** be set dynamically with vkCmdSetDepthClipEnableEXT before any draw call.

- **VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT** specifies that the **sampleLocationsEnable** state in VkPipelineSampleLocationsStateCreateInfoEXT will be ignored and **must** be set dynamically with vkCmdSetSampleLocationsEnableEXT before any draw call.

- **VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT** specifies that the **colorBlendOp** state in VkPipelineColorBlendAttachmentState, and **srcPremultiplied**, **dstPremultiplied**, and **blendOverlap** states in VkPipelineColorBlendAdvancedStateCreateInfoEXT will be ignored and **must** be set dynamically with vkCmdSetColorBlendAdvancedEXT before any draw call.

- **VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT** specifies that the **provokingVertexMode** state in VkPipelineRasterizationProvokingVertexStateCreateInfoEXT will be ignored and **must** be set dynamically with vkCmdSetProvokingVertexModeEXT before any draw call.

- **VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT** specifies that the **lineRasterizationMode** state in VkPipelineRasterizationLineStateCreateInfoEXT will be ignored and **must** be set dynamically with vkCmdSetLineRasterizationModeEXT before any draw call.

- **VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT** specifies that the **stippledLineEnable** state in VkPipelineRasterizationLineStateCreateInfoEXT will be ignored and **must** be set dynamically with vkCmdSetLineStippleEnableEXT before any draw call.

- **VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT** specifies that the **negativeOneToOne** state in
VkPipelineViewportDepthClipControlCreateInfoEXT will be ignored and **must** be set dynamically with `vkCmdSetDepthClipNegativeOneToOneEXT` before any draw call.

* **VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV** specifies that the `viewportWScalingEnable` state in VkPipelineViewportWScalingStateCreateInfoNV will be ignored and **must** be set dynamically with `vkCmdSetViewportWScalingEnableNV` before any draw call.

* **VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV** specifies that the `viewportCount`, and `pViewportSwizzles` states in VkPipelineViewportSwizzleStateCreateInfoNV will be ignored and **must** be set dynamically with `vkCmdSetViewportSwizzleNV` before any draw call.

* **VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV** specifies that the `coverageToColorEnable` state in VkPipelineCoverageToColorStateCreateInfoNV will be ignored and **must** be set dynamically with `vkCmdSetCoverageToColorEnableNV` before any draw call.

* **VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV** specifies that the `coverageToColorLocation` state in VkPipelineCoverageToColorStateCreateInfoNV will be ignored and **must** be set dynamically with `vkCmdSetCoverageToColorLocationNV` before any draw call.

* **VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV** specifies that the `coverageModulationMode` state in VkPipelineCoverageModulationStateCreateInfoNV will be ignored and **must** be set dynamically with `vkCmdSetCoverageModulationModeNV` before any draw call.

* **VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV** specifies that the `coverageModulationTableEnable` state in VkPipelineCoverageModulationStateCreateInfoNV will be ignored and **must** be set dynamically with `vkCmdSetCoverageModulationTableEnableNV` before any draw call.

* **VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV** specifies that the `representativeFragmentTestEnable` state in VkPipelineRepresentativeFragmentTestStateCreateInfoNV will be ignored and **must** be set dynamically with `vkCmdSetRepresentativeFragmentTestEnableNV` before any draw call.

* **VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV** specifies that the `coverageReductionMode` state in VkPipelineCoverageReductionStateCreateInfoNV will be ignored and **must** be set dynamically with `vkCmdSetCoverageReductionModeNV` before any draw call.

* **VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT** specifies that the `VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` and `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` flags will be ignored and **must** be set dynamically with `vkCmdSetAttachmentFeedbackLoopEnableEXT` before any draw call.
10.2.1. Valid Combinations of Stages for Graphics Pipelines

Primitive processing can be handled either on a per primitive basis by the vertex, tessellation, and geometry shader stages, or on a per mesh basis using task and mesh shader stages. If the pipeline includes a mesh shader stage, it uses the mesh pipeline, otherwise it uses the primitive pipeline.

If a task shader is omitted, the task shading stage is skipped.

If tessellation shader stages are omitted, the tessellation shading and fixed-function stages of the pipeline are skipped.

If a geometry shader is omitted, the geometry shading stage is skipped.

If a fragment shader is omitted, fragment color outputs have undefined values, and the fragment depth value is determined by Fragment Operations state. This can be useful for depth-only rendering.

Presence of a shader stage in a pipeline is indicated by including a valid VkPipelineShaderStageCreateInfo with module and pName selecting an entry point from a shader module, where that entry point is valid for the stage specified by stage.

Presence of some of the fixed-function stages in the pipeline is implicitly derived from enabled shaders and provided state. For example, the fixed-function tessellator is always present when the pipeline has valid Tessellation Control and Tessellation Evaluation shaders.

For example:

- Depth/stencil-only rendering in a subpass with no color attachments
  - Active Pipeline Shader Stages
    - Vertex Shader
  - Required: Fixed-Function Pipeline Stages
    - VkPipelineVertexInputStateCreateInfo
    - VkPipelineInputAssemblyStateCreateInfo
    - VkPipelineViewportStateCreateInfo
    - VkPipelineRasterizationStateCreateInfo
    - VkPipelineMultisampleStateCreateInfo
    - VkPipelineDepthStencilStateCreateInfo

- Color-only rendering in a subpass with no depth/stencil attachment
  - Active Pipeline Shader Stages
    - Vertex Shader
    - Fragment Shader
  - Required: Fixed-Function Pipeline Stages
    - VkPipelineVertexInputStateCreateInfo
    - VkPipelineInputAssemblyStateCreateInfo
10.2.2. Graphics Pipeline Shader Groups

Graphics pipelines can contain multiple shader groups that can be bound individually. Each shader group behaves as if it was a pipeline using the shader group’s state. When the pipeline is bound by
regular means, it behaves as if the state of group 0 is active, use
vkCmdBindPipelineShaderGroupNV to bind an individual shader group.

The primary purpose of shader groups is allowing the device to bind different pipeline state using
Device-Generated Commands.

The VkGraphicsPipelineShaderGroupsCreateInfoNV structure is defined as:

```c
// Provided by VK_NV_device_generated_commands
typedef struct VkGraphicsPipelineShaderGroupsCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    uint32_t groupCount;
    const VkGraphicsShaderGroupCreateInfoNV* pGroups;
    uint32_t pipelineCount;
    const VkPipeline* pPipelines;
} VkGraphicsPipelineShaderGroupsCreateInfoNV;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `groupCount` is the number of elements in the `pGroups` array.
- `pGroups` is a pointer to an array of VkGraphicsShaderGroupCreateInfoNV structures specifying
  which state of the original VkGraphicsPipelineCreateInfo each shader group overrides.
- `pipelineCount` is the number of elements in the `pPipelines` array.
- `pPipelines` is a pointer to an array of graphics VkPipeline structures which are referenced
  within the created pipeline, including all their shader groups.

When referencing shader groups by index, groups defined in the referenced pipelines are treated
as if they were defined as additional entries in `pGroups`. They are appended in the order they appear
in the `pPipelines` array and in the `pGroups` array when those pipelines were defined.

The application must maintain the lifetime of all such referenced pipelines based on the pipelines
that make use of them.

**Valid Usage**

- VUID-VkGraphicsPipelineShaderGroupsCreateInfoNV-groupCount-02879
groupCount must be at least 1 and as maximum
  VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV::maxGraphicsShaderGroupCount

- VUID-VkGraphicsPipelineShaderGroupsCreateInfoNV-groupCount-02880
  The sum of `groupCount` including those groups added from referenced `pPipelines` must
  also be as maximum `VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV`:
  maxGraphicsShaderGroupCount

- VUID-VkGraphicsPipelineShaderGroupsCreateInfoNV-pGroups-02881
  The state of the first element of `pGroups` must match its equivalent within the parent’s
VkGraphicsPipelineCreateInfo

- VUID-VkGraphicsPipelineShaderGroupsCreateInfoNV-pGroups-02882
  Each element of `pGroups` must in combination with the rest of the pipeline state yield a valid state configuration

- VUID-VkGraphicsPipelineShaderGroupsCreateInfoNV-pGroups-02884
  All elements of `pGroups` must use the same shader stage combinations unless any mesh shader stage is used, then either combination of task and mesh or just mesh shader is valid

- VUID-VkGraphicsPipelineShaderGroupsCreateInfoNV-pGroups-02885
  Mesh and regular primitive shading stages cannot be mixed across `pGroups`

- VUID-VkGraphicsPipelineShaderGroupsCreateInfoNV-pPipelines-02886
  Each element of `pPipelines` must have been created with identical state to the pipeline currently created except the state that can be overridden by `VkGraphicsShaderGroupCreateInfoNV`

- VUID-VkGraphicsPipelineShaderGroupsCreateInfoNV-deviceGeneratedCommands-02887
  The `deviceGeneratedCommands` feature must be enabled

Valid Usage (Implicit)

- VUID-VkGraphicsPipelineShaderGroupsCreateInfoNV-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_SHADER_GROUPS_CREATE_INFO_NV`

- VUID-VkGraphicsPipelineShaderGroupsCreateInfoNV-pGroups-parameter
  If `groupCount` is not 0, `pGroups` must be a valid pointer to an array of `groupCount` valid `VkGraphicsShaderGroupCreateInfoNV` structures

- VUID-VkGraphicsPipelineShaderGroupsCreateInfoNV-pPipelines-parameter
  If `pipelineCount` is not 0, `pPipelines` must be a valid pointer to an array of `pipelineCount` valid `VkPipeline` handles

The `VkGraphicsShaderGroupCreateInfoNV` structure provides the state overrides for each shader group. Each shader group behaves like a pipeline that was created from its state as well as the remaining parent's state. It is defined as:

```c
// Provided by VK_NV_device_generated_commands
typedef struct VkGraphicsShaderGroupCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    uint32_t stageCount;
    const VkPipelineShaderStageCreateInfo* pStages;
    const VkPipelineVertexInputStateCreateInfo* pVertexInputState;
    const VkPipelineTessellationStateCreateInfo* pTessellationState;
} VkGraphicsShaderGroupCreateInfoNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• stageCount is the number of entries in the pStages array.
• pStages is a pointer to an array VkPipelineShaderStageCreateInfo structures specifying the set of the shader stages to be included in this shader group.
• pVertexInputState is a pointer to a VkPipelineVertexInputStateCreateInfo structure.
• pTessellationState is a pointer to a VkPipelineTessellationStateCreateInfo structure, and is ignored if the shader group does not include a tessellation control shader stage and tessellation evaluation shader stage.

Valid Usage

• VUID-VkGraphicsShaderGroupCreateInfoNV-stageCount-02888
  For stageCount, the same restrictions as in VkGraphicsPipelineCreateInfo::stageCount apply
• VUID-VkGraphicsShaderGroupCreateInfoNV-pStages-02889
  For pStages, the same restrictions as in VkGraphicsPipelineCreateInfo::pStages apply
• VUID-VkGraphicsShaderGroupCreateInfoNV-pVertexInputState-02890
  For pVertexInputState, the same restrictions as in VkGraphicsPipelineCreateInfo::pVertexInputState apply
• VUID-VkGraphicsShaderGroupCreateInfoNV-pTessellationState-02891
  For pTessellationState, the same restrictions as in VkGraphicsPipelineCreateInfo::pTessellationState apply

Valid Usage (Implicit)

• VUID-VkGraphicsShaderGroupCreateInfoNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_GRAPHICS_SHADER_GROUP_CREATE_INFO_NV
• VUID-VkGraphicsShaderGroupCreateInfoNV-pNext-pNext
  pNext must be NULL
• VUID-VkGraphicsShaderGroupCreateInfoNV-pStages-parameter
  pStages must be a valid pointer to an array of stageCount valid VkPipelineShaderStageCreateInfo structures
• VUID-VkGraphicsShaderGroupCreateInfoNV-stageCount-arraylength
  stageCount must be greater than 0

10.3. Ray Tracing Pipelines

Ray tracing pipelines consist of multiple shader stages, fixed-function traversal stages, and a pipeline layout.

VK_SHADER_UNUSED_KHR is a special shader index used to indicate that a ray generation, miss, or callable shader member is not used.
```c
#define VK_SHADER_UNUSED_KHR (~0U)

or the equivalent

```c
#define VK_SHADER_UNUSED_NV VK_SHADER_UNUSED_KHR

```c
To create ray tracing pipelines, call:

```c
// Provided by VK_NV_ray_tracing
VkResult vkCreateRayTracingPipelinesNV(
    VkDevice device,
    VkPipelineCache pipelineCache,
    uint32_t createInfoCount,
    const VkRayTracingPipelineCreateInfoNV* pCreateInfos,
    const VkAllocationCallbacks* pAllocator,
    VkPipeline* pPipelines);
```

- `device` is the logical device that creates the ray tracing pipelines.
- `pipelineCache` is either `VK_NULL_HANDLE`, indicating that pipeline caching is disabled, or the handle of a valid pipeline cache object, in which case use of that cache is enabled for the duration of the command.
- `createInfoCount` is the length of the `pCreateInfos` and `pPipelines` arrays.
- `pCreateInfos` is a pointer to an array of `VkRayTracingPipelineCreateInfoNV` structures.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pPipelines` is a pointer to an array in which the resulting ray tracing pipeline objects are returned.

### Valid Usage

- **VUID-vkCreateRayTracingPipelinesNV-flags-03415**
  If the flags member of any element of `pCreateInfos` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, and the `basePipelineIndex` member of that same element is not -1, `basePipelineIndex` must be less than the index into `pCreateInfos` that corresponds to that element

- **VUID-vkCreateRayTracingPipelinesNV-flags-03416**
  If the flags member of any element of `pCreateInfos` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, the base pipeline must have been created with the `VK_PIPELINE_CREATE_ALLOW_DERIVATIVES_BIT` flag set

- **VUID-vkCreateRayTracingPipelinesNV-flags-03816**
  If the flags member of any element of `pCreateInfos` contains the `VK_PIPELINE_CREATE_DISPATCH_BASE` flag, `flags` must not contain the `VK_PIPELINE_CREATE_DISPATCH_BASE` flag

- **VUID-vkCreateRayTracingPipelinesNV-pipelineCache-02903**
  If `pipelineCache` was created with `VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT`,
Valid Usage (Implicit)

- **VUID-vkCreateRayTracingPipelinesNV-device-parameter**
  
  `device` must be a valid `VkDevice` handle.

- **VUID-vkCreateRayTracingPipelinesNV-pipelineCache-parameter**
  
  If `pipelineCache` is not `VK_NULL_HANDLE`, `pipelineCache` must be a valid `VkPipelineCache` handle.

- **VUID-vkCreateRayTracingPipelinesNV-pCreateInfos-parameter**
  
  `pCreateInfos` must be a valid pointer to an array of `createInfoCount` valid `VkRayTracingPipelineCreateInfoNV` structures.

- **VUID-vkCreateRayTracingPipelinesNV-pAllocator-parameter**
  
  If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure.

- **VUID-vkCreateRayTracingPipelinesNV-pPipelines-parameter**
  
  `pPipelines` must be a valid pointer to an array of `createInfoCount` `VkPipeline` handles.

- **VUID-vkCreateRayTracingPipelinesNV-createInfoCount-arraylength**
  
  `createInfoCount` must be greater than 0.

- **VUID-vkCreateRayTracingPipelinesNV-pipelineCache-parent**
  
  If `pipelineCache` is a valid handle, it must have been created, allocated, or retrieved from `device`.

Return Codes

**Success**

- `VK_SUCCESS`
- `VK_PIPELINE_COMPILE_REQUIRED_EXT`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_INVALID_SHADER_NV`

To create ray tracing pipelines, call:

```c
// Provided by VK_KHR_ray_tracing_pipeline
VkResult vkCreateRayTracingPipelinesKHR(  
    VkDevice device,  
    VkDeferredOperationKHR deferredOperation,  
    VkPipelineCache pipelineCache,  
    uint32_t createInfoCount,  
    // ...  
)`
```c
const VkRayTracingPipelineCreateInfoKHR* pCreateInfos,
const VkAllocationCallbacks* pAllocator,
VkPipeline* pPipelines);
```

- **device** is the logical device that creates the ray tracing pipelines.
- **deferredOperation** is `VK_NULL_HANDLE` or the handle of a valid `VkDeferredOperationKHR` request deferral object for this command.
- **pipelineCache** is either `VK_NULL_HANDLE`, indicating that pipeline caching is disabled, or the handle of a valid pipeline cache object, in which case use of that cache is enabled for the duration of the command.
- **createInfoCount** is the length of the `pCreateInfos` and `pPipelines` arrays.
- **pCreateInfos** is a pointer to an array of `VkRayTracingPipelineCreateInfoKHR` structures.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
- **pPipelines** is a pointer to an array in which the resulting ray tracing pipeline objects are returned.

The **VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS** error is returned if the implementation is unable to reuse the shader group handles provided in `VkRayTracingShaderGroupCreateInfoKHR ::pShaderGroupCaptureReplayHandle` when `VkPhysicalDeviceRayTracingPipelineFeaturesKHR ::rayTracingPipelineShaderGroupHandleCaptureReplay` is enabled.

---

### Valid Usage

- **VUID-vkCreateRayTracingPipelinesKHR-flags-03415**
  If the **flags** member of any element of `pCreateInfos` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, and the **basePipelineIndex** member of that same element is not -1, **basePipelineIndex** must be less than the index into `pCreateInfos` that corresponds to that element

- **VUID-vkCreateRayTracingPipelinesKHR-flags-03416**
  If the **flags** member of any element of `pCreateInfos` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, the base pipeline must have been created with the `VK_PIPELINE_CREATE_ALLOW_DERIVATIVES_BIT` flag set

- **VUID-vkCreateRayTracingPipelinesKHR-flags-03816**
  **flags** must not contain the `VK_PIPELINE_CREATE_DISPATCH_BASE` flag

- **VUID-vkCreateRayTracingPipelinesKHR-pipelineCache-02903**
  If pipelineCache was created with `VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT`, host access to pipelineCache must be externally synchronized

- **VUID-vkCreateRayTracingPipelinesKHR-deferredOperation-03677**
  If deferredOperation is not `VK_NULL_HANDLE`, it must be a valid `VkDeferredOperationKHR` object

- **VUID-vkCreateRayTracingPipelinesKHR-deferredOperation-03678**
  Any previous deferred operation that was associated with `deferredOperation` must be complete
The rayTracingPipeline feature must be enabled

If deferredOperation is not VK_NULL_HANDLE, the flags member of elements of pCreateInfos must not include VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT

Valid Usage (Implicit)

device must be a valid VkDevice handle

If deferredOperation is not VK_NULL_HANDLE, deferredOperation must be a valid VkDeferredOperationKHR handle

If pipelineCache is not VK_NULL_HANDLE, pipelineCache must be a valid VkPipelineCache handle

pCreateInfos must be a valid pointer to an array of createInfoCount valid VkRayTracingPipelineCreateInfoKHR structures

If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

pPipelines must be a valid pointer to an array of createInfoCount VkPipeline handles

createInfoCount must be greater than 0

If deferredOperation is a valid handle, it must have been created, allocated, or retrieved from device

If pipelineCache is a valid handle, it must have been created, allocated, or retrieved from device

Return Codes

Success

VK_SUCCESS
VK_OPERATION_DEFERRED_KHR
VK_OPERATION_NOT_DEFERRED_KHR
VK_PIPELINE_COMPILE_REQUIRED_EXT
The `VkRayTracingPipelineCreateInfoNV` structure is defined as:

```c
// Provided by VK_NV_ray_tracing
typedef struct VkRayTracingPipelineCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkPipelineCreateFlags flags;
    uint32_t stageCount;
    const VkPipelineShaderStageCreateInfo* pStages;
    uint32_t groupCount;
    const VkRayTracingShaderGroupCreateInfoNV* pGroups;
    uint32_t maxRecursionDepth;
    VkPipelineLayout layout;
    VkPipeline basePipelineHandle;
    int32_t basePipelineIndex;
} VkRayTracingPipelineCreateInfoNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkPipelineCreateFlagBits` specifying how the pipeline will be generated.
- `stageCount` is the number of entries in the `pStages` array.
- `pStages` is a pointer to an array of `VkPipelineShaderStageCreateInfo` structures specifying the set of the shader stages to be included in the ray tracing pipeline.
- `groupCount` is the number of entries in the `pGroups` array.
- `pGroups` is a pointer to an array of `VkRayTracingShaderGroupCreateInfoNV` structures describing the set of the shader stages to be included in each shader group in the ray tracing pipeline.
- `maxRecursionDepth` is the maximum recursion depth of shaders executed by this pipeline.
- `layout` is the description of binding locations used by both the pipeline and descriptor sets used with the pipeline.
- `basePipelineHandle` is a pipeline to derive from.
- `basePipelineIndex` is an index into the `pCreateInfos` parameter to use as a pipeline to derive from.

The parameters `basePipelineHandle` and `basePipelineIndex` are described in more detail in Pipeline Derivatives.

If a `VkPipelineCreateFlags2CreateInfoKHR` structure is present in the `pNext` chain,
VkPipelineCreateFlags2CreateInfoKHR::flags from that structure is used instead of flags from this structure.

**Valid Usage**

- **VUID-VkRayTracingPipelineCreateInfoNV-flags-07984**
  If flags contains the VK_PIPELINE_CREATE_DERIVATIVE_BIT flag, and basePipelineIndex is -1, basePipelineHandle must be a valid ray tracing VkPipeline handle.

- **VUID-VkRayTracingPipelineCreateInfoNV-flags-07985**
  If flags contains the VK_PIPELINE_CREATE_DERIVATIVE_BIT flag, and basePipelineHandle is VK_NULL_HANDLE, basePipelineIndex must be a valid index into the calling command's pCreateInfos parameter.

- **VUID-VkRayTracingPipelineCreateInfoNV-flags-07986**
  If flags contains the VK_PIPELINE_CREATE_DERIVATIVE_BIT flag, and basePipelineHandle is VK_NULL_HANDLE, basePipelineIndex must be a valid index into the calling command's pCreateInfos parameter.

- **VUID-VkRayTracingPipelineCreateInfoNV-stage-06232**
  The stage member of at least one element of pStages must be 777.
VK_SHADER_STAGE_RAYGEN_BIT_KHR

• VUID-VkRayTracingPipelineCreateInfoNV-flags-03456
  flags must not include VK_PIPELINE_CREATE_LIBRARY_BIT_KHR

• VUID-VkRayTracingPipelineCreateInfoNV-maxRecursionDepth-03457
  maxRecursionDepth must be less than or equal to
  VkPhysicalDeviceRayTracingPropertiesNV::maxRecursionDepth

• VUID-VkRayTracingPipelineCreateInfoNV-flags-03458
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR

• VUID-VkRayTracingPipelineCreateInfoNV-flags-03459
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR

• VUID-VkRayTracingPipelineCreateInfoNV-flags-03460
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR

• VUID-VkRayTracingPipelineCreateInfoNV-flags-03461
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR

• VUID-VkRayTracingPipelineCreateInfoNV-flags-03462
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR

• VUID-VkRayTracingPipelineCreateInfoNV-flags-03463
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR

• VUID-VkRayTracingPipelineCreateInfoNV-flags-03588
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR

• VUID-VkRayTracingPipelineCreateInfoNV-flags-04948
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_ALLOW_MOTION_BIT_NV

• VUID-VkRayTracingPipelineCreateInfoNV-flags-02957
  flags must not include both VK_PIPELINE_CREATE_DEFER_COMPILE_BIT_NV and
  VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT at the same time

• VUID-VkRayTracingPipelineCreateInfoNV-pipelineStageCreationFeedbackCount-06651
  If VkPipelineCreationFeedbackCreateInfo::pipelineStageCreationFeedbackCount is not 0, it
  must be equal to stageCount

• VUID-VkRayTracingPipelineCreateInfoNV-stage-06898
  The stage value in all pStages elements must be one of VK_SHADER_STAGE_RAYGEN_BIT_KHR,
  VK_SHADER_STAGE_ANY_HIT_BIT_KHR, VK_SHADER_STAGE_CLOSEST_HIT_BIT_KHR,
  VK_SHADER_STAGE_MISS_BIT_KHR, VK_SHADER_STAGE_INTERSECTION_BIT_KHR, or
  VK_SHADER_STAGE_CALLABLE_BIT_KHR

• VUID-VkRayTracingPipelineCreateInfoNV-flags-07402
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_OPACITY_MICROMAP_BIT_EXT

• VUID-VkRayTracingPipelineCreateInfoNV-flags-07998
  flags must not include VK_PIPELINE_CREATE_RAY_TRACING_DISPLACEMENT_MICROMAP_BIT_NV
Valid Usage (Implicit)

- VUID-VkRayTracingPipelineCreateInfoNV-sType-sType
  \textbf{sType} must be \texttt{VK_STRUCTURE_TYPE_RAY_TRACING_PIPELINE_CREATE_INFO_NV}

- VUID-VkRayTracingPipelineCreateInfoNV-pNext-pNext
  Each \texttt{pNext} member of any structure (including this one) in the \texttt{pNext} chain must be either \texttt{NULL} or a pointer to a valid instance of \texttt{VkPipelineCreateFlags2CreateInfoKHR} or \texttt{VkPipelineCreationFeedbackCreateInfo}

- VUID-VkRayTracingPipelineCreateInfoNV-sType-unique
  The \texttt{sType} value of each struct in the \texttt{pNext} chain must be unique

- VUID-VkRayTracingPipelineCreateInfoNV-flags-parameter
  flags must be a valid combination of \texttt{VkPipelineCreateFlagBits} values

- VUID-VkRayTracingPipelineCreateInfoNV-pStages-parameter
  \texttt{pStages} must be a valid pointer to an array of \texttt{stageCount} valid \texttt{VkPipelineShaderStageCreateInfo} structures

- VUID-VkRayTracingPipelineCreateInfoNV-pGroups-parameter
  \texttt{pGroups} must be a valid pointer to an array of \texttt{groupCount} valid \texttt{VkRayTracingShaderGroupCreateInfoNV} structures

- VUID-VkRayTracingPipelineCreateInfoNV-layout-parameter
  \texttt{layout} must be a valid \texttt{VkPipelineLayout} handle

- VUID-VkRayTracingPipelineCreateInfoNV-stageCount-arraylength
  \texttt{stageCount} must be greater than 0

- VUID-VkRayTracingPipelineCreateInfoNV-groupCount-arraylength
  \texttt{groupCount} must be greater than 0

- VUID-VkRayTracingPipelineCreateInfoNV-commonparent
  Both of \texttt{basePipelineHandle}, and \texttt{layout} that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same \texttt{VkDevice}

The \texttt{VkRayTracingPipelineCreateInfoKHR} structure is defined as:

```c
// Provided by VK_KHR_ray_tracing_pipeline
typedef struct VkRayTracingPipelineCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkPipelineCreateFlags flags;
    uint32_t stageCount;
    const VkPipelineShaderStageCreateInfo* pStages;
    uint32_t groupCount;
    const VkRayTracingShaderGroupCreateInfoKHR* pGroups;
    uint32_t maxPipelineRayRecursionDepth;
    const VkPipelineLibraryCreateInfoKHR* pLibraryInfo;
    const VkRayTracingPipelineInterfaceCreateInfoKHR* pLibraryInterface;
    const VkPipelineDynamicStateCreateInfo* pDynamicState;
    VkPipelineLayout layout;
} VkRayTracingPipelineCreateInfoKHR;
```
VK_PIPELINE_CREATE_LIBRARY_BIT_KHR is specified, this pipeline defines a pipeline library which cannot be bound as a ray tracing pipeline directly. Instead, pipeline libraries define common shaders and shader groups which can be included in future pipeline creation.

If pipeline libraries are included in pLibraryInfo, shaders defined in those libraries are treated as if they were defined as additional entries in pStages, appended in the order they appear in the pLibraries array and in the pStages array when those libraries were defined.

When referencing shader groups in order to obtain a shader group handle, groups defined in those libraries are treated as if they were defined as additional entries in pGroups, appended in the order
they appear in the `pLibraries` array and in the `pGroups` array when those libraries were defined. The shaders these groups reference are set when the pipeline library is created, referencing those specified in the pipeline library, not in the pipeline that includes it.

The default stack size for a pipeline if `VK_DYNAMIC_STATERAY_TRACING_PIPELINE_STACK_SIZE_KHR` is not provided is computed as described in Ray Tracing Pipeline Stack.

If a `VkPipelineCreateFlags2CreateInfoKHR` structure is present in the `pNext` chain, `VkPipelineCreateFlags2CreateInfoKHR::flags` from that structure is used instead of `flags` from this structure.

### Valid Usage

- **VUID-VkRayTracingPipelineCreateInfoKHR-flags-07984**
  If `flags` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, and `basePipelineIndex` is -1, `basePipelineHandle` must be a valid ray tracing `VkPipeline` handle.

- **VUID-VkRayTracingPipelineCreateInfoKHR-flags-07985**
  If `flags` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, and `basePipelineHandle` is `VK_NULL_HANDLE`, `basePipelineIndex` must be a valid index into the calling command's `pCreateInfos` parameter.

- **VUID-VkRayTracingPipelineCreateInfoKHR-flags-07986**
  If `flags` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, `basePipelineIndex` must be -1 or `basePipelineHandle` must be `VK_NULL_HANDLE`.

- **VUID-VkRayTracingPipelineCreateInfoKHR-layout-07987**
  If a push constant block is declared in a shader, a push constant range in `layout` must match both the shader stage and range.

- **VUID-VkRayTracingPipelineCreateInfoKHR-layout-07988**
  If a `resource variables` is declared in a shader, a descriptor slot in `layout` must match the shader stage.

- **VUID-VkRayTracingPipelineCreateInfoKHR-layout-07990**
  If a `resource variables` is declared in a shader, and the descriptor type is not `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`, a descriptor slot in `layout` must match the descriptor type.

- **VUID-VkRayTracingPipelineCreateInfoKHR-layout-07991**
  If a `resource variables` is declared in a shader as an array, a descriptor slot in `layout` must match the descriptor count.

- **VUID-VkRayTracingPipelineCreateInfoKHR-pStages-03426**
  The shader code for the entry points identified by `pStages`, and the rest of the state identified by this structure must adhere to the pipeline linking rules described in the Shader Interfaces chapter.

- **VUID-VkRayTracingPipelineCreateInfoKHR-layout-03428**
  The number of resources in `layout` accessible to each shader stage that is used by the pipeline must be less than or equal to `VkPhysicalDeviceLimits::maxPerStageResources`.

- **VUID-VkRayTracingPipelineCreateInfoKHR-flags-02904**
flags must not include VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV

- VUID-VkRayTracingPipelineCreateInfoKHR-pipelineCreationCacheControl-02905
  If the pipelineCreationCacheControl feature is not enabled, flags must not include VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT or VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT

- VUID-VkRayTracingPipelineCreateInfoKHR-stage-03425
  If flags does not include VK_PIPELINE_CREATE_LIBRARY_BIT_KHR, the stage member of at least one element of pStages, including those implicitly added by pLibraryInfo, must be VK_SHADER_STAGE_RAYGEN_BIT_KHR

- VUID-VkRayTracingPipelineCreateInfoKHR-maxPipelineRayRecursionDepth-03589
  maxPipelineRayRecursionDepth must be less than or equal to VkPhysicalDeviceRayTracingPipelinePropertiesKHR::maxRayRecursionDepth

- VUID-VkRayTracingPipelineCreateInfoKHR-flags-03465
  If flags includes VK_PIPELINE_CREATE_LIBRARY_BIT_KHR, pLibraryInterface must not be NULL

- VUID-VkRayTracingPipelineCreateInfoKHR-pLibraryInfo-03590
  If pLibraryInfo is not NULL and its libraryCount member is greater than 0, pLibraryInterface must not be NULL

- VUID-VkRayTracingPipelineCreateInfoKHR-pLibraries-03591
  Each element of pLibraryInfo->pLibraries must have been created with the value of maxPipelineRayRecursionDepth equal to that in this pipeline

- VUID-VkRayTracingPipelineCreateInfoKHR-pLibraryInfo-03592
  If pLibraryInfo is not NULL, each element of its pLibraries member must have been created with a layout that is compatible with the layout in this pipeline

- VUID-VkRayTracingPipelineCreateInfoKHR-pLibraryInfo-03593
  If pLibraryInfo is not NULL, each element of its pLibraries member must have been created with values of the maxPipelineRayPayloadSize and maxPipelineRayHitAttributeSize members of pLibraryInterface equal to those in this pipeline

- VUID-VkRayTracingPipelineCreateInfoKHR-flags-03594
  If flags includes VK_PIPELINE_CREATE_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR, each element of pLibraryInfo->pLibraries must have been created with the VK_PIPELINE_CREATE_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR bit set

- VUID-VkRayTracingPipelineCreateInfoKHR-flags-04718
  If flags includes VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR, each element of pLibraryInfo->pLibraries must have been created with the VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR bit set

- VUID-VkRayTracingPipelineCreateInfoKHR-flags-04719
  If flags includes VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR, each element of pLibraryInfo->pLibraries must have been created with the VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR bit set

- VUID-VkRayTracingPipelineCreateInfoKHR-flags-04720
  If flags includes VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR, each element of pLibraryInfo->pLibraries must have been created with the
VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR bit set

• VUID-VkRayTracingPipelineCreateInfoKHR-flags-04721
  If flags includes VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR, each element of pLibraryInfo->pLibraries must have been created with the VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR bit set

• VUID-VkRayTracingPipelineCreateInfoKHR-flags-04722
  If flags includes VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR, each element of pLibraryInfo->pLibraries must have been created with the VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR bit set

• VUID-VkRayTracingPipelineCreateInfoKHR-flags-04723
  If flags includes VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR, each element of pLibraryInfo->pLibraries must have been created with the VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR bit set

• VUID-VkRayTracingPipelineCreateInfoKHR-flags-03470
  If flags includes VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR, for any element of pGroups with a type of VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_KHR or VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_KHR, the anyHitShader of that element must not be VK_SHADER_UNUSED_KHR

• VUID-VkRayTracingPipelineCreateInfoKHR-flags-03471
  If flags includes VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR, for any element of pGroups with a type of VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_KHR or VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_KHR, the closestHitShader of that element must not be VK_SHADER_UNUSED_KHR

• VUID-VkRayTracingPipelineCreateInfoKHR-rayTraversalPrimitiveCulling-03596
  If the rayTraversalPrimitiveCulling feature is not enabled, flags must not include VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR

• VUID-VkRayTracingPipelineCreateInfoKHR-rayTraversalPrimitiveCulling-03597
  If the rayTraversalPrimitiveCulling feature is not enabled, flags must not include VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR

• VUID-VkRayTracingPipelineCreateInfoKHR-flags-06546
  flags must not include both VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR and VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR

• VUID-VkRayTracingPipelineCreateInfoKHR-flags-03598
  If flags includes VK_PIPELINE_CREATE_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR, rayTracingPipelineShaderGroupHandleCaptureReplay must be enabled

• VUID-VkRayTracingPipelineCreateInfoKHR-rayTracingPipelineShaderGroupHandleCaptureReplay-03599
If `VkPhysicalDeviceRayTracingPipelineFeaturesKHR::rayTracingPipelineShaderGroupHandleCaptureReplay` is `VK_TRUE` and the `pShaderGroupCaptureReplayHandle` member of any element of `pGroups` is not `NULL`, `flags` must include `VK_PIPELINE_CREATE_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR`.

- VUID-VkRayTracingPipelineCreateInfoKHR-pLibraryInfo-07999
  If `pLibraryInfo` is `NULL` or its `libraryCount` is `0`, `stageCount` must not be `0`.

- VUID-VkRayTracingPipelineCreateInfoKHR-flags-08700
  If `flags` does not include `VK_PIPELINE_CREATE_LIBRARY_BIT_KHR` and either `pLibraryInfo` is `NULL` or its `libraryCount` is `0`, `groupCount` must not be `0`.

- VUID-VkRayTracingPipelineCreateInfoKHR-pDynamicStates-03602
  Any element of the `pDynamicStates` member of `pDynamicState` must be `VK_DYNAMIC_STATE_RAY_TRACING_PIPELINE_STACK_SIZE_KHR`.

- VUID-VkRayTracingPipelineCreateInfoKHR-pipelineStageCreationFeedbackCount-06652
  If `VkPipelineCreationFeedbackCreateInfo::pipelineStageCreationFeedbackCount` is not `0`, it must be equal to `stageCount`.

- VUID-VkRayTracingPipelineCreateInfoKHR-stage-06899
  The `stage` value in all `pStages` elements must be one of `VK_SHADER_STAGE_RAYGEN_BIT_KHR`, `VK_SHADER_STAGE_ANY_HIT_BIT_KHR`, `VK_SHADER_STAGE_CLOSEST_HIT_BIT_KHR`, `VK_SHADER_STAGE_MISS_BIT_KHR`, `VK_SHADER_STAGE_INTERSECTION_BIT_KHR`, or `VK_SHADER_STAGE_CALLABLE_BIT_KHR`.

- VUID-VkRayTracingPipelineCreateInfoKHR-flags-07403
  If `flags` includes `VK_PIPELINE_CREATE_RAY_TRACING_OPACITY_MICROMAP_BIT_EXT`, each element of `pLibraryInfo->pLibraries` must have been created with the `VK_PIPELINE_CREATE_RAY_TRACING_OPACITY_MICROMAP_BIT_EXT` bit set.

- VUID-VkRayTracingPipelineCreateInfoKHR-flags-08701
  If `flags` includes `VK_PIPELINE_CREATE_RAY_TRACING_DISPLACEMENT_MICROMAP_BIT_NV`, each element of `pLibraryInfo->pLibraries` must have been created with the `VK_PIPELINE_CREATE_RAY_TRACING_DISPLACEMENT_MICROMAP_BIT_NV` bit set.

**Valid Usage (Implicit)**

- VUID-VkRayTracingPipelineCreateInfoKHR-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_RAY_TRACING_PIPELINE_CREATE_INFO_KHR`.

- VUID-VkRayTracingPipelineCreateInfoKHR-pNext-pNext
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkPipelineCreateFlags2CreateInfoKHR`, `VkPipelineCreationFeedbackCreateInfo`, or `VkPipelineRobustnessCreateInfoEXT`.

- VUID-VkRayTracingPipelineCreateInfoKHR-sType-unique
  The `sType` value of each struct in the `pNext` chain must be unique.

- VUID-VkRayTracingPipelineCreateInfoKHR-flags-parameter
  `flags` must be a valid combination of `VkPipelineCreateFlagBits` values.
• VUID-VkRayTracingPipelineCreateInfoKHR-pStages-parameter
  If stageCount is not 0, pStages must be a valid pointer to an array of stageCount valid
  VkPipelineShaderStageCreateInfo structures.

• VUID-VkRayTracingPipelineCreateInfoKHR-pGroups-parameter
  If groupCount is not 0, pGroups must be a valid pointer to an array of groupCount valid
  VkRayTracingShaderGroupCreateInfoKHR structures.

• VUID-VkRayTracingPipelineCreateInfoKHR-pLibraryInfo-parameter
  If pLibraryInfo is not NULL, pLibraryInfo must be a valid pointer to a valid
  VkPipelineLibraryCreateInfoKHR structure.

• VUID-VkRayTracingPipelineCreateInfoKHR-pLibraryInterface-parameter
  If pLibraryInterface is not NULL, pLibraryInterface must be a valid pointer to a valid
  VkRayTracingPipelineInterfaceCreateInfoKHR structure.

• VUID-VkRayTracingPipelineCreateInfoKHR-pDynamicState-parameter
  If pDynamicState is not NULL, pDynamicState must be a valid pointer to a valid
  VkPipelineDynamicStateCreateInfo structure.

• VUID-VkRayTracingPipelineCreateInfoKHR-layout-parameter
  layout must be a valid VkPipelineLayout handle.

• VUID-VkRayTracingPipelineCreateInfoKHR-commonparent
  Both of basePipelineHandle, and layout that are valid handles of non-ignored parameters
  must have been created, allocated, or retrieved from the same VkDevice

The VkRayTracingShaderGroupCreateInfoNV structure is defined as:

```c
// Provided by VK_NV_ray_tracing
typedef struct VkRayTracingShaderGroupCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkRayTracingShaderGroupTypeKHR type;
    uint32_t generalShader;
    uint32_t closestHitShader;
    uint32_t anyHitShader;
    uint32_t intersectionShader;
} VkRayTracingShaderGroupCreateInfoNV;
```

• sType is a VkStructureType value identifying this structure.

• pNext is NULL or a pointer to a structure extending this structure.

• type is the type of hit group specified in this structure.

• generalShader is the index of the ray generation, miss, or callable shader from
  VkRayTracingPipelineCreateInfoNV::pStages in the group if the shader group has type of
  VK_RAY_TRACING_SHADER_GROUP_TYPE_GENERAL_NV, and VK_SHADER_UNUSED_NV otherwise.

• closestHitShader is the optional index of the closest hit shader from
  VkRayTracingPipelineCreateInfoNV::pStages in the group if the shader group has type of
  VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_NV
• Any hit shader is the optional index of the any-hit shader from `VkRayTracingPipelineCreateInfoNV::pStages` in the group if the shader group has `type` of `VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_NV`, and `VK_SHADER_UNUSED_NV` otherwise.

• Intersection shader is the index of the intersection shader from `VkRayTracingPipelineCreateInfoNV::pStages` in the group if the shader group has `type` of `VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_NV`, and `VK_SHADER_UNUSED_NV` otherwise.

Valid Usage

• VUID-VkRayTracingShaderGroupCreateInfoNV-type-02413
  If `type` is `VK_RAY_TRACING_SHADER_GROUP_TYPE_GENERAL_NV` then `generalShader` must be a valid index into `VkRayTracingPipelineCreateInfoNV::pStages` referring to a shader of `VK_SHADER_STAGE_RAYGEN_BIT_NV`, `VK_SHADER_STAGE_MISS_BIT_NV`, or `VK_SHADER_STAGE_CALLABLE_BIT_NV`.

• VUID-VkRayTracingShaderGroupCreateInfoNV-type-02414
  If `type` is `VK_RAY_TRACING_SHADER_GROUP_TYPE_GENERAL_NV` then `closestHitShader`, `anyHitShader`, and `intersectionShader` must be `VK_SHADER_UNUSED_NV`.

• VUID-VkRayTracingShaderGroupCreateInfoNV-type-02415
  If `type` is `VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_NV` then `intersectionShader` must be a valid index into `VkRayTracingPipelineCreateInfoNV::pStages` referring to a shader of `VK_SHADER_STAGE_INTERSECTION_BIT_NV`.

• VUID-VkRayTracingShaderGroupCreateInfoNV-type-02416
  If `type` is `VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_NV` then `intersectionShader` must be `VK_SHADER_UNUSED_NV`.

• VUID-VkRayTracingShaderGroupCreateInfoNV-closestHitShader-02417
  `closestHitShader` must be either `VK_SHADER_UNUSED_NV` or a valid index into `VkRayTracingPipelineCreateInfoNV::pStages` referring to a shader of `VK_SHADER_STAGE_CLOSEST_HIT_BIT_NV`.

• VUID-VkRayTracingShaderGroupCreateInfoNV-anyHitShader-02418
  `anyHitShader` must be either `VK_SHADER_UNUSED_NV` or a valid index into `VkRayTracingPipelineCreateInfoNV::pStages` referring to a shader of `VK_SHADER_STAGE_ANY_HIT_BIT_NV`.

Valid Usage (Implicit)

• VUID-VkRayTracingShaderGroupCreateInfoNV-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_RAY_TRACING_SHADER_GROUP_CREATE_INFO_NV`.

• VUID-VkRayTracingShaderGroupCreateInfoNV-pNext-pNext
  `pNext` must be `NULL`.

• VUID-VkRayTracingShaderGroupCreateInfoNV-type-parameter
  `type` must be a valid `VkRayTracingShaderGroupTypeKHR` value.
The `VkRayTracingShaderGroupCreateInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_ray_tracing_pipeline
typedef struct VkRayTracingShaderGroupCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkRayTracingShaderGroupTypeKHR type;
    uint32_t generalShader;
    uint32_t closestHitShader;
    uint32_t anyHitShader;
    uint32_t intersectionShader;
    const void* pShaderGroupCaptureReplayHandle;
} VkRayTracingShaderGroupCreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `type` is the type of hit group specified in this structure.
- `generalShader` is the index of the ray generation, miss, or callable shader from `VkRayTracingPipelineCreateInfoKHR::pStages` in the group if the shader group has `type` of `VK_RAY_TRACING_SHADER_GROUP_TYPE_GENERAL_KHR`, and `VK_SHADER_UNUSED_KHR` otherwise.
- `closestHitShader` is the optional index of the closest hit shader from `VkRayTracingPipelineCreateInfoKHR::pStages` in the group if the shader group has `type` of `VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_KHR` or `VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_KHR`, and `VK_SHADER_UNUSED_KHR` otherwise.
- `anyHitShader` is the optional index of the any-hit shader from `VkRayTracingPipelineCreateInfoKHR::pStages` in the group if the shader group has `type` of `VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_KHR` or `VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_KHR`, and `VK_SHADER_UNUSED_KHR` otherwise.
- `intersectionShader` is the index of the intersection shader from `VkRayTracingPipelineCreateInfoKHR::pStages` in the group if the shader group has `type` of `VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_KHR`, and `VK_SHADER_UNUSED_KHR` otherwise.
- `pShaderGroupCaptureReplayHandle` is `NULL` or a pointer to replay information for this shader group queried from `vkGetRayTracingCaptureReplayShaderGroupHandlesKHR`, as described in Ray Tracing Capture Replay. Ignored if `VkPhysicalDeviceRayTracingPipelineFeaturesKHR::rayTracingPipelineShaderGroupHandleCaptureReplay` is `VK_FALSE`.

If the pipeline is created with `VK_PIPELINE_CREATE_LIBRARY_BIT_KHR` and the `pipelineLibraryGroupHandles` feature is enabled, `pShaderGroupCaptureReplayHandle` is inherited by all pipelines which link against this pipeline and remains bitwise identical for any pipeline which references this pipeline library.
Valid Usage

- **VUID-VkRayTracingShaderGroupCreateInfoKHR-type-03474**
  If `type` is `VK_RAY_TRACING_SHADER_GROUP_TYPE_GENERAL_KHR` then `generalShader` must be a valid index into `VkRayTracingPipelineCreateInfoKHR::pStages` referring to a shader of `VK_SHADER_STAGE_RAYGEN_BIT_KHR`, `VK_SHADER_STAGE_MISS_BIT_KHR`, or `VK_SHADER_STAGE_CALLABLE_BIT_KHR`.

- **VUID-VkRayTracingShaderGroupCreateInfoKHR-type-03475**
  If `type` is `VK_RAY_TRACING_SHADER_GROUP_TYPE_GENERAL_KHR` then `closestHitShader`, `anyHitShader`, and `intersectionShader` must be `VK_SHADER_UNUSED_KHR`.

- **VUID-VkRayTracingShaderGroupCreateInfoKHR-type-03476**
  If `type` is `VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_KHR` then `intersectionShader` must be a valid index into `VkRayTracingPipelineCreateInfoKHR::pStages` referring to a shader of `VK_SHADER_STAGE_INTERSECTION_BIT_KHR`.

- **VUID-VkRayTracingShaderGroupCreateInfoKHR-type-03477**
  If `type` is `VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_KHR` then `intersectionShader` must be `VK_SHADER_UNUSED_KHR`.

- **VUID-VkRayTracingShaderGroupCreateInfoKHR-closestHitShader-03478**
  `closestHitShader` must be either `VK_SHADER_UNUSED_KHR` or a valid index into `VkRayTracingPipelineCreateInfoKHR::pStages` referring to a shader of `VK_SHADER_STAGE_CLOSEST_HIT_BIT_KHR`.

- **VUID-VkRayTracingShaderGroupCreateInfoKHR-anyHitShader-03479**
  `anyHitShader` must be either `VK_SHADER_UNUSED_KHR` or a valid index into `VkRayTracingPipelineCreateInfoKHR::pStages` referring to a shader of `VK_SHADER_STAGE_ANY_HIT_BIT_KHR`.

- **VUID-VkRayTracingShaderGroupCreateInfoKHR-rayTracingPipelineShaderGroupHandleCaptureReplayMixed-03603**
  If `VkPhysicalDeviceRayTracingPipelineFeaturesKHR::rayTracingPipelineShaderGroupHandleCaptureReplayMixed` is `VK_FALSE` then `pShaderGroupCaptureReplayHandle` must not be provided if it has not been provided on a previous call to ray tracing pipeline creation.

- **VUID-VkRayTracingShaderGroupCreateInfoKHR-rayTracingPipelineShaderGroupHandleCaptureReplayMixed-03604**
  If `VkPhysicalDeviceRayTracingPipelineFeaturesKHR::rayTracingPipelineShaderGroupHandleCaptureReplayMixed` is `VK_FALSE` then the caller must guarantee that no ray tracing pipeline creation commands with `pShaderGroupCaptureReplayHandle` provided execute simultaneously with ray tracing pipeline creation commands without `pShaderGroupCaptureReplayHandle` provided.

Valid Usage (Implicit)

- **VUID-VkRayTracingShaderGroupCreateInfoKHR-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_RAY_TRACING_SHADER_GROUP_CREATE_INFO_KHR`.
• VUID-VkRayTracingShaderGroupCreateInfoKHR-pNext-pNext
  pNext must be NULL

• VUID-VkRayTracingShaderGroupCreateInfoKHR-type-parameter
  type must be a valid VkRayTracingShaderGroupTypeKHR value

Possible values of type in VkRayTracingShaderGroupCreateInfoKHR are:

```c
// Provided by VK_KHR_ray_tracing_pipeline
typedef enum VkRayTracingShaderGroupTypeKHR {
    VK_RAY_TRACING_SHADER_GROUP_TYPE_GENERAL_KHR = 0,
    VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_KHR = 1,
    VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_KHR = 2,
    // Provided by VK_NV_ray_tracing
    VK_RAY_TRACING_SHADER_GROUP_TYPE_GENERAL_NV =
    VK_RAY_TRACING_SHADER_GROUP_TYPE_GENERAL_KHR,
    // Provided by VK_NV_ray_tracing
    VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_NV =
    VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_KHR,
    // Provided by VK_NV_ray_tracing
    VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_NV =
    VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_KHR,
} VkRayTracingShaderGroupTypeKHR;
```

or the equivalent

```c
// Provided by VK_NV_ray_tracing
typedef VkRayTracingShaderGroupTypeKHR VkRayTracingShaderGroupTypeNV;
```

• VK_RAY_TRACING_SHADER_GROUP_TYPE_GENERAL_KHR indicates a shader group with a single
  VK_SHADER_STAGE_RAYGEN_BIT_KHR, VK_SHADER_STAGE_MISS_BIT_KHR, or
  VK_SHADER_STAGE_CALLABLE_BIT_KHR shader in it.

• VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_KHR specifies a shader group that only
  hits triangles and must not contain an intersection shader, only closest hit and any-hit shaders.

• VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_KHR specifies a shader group that only
  intersects with custom geometry and must contain an intersection shader and may contain
  closest hit and any-hit shaders.

Note
For current group types, the hit group type could be inferred from the presence or
absence of the intersection shader, but we provide the type explicitly for future hit
groups that do not have that property.

The VkRayTracingPipelineInterfaceCreateInfoKHR structure is defined as:

```c
// Provided by VK_KHR_ray_tracing_pipeline
```
typedef struct VkRayTracingPipelineInterfaceCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t maxPipelineRayPayloadSize;
    uint32_t maxPipelineRayHitAttributeSize;
} VkRayTracingPipelineInterfaceCreateInfoKHR;

• **sType** is a *VkStructureType* value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.
• **maxPipelineRayPayloadSize** is the maximum payload size in bytes used by any shader in the pipeline.
• **maxPipelineRayHitAttributeSize** is the maximum attribute structure size in bytes used by any shader in the pipeline.

maxPipelineRayPayloadSize is calculated as the maximum number of bytes used by any block declared in the *RayPayloadKHR* or *IncomingRayPayloadKHR* storage classes. maxPipelineRayHitAttributeSize is calculated as the maximum number of bytes used by any block declared in the *HitAttributeKHR* storage class. As variables in these storage classes do not have explicit offsets, the size should be calculated as if each variable has a scalar alignment equal to the largest scalar alignment of any of the block’s members.

**Note**
There is no explicit upper limit for maxPipelineRayPayloadSize, but in practice it should be kept as small as possible. Similar to invocation local memory, it must be allocated for each shader invocation and for devices which support many simultaneous invocations, this storage can rapidly be exhausted, resulting in failure.

**Valid Usage**

• VUID-VkRayTracingPipelineInterfaceCreateInfoKHR-maxPipelineRayHitAttributeSize-03605
  maxPipelineRayHitAttributeSize must be less than or equal to
  VkPhysicalDeviceRayTracingPipelinePropertiesKHR::maxRayHitAttributeSize

**Valid Usage (Implicit)**

• VUID-VkRayTracingPipelineInterfaceCreateInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_RAY_TRACING_PIPELINE_INTERFACE_CREATE_INFO_KHR

• VUID-VkRayTracingPipelineInterfaceCreateInfoKHR-pNext-pNext
  pNext must be NULL

To query the opaque handles of shaders in the ray tracing pipeline, call:
Provided by VK_KHR_ray_tracing_pipeline

```c
VkResult vkGetRayTracingShaderGroupHandlesKHR(
    VkDevice device,
    VkPipeline pipeline,
    uint32_t firstGroup,
    uint32_t groupCount,
    size_t dataSize,
    void* pData);
```

or the equivalent command

Provided by VK_NV_ray_tracing

```c
VkResult vkGetRayTracingShaderGroupHandlesNV(
    VkDevice device,
    VkPipeline pipeline,
    uint32_t firstGroup,
    uint32_t groupCount,
    size_t dataSize,
    void* pData);
```

- **device** is the logical device containing the ray tracing pipeline.
- **pipeline** is the ray tracing pipeline object containing the shaders.
- **firstGroup** is the index of the first group to retrieve a handle for from the `VkRayTracingPipelineCreateInfoKHR::pGroups` or `VkRayTracingPipelineCreateInfoNV::pGroups` array.
- **groupCount** is the number of shader handles to retrieve.
- **dataSize** is the size in bytes of the buffer pointed to by **pData**.
- **pData** is a pointer to a user-allocated buffer where the results will be written.

If **pipeline** was created with `VK_PIPELINE_CREATE_LIBRARY_BIT_KHR` and the `pipelineLibraryGroupHandles` feature is enabled applications can query group handles from that pipeline, even if the pipeline is a library and is never bound to a command buffer. These group handles remain bitwise identical for any **pipeline** which references the pipeline library. Group indices are assigned as-if the pipeline was created without `VK_PIPELINE_CREATE_LIBRARY_BIT_KHR`.

### Valid Usage

- VUID-vkGetRayTracingShaderGroupHandlesKHR-pipeline-04619 **pipeline** must be a ray tracing pipeline
- VUID-vkGetRayTracingShaderGroupHandlesKHR-firstGroup-04050 **firstGroup** must be less than the number of shader groups in **pipeline**
- VUID-vkGetRayTracingShaderGroupHandlesKHR-firstGroup-02419 The sum of **firstGroup** and **groupCount** must be less than or equal to the number of shader groups in **pipeline**
• VUID-vkGetRayTracingShaderGroupHandlesKHR-dataSize-02420
  
  *dataSize must be at least* \( \text{VkPhysicalDeviceRayTracingPipelinePropertiesKHR}::\text{shaderGroupHandleSize} \times \text{groupCount} \)

• VUID-vkGetRayTracingShaderGroupHandlesKHR-pipeline-07828
  
  If the pipelineLibraryGroupHandles feature is not enabled, pipeline must not have been created with \( \text{VK_PIPELINE_CREATE_LIBRARY_BIT_KHR} \)

---

**Valid Usage (Implicit)**

• VUID-vkGetRayTracingShaderGroupHandlesKHR-device-parameter
  
  device must be a valid \( \text{VkDevice} \) handle

• VUID-vkGetRayTracingShaderGroupHandlesKHR-pipeline-parameter
  
  pipeline must be a valid \( \text{VkPipeline} \) handle

• VUID-vkGetRayTracingShaderGroupHandlesKHR-pData-parameter
  
  pData must be a valid pointer to an array of dataSize bytes

• VUID-vkGetRayTracingShaderGroupHandlesKHR-dataSize-arraylength
  
  dataSize must be greater than 0

• VUID-vkGetRayTracingShaderGroupHandlesKHR-pipeline-parent
  
  pipeline must have been created, allocated, or retrieved from device

---

**Return Codes**

**Success**

• VK_SUCCESS

**Failure**

• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY

---

To query the opaque capture data of shader groups in a ray tracing pipeline, call:

```c
// Provided by VK_KHR_ray_tracing_pipeline
VkResult vkGetRayTracingCaptureReplayShaderGroupHandlesKHR(
    VkDevice device,  // logical device containing the ray tracing pipeline.
    VkPipeline pipeline,  // ray tracing pipeline object containing the shaders.
    uint32_t firstGroup,  // first shader group index to query.
    uint32_t groupCount,  // number of shader groups to query.
    size_t dataSize,  // size in bytes of the opaque capture data.
    void* pData);  // pointer to the opaque capture data.
```
• **firstGroup** is the index of the first group to retrieve a handle for from the `VkRayTracingPipelineCreateInfoKHR::pGroups` array.

• **groupCount** is the number of shader handles to retrieve.

• **dataSize** is the size in bytes of the buffer pointed to by `pData`.

• **pData** is a pointer to a user-allocated buffer where the results will be written.

Once queried, this opaque data can be provided at pipeline creation time (in a subsequent execution), using `VkRayTracingShaderGroupCreateInfoKHR::pShaderGroupCaptureReplayHandle`, as described in Ray Tracing Capture Replay.

If `pipeline` was created with `VK_PIPELINE_CREATE_LIBRARY_BIT_KHR` and the `pipelineLibraryGroupHandles` feature is enabled applications can query capture replay group handles from that pipeline. The capture replay handle remains bitwise identical for any `pipeline` which references the pipeline library. Group indices are assigned as-if the pipeline was created without `VK_PIPELINE_CREATE_LIBRARY_BIT_KHR`.

### Valid Usage

- VUID-vkGetRayTracingCaptureReplayShaderGroupHandlesKHR-pipeline-04620
  - `pipeline` must be a ray tracing pipeline

- VUID-vkGetRayTracingCaptureReplayShaderGroupHandlesKHR-firstGroup-04051
  - `firstGroup` must be less than the number of shader groups in `pipeline`

- VUID-vkGetRayTracingCaptureReplayShaderGroupHandlesKHR-firstGroup-03483
  - The sum of `firstGroup` and `groupCount` must be less than or equal to the number of shader groups in `pipeline`

- VUID-vkGetRayTracingCaptureReplayShaderGroupHandlesKHR-dataSize-03484
  - `dataSize` must be at least `VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupHandleCaptureReplaySize × groupCount`

- VUID-vkGetRayTracingCaptureReplayShaderGroupHandlesKHR-rayTracingPipelineShaderGroupHandleCaptureReplay-03606
  - `VkPhysicalDeviceRayTracingPipelineFeaturesKHR::rayTracingPipelineShaderGroupHandleCaptureReplay` must be enabled to call this function

- VUID-vkGetRayTracingCaptureReplayShaderGroupHandlesKHR-pipeline-03607
  - `pipeline` must have been created with a flags that included `VK_PIPELINE_CREATE_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR`

- VUID-vkGetRayTracingCaptureReplayShaderGroupHandlesKHR-pipeline-07829
  - If the `pipelineLibraryGroupHandles` feature is not enabled, `pipeline` must not have been created with `VK_PIPELINE_CREATE_LIBRARY_BIT_KHR`

### Valid Usage (Implicit)

- VUID-vkGetRayTracingCaptureReplayShaderGroupHandlesKHR-device-parameter
  - `device` must be a valid `VkDevice` handle
• VUID-vkGetRayTracingCaptureReplayShaderGroupHandlesKHR-pipeline-parameter
  pipeline must be a valid VkPipeline handle

• VUID-vkGetRayTracingCaptureReplayShaderGroupHandlesKHR-pData-parameter
  pData must be a valid pointer to an array of dataSize bytes

• VUID-vkGetRayTracingCaptureReplayShaderGroupHandlesKHR-dataSize-arraylength
  dataSize must be greater than 0

• VUID-vkGetRayTracingCaptureReplayShaderGroupHandlesKHR-pipeline-parent
  pipeline must have been created, allocated, or retrieved from device

Return Codes

Success
• VK_SUCCESS

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY

Ray tracing pipelines can contain more shaders than a graphics or compute pipeline, so to allow parallel compilation of shaders within a pipeline, an application can choose to defer compilation until a later point in time.

To compile a deferred shader in a pipeline call:

```
// Provided by VK_NV_ray_tracing
VkResult vkCompileDeferredNV(
  VkDevice device,
  VkPipeline pipeline,
  uint32_t shader);
```

• device is the logical device containing the ray tracing pipeline.
• pipeline is the ray tracing pipeline object containing the shaders.
• shader is the index of the shader to compile.

Valid Usage

• VUID-vkCompileDeferredNV-pipeline-04621
  pipeline must be a ray tracing pipeline

• VUID-vkCompileDeferredNV-pipeline-02237
  pipeline must have been created with VK_PIPELINE_CREATE_DEFER_COMPILE_BIT_NV

• VUID-vkCompileDeferredNV-shader-02238
  shader must not have been called as a deferred compile before
Valid Usage (Implicit)

- VUID-vkCompileDeferredNV-device-parameter
  
  `device` must be a valid `VkDevice` handle

- VUID-vkCompileDeferredNV-pipeline-parameter
  
  `pipeline` must be a valid `VkPipeline` handle

- VUID-vkCompileDeferredNV-pipeline-parent
  
  `pipeline` must have been created, allocated, or retrieved from `device`

Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

To query the pipeline stack size of shaders in a shader group in the ray tracing pipeline, call:

```c
// Provided by VK_KHR_ray_tracing_pipeline

VkDeviceSize vkGetRayTracingShaderGroupStackSizeKHR(
    VkDevice device,  
    VkPipeline pipeline,  
    uint32_t group,  
    VkShaderGroupShaderKHR groupShader);
```

- `device` is the logical device containing the ray tracing pipeline.
- `pipeline` is the ray tracing pipeline object containing the shaders groups.
- `group` is the index of the shader group to query.
- `groupShader` is the type of shader from the group to query.

The return value is the ray tracing pipeline stack size in bytes for the specified shader as called from the specified shader group.

Valid Usage

- VUID-vkGetRayTracingShaderGroupStackSizeKHR-pipeline-04622
  
  `pipeline` must be a ray tracing pipeline

- VUID-vkGetRayTracingShaderGroupStackSizeKHR-group-03608
  
  The value of `group` must be less than the number of shader groups in `pipeline`

- VUID-vkGetRayTracingShaderGroupStackSizeKHR-groupShader-03609
The shader identified by `groupShader` in `group` must not be `VK_SHADER_UNUSED_KHR`.

### Valid Usage (Implicit)

- **VUID-vkGetRayTracingShaderGroupStackSizeKHR-device-parameter**
  - `device` must be a valid `VkDevice` handle

- **VUID-vkGetRayTracingShaderGroupStackSizeKHR-pipeline-parameter**
  - `pipeline` must be a valid `VkPipeline` handle

- **VUID-vkGetRayTracingShaderGroupStackSizeKHR-groupShader-parameter**
  - `groupShader` must be a valid `VkShaderGroupShaderKHR` value

- **VUID-vkGetRayTracingShaderGroupStackSizeKHR-pipeline-parent**
  - `pipeline` must have been created, allocated, or retrieved from `device`

Possible values of `groupShader` in `vkGetRayTracingShaderGroupStackSizeKHR` are:

```c
// Provided by VK_KHR_ray_tracing_pipeline
typedef enum VkShaderGroupShaderKHR {
    VK_SHADER_GROUP_SHADER_GENERAL_KHR = 0,
    VK_SHADER_GROUP_SHADER_CLOSEST_HIT_KHR = 1,
    VK_SHADER_GROUP_SHADER_ANY_HIT_KHR = 2,
    VK_SHADER_GROUP_SHADER_INTERSECTION_KHR = 3,
} VkShaderGroupShaderKHR;
```

- `VK_SHADER_GROUP_SHADER_GENERAL_KHR` uses the shader specified in the group with `VkRayTracingShaderGroupCreateInfoKHR::generalShader`
- `VK_SHADER_GROUP_SHADER_CLOSEST_HIT_KHR` uses the shader specified in the group with `VkRayTracingShaderGroupCreateInfoKHR::closestHitShader`
- `VK_SHADER_GROUP_SHADER_ANY_HIT_KHR` uses the shader specified in the group with `VkRayTracingShaderGroupCreateInfoKHR::anyHitShader`
- `VK_SHADER_GROUP_SHADER_INTERSECTION_KHR` uses the shader specified in the group with `VkRayTracingShaderGroupCreateInfoKHR::intersectionShader`

To **dynamically set** the stack size for a ray tracing pipeline, call:

```c
// Provided by VK_KHR_ray_tracing_pipeline
void vkCmdSetRayTracingPipelineStackSizeKHR(
    VkCommandBuffer commandBuffer,  commandBuffer,
    uint32_t pipelineStackSize);  pipelineStackSize);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `pipelineStackSize` is the stack size to use for subsequent ray tracing trace commands.

This command sets the stack size for subsequent ray tracing commands when the ray tracing
pipeline is created with `VK_DYNAMIC_STATERAY_TRACING_PIPELINE_STACK_SIZE_KHR` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, the stack size is computed as described in Ray Tracing Pipeline Stack.

### Valid Usage

- VUID-vkCmdSetRayTracingPipelineStackSizeKHR-pipelineStackSize-03610
  pipelineStackSize **must** be large enough for any dynamic execution through the shaders in the ray tracing pipeline used by a subsequent trace call

### Valid Usage (Implicit)

- VUID-vkCmdSetRayTracingPipelineStackSizeKHR-commandBuffer-parameter
  commandBuffer **must** be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetRayTracingPipelineStackSizeKHR-commandBuffer-recording
  commandBuffer **must** be in the recording state
- VUID-vkCmdSetRayTracingPipelineStackSizeKHR-commandBuffer-cmdpool
  The `VkCommandPool` that commandBuffer was allocated from **must** support compute operations
- VUID-vkCmdSetRayTracingPipelineStackSizeKHR-renderpass
  This command **must** only be called outside of a render pass instance
- VUID-vkCmdSetRayTracingPipelineStackSizeKHR-videocoding
  This command **must** only be called outside of a video coding scope

### Host Synchronization

- Host access to commandBuffer **must** be externally synchronized
- Host access to the `VkCommandPool` that commandBuffer was allocated from **must** be externally synchronized

### Command Properties

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### 10.4. Pipeline Destruction

To destroy a pipeline, call:
void vkDestroyPipeline(
    VkDevice device,
    VkPipeline pipeline,
    const VkAllocationCallbacks* pAllocator);

- `device` is the logical device that destroys the pipeline.
- `pipeline` is the handle of the pipeline to destroy.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

### Valid Usage

- **VUID-vkDestroyPipeline-pipeline-00765**
  All submitted commands that refer to `pipeline` must have completed execution

- **VUID-vkDestroyPipeline-pipeline-00766**
  If `VkAllocationCallbacks` were provided when `pipeline` was created, a compatible set of callbacks must be provided here

- **VUID-vkDestroyPipeline-pipeline-00767**
  If no `VkAllocationCallbacks` were provided when `pipeline` was created, `pAllocator` must be `NULL`

### Valid Usage (Implicit)

- **VUID-vkDestroyPipeline-device-parameter**
  `device` must be a valid `VkDevice` handle

- **VUID-vkDestroyPipeline-pipeline-parameter**
  If `pipeline` is not `VK_NULL_HANDLE`, `pipeline` must be a valid `VkPipeline` handle

- **VUID-vkDestroyPipeline-pAllocator-parameter**
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

- **VUID-vkDestroyPipeline-pipeline-parent**
  If `pipeline` is a valid handle, it must have been created, allocated, or retrieved from `device`

### Host Synchronization

- Host access to `pipeline` must be externally synchronized

---

### 10.5. Multiple Pipeline Creation

Multiple pipelines can be created simultaneously by passing an array of `VkGraphicsPipelineCreateInfo`, `VkRayTracingPipelineCreateInfoKHR`,...
VkRayTracingPipelineCreateInfoNV, or VkComputePipelineCreateInfo structures into the vkCreateGraphicsPipelines, vkCreateRayTracingPipelinesKHR, vkCreateRayTracingPipelinesNV, and vkCreateComputePipelines commands, respectively. Applications can group together similar pipelines to be created in a single call, and implementations are encouraged to look for reuse opportunities within a group-create.

When an application attempts to create many pipelines in a single command, it is possible that some subset may fail creation. In that case, the corresponding entries in the pPipelines output array will be filled with VK_NULL_HANDLE values. If any pipeline fails creation despite valid arguments (for example, due to out of memory errors), the VkResult code returned by vkCreate*Pipelines will indicate why. The implementation will attempt to create all pipelines, and only return VK_NULL_HANDLE values for those that actually failed.

If creation fails for a pipeline that had VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT set, pipelines at an index in the pPipelines array greater than or equal to that of the failing pipeline must be set to VK_NULL_HANDLE.

If multiple pipelines fail to be created, the VkResult must be the return value of any of the pipelines which did not return VK_SUCCESS.

10.6. Pipeline Derivatives

A pipeline derivative is a child pipeline created from a parent pipeline, where the child and parent are expected to have much commonality.

The goal of derivative pipelines is that they be cheaper to create using the parent as a starting point, and that it be more efficient (on either host or device) to switch/bind between children of the same parent.

A derivative pipeline is created by setting the VK_PIPELINE_CREATE_DERIVATIVE_BIT flag in the Vk*PipelineCreateInfo structure. If this is set, then exactly one of basePipelineHandle or basePipelineIndex members of the structure must have a valid handle/index, and specifies the parent pipeline. If basePipelineHandle is used, the parent pipeline must have already been created. If basePipelineIndex is used, then the parent is being created in the same command. VK_NULL_HANDLE acts as the invalid handle for basePipelineHandle, and -1 is the invalid index for basePipelineIndex. If basePipelineIndex is used, the base pipeline must appear earlier in the array. The base pipeline must have been created with the VK_PIPELINE_CREATE_ALLOW_DERIVATIVES_BIT flag set.

10.7. Pipeline Cache

Pipeline cache objects allow the result of pipeline construction to be reused between pipelines and between runs of an application. Reuse between pipelines is achieved by passing the same pipeline cache object when creating multiple related pipelines. Reuse across runs of an application is achieved by retrieving pipeline cache contents in one run of an application, saving the contents, and using them to preinitialize a pipeline cache on a subsequent run. The contents of the pipeline cache objects are managed by the implementation. Applications can manage the host memory consumed by a pipeline cache object and control the amount of data retrieved from a pipeline.
Pipeline cache objects are represented by `VkPipelineCache` handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkPipelineCache)
```

### 10.7.1. Creating a Pipeline Cache

To create pipeline cache objects, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkCreatePipelineCache(
    VkDevice device, 
    const VkPipelineCacheCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator, 
    VkPipelineCache* pPipelineCache);
```

- `device` is the logical device that creates the pipeline cache object.
- `pCreateInfo` is a pointer to a `VkPipelineCacheCreateInfo` structure containing initial parameters for the pipeline cache object.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pPipelineCache` is a pointer to a `VkPipelineCache` handle in which the resulting pipeline cache object is returned.

**Note**

Applications can track and manage the total host memory size of a pipeline cache object using the `pAllocator`. Applications can limit the amount of data retrieved from a pipeline cache object in `vkGetPipelineCacheData`. Implementations should not internally limit the total number of entries added to a pipeline cache object or the total host memory consumed.

Once created, a pipeline cache can be passed to the `vkCreateGraphicsPipelines`, `vkCreateRayTracingPipelinesKHR`, `vkCreateRayTracingPipelinesNV`, and `vkCreateComputePipelines` commands. If the pipeline cache passed into these commands is not `VK_NULL_HANDLE`, the implementation will query it for possible reuse opportunities and update it with new content. The use of the pipeline cache object in these commands is internally synchronized, and the same pipeline cache object can be used in multiple threads simultaneously.

If flags of `pCreateInfo` includes `VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT`, all commands that modify the returned pipeline cache object must be externally synchronized.

**Note**

Implementations should make every effort to limit any critical sections to the actual accesses to the cache, which is expected to be significantly shorter than the
duration of the `vkCreate*Pipelines` commands.

Valid Usage (Implicit)

- **VUID-vkCreatePipelineCache-device-parameter**
  - `device` must be a valid `VkDevice` handle
- **VUID-vkCreatePipelineCache-pCreateInfo-parameter**
  - `pCreateInfo` must be a valid pointer to a valid `VkPipelineCacheCreateInfo` structure
- **VUID-vkCreatePipelineCache-pAllocator-parameter**
  - If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure
- **VUID-vkCreatePipelineCache-pPipelineCache-parameter**
  - `pPipelineCache` must be a valid pointer to a `VkPipelineCache` handle

Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

The `VkPipelineCacheCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPipelineCacheCreateInfo {
    VkStructureType  sType;
    const void*      pNext;
    VkPipelineCacheCreateFlags flags;
    size_t           initialDataSize;
    const void*      pInitialData;
} VkPipelineCacheCreateInfo;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkPipelineCacheCreateFlagBits` specifying the behavior of the pipeline cache.
- `initialDataSize` is the number of bytes in `pInitialData`. If `initialDataSize` is zero, the pipeline cache will initially be empty.
- `pInitialData` is a pointer to previously retrieved pipeline cache data. If the pipeline cache data is incompatible (as defined below) with the device, the pipeline cache will be initially empty. If
**Valid Usage**

- **VUID-VkPipelineCacheCreateInfo-initialDataSize-00768**
  If `initialDataSize` is not 0, it **must** be equal to the size of `pInitialData`, as returned by `vkGetPipelineCacheData` when `pInitialData` was originally retrieved.

- **VUID-VkPipelineCacheCreateInfo-initialDataSize-00769**
  If `initialDataSize` is not 0, `pInitialData` **must** have been retrieved from a previous call to `vkGetPipelineCacheData`.

- **VUID-VkPipelineCacheCreateInfo-pipelineCreationCacheControl-02892**
  If the `pipelineCreationCacheControl` feature is not enabled, **flags** **must** not include `VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT`.

**Valid Usage (Implicit)**

- **VUID-VkPipelineCacheCreateInfo-sType-sType**
  `sType` **must** be `VK_STRUCTURE_TYPE_PIPELINE_CACHE_CREATE_INFO`.

- **VUID-VkPipelineCacheCreateInfo-pNext-pNext**
  `pNext` **must** be `NULL`.

- **VUID-VkPipelineCacheCreateInfo-flags-parameter**
  `flags` **must** be a valid combination of `VkPipelineCacheCreateFlagBits` values.

- **VUID-VkPipelineCacheCreateInfo-pInitialData-parameter**
  If `initialDataSize` is not 0, `pInitialData` **must** be a valid pointer to an array of `initialDataSize` bytes.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkPipelineCacheCreateFlags;
```

`VkPipelineCacheCreateFlags` is a bitmask type for setting a mask of zero or more `VkPipelineCacheCreateFlagBits`.

Bits which **can** be set in `VkPipelineCacheCreateInfo::flags`, specifying behavior of the pipeline cache, are:

```c
// Provided by VK_EXT_pipeline_creation_cache_control
typedef enum VkPipelineCacheCreateFlagBits {
    // Provided by VK_VERSION_1_3
    VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT = 0x00000001,
    // Provided by VK_EXT_pipeline_creation_cache_control
    VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT_EXT = VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT,
};
```
vkPipelineCacheCreateFlagBits;

- **VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT** specifies that all commands that modify the created VkPipelineCache will be externally synchronized. When set, the implementation may skip any unnecessary processing needed to support simultaneous modification from multiple threads where allowed.

### 10.7.2. Merging Pipeline Caches

Pipeline cache objects can be merged using the command:

```c
// Provided by VK_VERSION_1_0
VkResult vkMergePipelineCaches(
    VkDevice device,
    VkPipelineCache dstCache,
    uint32_t srcCacheCount,
    const VkPipelineCache* pSrcCaches);
```

- **device** is the logical device that owns the pipeline cache objects.
- **dstCache** is the handle of the pipeline cache to merge results into.
- **srcCacheCount** is the length of the pSrcCaches array.
- **pSrcCaches** is a pointer to an array of pipeline cache handles, which will be merged into dstCache. The previous contents of dstCache are included after the merge.

**Note**

The details of the merge operation are implementation-dependent, but implementations should merge the contents of the specified pipelines and prune duplicate entries.

### Valid Usage

- VUID-vkMergePipelineCaches-dstCache-00770
  dstCache must not appear in the list of source caches

### Valid Usage (Implicit)

- VUID-vkMergePipelineCaches-device-parameter
device must be a valid VkDevice handle
- VUID-vkMergePipelineCaches-dstCache-parameter
dstCache must be a valid VkPipelineCache handle
- VUID-vkMergePipelineCaches-pSrcCaches-parameter
  pSrcCaches must be a valid pointer to an array of srcCacheCount valid VkPipelineCache handles
Host Synchronization

- Host access to dstCache must be externally synchronized

Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

10.7.3. Retrieving Pipeline Cache Data

Data can be retrieved from a pipeline cache object using the command:

```c
// Provided by VK_VERSION_1_0
VkResult vkGetPipelineCacheData(
    VkDevice device,
    VkPipelineCache pipelineCache,
    size_t* pDataSize,
    void* pData);
```

- device is the logical device that owns the pipeline cache.
- pipelineCache is the pipeline cache to retrieve data from.
- pDataSize is a pointer to a size_t value related to the amount of data in the pipeline cache, as described below.
- pData is either NULL or a pointer to a buffer.

If pData is NULL, then the maximum size of the data that can be retrieved from the pipeline cache, in bytes, is returned in pDataSize. Otherwise, pDataSize must point to a variable set by the user to the size of the buffer, in bytes, pointed to by pData, and on return the variable is overwritten with the amount of data actually written to pData. If pDataSize is less than the maximum size that can be retrieved by the pipeline cache, at most pDataSize bytes will be written to pData, and VK_INCOMPLETE
will be returned instead of \texttt{VK_SUCCESS}, to indicate that not all of the pipeline cache was returned.

Any data written to \texttt{pData} is valid and \textbf{can} be provided as the \texttt{pInitialData} member of the \texttt{VkPipelineCacheCreateInfo} structure passed to \texttt{vkCreatePipelineCache}.

Two calls to \texttt{vkGetPipelineCacheData} with the same parameters \textbf{must} retrieve the same data unless a command that modifies the contents of the cache is called between them.

The initial bytes written to \texttt{pData} \textbf{must} be a header as described in the Pipeline Cache Header section.

If \texttt{pDataSize} is less than what is necessary to store this header, nothing will be written to \texttt{pData} and zero will be written to \texttt{pDataSize}.

### Valid Usage (Implicit)

- \textbf{VUID-vkGetPipelineCacheData-device-parameter} \texttt{device} \textbf{must} be a valid \texttt{VkDevice} handle
- \textbf{VUID-vkGetPipelineCacheData-pipelineCache-parameter} \texttt{pipelineCache} \textbf{must} be a valid \texttt{VkPipelineCache} handle
- \textbf{VUID-vkGetPipelineCacheData-pDataSize-parameter} \texttt{pDataSize} \textbf{must} be a valid pointer to a \texttt{size_t} value
- \textbf{VUID-vkGetPipelineCacheData-pData-parameter} if the value referenced by \texttt{pDataSize} is not \texttt{0}, and \texttt{pData} is not \texttt{NULL}, \texttt{pData} \textbf{must} be a valid pointer to an array of \texttt{pDataSize} bytes
- \textbf{VUID-vkGetPipelineCacheData-pipelineCache-parent} \texttt{pipelineCache} \textbf{must} have been created, allocated, or retrieved from \texttt{device}

### Return Codes

#### Success

- \texttt{VK_SUCCESS}
- \texttt{VK_INCOMPLETE}

#### Failure

- \texttt{VK_ERROR_OUT_OF_HOST_MEMORY}
- \texttt{VK_ERROR_OUT_OF_DEVICE_MEMORY}

### 10.7.4. Pipeline Cache Header

Applications \textbf{can} store the data retrieved from the pipeline cache, and use these data, possibly in a future run of the application, to populate new pipeline cache objects. The results of pipeline compiles, however, \textbf{may} depend on the vendor ID, device ID, driver version, and other details of the device. To enable applications to detect when previously retrieved data is incompatible with the
device, the pipeline cache data must begin with a valid pipeline cache header.

Note
Structures described in this section are not part of the Vulkan API and are only used to describe the representation of data elements in pipeline cache data. Accordingly, the valid usage clauses defined for structures defined in this section do not define valid usage conditions for APIs accepting pipeline cache data as input, as providing invalid pipeline cache data as input to any Vulkan API commands will result in the provided pipeline cache data being ignored.

Version one of the pipeline cache header is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPipelineCacheHeaderVersionOne {
    uint32_t headerSize;
    VkPipelineCacheHeaderVersion headerVersion;
    uint32_t vendorID;
    uint32_t deviceID;
    uint8_t pipelineCacheUUID[VK_UUID_SIZE];
} VkPipelineCacheHeaderVersionOne;
```

- headerSize is the length in bytes of the pipeline cache header.
- headerVersion is a VkPipelineCacheHeaderVersion enum value specifying the version of the header. A consumer of the pipeline cache should use the cache version to interpret the remainder of the cache header.
- vendorID is the VkPhysicalDeviceProperties::vendorID of the implementation.
- deviceID is the VkPhysicalDeviceProperties::deviceID of the implementation.
- pipelineCacheUUID is the VkPhysicalDeviceProperties::pipelineCacheUUID of the implementation.

Unlike most structures declared by the Vulkan API, all fields of this structure are written with the least significant byte first, regardless of host byte-order.

The C language specification does not define the packing of structure members. This layout assumes tight structure member packing, with members laid out in the order listed in the structure, and the intended size of the structure is 32 bytes. If a compiler produces code that diverges from that pattern, applications must employ another method to set values at the correct offsets.

Valid Usage

- VUID-VkPipelineCacheHeaderVersionOne-headerSize-04967
  headerSize must be 32
- VUID-VkPipelineCacheHeaderVersionOne-headerVersion-04968
  headerVersion must be VK_PIPELINE_CACHE_HEADER_VERSION_ONE
- VUID-VkPipelineCacheHeaderVersionOne-headerSize-08990
  headerSize must not exceed the size of the pipeline cache
Valid Usage (Implicit)

- **VUID-VkPipelineCacheHeaderVersionOne-headerVersion-parameter**
  
  `headerVersion` must be a valid `VkPipelineCacheHeaderVersion` value

Possible values of the `headerVersion` value of the pipeline cache header are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkPipelineCacheHeaderVersion {
    VK_PIPELINE_CACHE_HEADER_VERSION_ONE = 1,
} VkPipelineCacheHeaderVersion;
```

- `VK_PIPELINE_CACHE_HEADER_VERSION_ONE` specifies version one of the pipeline cache, described by `VkPipelineCacheHeaderVersionOne`.

### 10.7.5. Destroying a Pipeline Cache

To destroy a pipeline cache, call:

```c
// Provided by VK_VERSION_1_0
void vkDestroyPipelineCache(
    VkDevice device,        // device is the logical device that destroys the pipeline cache object.
    VkPipelineCache pipelineCache,       // pipelineCache is the handle of the pipeline cache to destroy.
    const VkAllocationCallbacks* pAllocator);    // pAllocator controls host memory allocation as described in the Memory Allocation chapter.
```

Valid Usage

- **VUID-vkDestroyPipelineCache-pipelineCache-00771**
  
  If `VkAllocationCallbacks` were provided when `pipelineCache` was created, a compatible set of callbacks must be provided here

- **VUID-vkDestroyPipelineCache-pipelineCache-00772**
  
  If no `VkAllocationCallbacks` were provided when `pipelineCache` was created, `pAllocator` must be `NULL`

Valid Usage (Implicit)

- **VUID-vkDestroyPipelineCache-device-parameter**
  
  `device` must be a valid `VkDevice` handle
Host Synchronization

- Host access to pipelineCache must be externally synchronized

10.8. Specialization Constants

Specialization constants are a mechanism whereby constants in a SPIR-V module can have their constant value specified at the time the VkPipeline is created. This allows a SPIR-V module to have constants that can be modified while executing an application that uses the Vulkan API.

Note

Specialization constants are useful to allow a compute shader to have its local workgroup size changed at runtime by the user, for example.

Each VkPipelineShaderStageCreateInfo structure contains a pSpecializationInfo member, which can be NULL to indicate no specialization constants, or point to a VkSpecializationInfo structure.

The VkSpecializationInfo structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkSpecializationInfo {
    uint32_t mapEntryCount;
    const VkSpecializationMapEntry* pMapEntries;
    size_t dataSize;
    const void* pData;
} VkSpecializationInfo;
```

- **mapEntryCount** is the number of entries in the pMapEntries array.
- **pMapEntries** is a pointer to an array of VkSpecializationMapEntry structures, which map constant IDs to offsets in pData.
- **dataSize** is the byte size of the pData buffer.
- **pData** contains the actual constant values to specialize with.
**Valid Usage**

- VUID-VkSpecializationInfo-offset-00773
  The `offset` member of each element of `pMapEntries` must be less than `dataSize`

- VUID-VkSpecializationInfo-pMapEntries-00774
  The `size` member of each element of `pMapEntries` must be less than or equal to `dataSize` minus `offset`

- VUID-VkSpecializationInfo-constantID-04911
  The `constantID` value of each element of `pMapEntries` must be unique within `pMapEntries`

**Valid Usage (Implicit)**

- VUID-VkSpecializationInfo-pMapEntries-parameter
  If `mapEntryCount` is not 0, `pMapEntries` must be a valid pointer to an array of `mapEntryCount` valid `VkSpecializationMapEntry` structures

- VUID-VkSpecializationInfo-pData-parameter
  If `dataSize` is not 0, `pData` must be a valid pointer to an array of `dataSize` bytes

The `VkSpecializationMapEntry` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkSpecializationMapEntry {
    uint32_t constantID;
    uint32_t offset;
    size_t size;
} VkSpecializationMapEntry;
```

- `constantID` is the ID of the specialization constant in SPIR-V.
- `offset` is the byte offset of the specialization constant value within the supplied data buffer.
- `size` is the byte size of the specialization constant value within the supplied data buffer.

If a `constantID` value is not a specialization constant ID used in the shader, that map entry does not affect the behavior of the pipeline.

**Valid Usage**

- VUID-VkSpecializationMapEntry-constantID-00776
  For a `constantID` specialization constant declared in a shader, `size` must match the byte size of the `constantID`. If the specialization constant is of type `boolean`, `size` must be the byte size of `VkBool32`

In human readable SPIR-V:
From the above we have three specialization constants, one for each of the x, y & z elements of the WorkgroupSize vector.

Now to specialize the above via the specialization constants mechanism:

```c
const VkSpecializationMapEntry entries[] =
{
   {
      .constantID = 13,
      .offset = 0 * sizeof(uint32_t),
      .size = sizeof(uint32_t)
   },
   {
      .constantID = 42,
      .offset = 1 * sizeof(uint32_t),
      .size = sizeof(uint32_t)
   },
   {
      .constantID = 3,
      .offset = 2 * sizeof(uint32_t),
      .size = sizeof(uint32_t)
   }
};
const uint32_t data[] = { 16, 8, 4 }; // our workgroup size is 16x8x4

const VkSpecializationInfo info =
{
   .mapEntryCount = 3,
   .pMapEntries = entries,
   .dataSize = 3 * sizeof(uint32_t),
   .pData = data,
};
```

Then when calling `vkCreateComputePipelines`, and passing the `VkSpecializationInfo` we defined as the `pSpecializationInfo` parameter of `VkPipelineShaderStageCreateInfo`, we will create a compute pipeline with the runtime specified local workgroup size.
Another example would be that an application has a SPIR-V module that has some platform-dependent constants they wish to use.

In human readable SPIR-V:

```
OpDecorate %1 SpecId 0; // decorate our signed 32-bit integer constant
OpDecorate %2 SpecId 12; // decorate our 32-bit floating-point constant
%32 = OpTypeInt 32 1; // declare a signed 32-bit type
%float = OpTypeFloat 32; // declare a 32-bit floating-point type
%1 = OpSpecConstant %i32 -1; // some signed 32-bit integer constant
%2 = OpSpecConstant %float 0.5; // some 32-bit floating-point constant
```

From the above we have two specialization constants, one is a signed 32-bit integer and the second is a 32-bit floating-point value.

Now to specialize the above via the specialization constants mechanism:

```
struct SpecializationData {
    int32_t data0;
    float data1;
};

class VkSpecializationMapEntry entries[] =
{
    {
        .constantID = 0,
        .offset = offsetof(SpecializationData, data0),
        .size = sizeof(SpecializationData::data0)
    },
    {
        .constantID = 12,
        .offset = offsetof(SpecializationData, data1),
        .size = sizeof(SpecializationData::data1)
    }
};

SpecializationData data;
data.data0 = -42; // set the data for the 32-bit integer
data.data1 = 42.0f; // set the data for the 32-bit floating-point

class VkSpecializationInfo info =
{
    .mapEntryCount = 2,
    .pMapEntries = entries,
    .dataSize = sizeof(data),
    .pdata = &data,
};
```

It is legal for a SPIR-V module with specializations to be compiled into a pipeline where no
specialization information was provided. SPIR-V specialization constants contain default values such that if a specialization is not provided, the default value will be used. In the examples above, it would be valid for an application to only specialize some of the specialization constants within the SPIR-V module, and let the other constants use their default values encoded within the OpSpecConstant declarations.

10.9. Pipeline Libraries

A pipeline library is a special pipeline that was created using the VK_PIPELINE_CREATE_LIBRARY_BIT_KHR and cannot be bound, instead it defines a set of pipeline state which can be linked into other pipelines. For ray tracing pipelines this includes shaders and shader groups. For graphics pipelines this includes distinct library types defined by VkGraphicsPipelineLibraryFlagBitsEXT. The application must maintain the lifetime of a pipeline library based on the pipelines that link with it.

This linkage is achieved by using the following structure within the appropriate creation mechanisms:

The VkPipelineLibraryCreateInfoKHR structure is defined as:

```c
// Provided by VK_KHR_pipeline_library
typedef struct VkPipelineLibraryCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t libraryCount;
    const VkPipeline* pLibraries;
} VkPipelineLibraryCreateInfoKHR;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `libraryCount` is the number of pipeline libraries in `pLibraries`.
- `pLibraries` is a pointer to an array of VkPipeline structures specifying pipeline libraries to use when creating a pipeline.

Valid Usage

- VUID-VkPipelineLibraryCreateInfoKHR-pLibraries-03381
  Each element of `pLibraries` must have been created with VK_PIPELINE_CREATE_LIBRARY_BIT_KHR
- VUID-VkPipelineLibraryCreateInfoKHR-pLibraries-06855
  If any library in `pLibraries` was created with a shader stage with VkPipelineShaderStageModuleIdentifierCreateInfoEXT and `identifierSize` not equal to 0, the pipeline must be created with the VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT flag set
- VUID-VkPipelineLibraryCreateInfoKHR-pLibraries-08096
If any element of `pLibraries` was created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, all elements must have been created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- VUID-VkPipelineLibraryCreateInfoKHR-pipeline-07404
  If `pipeline` is being created with `VK_PIPELINE_CREATE_NO_PROTECTED_ACCESS_BIT_EXT`, every element of `pLibraries` must have been created with `VK_PIPELINE_CREATE_NO_PROTECTED_ACCESS_BIT_EXT`.

- VUID-VkPipelineLibraryCreateInfoKHR-pipeline-07405
  If `pipeline` is being created without `VK_PIPELINE_CREATE_NO_PROTECTED_ACCESS_BIT_EXT`, every element of `pLibraries` must have been created without `VK_PIPELINE_CREATE_NO_PROTECTED_ACCESS_BIT_EXT`.

- VUID-VkPipelineLibraryCreateInfoKHR-pipeline-07406
  If `pipeline` is being created with `VK_PIPELINE_CREATE_PROTECTED_ACCESS_ONLY_BIT_EXT`, every element of `pLibraries` must have been created with `VK_PIPELINE_CREATE_PROTECTED_ACCESS_ONLY_BIT_EXT`.

- VUID-VkPipelineLibraryCreateInfoKHR-pipeline-07407
  If `pipeline` is being created without `VK_PIPELINE_CREATE_PROTECTED_ACCESS_ONLY_BIT_EXT`, every element of `pLibraries` must have been created without `VK_PIPELINE_CREATE_PROTECTED_ACCESS_ONLY_BIT_EXT`.

Valid Usage (Implicit)

- VUID-VkPipelineLibraryCreateInfoKHR-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_LIBRARY_CREATE_INFO_KHR`.

- VUID-VkPipelineLibraryCreateInfoKHR-pLibraries-parameter
  If `libraryCount` is not 0, `pLibraries` must be a valid pointer to an array of `libraryCount` valid `VkPipeline` handles.

Pipelines created with `VK_PIPELINE_CREATE_LIBRARY_BIT_KHR` libraries can depend on other pipeline libraries in `VkPipelineLibraryCreateInfoKHR`.

A pipeline library is considered in-use, as long as one of the linking pipelines is in-use. This applies recursively if a pipeline library includes other pipeline libraries.

### 10.10. Pipeline Binding

Once a pipeline has been created, it can be bound to the command buffer using the command:

```c
// Provided by VK_VERSION_1_0
void vkCmdBindPipeline(
    VkCommandBuffer commandBuffer,
    VkPipelineBindPoint pipelineBindPoint,
    VkPipeline pipeline);
```
• commandBuffer is the command buffer that the pipeline will be bound to.

• pipelineBindPoint is a VkPipelineBindPoint value specifying to which bind point the pipeline is bound. Binding one does not disturb the others.

• pipeline is the pipeline to be bound.

Once bound, a pipeline binding affects subsequent commands that interact with the given pipeline type in the command buffer until a different pipeline of the same type is bound to the bind point, or until the pipeline bind point is disturbed by binding a shader object as described in Interaction with Pipelines. Commands that do not interact with the given pipeline type must not be affected by the pipeline state.

Valid Usage

• VUID-vkCmdBindPipeline-pipelineBindPoint-00777
  If pipelineBindPoint is VK_PIPELINE_BIND_POINT_COMPUTE, the VkCommandPool that commandBuffer was allocated from must support compute operations

• VUID-vkCmdBindPipeline-pipelineBindPoint-00778
  If pipelineBindPoint is VK_PIPELINE_BIND_POINT_GRAPHICS, the VkCommandPool that commandBuffer was allocated from must support graphics operations

• VUID-vkCmdBindPipeline-pipelineBindPoint-00779
  If pipelineBindPoint is VK_PIPELINE_BIND_POINT_COMPUTE, pipeline must be a compute pipeline

• VUID-vkCmdBindPipeline-pipelineBindPoint-00780
  If pipelineBindPoint is VK_PIPELINE_BIND_POINT_GRAPHICS, pipeline must be a graphics pipeline

• VUID-vkCmdBindPipeline-pipeline-00781
  If the variableMultisampleRate feature is not supported, pipeline is a graphics pipeline, the current subpass uses no attachments, and this is not the first call to this function with a graphics pipeline after transitioning to the current subpass, then the sample count specified by this pipeline must match that set in the previous pipeline

• VUID-vkCmdBindPipeline-variableSampleLocations-01525
  If VkPhysicalDeviceSampleLocationsPropertiesEXT::variableSampleLocations is VK_FALSE, and pipeline is a graphics pipeline created with a VkPipelineSampleLocationsStateCreateInfoEXT structure having its sampleLocationsEnable member set to VK_TRUE but without VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT enabled then the current render pass instance must have been begun by specifying a VkRenderPassSampleLocationsBeginInfoEXT structure whose pPostSubpassSampleLocations member contains an element with a subpassIndex matching the current subpass index and the sampleLocationsInfo member of that element must match the sampleLocationsInfo specified in VkPipelineSampleLocationsStateCreateInfoEXT when the pipeline was created

• VUID-vkCmdBindPipeline-None-02323
  This command must not be recorded when transform feedback is active

• VUID-vkCmdBindPipeline-pipelineBindPoint-02391
If `pipelineBindPoint` is `VK_PIPELINE_BIND_POINT_RAY_TRACING_KHR`, the `VkCommandPool` that `commandBuffer` was allocated from must support compute operations

- VUID-vkCmdBindPipeline-pipelineBindPoint-02392
  If `pipelineBindPoint` is `VK_PIPELINE_BIND_POINT_RAY_TRACING_KHR`, `pipeline` must be a ray tracing pipeline

- VUID-vkCmdBindPipeline-pipelineBindPoint-06721
  If `pipelineBindPoint` is `VK_PIPELINE_BIND_POINT_RAY_TRACING_KHR`, `commandBuffer` must not be a protected command buffer

- VUID-vkCmdBindPipeline-pipelineProtectedAccess-07408
  If the `pipelineProtectedAccess` feature is enabled, and `commandBuffer` is a protected command buffer, `pipeline` must have been created without `VK_PIPELINE_CREATE_NO_PROTECTED_ACCESS_BIT_EXT`

- VUID-vkCmdBindPipeline-pipelineProtectedAccess-07409
  If the `pipelineProtectedAccess` feature is enabled, and `commandBuffer` is not a protected command buffer, `pipeline` must have been created without `VK_PIPELINE_CREATE_PROTECTED_ACCESS_ONLY_BIT_EXT`

- VUID-vkCmdBindPipeline-pipeline-03382
  `pipeline` must not have been created with `VK_PIPELINE_CREATE_LIBRARY_BIT_KHR` set

- VUID-vkCmdBindPipeline-commandBuffer-04808
  If `commandBuffer` is a secondary command buffer with `VkCommandBufferInheritanceViewportScissorInfoNV::viewportScissor2D` enabled and `pipelineBindPoint` is `VK_PIPELINE_BIND_POINT_GRAPHICS`, then the `pipeline` must have been created with `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` or `VK_DYNAMIC_STATE_VIEWPORT`, and `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` or `VK_DYNAMIC_STATE_SCISSOR` enabled

- VUID-vkCmdBindPipeline-commandBuffer-04809
  If `commandBuffer` is a secondary command buffer with `VkCommandBufferInheritanceViewportScissorInfoNV::viewportScissor2D` enabled and `pipelineBindPoint` is `VK_PIPELINE_BIND_POINT_GRAPHICS` and `pipeline` was created with `VkPipelineDiscardRectangleStateCreateInfoEXT` structure and its `discardRectangleCount` member is not 0, or the pipeline was created with `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT` enabled, then the `pipeline` must have been created with `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` enabled

- VUID-vkCmdBindPipeline-pipelineBindPoint-04881
  If `pipelineBindPoint` is `VK_PIPELINE_BIND_POINT_GRAPHICS` and the `provokingVertexModePerPipeline` limit is `VK_FALSE`, then pipeline's `VkPipelineRasterizationProvokingVertexStateCreateInfoEXT::provokingVertexMode` must be the same as that of any other pipelines previously bound to this bind point within the current render pass instance, including any pipeline already bound when beginning the render pass instance

- VUID-vkCmdBindPipeline-pipelineBindPoint-04949
  If `pipelineBindPoint` is `VK_PIPELINE_BIND_POINT_SUBPASS_SHADING_HUAWEI`, the `VkCommandPool` that `commandBuffer` was allocated from must support compute operations

- VUID-vkCmdBindPipeline-pipelineBindPoint-04950
  If `pipelineBindPoint` is `VK_PIPELINE_BIND_POINT_SUBPASS_SHADING_HUAWEI`, `pipeline` must be a
subpass shading pipeline

- **VUID-vkCmdBindPipeline-pipelineBind-06653**
  If `pipelineBindPoint` is `VK_PIPELINE_BIND_POINT_GRAPHICS`, `pipeline` must have been created without `VK_PIPELINE_CREATE_LIBRARY_BIT_KHR`.

### Valid Usage (Implicit)

- **VUID-vkCmdBindPipeline-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- **VUID-vkCmdBindPipeline-pipelineBindPoint-parameter**
  `pipelineBindPoint` must be a valid `VkPipelineBindPoint` value.

- **VUID-vkCmdBindPipeline-pipeline-parameter**
  `pipeline` must be a valid `VkPipeline` handle.

- **VUID-vkCmdBindPipeline-commandBuffer-recording**
  `commandBuffer` must be in the recording state.

- **VUID-vkCmdBindPipeline-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, or compute operations.

- **VUID-vkCmdBindPipeline-videocoding**
  This command must only be called outside of a video coding scope.

- **VUID-vkCmdBindPipeline-commonparent**
  Both of `commandBuffer`, and `pipeline` must have been created, allocated, or retrieved from the same `VkDevice`.

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

### Command Properties

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</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Possible values of `vkCmdBindPipeline::pipelineBindPoint`, specifying the bind point of a pipeline object, are:
typedef enum VkPipelineBindPoint {
    VK_PIPELINE_BIND_POINT_GRAPHICS = 0,
    VK_PIPELINE_BIND_POINT_COMPUTE = 1,
} VkPipelineBindPoint;

#ifdef VK_ENABLE_BETA_EXTENSIONS
    VK_PIPELINE_BIND_POINT_EXECUTION_GRAPH_AMDX = 1000134000,
#endif

// Provided by VK_KHR_ray_tracing_pipeline
    VK_PIPELINE_BIND_POINT_RAY_TRACING_KHR = 1000165000,
// Provided by VK_HUAWEI_subpass_shading
    VK_PIPELINE_BIND_POINT_SUBPASS_SHADING_HUAWEI = 1000369003,
// Provided by VK_NV_ray_tracing
    VK_PIPELINE_BIND_POINT_RAY_TRACING_NV = VK_PIPELINE_BIND_POINT_RAY_TRACING_KHR,
} VkPipelineBindPoint;

• VK_PIPELINE_BIND_POINT_COMPUTE specifies binding as a compute pipeline.
• VK_PIPELINE_BIND_POINT_GRAPHICS specifies binding as a graphics pipeline.
• VK_PIPELINE_BIND_POINT_RAY_TRACING_KHR specifies binding as a ray tracing pipeline.
• VK_PIPELINE_BIND_POINT_SUBPASS_SHADING_HUAWEI specifies binding as a subpass shading pipeline.
• VK_PIPELINE_BIND_POINT_EXECUTION_GRAPH_AMDX specifies binding as an execution graph pipeline.

For pipelines that were created with the support of multiple shader groups (see Graphics Pipeline Shader Groups), the regular vkCmdBindPipeline command will bind Shader Group 0. To explicitly bind a shader group use:

// Provided by VK_NV.device_generated_commands
def void vkCmdBindPipelineShaderGroupNV(
    VkCommandBuffer commandBuffer,
    VkPipelineBindPoint pipelineBindPoint,
    VkPipeline pipeline,
    uint32_t groupIndex);

• commandBuffer is the command buffer that the pipeline will be bound to.
• pipelineBindPoint is a VkPipelineBindPoint value specifying the bind point to which the pipeline will be bound.
• pipeline is the pipeline to be bound.
• groupIndex is the shader group to be bound.

Valid Usage

• VUID-vkCmdBindPipelineShaderGroupNV-groupIndex-02893
groupIndex must be 0 or less than the effective VkGraphicsPipelineShaderGroupsCreateInfoNV::groupCount including the referenced
pipelines

- **VUID-vkCmdBindPipelineShaderGroupNV-pipelineBindPoint-02894**
  The `pipelineBindPoint` must be `VK_PIPELINE_BIND_POINT_GRAPHICS`

- **VUID-vkCmdBindPipelineShaderGroupNV-groupIndex-02895**
  The same restrictions as `vkCmdBindPipeline` apply as if the bound pipeline was created only with the Shader Group from the `groupIndex` information

- **VUID-vkCmdBindPipelineShaderGroupNV-deviceGeneratedCommands-02896**
  The `deviceGeneratedCommands` feature must be enabled

---

**Valid Usage (Implicit)**

- **VUID-vkCmdBindPipelineShaderGroupNV-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- **VUID-vkCmdBindPipelineShaderGroupNV-pipelineBindPoint-parameter**
  `pipelineBindPoint` must be a valid `VkPipelineBindPoint` value

- **VUID-vkCmdBindPipelineShaderGroupNV-pipeline-parameter**
  `pipeline` must be a valid `VkPipeline` handle

- **VUID-vkCmdBindPipelineShaderGroupNV-commandBuffer-recording**
  `commandBuffer` must be in the `recording state`

- **VUID-vkCmdBindPipelineShaderGroupNV-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, or compute operations

- **VUID-vkCmdBindPipelineShaderGroupNV-videocoding**
  This command must only be called outside of a video coding scope

- **VUID-vkCmdBindPipelineShaderGroupNV-commonparent**
  Both of `commandBuffer`, and `pipeline` must have been created, allocated, or retrieved from the same `VkDevice`

---

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

---

**Command Properties**

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</table>
10.10.1. Interaction with Shader Objects

If the shaderObject feature is enabled, applications can use both pipelines and shader objects at the same time. The interaction between pipelines and shader objects is described in Interaction with Pipelines.

10.11. Dynamic State

When a pipeline object is bound, any pipeline object state that is not specified as dynamic is applied to the command buffer state. Pipeline object state that is specified as dynamic is not applied to the command buffer state at this time. Instead, dynamic state can be modified at any time and persists for the lifetime of the command buffer, or until modified by another dynamic state setting command, or made invalid by another pipeline bind with that state specified as static.

When a pipeline object is bound, the following applies to each state parameter:

- If the state is not specified as dynamic in the new pipeline object, then that command buffer state is overwritten by the state in the new pipeline object. Before any draw or dispatch call with this pipeline there must not have been any calls to any of the corresponding dynamic state setting commands after this pipeline was bound.

- If the state is specified as dynamic in the new pipeline object, then that command buffer state is not disturbed. Before any draw or dispatch call with this pipeline there must have been at least one call to each of the corresponding dynamic state setting commands. The state-setting commands must be recorded after command buffer recording was begun, or after the last command binding a pipeline object with that state specified as static, whichever was the latter.

- If the state is not included (corresponding pointer in VkGraphicsPipelineCreateInfo was NULL or was ignored) in the new pipeline object, then that command buffer state is not disturbed. For example, mesh shading pipelines do not include vertex input state and therefore do not disturb any such command buffer state.

Dynamic state that does not affect the result of operations can be left undefined.

Note

For example, if blending is disabled by the pipeline object state then the dynamic color blend constants do not need to be specified in the command buffer, even if this state is specified as dynamic in the pipeline object.

10.12. Pipeline Properties and Shader Information

When a pipeline is created, its state and shaders are compiled into zero or more device-specific executables, which are used when executing commands against that pipeline. To query the properties of these pipeline executables, call:

```
// Provided by VK_KHR_pipeline_executable_properties
VkResult vkGetPipelineExecutablePropertiesKHR(
    VkDevice device,
```
const VkPipelineInfoKHR* pPipelineInfo,
uint32_t* pExecutableCount,
VkPipelineExecutablePropertiesKHR* pProperties);  

• device is the device that created the pipeline.  
• pPipelineInfo describes the pipeline being queried.  
• pExecutableCount is a pointer to an integer related to the number of pipeline executables available or queried, as described below.  
• pProperties is either NULL or a pointer to an array of VkPipelineExecutablePropertiesKHR structures.

If pProperties is NULL, then the number of pipeline executables associated with the pipeline is returned in pExecutableCount. Otherwise, pExecutableCount must point to a variable set by the user to the number of elements in the pProperties array, and on return the variable is overwritten with the number of structures actually written to pProperties. If pExecutableCount is less than the number of pipeline executables associated with the pipeline, at most pExecutableCount structures will be written, and VK_INCOMPLETE will be returned instead of VK_SUCCESS, to indicate that not all the available properties were returned.

Valid Usage  
• VUID-vkGetPipelineExecutablePropertiesKHR-pipelineExecutableInfo-03270  
The pipelineExecutableInfo feature must be enabled

• VUID-vkGetPipelineExecutablePropertiesKHR-pipeline-03271  
The pipeline member of pPipelineInfo must have been created with device

Valid Usage (Implicit)  
• VUID-vkGetPipelineExecutablePropertiesKHR-device-parameter  
device must be a valid VkDevice handle

• VUID-vkGetPipelineExecutablePropertiesKHR-pPipelineInfo-parameter  
pPipelineInfo must be a valid pointer to a valid VkPipelineInfoKHR structure

• VUID-vkGetPipelineExecutablePropertiesKHR-pExecutableCount-parameter  
pExecutableCount must be a valid pointer to a uint32_t value

• VUID-vkGetPipelineExecutablePropertiesKHR-pProperties-parameter  
If the value referenced by pExecutableCount is not 0, and pProperties is not NULL, pProperties must be a valid pointer to an array of pExecutableCount VkPipelineExecutablePropertiesKHR structures
Return Codes

Success
• VK_SUCCESS
• VK_INCOMPLETE

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY

The `VkPipelineExecutablePropertiesKHR` structure is defined as:

```c
// Provided by VK_KHR_pipeline_executable_properties
typedef struct VkPipelineExecutablePropertiesKHR {
    VkStructureType sType;
    void* pNext;
    VkShaderStageFlags stages;
    char name[VK_MAX_DESCRIPTION_SIZE];
    char description[VK_MAX_DESCRIPTION_SIZE];
    uint32_t subgroupSize;
} VkPipelineExecutablePropertiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `stages` is a bitmask of zero or more `VkShaderStageFlagBits` indicating which shader stages (if any) were principally used as inputs to compile this pipeline executable.
- `name` is an array of `VK_MAX_DESCRIPTION_SIZE` `char` containing a null-terminated UTF-8 string which is a short human readable name for this pipeline executable.
- `description` is an array of `VK_MAX_DESCRIPTION_SIZE` `char` containing a null-terminated UTF-8 string which is a human readable description for this pipeline executable.
- `subgroupSize` is the subgroup size with which this pipeline executable is dispatched.

Not all implementations have a 1:1 mapping between shader stages and pipeline executables and some implementations may reduce a given shader stage to fixed function hardware programming such that no pipeline executable is available. No guarantees are provided about the mapping between shader stages and pipeline executables and `stages` should be considered a best effort hint. Because the application cannot rely on the `stages` field to provide an exact description, `name` and `description` provide a human readable name and description which more accurately describes the given pipeline executable.

Valid Usage (Implicit)

- VUID-VkPipelineExecutablePropertiesKHR-sType-sType
`sType` must be `VK_STRUCTURE_TYPE_PIPELINE_EXECUTABLE_PROPERTIES_KHR`
To query the pipeline properties call:

```c
// Provided by VK_EXT_pipeline_properties
VkResult vkGetPipelinePropertiesEXT(
    VkDevice device,
    const VkPipelineInfoEXT* pPipelineInfo,
    VkBaseOutStructure* pPipelineProperties);
```

- `device` is the logical device that created the pipeline.
- `pPipelineInfo` is a pointer to a `VkPipelineInfoEXT` structure which describes the pipeline being queried.
- `pPipelineProperties` is a pointer to a `VkBaseOutStructure` structure in which the pipeline properties will be written.

To query a pipeline's `pipelineIdentifier` pass a `VkPipelinePropertiesIdentifierEXT` structure in `pPipelineProperties`. Each pipeline is associated with a `pipelineIdentifier` and the identifier is implementation specific.

### Valid Usage

- **VUID-vkGetPipelinePropertiesEXT-pipeline-06738**
  The `pipeline` member of `pPipelineInfo` must have been created with `device`

- **VUID-vkGetPipelinePropertiesEXT-pPipelineProperties-06739**
  `pPipelineProperties` must be a valid pointer to a `VkPipelinePropertiesIdentifierEXT` structure

- **VUID-vkGetPipelinePropertiesEXT-None-06766**
  The `pipelinePropertiesIdentifier` feature must be enabled

### Valid Usage (Implicit)

- **VUID-vkGetPipelinePropertiesEXT-device-parameter**
  `device` must be a valid `VkDevice` handle

- **VUID-vkGetPipelinePropertiesEXT-pPipelineInfo-parameter**
  `pPipelineInfo` must be a valid pointer to a valid `VkPipelineInfoEXT` structure

### Return Codes

**Success**
- `VK_SUCCESS`
The `VkPipelinePropertiesIdentifierEXT` structure is defined as:

```c
// Provided by VK_EXT_pipeline_properties
typedef struct VkPipelinePropertiesIdentifierEXT {
    VkStructureType sType;
    void* pNext;
    uint8_t pipelineIdentifier[VK_UUID_SIZE];
} VkPipelinePropertiesIdentifierEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **pipelineIdentifier** is an array of `VK_UUID_SIZE uint8_t` values into which the pipeline identifier will be written.

### Valid Usage (Implicit)

- VUID-VkPipelinePropertiesIdentifierEXT-sType-sType
  sType **must** be `VK_STRUCTURE_TYPE_PIPELINE_PROPERTIES_IDENTIFIER_EXT`
- VUID-VkPipelinePropertiesIdentifierEXT-pNext-pNext
  pNext **must** be `NULL`

The `VkPipelineInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_pipeline_executable_properties
typedef struct VkPipelineInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkPipeline pipeline;
} VkPipelineInfoKHR;
```

or the equivalent

```c
// Provided by VK_EXT_pipeline_properties
typedef VkPipelineInfoKHR VkPipelineInfoEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **pipeline** is a `VkPipeline` handle.
Valid Usage (Implicit)

- VUID-VkPipelineInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_PIPELINE_INFO_KHR
- VUID-VkPipelineInfoKHR-pNext-pNext
  pNext must be NULL
- VUID-VkPipelineInfoKHR-pipeline-parameter
  pipeline must be a valid VkPipeline handle

Each pipeline executable may have a set of statistics associated with it that are generated by the pipeline compilation process. These statistics may include things such as instruction counts, amount of spilling (if any), maximum number of simultaneous threads, or anything else which may aid developers in evaluating the expected performance of a shader. To query the compile time statistics associated with a pipeline executable, call:

```c
// Provided by VK_KHR_pipeline_executable_properties
VkResult vkGetPipelineExecutableStatisticsKHR(
    VkDevice device,
    const VkPipelineExecutableInfoKHR* pExecutableInfo,
    uint32_t* pStatisticCount,
    VkPipelineExecutableStatisticKHR* pStatistics);
```

- `device` is the device that created the pipeline.
- `pExecutableInfo` describes the pipeline executable being queried.
- `pStatisticCount` is a pointer to an integer related to the number of statistics available or queried, as described below.
- `pStatistics` is either NULL or a pointer to an array of VkPipelineExecutableStatisticKHR structures.

If `pStatistics` is NULL, then the number of statistics associated with the pipeline executable is returned in `pStatisticCount`. Otherwise, `pStatisticCount` must point to a variable set by the user to the number of elements in the `pStatistics` array, and on return the variable is overwritten with the number of structures actually written to `pStatistics`. If `pStatisticCount` is less than the number of statistics associated with the pipeline executable, at most `pStatisticCount` structures will be written, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available statistics were returned.

Valid Usage

- VUID-vkGetPipelineExecutableStatisticsKHR-pipelineExecutableInfo-03272
  The pipelineExecutableInfo feature must be enabled
- VUID-vkGetPipelineExecutableStatisticsKHR-pipeline-03273
  The pipeline member of pExecutableInfo must have been created with device
• **VUID-vkGetPipelineExecutableStatisticsKHR-pipeline-03274**
The *pipeline* member of *pExecutableInfo* must have been created with *VK_PIPELINE_CREATE_CAPTURE_STATISTICS_BIT_KHR*.

### Valid Usage (Implicit)

- **VUID-vkGetPipelineExecutableStatisticsKHR-device-parameter**
  *device* must be a valid *VkDevice* handle.

- **VUID-vkGetPipelineExecutableStatisticsKHR-pExecutableInfo-parameter**
  *pExecutableInfo* must be a valid pointer to a valid *VkPipelineExecutableInfoKHR* structure.

- **VUID-vkGetPipelineExecutableStatisticsKHR-pStatisticCount-parameter**
  *pStatisticCount* must be a valid pointer to a *uint32_t* value.

- **VUID-vkGetPipelineExecutableStatisticsKHR-pStatistics-parameter**
  If the value referenced by *pStatisticCount* is not 0, and *pStatistics* is not NULL, *pStatistics* must be a valid pointer to an array of *pStatisticCount* *VkPipelineExecutableStatisticKHR* structures.

### Return Codes

**Success**
- *VK_SUCCESS*
- *VK_INCOMPLETE*

**Failure**
- *VK_ERROR_OUT_OF_HOST_MEMORY*
- *VK_ERROR_OUT_OF_DEVICE_MEMORY*

The *VkPipelineExecutableInfoKHR* structure is defined as:

```c
// Provided by VK_KHR_pipeline_executable_properties
typedef struct VkPipelineExecutableInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkPipeline pipeline;
    uint32_t executableIndex;
} VkPipelineExecutableInfoKHR;
```

- *sType* is a *VkStructureType* value identifying this structure.
- *pNext* is *NULL* or a pointer to a structure extending this structure.
- *pipeline* is the pipeline to query.
- *executableIndex* is the index of the pipeline executable to query in the array of executable
properties returned by `vkGetPipelineExecutablePropertiesKHR`.

Valid Usage

• VUID-VkPipelineExecutableInfoKHR-executableIndex-03275
  `executableIndex` must be less than the number of pipeline executables associated with `pipeline` as returned in the `pExecutableCount` parameter of `vkGetPipelineExecutablePropertiesKHR`.

Valid Usage (Implicit)

• VUID-VkPipelineExecutableInfoKHR-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_EXECUTABLE_INFO_KHR`.

• VUID-VkPipelineExecutableInfoKHR-pNext-pNext
  `pNext` must be `NULL`.

• VUID-VkPipelineExecutableInfoKHR-pipeline-parameter
  `pipeline` must be a valid `VkPipeline` handle.

The `VkPipelineExecutableStatisticKHR` structure is defined as:

```c
// Provided by VK_KHR_pipeline_executable_properties
typedef struct VkPipelineExecutableStatisticKHR {
    VkStructureType sType;
    void* pNext;
    char name[VK_MAX_DESCRIPTION_SIZE];
    char description[VK_MAX_DESCRIPTION_SIZE];
    VkPipelineExecutableStatisticFormatKHR format;
    VkPipelineExecutableStatisticValueKHR value;
} VkPipelineExecutableStatisticKHR;
```

• `sType` is a `VkStructureType` value identifying this structure.

• `pNext` is `NULL` or a pointer to a structure extending this structure.

• `name` is an array of `VK_MAX_DESCRIPTION_SIZE` `char` containing a null-terminated UTF-8 string which is a short human readable name for this statistic.

• `description` is an array of `VK_MAX_DESCRIPTION_SIZE` `char` containing a null-terminated UTF-8 string which is a human readable description for this statistic.

• `format` is a `VkPipelineExecutableStatisticFormatKHR` value specifying the format of the data found in `value`.

• `value` is the value of this statistic.
Valid Usage (Implicit)

- VUID-VkPipelineExecutableStatisticKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_PIPELINE_EXECUTABLE_STATISTIC_KHR

- VUID-VkPipelineExecutableStatisticKHR-pNext-pNext
  pNext must be NULL

The VkPipelineExecutableStatisticFormatKHR enum is defined as:

```c
// Provided by VK_KHR_pipeline_executable_properties
typedef enum VkPipelineExecutableStatisticFormatKHR {
    VK_PIPELINE_EXECUTABLE_STATISTIC_FORMAT_BOOL32_KHR = 0,
    VK_PIPELINE_EXECUTABLE_STATISTIC_FORMAT_INT64_KHR = 1,
    VK_PIPELINE_EXECUTABLE_STATISTIC_FORMAT_UINT64_KHR = 2,
    VK_PIPELINE_EXECUTABLE_STATISTIC_FORMAT_FLOAT64_KHR = 3,
} VkPipelineExecutableStatisticFormatKHR;
```

- VK_PIPELINE_EXECUTABLE_STATISTIC_FORMAT_BOOL32_KHR specifies that the statistic is returned as a 32-bit boolean value which must be either VK_TRUE or VK_FALSE and should be read from the b32 field of VkPipelineExecutableStatisticValueKHR.

- VK_PIPELINE_EXECUTABLE_STATISTIC_FORMAT_INT64_KHR specifies that the statistic is returned as a signed 64-bit integer and should be read from the i64 field of VkPipelineExecutableStatisticValueKHR.

- VK_PIPELINE_EXECUTABLE_STATISTIC_FORMAT_UINT64_KHR specifies that the statistic is returned as an unsigned 64-bit integer and should be read from the u64 field of VkPipelineExecutableStatisticValueKHR.

- VK_PIPELINE_EXECUTABLE_STATISTIC_FORMAT_FLOAT64_KHR specifies that the statistic is returned as a 64-bit floating-point value and should be read from the f64 field of VkPipelineExecutableStatisticValueKHR.

The VkPipelineExecutableStatisticValueKHR union is defined as:

```c
// Provided by VK_KHR_pipeline_executable_properties
typedef union VkPipelineExecutableStatisticValueKHR {
    VkBool32 b32;
    int64_t i64;
    uint64_t u64;
    double f64;
} VkPipelineExecutableStatisticValueKHR;
```

- b32 is the 32-bit boolean value if the VkPipelineExecutableStatisticFormatKHR is VK_PIPELINE_EXECUTABLE_STATISTIC_FORMAT_BOOL32_KHR.

- i64 is the signed 64-bit integer value if the VkPipelineExecutableStatisticFormatKHR is VK_PIPELINE_EXECUTABLE_STATISTIC_FORMAT_INT64_KHR.
• `u64` is the unsigned 64-bit integer value if the `VkPipelineExecutableStatisticFormatKHR` is `VK_PIPELINE_EXECUTABLE_STATISTIC_FORMAT_UINT64_KHR`.

• `f64` is the 64-bit floating-point value if the `VkPipelineExecutableStatisticFormatKHR` is `VK_PIPELINE_EXECUTABLE_STATISTIC_FORMAT_FLOAT64_KHR`.

Each pipeline executable may have one or more text or binary internal representations associated with it which are generated as part of the compile process. These may include the final shader assembly, a binary form of the compiled shader, or the shader compiler’s internal representation at any number of intermediate compile steps. To query the internal representations associated with a pipeline executable, call:

```c
// Provided by VK_KHR_pipeline_executable_properties
VkResult vkGetPipelineExecutableInternalRepresentationsKHR(
    VkDevice device,
    const VkPipelineExecutableInfoKHR* pExecutableInfo,
    uint32_t* pInternalRepresentationCount,
    VkPipelineExecutableInternalRepresentationKHR* pInternalRepresentations);
```

• `device` is the device that created the pipeline.

• `pExecutableInfo` describes the pipeline executable being queried.

• `pInternalRepresentationCount` is a pointer to an integer related to the number of internal representations available or queried, as described below.

• `pInternalRepresentations` is either `NULL` or a pointer to an array of `VkPipelineExecutableInternalRepresentationKHR` structures.

If `pInternalRepresentations` is `NULL`, then the number of internal representations associated with the pipeline executable is returned in `pInternalRepresentationCount`. Otherwise, `pInternalRepresentationCount` must point to a variable set by the user to the number of elements in the `pInternalRepresentations` array, and on return the variable is overwritten with the number of structures actually written to `pInternalRepresentations`. If `pInternalRepresentationCount` is less than the number of internal representations associated with the pipeline executable, at most `pInternalRepresentationCount` structures will be written, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available representations were returned.

While the details of the internal representations remain implementation-dependent, the implementation should order the internal representations in the order in which they occur in the compiled pipeline with the final shader assembly (if any) last.

### Valid Usage

- `VUID-vkGetPipelineExecutableInternalRepresentationsKHR-pipelineExecutableInfo-03276`
  The `pipelineExecutableInfo` feature must be enabled

- `VUID-vkGetPipelineExecutableInternalRepresentationsKHR-pipeline-03277`
  The `pipeline` member of `pExecutableInfo` must have been created with `device`

- `VUID-vkGetPipelineExecutableInternalRepresentationsKHR-pipeline-03278`
The pipeline member of pExecutableInfo must have been created with VK_PIPELINE_CREATE_CAPTURE_INTERNAL_REPRESENTATIONS_BIT_KHR

Valid Usage (Implicit)

- VUID-vkGetPipelineExecutableInternalRepresentationsKHR-device-parameter
device must be a valid VkDevice handle

- VUID-vkGetPipelineExecutableInternalRepresentationsKHR-pExecutableInfo-parameter
pExecutableInfo must be a valid pointer to a valid VkPipelineExecutableInfoKHR structure

- VUID-vkGetPipelineExecutableInternalRepresentationsKHR-pInternalRepresentationCount-parameter
pInternalRepresentationCount must be a valid pointer to a uint32_t value

- VUID-vkGetPipelineExecutableInternalRepresentationsKHR-pInternalRepresentations-parameter
If the value referenced by pInternalRepresentationCount is not 0, and
pInternalRepresentations is not NULL, pInternalRepresentations must be a valid pointer to
an array of pInternalRepresentationCount
VkPipelineExecutableInternalRepresentationKHR structures

Return Codes

Success
- VK_SUCCESS
- VK_INCOMPLETE

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkPipelineExecutableInternalRepresentationKHR structure is defined as:

```c
// Provided by VK_KHR_pipeline_executable_properties
typedef struct VkPipelineExecutableInternalRepresentationKHR {
    VkStructureType sType;
    void* pNext;
    char name[VK_MAX_DESCRIPTION_SIZE];
    char description[VK_MAX_DESCRIPTION_SIZE];
    VkBool32 isText;
    size_t dataSize;
    void* pData;
} VkPipelineExecutableInternalRepresentationKHR;
```
• **sType** is a *VkStructureType* value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **name** is an array of *VK_MAX_DESCRIPTION_SIZE* char containing a null-terminated UTF-8 string which is a short human readable name for this internal representation.

• **description** is an array of *VK_MAX_DESCRIPTION_SIZE* char containing a null-terminated UTF-8 string which is a human readable description for this internal representation.

• **isText** specifies whether the returned data is text or opaque data. If **isText** is **VK_TRUE** then the data returned in **pData** is text and is guaranteed to be a null-terminated UTF-8 string.

• **dataSize** is an integer related to the size, in bytes, of the internal representation’s data, as described below.

• **pData** is either **NULL** or a pointer to a block of data into which the implementation will write the internal representation.

If **pData** is **NULL**, then the size, in bytes, of the internal representation data is returned in **dataSize**. Otherwise, **dataSize** must be the size of the buffer, in bytes, pointed to by **pData** and on return **dataSize** is overwritten with the number of bytes of data actually written to **pData** including any trailing null character. If **dataSize** is less than the size, in bytes, of the internal representation’s data, at most **dataSize** bytes of data will be written to **pData**, and **VK_INCOMPLETE** will be returned instead of **VK_SUCCESS**, to indicate that not all the available representation was returned.

If **isText** is **VK_TRUE** and **pData** is not **NULL** and **dataSize** is not zero, the last byte written to **pData** will be a null character.

**Valid Usage (Implicit)**

- VUID-VkPipelineExecutableInternalRepresentationKHR-sType-sType
  - **sType** must be **VK_STRUCTURE_TYPE_PIPELINE_EXECUTABLE_INTERNAL_REPRESENTATION_KHR**

- VUID-VkPipelineExecutableInternalRepresentationKHR-pNext-pNext
  - **pNext** must be **NULL**

Information about a particular shader that has been compiled as part of a pipeline object can be extracted by calling:

```c
// Provided by VK_AMD_shader_info
VkResult vkGetShaderInfoAMD(
    VkDevice device,  // device that created pipeline.
    VkPipeline pipeline,  // target of the query.
    VkShaderStageFlagBits shaderStage,  // shader stage.
    VkShaderInfoTypeAMD infoType,  // info type.
    size_t pInfoSize,  // size of the buffer pointed to by pInfo.
    void* pInfo);  // pointer to the buffer.
```

- **device** is the device that created **pipeline**.

- **pipeline** is the target of the query.
• shaderStage is a VkShaderStageFlagBits specifying the particular shader within the pipeline about which information is being queried.

• infoType describes what kind of information is being queried.

• pInfoSize is a pointer to a value related to the amount of data the query returns, as described below.

• pInfo is either NULL or a pointer to a buffer.

If pInfo is NULL, then the maximum size of the information that can be retrieved about the shader, in bytes, is returned in pInfoSize. Otherwise, pInfoSize must point to a variable set by the user to the size of the buffer, in bytes, pointed to by pInfo, and on return the variable is overwritten with the amount of data actually written to pInfo. If pInfoSize is less than the maximum size that can be retrieved by the pipeline cache, then at most pInfoSize bytes will be written to pInfo, and VK_INCOMPLETE will be returned, instead of VK_SUCCESS, to indicate that not all required of the pipeline cache was returned.

Not all information is available for every shader and implementations may not support all kinds of information for any shader. When a certain type of information is unavailable, the function returns VK_ERROR_FEATURE_NOT_PRESENT.

If information is successfully and fully queried, the function will return VK_SUCCESS.

For infoType VK_SHADER_INFO_TYPE_STATISTICS_AMD, a VkShaderStatisticsInfoAMD structure will be written to the buffer pointed to by pInfo. This structure will be populated with statistics regarding the physical device resources used by that shader along with other miscellaneous information and is described in further detail below.

For infoType VK_SHADER_INFO_TYPE_DISASSEMBLY_AMD, pInfo is a pointer to a UTF-8 null-terminated string containing human-readable disassembly. The exact formatting and contents of the disassembly string are vendor-specific.

The formatting and contents of all other types of information, including infoType VK_SHADER_INFO_TYPE_BINARY_AMD, are left to the vendor and are not further specified by this extension.

---

**Valid Usage (Implicit)**

- VUID-vkGetShaderInfoAMD-device-parameter device must be a valid VkDevice handle
- VUID-vkGetShaderInfoAMD-pipeline-parameter pipeline must be a valid VkPipeline handle
- VUID-vkGetShaderInfoAMD-shaderStage-parameter shaderStage must be a valid VkShaderStageFlagBits value
- VUID-vkGetShaderInfoAMD-infoType-parameter infoType must be a valid VkShaderInfoTypeAMD value
- VUID-vkGetShaderInfoAMD-pInfoSize-parameter pInfoSize must be a valid pointer to a size_t value
• VUID-vkGetShaderInfoAMD-pInfo-parameter
If the value referenced by pInfoSize is not 0, and pInfo is not NULL, pInfo must be a valid
pointer to an array of pInfoSize bytes

• VUID-vkGetShaderInfoAMD-pipeline-parent
pipeline must have been created, allocated, or retrieved from device

Return Codes

Success
• VK_SUCCESS
• VK_INCOMPLETE

Failure
• VK_ERROR_FEATURE_NOT_PRESENT
• VK_ERROR_OUT_OF_HOST_MEMORY

Possible values of vkGetShaderInfoAMD::infoType, specifying the information being queried from a
shader, are:

```
// Provided by VK_AMD_shader_info
typedef enum VkShaderInfoTypeAMD {
    VK_SHADER_INFO_TYPE_STATISTICS_AMD = 0,
    VK_SHADER_INFO_TYPE_BINARY_AMD = 1,
    VK_SHADER_INFO_TYPE_DISASSEMBLY_AMD = 2,
} VkShaderInfoTypeAMD;
```

• VK_SHADER_INFO_TYPE_STATISTICS_AMD specifies that device resources used by a shader will be
queried.

• VK_SHADER_INFO_TYPE_BINARY_AMD specifies that implementation-specific information will be
queried.

• VK_SHADER_INFO_TYPE_DISASSEMBLY_AMD specifies that human-readable disassembly of a shader.

The VkShaderStatisticsInfoAMD structure is defined as:

```
// Provided by VK_AMD_shader_info
typedef struct VkShaderStatisticsInfoAMD {
    VkShaderStageFlags shaderStageMask;
    VkShaderResourceUsageAMD resourceUsage;
    uint32_t numPhysicalVgprs;
    uint32_t numPhysicalSgprs;
    uint32_t numAvailableVgprs;
    uint32_t numAvailableSgprs;
    uint32_t computeWorkGroupSize[3];
} VkShaderStatisticsInfoAMD;
```
shaderStageMask are the combination of logical shader stages contained within this shader.

resourceUsage is a VkShaderResourceUsageAMD structure describing internal physical device resources used by this shader.

numPhysicalVgprs is the maximum number of vector instruction general-purpose registers (VGPRs) available to the physical device.

numPhysicalSgprs is the maximum number of scalar instruction general-purpose registers (SGPRs) available to the physical device.

numAvailableVgprs is the maximum limit of VGPRs made available to the shader compiler.

numAvailableSgprs is the maximum limit of SGPRs made available to the shader compiler.

computeWorkGroupSize is the local workgroup size of this shader in { X, Y, Z } dimensions.

Some implementations may merge multiple logical shader stages together in a single shader. In such cases, shaderStageMask will contain a bitmask of all of the stages that are active within that shader. Consequently, if specifying those stages as input to vkGetShaderInfoAMD, the same output information may be returned for all such shader stage queries.

The number of available VGPRs and SGPRs (numAvailableVgprs and numAvailableSgprs respectively) are the shader-addressable subset of physical registers that is given as a limit to the compiler for register assignment. These values may further be limited by implementations due to performance optimizations where register pressure is a bottleneck.

The VkShaderResourceUsageAMD structure is defined as:

```c
// Provided by VK_AMD_shader_info
typedef struct VkShaderResourceUsageAMD {
    uint32_t numUsedVgprs;
    uint32_t numUsedSgprs;
    uint32_t ldsSizePerLocalWorkGroup;
    size_t ldsUsageSizeInBytes;
    size_t scratchMemUsageInBytes;
} VkShaderResourceUsageAMD;
```

- numUsedVgprs is the number of vector instruction general-purpose registers used by this shader.
- numUsedSgprs is the number of scalar instruction general-purpose registers used by this shader.
- ldsSizePerLocalWorkGroup is the maximum local data store size per work group in bytes.
- ldsUsageSizeInBytes is the LDS usage size in bytes per work group by this shader.
- scratchMemUsageInBytes is the scratch memory usage in bytes by this shader.

10.13. Pipeline Compiler Control

The compilation of a pipeline can be tuned by adding a VkPipelineCompilerControlCreateInfoAMD structure to the pNext chain of VkGraphicsPipelineCreateInfo or VkComputePipelineCreateInfo.
typedef struct VkPipelineCompilerControlCreateInfoAMD {
    VkStructureType sType;
    const void* pNext;
    VkPipelineCompilerControlFlagsAMD compilerControlFlags;
} VkPipelineCompilerControlCreateInfoAMD;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• compilerControlFlags is a bitmask of VkPipelineCompilerControlFlagBitsAMD affecting how the pipeline will be compiled.

Valid Usage (Implicit)

• VUID-VkPipelineCompilerControlCreateInfoAMD-sType-sType
  sType must be VK_STRUCTURE_TYPE_PIPELINE_COMPILER_CONTROL_CREATE_INFO_AMD
• VUID-VkPipelineCompilerControlCreateInfoAMD-compilerControlFlags-zerobitmask
  compilerControlFlags must be 0

There are currently no available flags for this extension; flags will be added by future versions of this extension.

typedef enum VkPipelineCompilerControlFlagBitsAMD {
} VkPipelineCompilerControlFlagBitsAMD;

typedef VkFlags VkPipelineCompilerControlFlagsAMD;

 VkPipelineCompilerControlFlagsAMD is a bitmask type for setting a mask of zero or more VkPipelineCompilerControlFlagBitsAMD.

10.14. Pipeline Creation Feedback

Feedback about the creation of a particular pipeline object can be obtained by adding a VkPipelineCreationFeedbackCreateInfo structure to the pNext chain of VkGraphicsPipelineCreateInfo, VkRayTracingPipelineCreateInfoKHR, VkRayTracingPipelineCreateInfoNV, or VkComputePipelineCreateInfo. The VkPipelineCreationFeedbackCreateInfo structure is defined as:

typedef struct VkPipeline CreationFeedbackCreateInfo {
    VkStructureType sType;
    const void* pNext;
} VkPipelineCreationFeedbackCreateInfo;
VkPipelineCreationFeedback* pPipelineCreationFeedback;
uint32_t pipelineStageCreationFeedbackCount;
VkPipelineCreationFeedback* pPipelineStageCreationFeedbacks;
} VkPipelineCreationFeedbackCreateInfo;

or the equivalent

// Provided by VK_EXT_pipeline_creation_feedback
typedef VkPipelineCreationFeedbackCreateInfo VkPipelineCreationFeedbackCreateInfoEXT;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• pPipelineCreationFeedback is a pointer to a VkPipelineCreationFeedback structure.
• pipelineStageCreationFeedbackCount is the number of elements in pPipelineStageCreationFeedbacks.
• pPipelineStageCreationFeedbacks is a pointer to an array of pipelineStageCreationFeedbackCount VkPipelineCreationFeedback structures.

An implementation should write pipeline creation feedback to pPipelineCreationFeedback and may write pipeline stage creation feedback to pPipelineStageCreationFeedbacks. An implementation must set or clear the VK_PIPELINE_CREATION_FEEDBACK_VALID_BIT in VkPipelineCreationFeedback::flags for pPipelineCreationFeedback and every element of pPipelineStageCreationFeedbacks.

Note
One common scenario for an implementation to skip per-stage feedback is when VK_PIPELINE_CREATION_FEEDBACK_APPLICATION_PIPELINE_CACHE_HIT_BIT is set in pPipelineCreationFeedback.

When chained to VkRayTracingPipelineCreateInfoKHR, VkRayTracingPipelineCreateInfoNV, or VkGraphicsPipelineCreateInfo, the i element of pPipelineStageCreationFeedbacks corresponds to the i element of VkRayTracingPipelineCreateInfoKHR::pStages, VkRayTracingPipelineCreateInfoNV::pStages, or VkGraphicsPipelineCreateInfo::pStages. When chained to VkComputePipelineCreateInfo, the first element of pPipelineStageCreationFeedbacks corresponds to VkComputePipelineCreateInfo::stage.

Valid Usage (Implicit)

• VUID-VkPipelineCreationFeedbackCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_PIPELINE_CREATION_FEEDBACK_CREATE_INFO

• VUID-VkPipelineCreationFeedbackCreateInfo-pPipelineCreationFeedback-parameter
  pPipelineCreationFeedback must be a valid pointer to a VkPipelineCreationFeedback structure

• VUID-VkPipelineCreationFeedbackCreateInfo-pPipelineStageCreationFeedbacks-parameter
If `pipelineStageCreationFeedbackCount` is not 0, `pPipelineStageCreationFeedbacks` must be a valid pointer to an array of `pipelineStageCreationFeedbackCount` `VkPipelineCreationFeedback` structures.

The `VkPipelineCreationFeedback` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPipelineCreationFeedback {
    VkPipelineCreationFeedbackFlags flags;
    uint64_t duration;
} VkPipelineCreationFeedback;
```

or the equivalent

```c
// Provided by VK_EXT_pipeline_creation_feedback
typedef VkPipelineCreationFeedback VkPipelineCreationFeedbackEXT;
```

- `flags` is a bitmask of `VkPipelineCreationFeedbackFlagBits` providing feedback about the creation of a pipeline or of a pipeline stage.
- `duration` is the duration spent creating a pipeline or pipeline stage in nanoseconds.

If the `VK_PIPELINE_CREATION_FEEDBACK_VALID_BIT` is not set in `flags`, an implementation must not set any other bits in `flags`, and the values of all other `VkPipelineCreationFeedback` data members are undefined.

Possible values of the `flags` member of `VkPipelineCreationFeedback` are:

```c
// Provided by VK_VERSION_1_3
typedef enum VkPipelineCreationFeedbackFlagBits {
    VK_PIPELINE_CREATION_FEEDBACK_VALID_BIT = 0x00000001,
    VK_PIPELINE_CREATION_FEEDBACK_APPLICATION_PIPELINE_CACHE_HIT_BIT = 0x00000002,
    VK_PIPELINE_CREATION_FEEDBACK_BASE_PIPELINE_ACCELERATION_BIT = 0x00000004,
    VK_PIPELINE_CREATION_FEEDBACK_VALID_BIT_EXT = VK_PIPELINE_CREATION_FEEDBACK_VALID_BIT,
    VK_PIPELINE_CREATION_FEEDBACK_APPLICATION_PIPELINE_CACHE_HIT_BIT_EXT = VK_PIPELINE_CREATION_FEEDBACK_APPLICATION_PIPELINE_CACHE_HIT_BIT,
    VK_PIPELINE_CREATION_FEEDBACK_BASE_PIPELINE_ACCELERATION_BIT_EXT = VK_PIPELINE_CREATION_FEEDBACK_BASE_PIPELINE_ACCELERATION_BIT,
} VkPipelineCreationFeedbackFlagBits;
```

or the equivalent

```c
// Provided by VK_EXT_pipeline_creation_feedback
typedef VkPipelineCreationFeedbackFlagBits VkPipelineCreationFeedbackFlagBitsEXT;
```
* **VK_PIPELINE_CREATION_FEEDBACK_VALID_BIT** indicates that the feedback information is valid.

* **VK_PIPELINE_CREATION_FEEDBACK_APPLICATION_PIPELINE_CACHE_HIT_BIT** indicates that a readily usable pipeline or pipeline stage was found in the `pipelineCache` specified by the application in the pipeline creation command.

An implementation **should** set the **VK_PIPELINE_CREATION_FEEDBACK_APPLICATION_PIPELINE_CACHE_HIT_BIT** bit if it was able to avoid the large majority of pipeline or pipeline stage creation work by using the `pipelineCache` parameter of `vkCreateGraphicsPipelines`, `vkCreateRayTracingPipelinesKHR`, `vkCreateRayTracingPipelinesNV`, or `vkCreateComputePipelines`. When an implementation sets this bit for the entire pipeline, it **may** leave it unset for any stage.

**Note**

Implementations are encouraged to provide a meaningful signal to applications using this bit. The intention is to communicate to the application that the pipeline or pipeline stage was created “as fast as it gets” using the pipeline cache provided by the application. If an implementation uses an internal cache, it is discouraged from setting this bit as the feedback would be unactionable.

* **VK_PIPELINE_CREATION_FEEDBACK_BASE_PIPELINE_ACCELERATION_BIT** indicates that the base pipeline specified by the `basePipelineHandle` or `basePipelineIndex` member of the `Vk*PipelineCreateInfo` structure was used to accelerate the creation of the pipeline.

An implementation **should** set the **VK_PIPELINE_CREATION_FEEDBACK_BASE_PIPELINE_ACCELERATION_BIT** bit if it was able to avoid a significant amount of work by using the base pipeline.

**Note**

While “significant amount of work” is subjective, implementations are encouraged to provide a meaningful signal to applications using this bit. For example, a 1% reduction in duration may not warrant setting this bit, while a 50% reduction would.

```c
// Provided by VK_VERSION_1_3
typedef VkFlags VkPipelineCreationFeedbackFlags;
```

or the equivalent

```c
// Provided by VK_EXT_pipeline_creation_feedback
typedef VkPipelineCreationFeedbackFlags VkPipelineCreationFeedbackFlagsEXT;
```

`VkPipelineCreationFeedbackFlags` is a bitmask type for providing zero or more `VkPipelineCreationFeedbackFlagBits`. 837
Chapter 11. Memory Allocation

Vulkan memory is broken up into two categories, *host memory* and *device memory*.

### 11.1. Host Memory

Host memory is memory needed by the Vulkan implementation for non-device-visible storage.

*Note*

This memory *may* be used to store the implementation's representation and state of Vulkan objects.

Vulkan provides applications the opportunity to perform host memory allocations on behalf of the Vulkan implementation. If this feature is not used, the implementation will perform its own memory allocations. Since most memory allocations are off the critical path, this is not meant as a performance feature. Rather, this *can* be useful for certain embedded systems, for debugging purposes (e.g. putting a guard page after all host allocations), or for memory allocation logging.

Allocators are provided by the application as a pointer to a *VkAllocationCallbacks* structure:

```c
// Provided by VK_VERSION_1_0
typedef struct VkAllocationCallbacks {
    void* pUserData;
    PFN_vkAllocationFunction pfnAllocation;
    PFN_vkReallocationFunction pfnReallocation;
    PFN_vkFreeFunction pfnFree;
    PFN_vkInternalAllocationNotification pfnInternalAllocation;
    PFN_vkInternalFreeNotification pfnInternalFree;
} VkAllocationCallbacks;
```

- *pUserData* is a value to be interpreted by the implementation of the callbacks. When any of the callbacks in *VkAllocationCallbacks* are called, the Vulkan implementation will pass this value as the first parameter to the callback. This value *can* vary each time an allocator is passed into a command, even when the same object takes an allocator in multiple commands.

- *pfnAllocation* is a *PFN_vkAllocationFunction* pointer to an application-defined memory allocation function.

- *pfnReAllocation* is a *PFN_vkReallocationFunction* pointer to an application-defined memory reallocation function.

- *pfnFree* is a *PFN_vkFreeFunction* pointer to an application-defined memory free function.

- *pfnInternalAllocation* is a *PFN_vkInternalAllocationNotification* pointer to an application-defined function that is called by the implementation when the implementation makes internal allocations.

- *pfnInternalFree* is a *PFN_vkInternalFreeNotification* pointer to an application-defined function that is called by the implementation when the implementation frees internal allocations.
Valid Usage

- VUID-VkAllocationCallbacks-pfnAllocation-00632
  `pfnAllocation` must be a valid pointer to a valid user-defined `PFN_vkAllocationFunction`

- VUID-VkAllocationCallbacks-pfnReallocation-00633
  `pfnReallocation` must be a valid pointer to a valid user-defined `PFN_vkReallocationFunction`

- VUID-VkAllocationCallbacks-pfnFree-00634
  `pfnFree` must be a valid pointer to a valid user-defined `PFN_vkFreeFunction`

- VUID-VkAllocationCallbacks-pfnInternalAllocation-00635
  If either of `pfnInternalAllocation` or `pfnInternalFree` is not NULL, both must be valid callbacks

The type of `pfnAllocation` is:

```c
// Provided by VK_VERSION_1_0
typedef void* (VKAPI_PTR *PFN_vkAllocationFunction)(
    void* pUserData,
    size_t size,
    size_t alignment,
    VkSystemAllocationScope allocationScope);
```

- `pUserData` is the value specified for `VkAllocationCallbacks::pUserData` in the allocator specified by the application.
- `size` is the size in bytes of the requested allocation.
- `alignment` is the requested alignment of the allocation in bytes and must be a power of two.
- `allocationScope` is a `VkSystemAllocationScope` value specifying the allocation scope of the lifetime of the allocation, as described here.

If `pfnAllocation` is unable to allocate the requested memory, it must return NULL. If the allocation was successful, it must return a valid pointer to memory allocation containing at least `size` bytes, and with the pointer value being a multiple of `alignment`.

Note
Correct Vulkan operation cannot be assumed if the application does not follow these rules.

For example, `pfnAllocation` (or `pfnReallocation`) could cause termination of running Vulkan instance(s) on a failed allocation for debugging purposes, either directly or indirectly. In these circumstances, it cannot be assumed that any part of any affected `VkInstance` objects are going to operate correctly (even `vkDestroyInstance`), and the application must ensure it cleans up properly via other means (e.g. process termination).
If `pfnAllocation` returns `NULL`, and if the implementation is unable to continue correct processing of the current command without the requested allocation, it **must** treat this as a runtime error, and generate `VK_ERROR_OUT_OF_HOST_MEMORY` at the appropriate time for the command in which the condition was detected, as described in Return Codes.

If the implementation is able to continue correct processing of the current command without the requested allocation, then it **may** do so, and **must** not generate `VK_ERROR_OUT_OF_HOST_MEMORY` as a result of this failed allocation.

The type of `pfnReallocation` is:

```c
// Provided by VK_VERSION_1_0
typedef void* (VKAPI_PTR *PFN_vkReallocationFunction)(
    void* pUserData,
    void* pOriginal,
    size_t size,
    size_t alignment,
    VkSystemAllocationScope allocationScope);
```

- `pUserData` is the value specified for `VkAllocationCallbacks::pUserData` in the allocator specified by the application.
- `pOriginal` **must** be either `NULL` or a pointer previously returned by `pfnReallocation` or `pfnAllocation` of a compatible allocator.
- `size` is the size in bytes of the requested allocation.
- `alignment` is the requested alignment of the allocation in bytes and **must** be a power of two.
- `allocationScope` is a `VkSystemAllocationScope` value specifying the allocation scope of the lifetime of the allocation, as described here.

If the reallocation was successful, `pfnReallocation` **must** return an allocation with enough space for `size` bytes, and the contents of the original allocation from bytes zero to `min(original size, new size) - 1` **must** be preserved in the returned allocation. If `size` is larger than the old size, the contents of the additional space are undefined. If satisfying these requirements involves creating a new allocation, then the old allocation **should** be freed.

If `pOriginal` is `NULL`, then `pfnReallocation` **must** behave equivalently to a call to `PFN_vkAllocationFunction` with the same parameter values (without `pOriginal`).

If `size` is zero, then `pfnReallocation` **must** behave equivalently to a call to `PFN_vkFreeFunction` with the same `pUserData` parameter value, and `pMemory` equal to `pOriginal`.

If `pOriginal` is non-`NULL`, the implementation **must** ensure that `alignment` is equal to the `alignment` used to originally allocate `pOriginal`.

If this function fails and `pOriginal` is non-`NULL` the application **must** not free the old allocation.

`pfnReallocation` **must** follow the same rules for return values as `PFN_vkAllocationFunction`.

The type of `pfnFree` is:
pUserData is the value specified for VkAllocationCallbacks::pUserData in the allocator specified by the application.

pMemory is the allocation to be freed.

pMemory may be NULL, which the callback must handle safely. If pMemory is non-NULL, it must be a pointer previously allocated by pfnAllocation or pfnReallocation. The application should free this memory.

The type of pfnInternalAllocation is:

typedef void (VKAPI_PTR *PFN_vkInternalAllocationNotification)(
    void* pUserData,
    size_t size,
    VkInternalAllocationType allocationType,
    VkSystemAllocationScope allocationScope);

pUserData is the value specified for VkAllocationCallbacks::pUserData in the allocator specified by the application.

size is the requested size of an allocation.

allocationType is a VkInternalAllocationType value specifying the requested type of an allocation.

allocationScope is a VkSystemAllocationScope value specifying the allocation scope of the lifetime of the allocation, as described here.

This is a purely informational callback.

The type of pfnInternalFree is:

typedef void (VKAPI_PTR *PFN_vkInternalFreeNotification)(
    void* pUserData,
    size_t size,
    VkInternalAllocationType allocationType,
    VkSystemAllocationScope allocationScope);

pUserData is the value specified for VkAllocationCallbacks::pUserData in the allocator specified by the application.

size is the requested size of an allocation.
• allocationType is a VkInternalAllocationType value specifying the requested type of an allocation.

• allocationScope is a VkSystemAllocationScope value specifying the allocation scope of the lifetime of the allocation, as described here.

Each allocation has an allocation scope defining its lifetime and which object it is associated with. Possible values passed to the allocationScope parameter of the callback functions specified by VkAllocationCallbacks, indicating the allocation scope, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkSystemAllocationScope {
    VK_SYSTEM_ALLOCATION_SCOPE_COMMAND = 0,
    VK_SYSTEM_ALLOCATION_SCOPE_OBJECT = 1,
    VK_SYSTEM_ALLOCATION_SCOPE_CACHE = 2,
    VK_SYSTEM_ALLOCATION_SCOPE_DEVICE = 3,
    VK_SYSTEM_ALLOCATION_SCOPE_INSTANCE = 4,
} VkSystemAllocationScope;
```

• VK_SYSTEM_ALLOCATION_SCOPE_COMMAND specifies that the allocation is scoped to the duration of the Vulkan command.

• VK_SYSTEM_ALLOCATION_SCOPE_OBJECT specifies that the allocation is scoped to the lifetime of the Vulkan object that is being created or used.

• VK_SYSTEM_ALLOCATION_SCOPE_CACHE specifies that the allocation is scoped to the lifetime of a VkPipelineCache or VkValidationCacheEXT object.

• VK_SYSTEM_ALLOCATION_SCOPE_DEVICE specifies that the allocation is scoped to the lifetime of the Vulkan device.

• VK_SYSTEM_ALLOCATION_SCOPE_INSTANCE specifies that the allocation is scoped to the lifetime of the Vulkan instance.

Most Vulkan commands operate on a single object, or there is a single object that is being created or manipulated. When an allocation uses an allocation scope of VK_SYSTEM_ALLOCATION_SCOPE_OBJECT or VK_SYSTEM_ALLOCATION_SCOPE_CACHE, the allocation is scoped to the object being created or manipulated.

When an implementation requires host memory, it will make callbacks to the application using the most specific allocator and allocation scope available:

• If an allocation is scoped to the duration of a command, the allocator will use the VK_SYSTEM_ALLOCATION_SCOPE_COMMAND allocation scope. The most specific allocator available is used: if the object being created or manipulated has an allocator, that object's allocator will be used, else if the parent VkDevice has an allocator it will be used, else if the parent VkInstance has an allocator it will be used. Else,

• If an allocation is associated with a VkValidationCacheEXT or VkPipelineCache object, the allocator will use the VK_SYSTEM_ALLOCATION_SCOPE_CACHE allocation scope. The most specific allocator available is used (cache, else device, else instance). Else,
• If an allocation is scoped to the lifetime of an object, that object is being created or manipulated by the command, and that object's type is not VkDevice or VkInstance, the allocator will use an allocation scope of VK_SYSTEM_ALLOCATION_SCOPE_OBJECT. The most specific allocator available is used (object, else device, else instance). Else,

• If an allocation is scoped to the lifetime of a device, the allocator will use an allocation scope of VK_SYSTEM_ALLOCATION_SCOPE_DEVICE. The most specific allocator available is used (device, else instance). Else,

• If the allocation is scoped to the lifetime of an instance and the instance has an allocator, its allocator will be used with an allocation scope of VK_SYSTEM_ALLOCATION_SCOPE_INSTANCE.

• Otherwise an implementation will allocate memory through an alternative mechanism that is unspecified.

Objects that are allocated from pools do not specify their own allocator. When an implementation requires host memory for such an object, that memory is sourced from the object's parent pool's allocator.

The application is not expected to handle allocating memory that is intended for execution by the host due to the complexities of differing security implementations across multiple platforms. The implementation will allocate such memory internally and invoke an application provided informational callback when these internal allocations are allocated and freed. Upon allocation of executable memory, pfnInternalAllocation will be called. Upon freeing executable memory, pfnInternalFree will be called. An implementation will only call an informational callback for executable memory allocations and frees.

The allocationType parameter to the pfnInternalAllocation and pfnInternalFree functions may be one of the following values:

// Provided by VK_VERSION_1_0
typedef enum VkInternalAllocationType {
    VK_INTERNAL_ALLOCATION_TYPE_EXECUTABLE = 0,
} VkInternalAllocationType;

• VK_INTERNAL_ALLOCATION_TYPE_EXECUTABLE specifies that the allocation is intended for execution by the host.

An implementation must only make calls into an application-provided allocator during the execution of an API command. An implementation must only make calls into an application-provided allocator from the same thread that called the provoking API command. The implementation should not synchronize calls to any of the callbacks. If synchronization is needed, the callbacks must provide it themselves. The informational callbacks are subject to the same restrictions as the allocation callbacks.

If an implementation intends to make calls through a VkAllocationCallbacks structure between the time a vkCreate* command returns and the time a corresponding vkDestroy* command begins, that implementation must save a copy of the allocator before the vkCreate* command returns. The callback functions and any data structures they rely upon must remain valid for the lifetime of the object they are associated with.
If an allocator is provided to a `vkCreate*` command, a compatible allocator must be provided to the corresponding `vkDestroy*` command. Two `VkAllocationCallbacks` structures are compatible if memory allocated with `pfnAllocation` or `pfnReallocation` in each can be freed with `pfnReallocation` or `pfnFree` in the other. An allocator must not be provided to a `vkDestroy*` command if an allocator was not provided to the corresponding `vkCreate*` command.

If a non-NULL allocator is used, the `pfnAllocation`, `pfnReallocation` and `pfnFree` members must be non-NULL and point to valid implementations of the callbacks. An application can choose to not provide informational callbacks by setting both `pfnInternalAllocation` and `pfnInternalFree` to NULL. `pfnInternalAllocation` and `pfnInternalFree` must either both be NULL or both be non-NULL.

If `pfnAllocation` or `pfnReallocation` fail, the implementation may fail object creation and/or generate a `VK_ERROR_OUT_OF_HOST_MEMORY` error, as appropriate.

Allocation callbacks must not call any Vulkan commands.

The following sets of rules define when an implementation is permitted to call the allocator callbacks.

`pfnAllocation` or `pfnReallocation` may be called in the following situations:

- Allocations scoped to a `VkDevice` or `VkInstance` may be allocated from any API command.
- Allocations scoped to a command may be allocated from any API command.
- Allocations scoped to a `VkPipelineCache` may only be allocated from:
  - `vkCreatePipelineCache`
  - `vkMergePipelineCaches` for `dstCache`
  - `vkCreateGraphicsPipelines` for `pipelineCache`
  - `vkCreateComputePipelines` for `pipelineCache`
- Allocations scoped to a `VkValidationCacheEXT` may only be allocated from:
  - `vkCreateValidationCacheEXT`
  - `vkMergeValidationCachesEXT` for `dstCache`
  - `vkCreateShaderModule` for `validationCache` in `VkShaderModuleValidationCacheCreateInfoEXT`
- Allocations scoped to a `VkDescriptorPool` may only be allocated from:
  - any command that takes the pool as a direct argument
  - `vkAllocateDescriptorSets` for the `descriptorPool` member of its `pAllocateInfo` parameter
  - `vkCreateDescriptorPool`
- Allocations scoped to a `VkCommandPool` may only be allocated from:
  - any command that takes the pool as a direct argument
  - `vkCreateCommandPool`
  - `vkAllocateCommandBuffers` for the `commandPool` member of its `pAllocateInfo` parameter
  - any `vkCmd*` command whose `commandBuffer` was allocated from that `VkCommandPool`
• Allocations scoped to any other object **may** only be allocated in that object's **vkCreate** command.

**PFNFree** or **PFNReallocation** with zero size, **may** be called in the following situations:

• Allocations scoped to a **VkDevice** or **VkInstance** **may** be freed from any API command.

• Allocations scoped to a command **must** be freed by any API command which allocates such memory.

• Allocations scoped to a **VkPipelineCache** **may** be freed from **vkDestroyPipelineCache**.

• Allocations scoped to a **VkValidationCacheEXT** **may** be freed from **vkDestroyValidationCacheEXT**.

• Allocations scoped to a **VkDescriptorPool** **may** be freed from
  ◦ any command that takes the pool as a direct argument

• Allocations scoped to a **VkCommandPool** **may** be freed from:
  ◦ any command that takes the pool as a direct argument
  ◦ **vkResetCommandBuffer** whose **commandBuffer** was allocated from that **VkCommandPool**

• Allocations scoped to any other object **may** be freed in that object's **vkDestroy** command.

• Any command that allocates host memory **may** also free host memory of the same scope.

---

### 11.2. Device Memory

**Device memory** is memory that is visible to the device — for example the contents of the image or buffer objects, which **can** be natively used by the device.

#### 11.2.1. Device Memory Properties

Memory properties of a physical device describe the memory heaps and memory types available.

To query memory properties, call:

```c
// Provided by VK_VERSION_1_0
void vkGetPhysicalDeviceMemoryProperties(
    VkPhysicalDevice physicalDevice,
    VkPhysicalDeviceMemoryProperties* pMemoryProperties);
```

• **physicalDevice** is the handle to the device to query.

• **pMemoryProperties** is a pointer to a **VkPhysicalDeviceMemoryProperties** structure in which the properties are returned.

---

**Valid Usage (Implicit)**

• **VUID-vkGetPhysicalDeviceMemoryProperties-physicalDevice-parameter**
  **physicalDevice** **must** be a valid **VkPhysicalDevice** handle

• **VUID-vkGetPhysicalDeviceMemoryProperties-pMemoryProperties-parameter**
The `VkPhysicalDeviceMemoryProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPhysicalDeviceMemoryProperties {
    uint32_t memoryTypeCount;
    VkMemoryType memoryTypes[VK_MAX_MEMORY_TYPES];
    uint32_t memoryHeapCount;
    VkMemoryHeap memoryHeaps[VK_MAX_MEMORY_HEAPS];
} VkPhysicalDeviceMemoryProperties;
```

- `memoryTypeCount` is the number of valid elements in the `memoryTypes` array.
- `memoryTypes` is an array of `VK_MAX_MEMORY_TYPES` `VkMemoryType` structures describing the memory types that can be used to access memory allocated from the heaps specified by `memoryHeaps`.
- `memoryHeapCount` is the number of valid elements in the `memoryHeaps` array.
- `memoryHeaps` is an array of `VK_MAX_MEMORY_HEAPS` `VkMemoryHeap` structures describing the memory heaps from which memory can be allocated.

The `VkPhysicalDeviceMemoryProperties` structure describes a number of memory heaps as well as a number of memory types that can be used to access memory allocated in those heaps. Each heap describes a memory resource of a particular size, and each memory type describes a set of memory properties (e.g. host cached vs. uncached) that can be used with a given memory heap. Allocations using a particular memory type will consume resources from the heap indicated by that memory type’s heap index. More than one memory type may share each heap, and the heaps and memory types provide a mechanism to advertise an accurate size of the physical memory resources while allowing the memory to be used with a variety of different properties.

The number of memory heaps is given by `memoryHeapCount` and is less than or equal to `VK_MAX_MEMORY_HEAPS`. Each heap is described by an element of the `memoryHeaps` array as a `VkMemoryHeap` structure. The number of memory types available across all memory heaps is given by `memoryTypeCount` and is less than or equal to `VK_MAX_MEMORY_TYPES`. Each memory type is described by an element of the `memoryTypes` array as a `VkMemoryType` structure.

At least one heap must include `VK_MEMORY_HEAP_DEVICE_LOCAL_BIT` in `VkMemoryHeap::flags`. If there are multiple heaps that all have similar performance characteristics, they may all include `VK_MEMORY_HEAP_DEVICE_LOCAL_BIT`. In a unified memory architecture (UMA) system there is often only a single memory heap which is considered to be equally “local” to the host and to the device, and such an implementation must advertise the heap as device-local.

Each memory type returned by `vkGetPhysicalDeviceMemoryProperties` must have its `propertyFlags` set to one of the following values:

- 0
- `VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORY_PROPERTY_HOST_COHERENT_BIT`
- `VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORY_PROPERTY_HOST_CACHED_BIT`
- `VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORY_PROPERTY_HOST_COHERENT_BIT | VK_MEMORY_PROPERTY_HOST_CACHED_BIT`
- `VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT`
- `VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT | VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORY_PROPERTY_HOST_COHERENT_BIT`
- `VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT | VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORY_PROPERTY_HOST_CACHED_BIT | VK_MEMORY_PROPERTY_HOST_COHERENT_BIT`
- `VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT | VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORY_PROPERTY_HOST_CACHED_BIT | VK_MEMORY_PROPERTY_HOST_COHERENT_BIT | VK_MEMORY_PROPERTY_DEVICE_LOCOHERENT_BIT_AMD`
- `VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT | VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORY_PROPERTY_HOST_CACHED_BIT | VK_MEMORY_PROPERTY_HOST_COHERENT_BIT | VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD`
- `VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT | VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORY_PROPERTY_HOST_CACHED_BIT | VK_MEMORY_PROPERTY_HOST_COHERENT_BIT | VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD`
- `VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT | VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORY_PROPERTY_HOST_CACHED_BIT | VK_MEMORY_PROPERTY_HOST_COHERENT_BIT | VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD`
VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD | VK_MEMORY_PROPERTY_DEVICE_UNCACHED_BIT_AMD

• VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORY_PROPERTY_HOST_CACHED_BIT | VK_MEMORY_PROPERTY_HOST_COHERENT_BIT | VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD | VK_MEMORY_PROPERTY_DEVICE_UNCACHED_BIT_AMD

• VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT | VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD | VK_MEMORY_PROPERTY_DEVICE_UNCACHED_BIT_AMD

• VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT | VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORY_PROPERTY_HOST_COHERENT_BIT | VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD | VK_MEMORY_PROPERTY_DEVICE_UNCACHED_BIT_AMD

• VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT | VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORYPROPERTY_HOST_CACHED_BIT | VK_MEMORY_PROPERTY_HOST_COHERENT_BIT | VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD | VK_MEMORY_PROPERTY_DEVICE_UNCACHED_BIT_AMD

• VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT | VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORYPROPERTY_HOST_CACHED_BIT | VK_MEMORY_PROPERTY_HOST_COHERENT_BIT | VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD | VK_MEMORY_PROPERTY_DEVICE_UNCACHED_BIT_AMD

• VK_MEMORYPROPERTY_DEVICE_LOCAL_BIT | VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORYPROPERTY_HOST_CACHED_BIT | VK_MEMORY_PROPERTY_HOST_COHERENT_BIT | VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD | VK_MEMORY_PROPERTY_DEVICE_UNCACHED_BIT_AMD

• VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT | VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT | VK_MEMORYPROPERTY_HOST_CACHED_BIT | VK_MEMORY_PROPERTY_HOST_COHERENT_BIT | VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD | VK_MEMORY_PROPERTY_DEVICE_UNCACHED_BIT_AMD

There must be at least one memory type with both the VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT and VK_MEMORY_PROPERTY_HOST_COHERENT_BIT bits set in its propertyFlags. There must be at least one memory type with the VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT bit set in its propertyFlags. If the deviceCoherentMemory feature is enabled, there must be at least one memory type with the VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD bit set in its propertyFlags.

For each pair of elements \( X \) and \( Y \) returned in memoryTypes, \( X \) must be placed at a lower index position than \( Y \) if:

- the set of bit flags returned in the propertyFlags member of \( X \) is a strict subset of the set of bit flags returned in the propertyFlags member of \( Y \); or

- the propertyFlags members of \( X \) and \( Y \) are equal, and \( X \) belongs to a memory heap with greater performance (as determined in an implementation-specific manner); or

- the propertyFlags members of \( Y \) includes VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD or VK_MEMORY_PROPERTY_DEVICE_UNCACHED_BIT_AMD and \( X \) does not

\[ \text{Note} \]

There is no ordering requirement between \( X \) and \( Y \) elements for the case their propertyFlags members are not in a subset relation. That potentially allows more than one possible way to order the same set of memory types. Notice that the list of all allowed memory property flag combinations is written in a valid order. But if
instead \texttt{VK\_MEMORY\_PROPERTY\_DEVICE\_LOCAL\_BIT} was before \texttt{VK\_MEMORY\_PROPERTY\_HOST\_VISIBLE\_BIT} | \texttt{VK\_MEMORY\_PROPERTY\_HOST\_COHERENT\_BIT}, the list would still be in a valid order.

There may be a performance penalty for using device coherent or uncached device memory types, and using these accidentally is undesirable. In order to avoid this, memory types with these properties always appear at the end of the list; but are subject to the same rules otherwise.

This ordering requirement enables applications to use a simple search loop to select the desired memory type along the lines of:

```c
// Find a memory in `memoryTypeBitsRequirement` that includes all of 'requiredProperties'
int32_t findProperties(const VkPhysicalDeviceMemoryProperties* pMemoryProperties,
                        uint32_t memoryTypeBitsRequirement,
                        VkMemoryPropertyFlags requiredProperties)
{
    const uint32_t memoryCount = pMemoryProperties->memoryTypeCount;
    for (uint32_t memoryIndex = 0; memoryIndex < memoryCount; ++memoryIndex)
    {
        const uint32_t memoryTypeBits = (1 << memoryIndex);
        const bool isRequiredMemoryType = memoryTypeBitsRequirement & memoryTypeBits;
        const VkMemoryPropertyFlags properties = pMemoryProperties->memoryTypes[memoryIndex].propertyFlags;
        const bool hasRequiredProperties = (properties & requiredProperties) == requiredProperties;

        if (isRequiredMemoryType && hasRequiredProperties)
            return static_cast<int32_t>(memoryIndex);
    }

    // failed to find memory type
    return -1;
}
```

// Try to find an optimal memory type, or if it does not exist try fallback memory type
// 'device' is the VkDevice
// 'image' is the VkImage that requires memory to be bound
// 'memoryProperties' properties as returned by vkGetPhysicalDeviceMemoryProperties
// 'requiredProperties' are the property flags that must be present
// 'optimalProperties' are the property flags that are preferred by the application
VkMemoryRequirements memoryRequirements;
vkGetImageMemoryRequirements(device, image, &memoryRequirements);
int32_t memoryType = findProperties(&memoryProperties, memoryRequirements.memoryTypeBits, optimalProperties);
if (memoryType == -1) // not found; try fallback properties
    memoryType = findProperties(&memoryProperties, memoryRequirements.memoryTypeBits, optimalProperties);
```
VK_MAX_MEMORY_TYPES is the length of an array of VkMemoryType structures describing memory types, as returned in VkPhysicalDeviceMemoryProperties::memoryTypes.

#define VK_MAX_MEMORY_TYPES 32U

VK_MAX_MEMORY_HEAPS is the length of an array of VkMemoryHeap structures describing memory heaps, as returned in VkPhysicalDeviceMemoryProperties::memoryHeaps.

#define VK_MAX_MEMORY_HEAPS 16U

To query memory properties, call:

// Provided by VK_VERSION_1_1
void vkGetPhysicalDeviceMemoryProperties2(
    VkPhysicalDevice physicalDevice,
    VkPhysicalDeviceMemoryProperties2* pMemoryProperties);

or the equivalent command

// Provided by VK_KHR_get_physical_device_properties2
void vkGetPhysicalDeviceMemoryProperties2KHR(
    VkPhysicalDevice physicalDevice,
    VkPhysicalDeviceMemoryProperties2* pMemoryProperties);

- physicalDevice is the handle to the device to query.
- pMemoryProperties is a pointer to a VkPhysicalDeviceMemoryProperties2 structure in which the properties are returned.

vkGetPhysicalDeviceMemoryProperties2 behaves similarly to vkGetPhysicalDeviceMemoryProperties, with the ability to return extended information in a pNext chain of output structures.

Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceMemoryProperties2-physicalDevice-parameter physicalDevice must be a valid VkPhysicalDevice handle
- VUID-vkGetPhysicalDeviceMemoryProperties2-pMemoryProperties-parameter pMemoryProperties must be a valid pointer to a VkPhysicalDeviceMemoryProperties2 structure

The VkPhysicalDeviceMemoryProperties2 structure is defined as:
```c
typedef struct VkPhysicalDeviceMemoryProperties2 {
    VkStructureType sType;
    void* pNext;
    VkPhysicalDeviceMemoryProperties memoryProperties;
} VkPhysicalDeviceMemoryProperties2;
```

or the equivalent

```c
// Provided by VK_KHR_get_physical_device_properties2
typedef VkPhysicalDeviceMemoryProperties2 VkPhysicalDeviceMemoryProperties2KHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `memoryProperties` is a `VkPhysicalDeviceMemoryProperties` structure which is populated with the same values as in `vkGetPhysicalDeviceMemoryProperties`.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceMemoryProperties2-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_PROPERTIES_2`
- VUID-VkPhysicalDeviceMemoryProperties2-pNext-pNext
  - `pNext` must be `NULL` or a pointer to a valid instance of `VkPhysicalDeviceMemoryBudgetPropertiesEXT`
- VUID-VkPhysicalDeviceMemoryProperties2-sType-unique
  - The `sType` value of each struct in the `pNext` chain must be unique

The `VkMemoryHeap` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkMemoryHeap {
    VkDeviceSize size;
    VkMemoryHeapFlags flags;
} VkMemoryHeap;
```

- `size` is the total memory size in bytes in the heap.
- `flags` is a bitmask of `VkMemoryHeapFlagBits` specifying attribute flags for the heap.

Bits which may be set in `VkMemoryHeap::flags`, indicating attribute flags for the heap, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkMemoryHeapFlagBits {
    VK_MEMORY_HEAP_DEVICE_LOCAL_BIT = 0x00000001,
};
```
• **VK_MEMORY_HEAP_DEVICE_LOCAL_BIT** specifies that the heap corresponds to device-local memory. Device-local memory may have different performance characteristics than host-local memory, and may support different memory property flags.

• **VK_MEMORY_HEAP_MULTI_INSTANCE_BIT** specifies that in a logical device representing more than one physical device, there is a per-physical device instance of the heap memory. By default, an allocation from such a heap will be replicated to each physical device's instance of the heap.

```
// Provided by VK_VERSION_1_0
typedef VkFlags VkMemoryHeapFlags;
```

**VkMemoryHeapFlags** is a bitmask type for setting a mask of zero or more **VkMemoryHeapFlagBits**.

The **VkMemoryType** structure is defined as:

```
// Provided by VK_VERSION_1_0
typedef struct VkMemoryType {
    VkMemoryPropertyFlags propertyFlags;
    uint32_t heapIndex;
} VkMemoryType;
```

- **heapIndex** describes which memory heap this memory type corresponds to, and **must** be less than **memoryHeapCount** from the **VkPhysicalDeviceMemoryProperties** structure.

- **propertyFlags** is a bitmask of **VkMemoryPropertyFlagBits** of properties for this memory type.

Bits which may be set in **VkMemoryType::propertyFlags**, indicating properties of a memory type, are:

```
// Provided by VK_VERSION_1_0
typedef enum VkMemoryPropertyFlagBits {
    VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT = 0x00000001,
    VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT = 0x00000002,
    VK_MEMORY_PROPERTY_HOST_COHERENT_BIT = 0x00000004,
    VK_MEMORY_PROPERTY_HOST_CACHED_BIT = 0x00000008,
    VK_MEMORY_PROPERTY_LAZILY_ALLOCATED_BIT = 0x00000010,
    // Provided by VK_VERSION_1_1
    VK_MEMORY_PROPERTY_PROTECTED_BIT = 0x00000020,
    // Provided by VK_AMD_device_coherent_memory
    VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD = 0x00000040,
    // Provided by VK_AMD_device_coherent_memory
    VK_MEMORY_PROPERTY_DEVICE_UNCACHED_BIT_AMD = 0x00000080,
}
```
• **VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT** bit specifies that memory allocated with this type is the most efficient for device access. This property will be set if and only if the memory type belongs to a heap with the **VK_MEMORY_HEAP_DEVICE_LOCAL_BIT** set.

• **VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT** bit specifies that memory allocated with this type can be mapped for host access using **vkMapMemory**.

• **VK_MEMORY_PROPERTY_HOST_COHERENT_BIT** bit specifies that the host cache management commands **vkFlushMappedMemoryRanges** and **vkInvalidateMappedMemoryRanges** are not needed to flush host writes to the device or make device writes visible to the host, respectively.

• **VK_MEMORY_PROPERTY_HOST_CACHED_BIT** bit specifies that memory allocated with this type is cached on the host. Host memory accesses to uncached memory are slower than to cached memory, however uncached memory is always host coherent.

• **VK_MEMORY_PROPERTY_LAZILY_ALLOCATED_BIT** bit specifies that the memory type only allows device access to the memory. Memory types must not have both **VK_MEMORY_PROPERTY_LAZILY_ALLOCATED_BIT** and **VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT** set. Additionally, the object’s backing memory may be provided by the implementation lazily as specified in Lazy Allocated Memory.

• **VK_MEMORY_PROPERTY_PROTECTED_BIT** bit specifies that the memory type only allows device access to the memory, and allows protected queue operations to access the memory. Memory types must not have **VK_MEMORY_PROPERTY_PROTECTED_BIT** set and any of **VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT**, **VK_MEMORY_PROPERTY_HOST_COHERENT_BIT**, or **VK_MEMORY_PROPERTY_HOST_CACHED_BIT** set.

• **VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD** bit specifies that device accesses to allocations of this memory type are automatically made available and visible.

• **VK_MEMORY_PROPERTY_DEVICE_UNCACHED_BIT_AMD** bit specifies that memory allocated with this type is not cached on the device. Uncached device memory is always device coherent.

• **VK_MEMORY_PROPERTY_RDMA_CAPABLE_BIT_NV** bit specifies that external devices can access this memory directly.

For any memory allocated with both the **VK_MEMORY_PROPERTY_HOST_COHERENT_BIT** and the **VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD**, host or device accesses also perform automatic memory domain transfer operations, such that writes are always automatically available and visible to both host and device memory domains.

**Note**

Device coherence is a useful property for certain debugging use cases (e.g. crash analysis, where performing separate coherence actions could mean values are not reported correctly). However, device coherent accesses may be slower than equivalent accesses without device coherence, particularly if they are also device uncached. For device uncached memory in particular, repeated accesses to the same or neighbouring memory locations over a short time period (e.g. within a
frame) may be slower than it would be for the equivalent cached memory type. As such, it is generally inadvisable to use device coherent or device uncached memory except when really needed.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkMemoryPropertyFlags;
```

`VkMemoryPropertyFlags` is a bitmask type for setting a mask of zero or more `VkMemoryPropertyFlagBits`.

If the `VkPhysicalDeviceMemoryBudgetPropertiesEXT` structure is included in the `pNext` chain of `VkPhysicalDeviceMemoryProperties2`, it is filled with the current memory budgets and usages.

The `VkPhysicalDeviceMemoryBudgetPropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_memory_budget
typedef struct VkPhysicalDeviceMemoryBudgetPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    VkDeviceSize heapBudget[VK_MAX_MEMORY_HEAPS];
    VkDeviceSize heapUsage[VK_MAX_MEMORY_HEAPS];
} VkPhysicalDeviceMemoryBudgetPropertiesEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `heapBudget` is an array of `VK_MAX_MEMORY_HEAPS` `VkDeviceSize` values in which memory budgets are returned, with one element for each memory heap. A heap's budget is a rough estimate of how much memory the process can allocate from that heap before allocations may fail or cause performance degradation. The budget includes any currently allocated device memory.
- `heapUsage` is an array of `VK_MAX_MEMORY_HEAPS` `VkDeviceSize` values in which memory usages are returned, with one element for each memory heap. A heap's usage is an estimate of how much memory the process is currently using in that heap.

The values returned in this structure are not invariant. The `heapBudget` and `heapUsage` values must be zero for array elements greater than or equal to `VkPhysicalDeviceMemoryProperties::memoryHeapCount`. The `heapBudget` value must be non-zero for array elements less than `VkPhysicalDeviceMemoryProperties::memoryHeapCount`. The `heapBudget` value must be less than or equal to `VkMemoryHeap::size` for each heap.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceMemoryBudgetPropertiesEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_BUDGET_PROPERTIES_EXT`
11.2.2. Device Memory Objects

A Vulkan device operates on data in device memory via memory objects that are represented in the API by a `VkDeviceMemory` handle:

```
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkDeviceMemory)
```

11.2.3. Device Memory Allocation

To allocate memory objects, call:

```
// Provided by VK_VERSION_1_0
VkResult vkAllocateMemory(
    VkDevice device,
    const VkMemoryAllocateInfo* pAllocateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkDeviceMemory* pMemory);
```

- `device` is the logical device that owns the memory.
- `pAllocateInfo` is a pointer to a `VkMemoryAllocateInfo` structure describing parameters of the allocation. A successfully returned allocation must use the requested parameters—no substitution is permitted by the implementation.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pMemory` is a pointer to a `VkDeviceMemory` handle in which information about the allocated memory is returned.

Allocations returned by `vkAllocateMemory` are guaranteed to meet any alignment requirement of the implementation. For example, if an implementation requires 128 byte alignment for images and 64 byte alignment for buffers, the device memory returned through this mechanism would be 128-byte aligned. This ensures that applications can correctly suballocate objects of different types (with potentially different alignment requirements) in the same memory object.

When memory is allocated, its contents are undefined with the following constraint:

- The contents of unprotected memory must not be a function of the contents of data protected memory objects, even if those memory objects were previously freed.

**Note**

The contents of memory allocated by one application should not be a function of data from protected memory objects of another application, even if those memory objects were previously freed.

The maximum number of valid memory allocations that can exist simultaneously within a `VkDevice` may be restricted by implementation- or platform-dependent limits. The `maxMemoryAllocationCount` feature describes the number of allocations that can exist simultaneously.
before encountering these internal limits.

---

**Note**

For historical reasons, if `maxMemoryAllocationCount` is exceeded, some implementations may return `VK_ERROR_TOO_MANY_OBJECTS`. Exceeding this limit will result in undefined behavior, and an application should not rely on the use of the returned error code in order to identify when the limit is reached.

---

**Note**

Many protected memory implementations involve complex hardware and system software support, and often have additional and much lower limits on the number of simultaneous protected memory allocations (from memory types with the `VK_MEMORY_PROPERTY_PROTECTED_BIT` property) than for non-protected memory allocations. These limits can be system-wide, and depend on a variety of factors outside of the Vulkan implementation, so they cannot be queried in Vulkan. Applications **should** use as few allocations as possible from such memory types by suballocating aggressively, and be prepared for allocation failure even when there is apparently plenty of capacity remaining in the memory heap. As a guideline, the Vulkan conformance test suite requires that at least 80 minimum-size allocations can exist concurrently when no other uses of protected memory are active in the system.

---

Some platforms **may** have a limit on the maximum size of a single allocation. For example, certain systems **may** fail to create allocations with a size greater than or equal to 4GB. Such a limit is implementation-dependent, and if such a failure occurs then the error `VK_ERROR_OUT_OF_DEVICE_MEMORY` **must** be returned. This limit is advertised in `VkPhysicalDeviceMaintenance3Properties::maxMemoryAllocationSize`.

The cumulative memory size allocated to a heap **can** be limited by the size of the specified heap. In such cases, allocated memory is tracked on a per-device and per-heap basis. Some platforms allow overallocation into other heaps. The overallocation behavior **can** be specified through the `VK_AMD_memory_overallocation_behavior` extension.

If the `VkPhysicalDevicePageableDeviceLocalMemoryFeaturesEXT:: pageableDeviceLocalMemory` feature is enabled, memory allocations made from a heap that includes `VK_MEMORY_HEAP_DEVICE_LOCAL_BIT` in `VkMemoryHeap::flags` **may** be transparently moved to host-local memory allowing multiple applications to share device-local memory. If there is no space left in device-local memory when this new allocation is made, other allocations **may** be moved out transparently to make room. The operating system will determine which allocations to move to device-local memory or host-local memory based on platform-specific criteria. To help the operating system make good choices, the application **should** set the appropriate memory priority with `VkMemoryPriorityAllocateInfoEXT` and adjust it as necessary with `vkSetDeviceMemoryPriorityEXT`. Higher priority allocations will moved to device-local memory first.

Memory allocations made on heaps without the `VK_MEMORY_HEAP_DEVICE_LOCAL_BIT` property will not be transparently promoted to device-local memory by the operating system.
Valid Usage

• VUID-vkAllocateMemory-pAllocateInfo-01713
  pAllocateInfo->allocationSize must be less than or equal to
  VkPhysicalDeviceMemoryProperties::memoryHeaps[memindex].size where memindex =
  VkPhysicalDeviceMemoryProperties::memoryTypes[pAllocateInfo->memoryTypeIndex]
  .heapIndex as returned by vkGetPhysicalDeviceMemoryProperties for the
  VkPhysicalDevice that device was created from

• VUID-vkAllocateMemory-pAllocateInfo-01714
  pAllocateInfo->memoryTypeIndex must be less than VkPhysicalDeviceMemoryProperties
  ::memoryTypeCount as returned by vkGetPhysicalDeviceMemoryProperties for the
  VkPhysicalDevice that device was created from

• VUID-vkAllocateMemory-deviceCoherentMemory-02790
  If the deviceCoherentMemory feature is not enabled, pAllocateInfo->memoryTypeIndex must
  not identify a memory type supporting VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD

• VUID-vkAllocateMemory-maxMemoryAllocationCount-04101
  There must be less than VkPhysicalDeviceLimits::maxMemoryAllocationCount device memory
  allocations currently allocated on the device

Valid Usage (Implicit)

• VUID-vkAllocateMemory-device-parameter
  device must be a valid VkDevice handle

• VUID-vkAllocateMemory-pAllocateInfo-parameter
  pAllocateInfo must be a valid pointer to a valid VkMemoryAllocateInfo structure

• VUID-vkAllocateMemory-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid
  VkAllocationCallbacks structure

• VUID-vkAllocateMemory-pMemory-parameter
  pMemory must be a valid pointer to a VkDeviceMemory handle

Return Codes

Success
  • VK_SUCCESS

Failure
  • VK_ERROR_OUT_OF_HOST_MEMORY
  • VK_ERROR_OUT_OF_DEVICE_MEMORY
  • VK_ERROR_INVALID_EXTERNAL_HANDLE
  • VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS_KHR
The *VkMemoryAllocateInfo* structure is defined as:

```
// Provided by VK_VERSION_1_0
typedef struct VkMemoryAllocateInfo {
    VkStructureType sType;
    const void* pNext;
    VkDeviceSize allocationSize;
    uint32_t memoryTypeIndex;
} VkMemoryAllocateInfo;
```

- `sType` is a *VkStructureType* value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `allocationSize` is the size of the allocation in bytes.
- `memoryTypeIndex` is an index identifying a memory type from the `memoryTypes` array of the *VkPhysicalDeviceMemoryProperties* structure.

The internal data of an allocated device memory object must include a reference to implementation-specific resources, referred to as the memory object's *payload*. Applications can also import and export that internal data to and from device memory objects to share data between Vulkan instances and other compatible APIs. A *VkMemoryAllocateInfo* structure defines a memory import operation if its `pNext` chain includes one of the following structures:

- *VkImportMemoryWin32HandleInfoKHR* with a non-zero `handleType` value
- *VkImportMemoryFdInfoKHR* with a non-zero `handleType` value
- *VkImportMemoryHostPointerInfoEXT* with a non-zero `handleType` value
- *VkImportAndroidHardwareBufferInfoANDROID* with a non-`NULL` `buffer` value
- *VkImportMemoryZirconHandleInfoFUCHSIA* with a non-zero `handleType` value
- *VkImportMemoryBufferCollectionFUCHSIA*
- *VkImportScreenBufferInfoQNX* with a non-`NULL` `buffer` value

If the parameters define an import operation and the external handle type is

```
VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_BIT,
VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_KMT_BIT,
```

or

```
VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_RESOURCE_BIT,
```

`allocationSize` is ignored. The implementation must query the size of these allocations from the OS.

Whether device memory objects constructed via a memory import operation hold a reference to their payload depends on the properties of the handle type used to perform the import, as defined below for each valid handle type. Importing memory must not modify the content of the memory. Implementations must ensure that importing memory does not enable the importing Vulkan instance to access any memory or resources in other Vulkan instances other than that corresponding to the memory object imported. Implementations must also ensure accessing imported memory which has not been initialized does not allow the importing Vulkan instance to obtain data from the exporting Vulkan instance or vice-versa.
Note

How exported and imported memory is isolated is left to the implementation, but applications should be aware that such isolation may prevent implementations from placing multiple exportable memory objects in the same physical or virtual page. Hence, applications should avoid creating many small external memory objects whenever possible.

Importing memory must not increase overall heap usage within a system. However, it must affect the following per-process values:

- VkPhysicalDeviceMaintenance3Properties::maxMemoryAllocationCount
- VkPhysicalDeviceMemoryBudgetPropertiesEXT::heapUsage

When performing a memory import operation, it is the responsibility of the application to ensure the external handles and their associated payloads meet all valid usage requirements. However, implementations must perform sufficient validation of external handles and payloads to ensure that the operation results in a valid memory object which will not cause program termination, device loss, queue stalls, or corruption of other resources when used as allowed according to its allocation parameters. If the external handle provided does not meet these requirements, the implementation must fail the memory import operation with the error code VK_ERROR_INVALID_EXTERNAL_HANDLE. If the parameters define an export operation and the external handle type is VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID, implementations should not strictly follow memoryTypeIndex. Instead, they should modify the allocation internally to use the required memory type for the application's given usage. This is because for an export operation, there is currently no way for the client to know the memory type index before allocating.

Valid Usage

- VUID-VkMemoryAllocateInfo-None-06657
  The parameters must not define more than one import operation

- VUID-VkMemoryAllocateInfo-allocationSize-07897
  If the parameters do not define an import or export operation, allocationSize must be greater than 0

- VUID-VkMemoryAllocateInfo-allocationSize-07899
  If the parameters define an export operation and the handle type is not VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID, allocationSize must be greater than 0

- VUID-VkMemoryAllocateInfo-buffer-06380
  If the parameters define an import operation from an VkBufferCollectionFUCHSIA, and VkMemoryDedicatedAllocateInfo::buffer is present and non-NULL, VkImportMemoryBufferCollectionFUCHSIA::collection and VkImportMemoryBufferCollectionFUCHSIA::index must match VkBufferCollectionBufferCreateInfoFUCHSIA::collection and VkBufferCollectionBufferCreateInfoFUCHSIA::index, respectively, of the VkBufferCollectionBufferCreateInfoFUCHSIA structure used to create the
VkMemoryDedicatedAllocateInfo::buffer

- VUID-VkMemoryAllocateInfo-image-06381
  If the parameters define an import operation from an VkBufferCollectionFUCHSIA, and VkMemoryDedicatedAllocateInfo::image is present and non-NULL, VkImportMemoryBufferCollectionFUCHSIA::collection and VkImportMemoryBufferCollectionFUCHSIA::index must match VkBufferCollectionImageCreateInfoFUCHSIA::collection and VkBufferCollectionImageCreateInfoFUCHSIA::index, respectively, of the VkBufferCollectionImageCreateInfoFUCHSIA structure used to create the VkMemoryDedicatedAllocateInfo::image

- VUID-VkMemoryAllocateInfo-allocationSize-06382
  If the parameters define an import operation from an VkBufferCollectionFUCHSIA, allocationSize must match VkMemoryRequirements::size value retrieved by vkGetImageMemoryRequirements or vkGetBufferMemoryRequirements for image-based or buffer-based collections respectively

- VUID-VkMemoryAllocateInfo-pNext-06383
  If the parameters define an import operation from an VkBufferCollectionFUCHSIA, the pNext chain must include a VkMemoryDedicatedAllocateInfo structure with either its image or buffer field set to a value other than VK_NULL_HANDLE

- VUID-VkMemoryAllocateInfo-image-06384
  If the parameters define an import operation from an VkBufferCollectionFUCHSIA and VkMemoryDedicatedAllocateInfo::image is not VK_NULL_HANDLE, the image must be created with a VkBufferCollectionImageCreateInfoFUCHSIA structure chained to its VkImageCreateInfo::pNext pointer

- VUID-VkMemoryAllocateInfo-buffer-06385
  If the parameters define an import operation from an VkBufferCollectionFUCHSIA and VkMemoryDedicatedAllocateInfo::buffer is not VK_NULL_HANDLE, the buffer must be created with a VkBufferCollectionBufferCreateInfoFUCHSIA structure chained to its VkBufferCreateInfo::pNext pointer

- VUID-VkMemoryAllocateInfo-memoryTypeIndex-06386
  If the parameters define an import operation from an VkBufferCollectionFUCHSIA, memoryTypeIndex must be from VkBufferCollectionPropertiesFUCHSIA as retrieved by vkGetBufferCollectionPropertiesFUCHSIA

- VUID-VkMemoryAllocateInfo-pNext-00639
  If the pNext chain includes a VkExportMemoryAllocateInfo structure, and any of the handle types specified in VkExportMemoryAllocateInfo::handleTypes require a dedicated allocation, as reported by vkGetPhysicalDeviceImageFormatProperties2 in VkExternalImageFormatProperties::externalMemoryProperties.externalMemoryFeatures, or by vkGetPhysicalDeviceExternalBufferProperties in VkExternalBufferProperties::externalMemoryProperties.externalMemoryFeatures, the pNext chain must include a VkMemoryDedicatedAllocateInfo or VkDedicatedAllocationMemoryAllocateInfoNV structure with either its image or buffer member set to a value other than VK_NULL_HANDLE

- VUID-VkMemoryAllocateInfo-pNext-00640
  If the pNext chain includes a VkExportMemoryAllocateInfo structure, it must not include a VkExportMemoryAllocateInfoNV or VkExportMemoryWin32HandleInfoNV structure
If the `pNext` chain includes a `VkImportMemoryWin32HandleInfoKHR` structure, it must not include a `VkImportMemoryWin32HandleInfoNV` structure.

If the parameters define an import operation, the external handle specified was created by the Vulkan API, and the external handle type is `VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT`, then the values of `allocationSize` and `memoryTypeIndex` must match those specified when the payload being imported was created.

If the parameters define an import operation and the external handle specified was created by the Vulkan API, the device mask specified by `VkMemoryAllocateFlagsInfo` must match the mask specified when the payload being imported was allocated.

If the parameters define an import operation and the external handle specified was created by the Vulkan API, the list of physical devices that comprise the logical device passed to `vkAllocateMemory` must match the list of physical devices that comprise the logical device on which the payload was originally allocated.

If the parameters define an import operation and the external handle is an NT handle or a global share handle created outside of the Vulkan API, the value of `memoryTypeIndex` must be one of those returned by `vkGetMemoryWin32HandlePropertiesKHR`.

If the parameters define an import operation and the external handle type is `VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT` or `VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT`, then the values of `allocationSize` and `memoryTypeIndex` must match those specified when the payload being imported was created.

If the parameters define an import operation and the external handle type is `VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_HEAP_BIT`, `allocationSize` must match the size specified when creating the Direct3D 12 heap from which the payload was extracted.

If the parameters define an import operation and the external handle is a POSIX file descriptor created outside of the Vulkan API, the value of `memoryTypeIndex` must be one of those returned by `vkGetMemoryFdPropertiesKHR`.

If the protectedMemory feature is not enabled, the `VkMemoryAllocateInfo::memoryTypeIndex` must not indicate a memory type that reports `VK_MEMORY_PROPERTY_PROTECTED_BIT`.

If the parameters define an import operation and the external handle is a host pointer, the value of `memoryTypeIndex` must be one of those returned by `vkGetMemoryHostPointerPropertiesEXT`.
If the parameters define an import operation and the external handle is a host pointer, `allocationSize` must be an integer multiple of `VkPhysicalDeviceExternalMemoryHostPropertiesEXT::minImportedHostPointerAlignment`.

If the parameters define an import operation and the external handle is a host pointer, the `pNext` chain must not include a `VkDedicatedAllocationMemoryAllocateInfoNV` structure with either its `image` or `buffer` field set to a value other than `VK_NULL_HANDLE`.

If the parameters define an import operation and the external handle is a host pointer, the `pNext` chain must not include a `VkMemoryDedicatedAllocateInfo` structure with either its `image` or `buffer` field set to a value other than `VK_NULL_HANDLE`.

If the parameters define an import operation and the external handle type is `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID`, `allocationSize` must be the size returned by `vkGetAndroidHardwareBufferPropertiesANDROID` for the Android hardware buffer.

If the parameters define an import operation and the external handle type is `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID`, and the `pNext` chain does not include a `VkMemoryDedicatedAllocateInfo` structure or the `VkMemoryDedicatedAllocateInfo::image` is `VK_NULL_HANDLE`, the Android hardware buffer must have an `AHardwareBuffer_Desc::format` of `AHARDWAREBUFFER_FORMAT_BLOB` and an `AHardwareBuffer_Desc::usage` that includes `AHARDWAREBUFFER_USAGE_GPU_DATA_BUFFER`.

If the parameters define an import operation and the external handle type is `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID`, `memoryTypeIndex` must be one of those returned by `vkGetAndroidHardwareBufferPropertiesANDROID` for the Android hardware buffer.

If the parameters do not define an import operation, and the `pNext` chain includes a `VkExportMemoryAllocateInfo` structure with `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID` included in its `handleTypes` member, and the `pNext` chain includes a `VkMemoryDedicatedAllocateInfo` structure with `image` not equal to `VK_NULL_HANDLE`, then `allocationSize` must be 0.

If the parameters define an export operation, the handle type is `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID`, and the `pNext` chain does not include a `VkMemoryDedicatedAllocateInfo` structure, `allocationSize` must be greater than 0.

If the parameters define an export operation, the handle type is `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID`, and the `pNext` chain includes a `VkMemoryDedicatedAllocateInfo` structure with `buffer` set to a valid `VkBuffer` object, `allocationSize` must be greater than 0.
If the parameters define an import operation, the external handle is an Android hardware buffer, and the `pNext` chain includes a `VkMemoryDedicatedAllocateInfo` with `image` that is not `VK_NULL_HANDLE`, the Android hardware buffer's `AHardwareBuffer::usage` must include at least one of `AHARDWAREBUFFER_USAGE_GPU_FRAMEBUFFER`, `AHARDWAREBUFFER_USAGE_GPU_SAMPLED_IMAGE` or `AHARDWAREBUFFER_USAGE_GPU_DATA_BUFFER`.

If the parameters define an import operation, the external handle is an Android hardware buffer, and the `pNext` chain includes a `VkMemoryDedicatedAllocateInfo` with `image` that is not `VK_NULL_HANDLE`, the format of `image` must be `VK_FORMAT_UNDEFINED` or the format returned by `vkGetAndroidHardwareBufferPropertiesANDROID` in `VkAndroidHardwareBufferFormatPropertiesANDROID::format` for the Android hardware buffer.

If the parameters define an import operation, the external handle is an Android hardware buffer, and the `pNext` chain includes a `VkMemoryDedicatedAllocateInfo` structure with `image` that is not `VK_NULL_HANDLE`, the width, height, and array layer dimensions of `image` and the Android hardware buffer's `AHardwareBuffer_Desc` must be identical.

If the parameters define an import operation, the external handle is an Android hardware buffer, and the `pNext` chain includes a `VkMemoryDedicatedAllocateInfo` structure with `image` that is not `VK_NULL_HANDLE`, and the Android hardware buffer's `AHardwareBuffer::usage` includes `AHARDWAREBUFFER_USAGE_GPU_MIPMAP_COMPLETE`, the `image` must have a complete mipmap chain.

If the parameters define an import operation, the external handle is an Android hardware buffer, and the `pNext` chain includes a `VkMemoryDedicatedAllocateInfo` structure with `image` that is not `VK_NULL_HANDLE`, and the Android hardware buffer's `AHardwareBuffer::usage` does not include `AHARDWAREBUFFER_USAGE_GPU_MIPMAP_COMPLETE`, the `image` must have exactly one mipmap level.

If the parameters define an import operation, the external handle is an Android hardware buffer, and the `pNext` chain includes a `VkMemoryDedicatedAllocateInfo` structure with `image` that is not `VK_NULL_HANDLE`, each bit set in the usage of `image` must be listed in `AHardwareBuffer Usage Equivalence`, and if there is a corresponding `AHARDWAREBUFFER_USAGE` bit listed that bit must be included in the Android hardware buffer's `AHardwareBuffer_Desc::usage`.

If the parameters define an import operation and the external handle type is `VK_EXTERNAL_MEMORY_HANDLE_TYPE_SCREEN_BUFFER_BIT_QNX`, `VkPhysicalDeviceExternalMemoryScreenBufferFeaturesQNX::screenBufferImport` must be enabled.

If the parameters define an import operation and the external handle type is `VK_EXTERNAL_MEMORY_HANDLE_TYPE_SCREEN_BUFFER_BIT_QNX`, `allocationSize` must be the size...
- VUID-VkMemoryAllocateInfo-memoryTypeIndex-08943
  If the parameters define an import operation and the external handle type is VK_EXTERNAL_MEMORY_HANDLE_TYPE_SCREEN_BUFFER_BIT_QNX, memoryTypeIndex must be one of those returned by vkGetScreenBufferPropertiesQNX for the QNX Screen buffer

- VUID-VkMemoryAllocateInfo-pNext-08944
  If the parameters define an import operation, the external handle is a QNX Screen buffer, and the pNext chain includes a VkMemoryDedicatedAllocateInfo with image that is not VK_NULL_HANDLE, the QNX Screen's buffer must be a valid QNX Screen buffer

- VUID-VkMemoryAllocateInfo-pNext-08945
  If the parameters define an import operation, the external handle is a QNX Screen buffer, and the pNext chain includes a VkMemoryDedicatedAllocateInfo structure with image that is not VK_NULL_HANDLE, the format of image must be VK_FORMAT_UNDEFINED or the format returned by vkGetScreenBufferPropertiesQNX in VkScreenBufferFormatPropertiesQNX::format for the QNX Screen buffer

- VUID-VkMemoryAllocateInfo-pNext-08946
  If the parameters define an import operation, the external handle is a QNX Screen buffer, and the pNext chain includes a VkMemoryDedicatedAllocateInfo structure with image that is not VK_NULL_HANDLE, the width, height, and array layer dimensions of image and the QNX Screen buffer's _screen_buffer must be identical

- VUID-VkMemoryAllocateInfo-opaqueCaptureAddress-03329
  If VkMemoryOpaqueCaptureAddressAllocateInfo::opaqueCaptureAddress is not zero, VkMemoryAllocateFlagsInfo::flags must include VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT

- VUID-VkMemoryAllocateInfo-flags-03330
  If VkMemoryAllocateFlagsInfo::flags includes VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT, the bufferDeviceAddressCaptureReplay feature must be enabled

- VUID-VkMemoryAllocateInfo-flags-03331
  If VkMemoryAllocateFlagsInfo::flags includes VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT, the bufferDeviceAddress feature must be enabled

- VUID-VkMemoryAllocateInfo-pNext-03332
  If the pNext chain includes a VkImportMemoryHostPointerInfoEXT structure, VkMemoryOpaqueCaptureAddressAllocateInfo::opaqueCaptureAddress must be zero

- VUID-VkMemoryAllocateInfo-opaqueCaptureAddress-03333
  If the parameters define an import operation, VkMemoryOpaqueCaptureAddressAllocateInfo::opaqueCaptureAddress must be zero

- VUID-VkMemoryAllocateInfo-None-04749
  If the parameters define an import operation and the external handle type is VK_EXTERNAL_MEMORY_HANDLE_TYPE_ZIRCON_VMO_BIT_FUCHSIA, the value of memoryTypeIndex must be an index identifying a memory type from the memoryTypeBits field of the VkMemoryZirconHandlePropertiesFUCHSIA structure populated by a call to vkGetMemoryZirconHandlePropertiesFUCHSIA
If the parameters define an import operation and the external handle type is `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ZIRCON_VMO_BIT_FUCHSIA`, the value of `allocationSize` must be greater than 0.

If the parameters define an import operation and the external handle type is `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ZIRCON_VMO_BIT_FUCHSIA`, the value of `allocationSize` must be less than or equal to the size of the VMO as determined by `zx_vmo_get_size(handle)` where `handle` is the VMO handle to the imported external memory.

If the `pNext` chain includes a `VkExportMetalObjectCreateInfoEXT` structure, its `exportObjectType` member must be `VK_EXPORT_METAL_OBJECT_TYPE_METAL_BUFFER_BIT_EXT`.

Valid Usage (Implicit)

- `VUID-VkMemoryAllocateInfo-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO`.
- `VUID-VkMemoryAllocateInfo-pNext-pNext`  
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkDedicatedAllocationMemoryAllocateInfoNV`, `VkExportMemoryAllocateInfo`, `VkExportMemoryWin32HandleInfoKHR`, `VkExportMetalObjectCreateInfoEXT`, `VkImportAndroidHardwareBufferInfoANDROID`, `VkImportMemoryBufferCollectionFUCHSIA`, `VkImportSpoolCameraTextureInfoEXT`, `VkImportVideoSurfaceInfoVULKAN`, `VkImportMemoryFdInfoKHR`, `VkImportMemoryHostPointerInfoEXT`, `VkImportMemoryWin32HandleInfoKHR`, `VkImportMemoryWin32HandleInfoNV`, `VkImportMemoryZirconHandleInfoFUCHSIA`, `VkImportMetalBufferInfoEXT`, `VkImportScreenBufferInfoQNX`, `VkMemoryAllocateFlagsInfo`, `VkMemoryOpaqueCaptureAddressAllocateInfo`, or `VkMemoryPriorityAllocateInfoEXT`.
- `VUID-VkMemoryAllocateInfo-sType-unique`  
  The `sType` value of each struct in the `pNext` chain must be unique, with the exception of structures of type `VkExportMetalObjectCreateInfoEXT`.

If the `pNext` chain includes a `VkMemoryDedicatedAllocateInfo` structure, then that structure includes a handle of the sole buffer or image resource that the memory can be bound to.

The `VkMemoryDedicatedAllocateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkMemoryDedicatedAllocateInfo {
    VkStructureType sType;
    const void* pNext;
    VkImage image;
    VkBuffer buffer;
} VkMemoryDedicatedAllocateInfo;
```
or the equivalent

```c
// Provided by VK_KHR_dedicated_allocation
typedef VkMemoryDedicatedAllocateInfo VkMemoryDedicatedAllocateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `image` is `VK_NULL_HANDLE` or a handle of an image which this memory will be bound to.
- `buffer` is `VK_NULL_HANDLE` or a handle of a buffer which this memory will be bound to.

### Valid Usage

- **VUID-VkMemoryDedicatedAllocateInfo-image-01432**
  At least one of `image` and `buffer` must be `VK_NULL_HANDLE`

- **VUID-VkMemoryDedicatedAllocateInfo-image-02964**
  If `image` is not `VK_NULL_HANDLE` and the memory is not an imported Android Hardware Buffer or an imported QNX Screen buffer, `VkMemoryAllocateInfo::allocationSize` must equal the `VkMemoryRequirements::size` of the image

- **VUID-VkMemoryDedicatedAllocateInfo-image-01434**
  If `image` is not `VK_NULL_HANDLE`, `image` must have been created without `VK_IMAGE_CREATE_SPARSE_BINDING_BIT` set in `VkImageCreateInfo::flags`

- **VUID-VkMemoryDedicatedAllocateInfo-buffer-02965**
  If `buffer` is not `VK_NULL_HANDLE` and the memory is not an imported Android Hardware Buffer or an imported QNX Screen buffer, `VkMemoryAllocateInfo::allocationSize` must equal the `VkMemoryRequirements::size` of the buffer

- **VUID-VkMemoryDedicatedAllocateInfo-buffer-01436**
  If `buffer` is not `VK_NULL_HANDLE`, `buffer` must have been created without `VK_BUFFER_CREATE_SPARSE_BINDING_BIT` set in `VkBufferCreateInfo::flags`

- **VUID-VkMemoryDedicatedAllocateInfo-image-01876**
  If `image` is not `VK_NULL_HANDLE` and `VkMemoryAllocateInfo` defines a memory import operation with handle type `VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT`, `VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT`, `VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_BIT`, `VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_KMT_BIT`, `VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_HEAP_BIT`, or `VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_RESOURCE_BIT`, and the external handle was created by the Vulkan API, then the memory being imported must also be a dedicated image allocation and `image` must be identical to the image associated with the imported memory

- **VUID-VkMemoryDedicatedAllocateInfo-buffer-01877**
  If `buffer` is not `VK_NULL_HANDLE` and `VkMemoryAllocateInfo` defines a memory import operation with handle type `VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT`,
VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT,
VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_BIT,
VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_KMT_BIT,
VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_HEAP_BIT, or
VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_RESOURCE_BIT, and the external handle was created
by the Vulkan API, then the memory being imported must also be a dedicated buffer allocation and buffer must be identical to the buffer associated with the imported memory

• VUID-VkMemoryDedicatedAllocateInfo-image-01878
If image is not VK_NULL_HANDLE and VkMemoryAllocateInfo defines a memory import operation with handle type VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT, the memory being imported must also be a dedicated image allocation and image must be identical to the image associated with the imported memory

• VUID-VkMemoryDedicatedAllocateInfo-buffer-01879
If buffer is not VK_NULL_HANDLE and VkMemoryAllocateInfo defines a memory import operation with handle type VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT, the memory being imported must also be a dedicated buffer allocation and buffer must be identical to the buffer associated with the imported memory

• VUID-VkMemoryDedicatedAllocateInfo-image-01797
If image is not VK_NULL_HANDLE, image must not have been created with VK_IMAGE_CREATE_DISJOINT_BIT set in VkImageCreateInfo::flags

• VUID-VkMemoryDedicatedAllocateInfo-image-04751
If image is not VK_NULL_HANDLE and VkMemoryAllocateInfo defines a memory import operation with handle type VK_EXTERNAL_MEMORY_HANDLE_TYPE_ZIRCON_VMO_BIT_FUCHSIA, the memory being imported must also be a dedicated image allocation and image must be identical to the image associated with the imported memory

• VUID-VkMemoryDedicatedAllocateInfo-buffer-04752
If buffer is not VK_NULL_HANDLE and VkMemoryAllocateInfo defines a memory import operation with handle type VK_EXTERNAL_MEMORY_HANDLE_TYPE_ZIRCON_VMO_BIT_FUCHSIA, the memory being imported must also be a dedicated buffer allocation and buffer must be identical to the buffer associated with the imported memory

Valid Usage (Implicit)

• VUID-VkMemoryDedicatedAllocateInfo-sType-sType
sType must be VK_STRUCTURE_TYPE_MEMORY_DEDICATED_ALLOCATE_INFO

• VUID-VkMemoryDedicatedAllocateInfo-image-parameter
If image is not VK_NULL_HANDLE, image must be a valid VkImage handle

• VUID-VkMemoryDedicatedAllocateInfo-buffer-parameter
If buffer is not VK_NULL_HANDLE, buffer must be a valid VkBuffer handle

• VUID-VkMemoryDedicatedAllocateInfo-commonparent
Both of buffer, and image that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice
If the `pNext` chain includes a `VkDedicatedAllocationMemoryAllocateInfoNV` structure, then that structure includes a handle of the sole buffer or image resource that the memory can be bound to.

The `VkDedicatedAllocationMemoryAllocateInfoNV` structure is defined as:

```c
// Provided by VK_NV_dedicated_allocation
typedef struct VkDedicatedAllocationMemoryAllocateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkImage image;
    VkBuffer buffer;
} VkDedicatedAllocationMemoryAllocateInfoNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `image` is `VK_NULL_HANDLE` or a handle of an image which this memory will be bound to.
- `buffer` is `VK_NULL_HANDLE` or a handle of a buffer which this memory will be bound to.

### Valid Usage

- **VUID-VkDedicatedAllocationMemoryAllocateInfoNV-image-00649**
  At least one of `image` and `buffer` must be `VK_NULL_HANDLE`

- **VUID-VkDedicatedAllocationMemoryAllocateInfoNV-image-00650**
  If `image` is not `VK_NULL_HANDLE`, the image must have been created with `VkDedicatedAllocationImageCreateInfoNV::dedicatedAllocation` equal to `VK_TRUE`

- **VUID-VkDedicatedAllocationMemoryAllocateInfoNV-buffer-00651**
  If `buffer` is not `VK_NULL_HANDLE`, the buffer must have been created with `VkDedicatedAllocationBufferCreateInfoNV::dedicatedAllocation` equal to `VK_TRUE`

- **VUID-VkDedicatedAllocationMemoryAllocateInfoNV-image-00652**
  If `image` is not `VK_NULL_HANDLE`, `VkMemoryAllocateInfo::allocationSize` must equal the `VkMemoryRequirements::size` of the image

- **VUID-VkDedicatedAllocationMemoryAllocateInfoNV-buffer-00653**
  If `buffer` is not `VK_NULL_HANDLE`, `VkMemoryAllocateInfo::allocationSize` must equal the `VkMemoryRequirements::size` of the buffer

- **VUID-VkDedicatedAllocationMemoryAllocateInfoNV-image-00654**
  If `image` is not `VK_NULL_HANDLE` and `VkMemoryAllocateInfo` defines a memory import operation, the memory being imported must also be a dedicated image allocation and `image` must be identical to the image associated with the imported memory

- **VUID-VkDedicatedAllocationMemoryAllocateInfoNV-buffer-00655**
  If `buffer` is not `VK_NULL_HANDLE` and `VkMemoryAllocateInfo` defines a memory import operation, the memory being imported must also be a dedicated buffer allocation and `buffer` must be identical to the buffer associated with the imported memory
Valid Usage (Implicit)

- VUID-VkDedicatedAllocationMemoryAllocateInfoNV-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_DEDICATED_ALLOCATION_MEMORY_ALLOCATE_INFO_NV`

- VUID-VkDedicatedAllocationMemoryAllocateInfoNV-image-parameter
  
  If `image` is not `VK_NULL_HANDLE`, `image` must be a valid `VkImage` handle

- VUID-VkDedicatedAllocationMemoryAllocateInfoNV-buffer-parameter
  
  If `buffer` is not `VK_NULL_HANDLE`, `buffer` must be a valid `VkBuffer` handle

- VUID-VkDedicatedAllocationMemoryAllocateInfoNV-commonparent
  
  Both of `buffer` and `image` that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same `VkDevice`

If the `pNext` chain includes a `VkMemoryPriorityAllocateInfoEXT` structure, then that structure includes a priority for the memory.

The `VkMemoryPriorityAllocateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_memory_priority
typedef struct VkMemoryPriorityAllocateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    float priority;
} VkMemoryPriorityAllocateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `priority` is a floating-point value between `0` and `1`, indicating the priority of the allocation relative to other memory allocations. Larger values are higher priority. The granularity of the priorities is implementation-dependent.

Memory allocations with higher priority may be more likely to stay in device-local memory when the system is under memory pressure.

If this structure is not included, it is as if the `priority` value were `0.5`.

Valid Usage

- VUID-VkMemoryPriorityAllocateInfoEXT-priority-02602
  
  `priority` must be between `0` and `1`, inclusive

Valid Usage (Implicit)

- VUID-VkMemoryPriorityAllocateInfoEXT-sType-sType
To modify the priority of an existing memory allocation, call:

```c
void vkSetDeviceMemoryPriorityEXT(
    VkDevice device,
    VkDeviceMemory memory,
    float priority);
```

- `device` is the logical device that owns the memory.
- `memory` is the `VkDeviceMemory` object to which the new priority will be applied.
- `priority` is a floating-point value between 0 and 1, indicating the priority of the allocation relative to other memory allocations. Larger values are higher priority. The granularity of the priorities is implementation-dependent.

Memory allocations with higher priority may be more likely to stay in device-local memory when the system is under memory pressure.

**Valid Usage**

- VUID-vkSetDeviceMemoryPriorityEXT-priority-06258  
  `priority` must be between 0 and 1, inclusive

**Valid Usage (Implicit)**

- VUID-vkSetDeviceMemoryPriorityEXT-device-parameter  
  `device` must be a valid `VkDevice` handle
- VUID-vkSetDeviceMemoryPriorityEXT-memory-parameter  
  `memory` must be a valid `VkDeviceMemory` handle
- VUID-vkSetDeviceMemoryPriorityEXT-memory-parent  
  `memory` must have been created, allocated, or retrieved from `device`

When allocating memory whose payload may be exported to another process or Vulkan instance, add a `VkExportMemoryAllocateInfo` structure to the `pNext` chain of the `VkMemoryAllocateInfo` structure, specifying the handle types that may be exported.

The `VkExportMemoryAllocateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkExportMemoryAllocateInfo {
    VkStructureType sType;
    const void* pNext;
} VkExportMemoryAllocateInfo;
```
VkExternalMemoryHandleTypeFlags handleTypes;
} VkExportMemoryAllocateInfo;

or the equivalent

// Provided by VK_KHR_external_memory
typedef VkExportMemoryAllocateInfo VkExportMemoryAllocateInfoKHR;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **handleTypes** is zero or a bitmask of `VkExternalMemoryHandleTypeFlagBits` specifying one or more memory handle types the application can export from the resulting allocation. The application can request multiple handle types for the same allocation.

### Valid Usage

- VUID-VkExportMemoryAllocateInfo-handleTypes-00656
  The bits in **handleTypes** must be supported and compatible, as reported by `VkExternalImageFormatProperties` or `VkExternalBufferProperties`.

### Valid Usage (Implicit)

- VUID-VkExportMemoryAllocateInfo-sType-sType
  **sType** must be `VK_STRUCTURE_TYPE_EXPORT_MEMORY_ALLOCATE_INFO`.
- VUID-VkExportMemoryAllocateInfo-handleTypes-parameter
  **handleTypes** must be a valid combination of `VkExternalMemoryHandleTypeFlagBits` values.

When allocating memory that may be exported to another process or Vulkan instance, add a `VkExportMemoryAllocateInfoNV` structure to the **pNext** chain of the `VkMemoryAllocateInfo` structure, specifying the handle types that may be exported.

The `VkExportMemoryAllocateInfoNV` structure is defined as:

// Provided by VK_NV_external_memory
typedef struct VkExportMemoryAllocateInfoNV {
    VkStructureType                      sType;
    const void*                          pNext;
    VkExternalMemoryHandleTypeFlagsNV    handleTypes;
} VkExportMemoryAllocateInfoNV;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
• **handleTypes** is a bitmask of `VkExternalMemoryHandleTypeFlagBitsNV` specifying one or more memory handle types that **may** be exported. Multiple handle types **may** be requested for the same allocation as long as they are compatible, as reported by `vkGetPhysicalDeviceExternalImageFormatPropertiesNV`.

### Valid Usage (Implicit)

- **VUID-VkExportMemoryAllocateInfoNV-sType-sType**
sType **must** be `VK_STRUCTURE_TYPE_EXPORT_MEMORY_ALLOCATE_INFO_NV`
- **VUID-VkExportMemoryAllocateInfoNV-handleTypes-parameter**
  handleTypes **must** be a valid combination of `VkExternalMemoryHandleTypeFlagBitsNV` values

#### 11.2.4. Win32 External Memory

To specify additional attributes of NT handles exported from a memory object, add a `VkExportMemoryWin32HandleInfoKHR` structure to the `pNext` chain of the `VkMemoryAllocateInfo` structure. The `VkExportMemoryWin32HandleInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_external_memory_win32
typedef struct VkExportMemoryWin32HandleInfoKHR {
    VkStructureType sType;
    const void* pNext;
    const SECURITY_ATTRIBUTES* pAttributes;
    DWORD dwAccess;
    LPCWSTR name;
} VkExportMemoryWin32HandleInfoKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **pAttributes** is a pointer to a Windows `SECURITY_ATTRIBUTES` structure specifying security attributes of the handle.
- **dwAccess** is a `DWORD` specifying access rights of the handle.
- **name** is a null-terminated UTF-16 string to associate with the payload referenced by NT handles exported from the created memory.

If `VkExportMemoryAllocateInfo` is not included in the same `pNext` chain, this structure is ignored.

If `VkExportMemoryAllocateInfo` is included in the `pNext` chain of `VkMemoryAllocateInfo` with a Windows `handleType`, but either `VkExportMemoryWin32HandleInfoKHR` is not included in the `pNext` chain, or it is included but `pAttributes` is set to `NULL`, default security descriptor values will be used, and child processes created by the application will not inherit the handle, as described in the MSDN documentation for “Synchronization Object Security and Access Rights”. Further, if the structure is not present, the access rights used depend on the handle type.
For handles of the following types:

- `VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT`

The implementation must ensure the access rights allow read and write access to the memory.


### Valid Usage

- **VUID-VkExportMemoryWin32HandleInfoKHR-handleTypes-00657**
  
  If `VkExportMemoryAllocateInfo::handleTypes` does not include `VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT`, a `VkExportMemoryWin32HandleInfoKHR` structure must not be included in the `pNext` chain of `VkMemoryAllocateInfo`.

### Valid Usage (Implicit)

- **VUID-VkExportMemoryWin32HandleInfoKHR-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_EXPORT_MEMORY_WIN32_HANDLE_INFO_KHR`.

- **VUID-VkExportMemoryWin32HandleInfoKHR-pAttributes-parameter**
  
  If `pAttributes` is not `NULL`, `pAttributes` must be a valid pointer to a valid `SECURITY_ATTRIBUTES` value.

To import memory from a Windows handle, add a `VkImportMemoryWin32HandleInfoKHR` structure to the `pNext` chain of the `VkMemoryAllocateInfo` structure.

The `VkImportMemoryWin32HandleInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_external_memory_win32
typedef struct VkImportMemoryWin32HandleInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkExternalMemoryHandleTypeFlagBits handleType;
    HANDLE handle;
    LPCWSTR name;
} VkImportMemoryWin32HandleInfoKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.

- **pNext** is `NULL` or a pointer to a structure extending this structure.

- **handleType** is a `VkExternalMemoryHandleTypeFlagBits` value specifying the type of `handle` or `name`.

- **handle** is `NULL` or the external handle to import.
Importing memory object payloads from Windows handles does not transfer ownership of the handle to the Vulkan implementation. For handle types defined as NT handles, the application must release handle ownership using the `CloseHandle` system call when the handle is no longer needed. For handle types defined as NT handles, the imported memory object holds a reference to its payload.

**Note**
Non-NT handle import operations do not add a reference to their associated payload. If the original object owning the payload is destroyed, all resources and handles sharing that payload will become invalid.

Applications can import the same payload into multiple instances of Vulkan, into the same instance from which it was exported, and multiple times into a given Vulkan instance. In all cases, each import operation must create a distinct `VkDeviceMemory` object.

### Valid Usage

- **VUID-VkImportMemoryWin32HandleInfoKHR-handleType-00658**
  If `handleType` is not 0, it must be supported for import, as reported by `VkExternalImageFormatProperties` or `VkExternalBufferProperties`.

- **VUID-VkImportMemoryWin32HandleInfoKHR-handle-00659**
  The memory from which `handle` was exported, or the memory named by `name` must have been created on the same underlying physical device as `device`.

- **VUID-VkImportMemoryWin32HandleInfoKHR-handleType-00660**
  If `handleType` is not 0, it must be defined as an NT handle or a global share handle.

- **VUID-VkImportMemoryWin32HandleInfoKHR-handleType-01439**
  If `handleType` is not `VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT`, `VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_BIT`, `VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_HEAP_BIT`, or `VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_RESOURCE_BIT`, `name` must be NULL.

- **VUID-VkImportMemoryWin32HandleInfoKHR-handleType-01440**
  If `handleType` is not 0 and `handle` is NULL, `name` must name a valid memory resource of the type specified by `handleType`.

- **VUID-VkImportMemoryWin32HandleInfoKHR-handleType-00661**
  If `handleType` is not 0 and `name` is NULL, `handle` must be a valid handle of the type specified by `handleType`.

- **VUID-VkImportMemoryWin32HandleInfoKHR-handle-01441**
  If `handle` is not NULL, `name` must be NULL.

- **VUID-VkImportMemoryWin32HandleInfoKHR-handle-01518**
  If `handle` is not NULL, it must obey any requirements listed for `handleType` in external memory handle types compatibility.

- **VUID-VkImportMemoryWin32HandleInfoKHR-name-01519**
  If `handle` is not NULL, it must obey any requirements listed for `handleType` in external memory handle types compatibility.
If `name` is not `NULL`, it must obey any requirements listed for `handleType` in external memory handle types compatibility.

Valid Usage (Implicit)

- `VUID-VkImportMemoryWin32HandleInfoKHR-sType-sType` `sType` must be `VK_STRUCTURE_TYPE_IMPORT_MEMORY_WIN32_HANDLE_INFO_KHR`
- `VUID-VkImportMemoryWin32HandleInfoKHR-handleType-parameter` If `handleType` is not 0, `handleType` must be a valid `VkExternalMemoryHandleTypeFlagBits` value

To export a Windows handle representing the payload of a Vulkan device memory object, call:

```c
// Provided by VK_KHR_external_memory_win32
VkResult vkGetMemoryWin32HandleKHR(
    VkDevice device,
    const VkMemoryGetWin32HandleInfoKHR* pGetWin32HandleInfo,
    HANDLE* pHandle);
```

- `device` is the logical device that created the device memory being exported.
- `pGetWin32HandleInfo` is a pointer to a `VkMemoryGetWin32HandleInfoKHR` structure containing parameters of the export operation.
- `pHandle` will return the Windows handle representing the payload of the device memory object.

For handle types defined as NT handles, the handles returned by `vkGetMemoryWin32HandleKHR` are owned by the application and hold a reference to their payload. To avoid leaking resources, the application must release ownership of them using the `CloseHandle` system call when they are no longer needed.

**Note**

Non-NT handle types do not add a reference to their associated payload. If the original object owning the payload is destroyed, all resources and handles sharing that payload will become invalid.

Valid Usage (Implicit)

- `VUID-vkGetMemoryWin32HandleKHR-device-parameter` `device` must be a valid `VkDevice` handle
- `VUID-vkGetMemoryWin32HandleKHR-pGetWin32HandleInfo-parameter` `pGetWin32HandleInfo` must be a valid pointer to a valid `VkMemoryGetWin32HandleInfoKHR` structure
- `VUID-vkGetMemoryWin32HandleKHR-pHandle-parameter` `pHandle` must be a valid pointer to a `HANDLE` value
Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_TOO_MANY_OBJECTS
- VK_ERROR_OUT_OF_HOST_MEMORY

The `VkMemoryGetWin32HandleInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_external_memory_win32
typedef struct VkMemoryGetWin32HandleInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkDeviceMemory memory;
    VkExternalMemoryHandleTypeFlagBits handleType;
} VkMemoryGetWin32HandleInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `memory` is the memory object from which the handle will be exported.
- `handleType` is a `VkExternalMemoryHandleTypeFlagBits` value specifying the type of handle requested.

The properties of the handle returned depend on the value of `handleType`. See `VkExternalMemoryHandleTypeFlagBits` for a description of the properties of the defined external memory handle types.

**Valid Usage**

- VUID-VkMemoryGetWin32HandleInfoKHR-handleType-00662
  `handleType` must have been included in `VkExportMemoryAllocateInfo::handleTypes` when `memory` was created

- VUID-VkMemoryGetWin32HandleInfoKHR-handleType-00663
  If `handleType` is defined as an NT handle, `vkGetMemoryWin32HandleKHR` must be called no more than once for each valid unique combination of `memory` and `handleType`

- VUID-VkMemoryGetWin32HandleInfoKHR-handleType-00664
  `handleType` must be defined as an NT handle or a global share handle

**Valid Usage (Implicit)**

- VUID-VkMemoryGetWin32HandleInfoKHR-sType-sType
sType must be VK_STRUCTURE_TYPE_MEMORY_GET_WIN32_HANDLE_INFO_KHR

- VUID-VkMemoryGetWin32HandleInfoKHR-pNext-pNext
  pNext must be NULL

- VUID-VkMemoryGetWin32HandleInfoKHR-memory-parameter
  memory must be a valid VkDeviceMemory handle

- VUID-VkMemoryGetWin32HandleInfoKHR-handleType-parameter
  handleType must be a valid VkExternalMemoryHandleTypeFlagBits value

Windows memory handles compatible with Vulkan may also be created by non-Vulkan APIs using methods beyond the scope of this specification. To determine the correct parameters to use when importing such handles, call:

```c
// Provided by VK_KHR_external_memory_win32
VkResult vkGetMemoryWin32HandlePropertiesKHR(
    VkDevice device,
    VkExternalMemoryHandleTypeFlagBits handleType,
    HANDLE handle,
    VkMemoryWin32HandlePropertiesKHR* pMemoryWin32HandleProperties);
```

- device is the logical device that will be importing handle.
- handleType is a VkExternalMemoryHandleTypeFlagBits value specifying the type of the handle handle.
- handle is the handle which will be imported.
- pMemoryWin32HandleProperties is a pointer to a VkMemoryWin32HandlePropertiesKHR structure in which properties of handle are returned.

### Valid Usage

- VUID-vkGetMemoryWin32HandlePropertiesKHR-handle-00665
  handle must point to a valid Windows memory handle

- VUID-vkGetMemoryWin32HandlePropertiesKHR-handleType-00666
  handleType must not be one of the handle types defined as opaque

### Valid Usage (Implicit)

- VUID-vkGetMemoryWin32HandlePropertiesKHR-device-parameter
  device must be a valid VkDevice handle

- VUID-vkGetMemoryWin32HandlePropertiesKHR-handleType-parameter
  handleType must be a valid VkExternalMemoryHandleTypeFlagBits value

- VUID-vkGetMemoryWin32HandlePropertiesKHR-pMemoryWin32HandleProperties-parameter
  pMemoryWin32HandleProperties must be a valid pointer to a
The `VkMemoryWin32HandlePropertiesKHR` structure returned is defined as:

```
// Provided by VK_KHR_external_memory_win32
typedef struct VkMemoryWin32HandlePropertiesKHR {
    VkStructureType sType;
    void* pNext;
    uint32_t memoryTypeBits;
} VkMemoryWin32HandlePropertiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `memoryTypeBits` is a bitmask containing one bit set for every memory type which the specified windows handle can be imported as.

**Valid Usage (Implicit)**

- `VUID-VkMemoryWin32HandlePropertiesKHR-sType-sType` 
  `sType` must be `VK_STRUCTURE_TYPE_MEMORY_WIN32_HANDLE_PROPERTIES_KHR`
- `VUID-VkMemoryWin32HandlePropertiesKHR-pNext-pNext` 
  `pNext` must be `NULL`

When `VkExportMemoryAllocateInfoNV::handleTypes` includes `VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT_NV`, add a `VkExportMemoryWin32HandleInfoNV` structure to the `pNext` chain of the `VkExportMemoryAllocateInfoNV` structure to specify security attributes and access rights for the memory object's external handle.

The `VkExportMemoryWin32HandleInfoNV` structure is defined as:

```
// Provided by VK_NV_external_memory_win32
typedef struct VkExportMemoryWin32HandleInfoNV {
    VkStructureType sType;
    const void* pNext;
}
```
const SECURITY_ATTRIBUTES* pAttributes;
DWORD dwAccess;
} VkExportMemoryWin32HandleInfoNV;

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **pAttributes** is a pointer to a Windows SECURITY_ATTRIBUTES structure specifying security attributes of the handle.
- **dwAccess** is a DWORD specifying access rights of the handle.

If this structure is not present, or if **pAttributes** is set to NULL, default security descriptor values will be used, and child processes created by the application will not inherit the handle, as described in the MSDN documentation for “Synchronization Object Security and Access Rights”¹. Further, if the structure is not present, the access rights will be

```
DXGI_SHARED_RESOURCE_READ | DXGI_SHARED_RESOURCE_WRITE
```


### Valid Usage (Implicit)

- VUID-VkExportMemoryWin32HandleInfoNV-sType-sType  
  
  **sType** **must** be **VK_STRUCTURE_TYPE_EXPORT_MEMORY_WIN32_HANDLE_INFO_NV**

- VUID-VkExportMemoryWin32HandleInfoNV-pAttributes-parameter  
  
  If **pAttributes** is not NULL, **pAttributes** **must** be a valid pointer to a valid SECURITY_ATTRIBUTES value

To import memory created on the same physical device but outside of the current Vulkan instance, add a VkImportMemoryWin32HandleInfoNV structure to the **pNext** chain of the VkMemoryAllocateInfo structure, specifying a handle to and the type of the memory.

The VkImportMemoryWin32HandleInfoNV structure is defined as:

```c
// Provided by VK_NV_external_memory_win32
typedef struct VkImportMemoryWin32HandleInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkExternalMemoryHandleTypeFlagsNV handleType;
    HANDLE handle;
} VkImportMemoryWin32HandleInfoNV;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- `handleType` is 0 or a `VkExternalMemoryHandleTypeFlagBitsNV` value specifying the type of memory handle in `handle`.
- `handle` is a Windows HANDLE referring to the memory.

If `handleType` is 0, this structure is ignored by consumers of the `VkMemoryAllocateInfo` structure it is chained from.

### Valid Usage

- VUID-VkImportMemoryWin32HandleInfoNV-handleType-01327
  `handleType` must not have more than one bit set
- VUID-VkImportMemoryWin32HandleInfoNV-handle-01328
  `handle` must be a valid handle to memory, obtained as specified by `handleType`

### Valid Usage (Implicit)

- VUID-VkImportMemoryWin32HandleInfoNV-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_IMPORT_MEMORY_WIN32_HANDLE_INFO_NV`
- VUID-VkImportMemoryWin32HandleInfoNV-handleType-parameter
  `handleType` must be a valid combination of `VkExternalMemoryHandleTypeFlagBitsNV` values

Bits which can be set in `handleType` are:

Possible values of `VkImportMemoryWin32HandleInfoNV::handleType`, specifying the type of an external memory handle, are:

```cpp
// Provided by VK_NV_external_memory_capabilities
typedef enum VkExternalMemoryHandleTypeFlagBitsNV {
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT_NV = 0x00000001,
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT_NV = 0x00000002,
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_IMAGE_BIT_NV = 0x00000004,
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_IMAGE_KMT_BIT_NV = 0x00000008,
} VkExternalMemoryHandleTypeFlagBitsNV;
```

- `VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT_NV` specifies a handle to memory returned by `vkGetMemoryWin32HandleNV`.
- `VK_EXTERNAL_MEMORY.Handle_TYPE_OPAQUE_WIN32_BIT_NV` specifies a handle to memory returned by `vkGetMemoryWin32HandleNV`, or one duplicated from such a handle using `DuplicateHandle()`.
- `VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_IMAGE_BIT_NV` specifies a valid NT handle to memory returned by `IDXGIResource1::CreateSharedHandle`, or a handle duplicated from such a handle using `DuplicateHandle()`.
- `VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_IMAGE_KMT_BIT_NV` specifies a handle to memory returned
VkExternalMemoryHandleTypeFlagsNV is a bitmask type for setting a mask of zero or more VkExternalMemoryHandleTypeFlagBitsNV.

To retrieve the handle corresponding to a device memory object created with VkExportMemoryAllocateInfoNV::handleTypes set to include VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT_NV or VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT_NV, call:

```
// Provided by VK_NV_external_memory_win32
VkResult vkGetMemoryWin32HandleNV(
    VkDevice device,
    VkDeviceMemory memory,
    VkExternalMemoryHandleTypeFlagsNV handleType,
    HANDLE* pHandle);
```

- **device** is the logical device that owns the memory.
- **memory** is the VkDeviceMemory object.
- **handleType** is a bitmask of VkExternalMemoryHandleTypeFlagBitsNV containing a single bit specifying the type of handle requested.
- **handle** is a pointer to a Windows HANDLE in which the handle is returned.

### Valid Usage

- **VUID-vkGetMemoryWin32HandleNV-handleType-01326**
  handleType must be a flag specified in VkExportMemoryAllocateInfoNV::handleTypes when allocating memory

### Valid Usage (Implicit)

- **VUID-vkGetMemoryWin32HandleNV-device-parameter**
  device must be a valid VkDevice handle

- **VUID-vkGetMemoryWin32HandleNV-memory-parameter**
  memory must be a valid VkDeviceMemory handle

- **VUID-vkGetMemoryWin32HandleNV-handleType-parameter**
  handleType must be a valid combination of VkExternalMemoryHandleTypeFlagBitsNV values

- **VUID-vkGetMemoryWin32HandleNV-handleType-requiredbitmask**
  handleType must not be 0
11.2.5. File Descriptor External Memory

To import memory from a POSIX file descriptor handle, add a `VkImportMemoryFdInfoKHR` structure to the `pNext` chain of the `VkMemoryAllocateInfo` structure. The `VkImportMemoryFdInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_external_memory_fd
typedef struct VkImportMemoryFdInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkExternalMemoryHandleTypeFlagBits handleType;
    int fd;
} VkImportMemoryFdInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `handleType` is a `VkExternalMemoryHandleTypeFlagBits` value specifying the handle type of `fd`.
- `fd` is the external handle to import.

Importing memory from a file descriptor transfers ownership of the file descriptor from the application to the Vulkan implementation. The application **must** not perform any operations on the file descriptor after a successful import. The imported memory object holds a reference to its payload.

Applications **can** import the same payload into multiple instances of Vulkan, into the same instance from which it was exported, and multiple times into a given Vulkan instance. In all cases, each import operation **must** create a distinct `VkDeviceMemory` object.
Valid Usage

- **VUID-VkImportMemoryFdInfoKHR-handleType-00667**
  If `handleType` is not 0, it must be supported for import, as reported by `VkExternalImageFormatProperties` or `VkExternalBufferProperties`.

- **VUID-VkImportMemoryFdInfoKHR-fd-00668**
  The memory from which `fd` was exported must have been created on the same underlying physical device as `device`.

- **VUID-VkImportMemoryFdInfoKHR-handleType-00669**
  If `handleType` is not 0, it must be `VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT` or `VK_EXTERNAL_MEMORY_HANDLE_TYPE_DMA_BUF_BIT_EXT`.

- **VUID-VkImportMemoryFdInfoKHR-handleType-00669**
  If `handleType` is not 0, `fd` must be a valid handle of the type specified by `handleType`.

- **VUID-VkImportMemoryFdInfoKHR-fd-01746**
  The memory represented by `fd` must have been created from a physical device and driver that is compatible with `device` and `handleType`, as described in External memory handle types compatibility.

- **VUID-VkImportMemoryFdInfoKHR-fd-01520**
  `fd` must obey any requirements listed for `handleType` in external memory handle types compatibility.

Valid Usage (Implicit)

- **VUID-VkImportMemoryFdInfoKHR-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_IMPORT_MEMORY_FD_INFO_KHR`.

- **VUID-VkImportMemoryFdInfoKHR-handleType-parameter**
  If `handleType` is not 0, `handleType` must be a valid `VkExternalMemoryHandleTypeFlagBits` value.

To export a POSIX file descriptor referencing the payload of a Vulkan device memory object, call:

```
// Provided by VK_KHR_external_memory_fd
VkResult vkGetMemoryFdKHR(
    VkDevice device,
    const VkMemoryGetFdInfoKHR* pGetFdInfo,
    int* pFd);
```

- `device` is the logical device that created the device memory being exported.

- `pGetFdInfo` is a pointer to a `VkMemoryGetFdInfoKHR` structure containing parameters of the export operation.

- `pFd` will return a file descriptor referencing the payload of the device memory object.
Each call to `vkGetMemoryFdKHR` must create a new file descriptor holding a reference to the memory object's payload and transfer ownership of the file descriptor to the application. To avoid leaking resources, the application must release ownership of the file descriptor using the `close` system call when it is no longer needed, or by importing a Vulkan memory object from it. Where supported by the operating system, the implementation must set the file descriptor to be closed automatically when an `execve` system call is made.

**Valid Usage (Implicit)**

- VUID-vkGetMemoryFdKHR-device-parameter
  - `device` must be a valid `VkDevice` handle
- VUID-vkGetMemoryFdKHR-pGetFdInfo-parameter
  - `pGetFdInfo` must be a valid pointer to a valid `VkMemoryGetFdInfoKHR` structure
- VUID-vkGetMemoryFdKHR-pFd-parameter
  - `pFd` must be a valid pointer to an `int` value

**Return Codes**

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_TOO_MANY_OBJECTS`
- `VK_ERROR_OUT_OF_HOST_MEMORY`

The `VkMemoryGetFdInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_external_memory_fd
typedef struct VkMemoryGetFdInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkDeviceMemory memory;
    VkExternalMemoryHandleTypeFlagBits handleType;
} VkMemoryGetFdInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `memory` is the memory object from which the handle will be exported.
- `handleType` is a `VkExternalMemoryHandleTypeFlagBits` value specifying the type of handle requested.

The properties of the file descriptor exported depend on the value of `handleType`. See `VkExternalMemoryHandleTypeFlagBits` for a description of the properties of the defined external
memory handle types.

Note

The size of the exported file may be larger than the size requested by VkMemoryAllocateInfo::allocationSize. If handleType is VK_EXTERNAL_MEMORY_HANDLE_TYPE_DMA_BUF_BIT_EXT, then the application can query the file’s actual size with lseek.

Valid Usage

- VUID-VkMemoryGetFdInfoKHR-handleType-00671
  handleType must have been included in VkExportMemoryAllocateInfo::handleTypes when memory was created

- VUID-VkMemoryGetFdInfoKHR-handleType-00672
  handleType must be VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT or VK_EXTERNAL_MEMORY_HANDLE_TYPE_DMA_BUF_BIT_EXT

Valid Usage (Implicit)

- VUID-VkMemoryGetFdInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_MEMORY_GET_FD_INFO_KHR

- VUID-VkMemoryGetFdInfoKHR-pNext-pNext
  pNext must be NULL

- VUID-VkMemoryGetFdInfoKHR-memory-parameter
  memory must be a valid VkDeviceMemory handle

- VUID-VkMemoryGetFdInfoKHR-handleType-parameter
  handleType must be a valid VkExternalMemoryHandleTypeFlagBits value

POSIX file descriptor memory handles compatible with Vulkan may also be created by non-Vulkan APIs using methods beyond the scope of this specification. To determine the correct parameters to use when importing such handles, call:

```c
// Provided by VK_KHR_external_memory_fd
VkResult vkGetMemoryFdPropertiesKHR(
    VkDevice device,
    VkExternalMemoryHandleTypeFlagBits handleType,
    int fd,
    VkMemoryFdPropertiesKHR* pMemoryFdProperties);
```

- device is the logical device that will be importing fd.
- handleType is a VkExternalMemoryHandleTypeFlagBits value specifying the type of the handle fd.
• *fd* is the handle which will be imported.

• *pMemoryFdProperties* is a pointer to a *VkMemoryFdPropertiesKHR* structure in which the properties of the handle *fd* are returned.

### Valid Usage

- VUID-vkGetMemoryFdPropertiesKHR-fd-00673
  
  *fd* must point to a valid POSIX file descriptor memory handle

- VUID-vkGetMemoryFdPropertiesKHR-handleType-00674
  
  *handleType* must not be *VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT*

### Valid Usage (Implicit)

- VUID-vkGetMemoryFdPropertiesKHR-device-parameter
  
  *device* must be a valid *VkDevice* handle

- VUID-vkGetMemoryFdPropertiesKHR-handleType-parameter
  
  *handleType* must be a valid *VkExternalMemoryHandleTypeFlagBits* value

- VUID-vkGetMemoryFdPropertiesKHR-pMemoryFdProperties-parameter
  
  *pMemoryFdProperties* must be a valid pointer to a *VkMemoryFdPropertiesKHR* structure

### Return Codes

**Success**

- *VK_SUCCESS*

**Failure**

- *VK_ERROR_OUT_OF_HOST_MEMORY*

- *VK_ERROR_INVALID_EXTERNAL_HANDLE*

The *VkMemoryFdPropertiesKHR* structure returned is defined as:

```c
// Provided by VK_KHR_external_memory_fd
typedef struct VkMemoryFdPropertiesKHR {
    VkStructureType   sType;
    void*             pNext;
    uint32_t          memoryTypeBits;
} VkMemoryFdPropertiesKHR;
```

• *sType* is a *VkStructureType* value identifying this structure.

• *pNext* is NULL or a pointer to a structure extending this structure.

• *memoryTypeBits* is a bitmask containing one bit set for every memory type which the specified file descriptor can be imported as.
Valid Usage (Implicit)

- VUID-VkMemoryFdPropertiesKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_MEMORY_FD_PROPERTIES_KHR
- VUID-VkMemoryFdPropertiesKHR-pNext-pNext
  pNext must be NULL

11.2.6. Host External Memory

To import memory from a host pointer, add a VkImportMemoryHostPointerInfoEXT structure to the pNext chain of the VkMemoryAllocateInfo structure. The VkImportMemoryHostPointerInfoEXT structure is defined as:

```c
// Provided by VK_EXT_external_memory_host
typedef struct VkImportMemoryHostPointerInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkExternalMemoryHandleTypeFlagBits handleType;
    void* pHostPointer;
} VkImportMemoryHostPointerInfoEXT;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- handleType is a VkExternalMemoryHandleTypeFlagBits value specifying the handle type.
- pHostPointer is the host pointer to import from.

Importing memory from a host pointer shares ownership of the memory between the host and the Vulkan implementation. The application can continue to access the memory through the host pointer but it is the application’s responsibility to synchronize device and non-device access to the payload as defined in Host Access to Device Memory Objects.

Applications can import the same payload into multiple instances of Vulkan and multiple times into a given Vulkan instance. However, implementations may fail to import the same payload multiple times into a given physical device due to platform constraints.

Importing memory from a particular host pointer may not be possible due to additional platform-specific restrictions beyond the scope of this specification in which case the implementation must fail the memory import operation with the error code VK_ERROR_INVALID_EXTERNAL_HANDLE_KHR.

Whether device memory objects imported from a host pointer hold a reference to their payload is undefined. As such, the application must ensure that the imported memory range remains valid and accessible for the lifetime of the imported memory object.
Valid Usage

- VUID-VkImportMemoryHostPointerInfoEXT-handleType-01747
  If handleType is not 0, it must be supported for import, as reported in VkExternalMemoryProperties

- VUID-VkImportMemoryHostPointerInfoEXT-handleType-01748
  If handleType is not 0, it must be VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_ALLOCATION_BIT_EXT or VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_MAPPED_FOREIGN_MEMORY_BIT_EXT

- VUID-VkImportMemoryHostPointerInfoEXT-pHostPointer-01749
  pHostPointer must be a pointer aligned to an integer multiple of VkPhysicalDeviceExternalMemoryPropertiesEXT::minImportedHostPointerAlignment

- VUID-VkImportMemoryHostPointerInfoEXT-handleType-01750
  If handleType is VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_ALLOCATION_BIT_EXT, pHostPointer must be a pointer to allocationSize number of bytes of host memory, where allocationSize is the member of the VkMemoryAllocateInfo structure this structure is chained to

- VUID-VkImportMemoryHostPointerInfoEXT-handleType-01751
  If handleType is VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_MAPPED_FOREIGN_MEMORY_BIT_EXT, pHostPointer must be a pointer to allocationSize number of bytes of host mapped foreign memory, where allocationSize is the member of the VkMemoryAllocateInfo structure this structure is chained to

Valid Usage (Implicit)

- VUID-VkImportMemoryHostPointerInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_IMPORT_MEMORY_HOST_POINTER_INFO_EXT

- VUID-VkImportMemoryHostPointerInfoEXT-handleType-parameter
  handleType must be a valid VkExternalMemoryHandleTypeFlagBits value

- VUID-VkImportMemoryHostPointerInfoEXT-pHostPointer-parameter
  pHostPointer must be a pointer value

To determine the correct parameters to use when importing host pointers, call:

```c
// Provided by VK_EXT_external_memory_host
VkResult vkGetMemoryHostPointerPropertiesEXT(
    VkDevice device,                  
    VkExternalMemoryHandleTypeFlagBits handleType, 
    const void* pHostPointer,          
    VkMemoryHostPointerPropertiesEXT* pMemoryHostPointerProperties);
```

- device is the logical device that will be importing pHostPointer.
- handleType is a VkExternalMemoryHandleTypeFlagBits value specifying the type of the handle
pHostPointer.

- pHostPointer is the host pointer to import from.
- pMemoryHostPointerProperties is a pointer to a VkMemoryHostPointerPropertiesEXT structure in which the host pointer properties are returned.

## Valid Usage

- VUID-vkGetMemoryHostPointerPropertiesEXT-handleType-01752
  
  handleType must be VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_ALLOCATION_BIT_EXT or VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_MAPPED_FOREIGN_MEMORY_BIT_EXT

- VUID-vkGetMemoryHostPointerPropertiesEXT-pHostPointer-01753
  
  pHostPointer must be a pointer aligned to an integer multiple of VkPhysicalDeviceExternalMemoryHostPropertiesEXT::minImportedHostPointerAlignment

- VUID-vkGetMemoryHostPointerPropertiesEXT-handleType-01754
  
  If handleType is VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_ALLOCATION_BIT_EXT, pHostPointer must be a pointer to host memory

- VUID-vkGetMemoryHostPointerPropertiesEXT-handleType-01755
  
  If handleType is VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_MAPPED_FOREIGN_MEMORY_BIT_EXT, pHostPointer must be a pointer to host mapped foreign memory

## Valid Usage (Implicit)

- VUID-vkGetMemoryHostPointerPropertiesEXT-device-parameter
  
  device must be a valid VkDevice handle

- VUID-vkGetMemoryHostPointerPropertiesEXT-handleType-parameter
  
  handleType must be a valid VkExternalMemoryHandleTypeFlagBits value

- VUID-vkGetMemoryHostPointerPropertiesEXT-pHostPointer-parameter
  
  pHostPointer must be a pointer value

- VUID-vkGetMemoryHostPointerPropertiesEXT-pMemoryHostPointerProperties-parameter
  
  pMemoryHostPointerProperties must be a valid pointer to a VkMemoryHostPointerPropertiesEXT structure

## Return Codes

### Success

- VK_SUCCESS

### Failure

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_INVALID_EXTERNAL_HANDLE
The VkMemoryHostPointerPropertiesEXT structure is defined as:

```c
typedef struct VkMemoryHostPointerPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t memoryTypeBits;
} VkMemoryHostPointerPropertiesEXT;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **memoryTypeBits** is a bitmask containing one bit set for every memory type which the specified host pointer can be imported as.

The value returned by `memoryTypeBits` must only include bits that identify memory types which are host visible.

---

Valid Usage (Implicit)

- VUID-VkMemoryHostPointerPropertiesEXT-sType-sType
  
  sType must be VK_STRUCTURE_TYPE_MEMORY_HOST_POINTER_PROPERTIES_EXT

- VUID-VkMemoryHostPointerPropertiesEXT-pNext-pNext

  pNext must be NULL

---

11.2.7. Android Hardware Buffer External Memory

To import memory created outside of the current Vulkan instance from an Android hardware buffer, add a `VkImportAndroidHardwareBufferInfoANDROID` structure to the `pNext` chain of the `VkMemoryAllocateInfo` structure. The `VkImportAndroidHardwareBufferInfoANDROID` structure is defined as:

```c
typedef struct VkImportAndroidHardwareBufferInfoANDROID {
    VkStructureType sType;
    const void* pNext;
    struct AHardwareBuffer* buffer;
} VkImportAndroidHardwareBufferInfoANDROID;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **buffer** is the Android hardware buffer to import.

If the `vkAllocateMemory` command succeeds, the implementation must acquire a reference to the imported hardware buffer, which it must release when the device memory object is freed. If the
command fails, the implementation **must** not retain a reference.

### Valid Usage

- **VUID-VkImportAndroidHardwareBufferInfoANDROID-buffer-01880**
  If `buffer` is not **NULL**, Android hardware buffers **must** be supported for import, as reported by `VkExternalImageFormatProperties` or `VkExternalBufferProperties`.

- **VUID-VkImportAndroidHardwareBufferInfoANDROID-buffer-01881**
  If `buffer` is not **NULL**, it **must** be a valid Android hardware buffer object with `AHardwareBuffer_Desc::usage` compatible with Vulkan as described in [Android Hardware Buffers](#).

### Valid Usage (Implicit)

- **VUID-VkImportAndroidHardwareBufferInfoANDROID-sType-sType**
  `sType` **must** be `VK_STRUCTURE_TYPE_IMPORT_ANDROID_HARDWARE_BUFFER_INFO_ANDROID`.

- **VUID-VkImportAndroidHardwareBufferInfoANDROID-buffer-parameter**
  `buffer` **must** be a valid pointer to an `AHardwareBuffer` value.

To export an Android hardware buffer referencing the payload of a Vulkan device memory object, call:

```c
// Provided by VK_ANDROID_external_memory_android_hardware_buffer
VkResult vkGetMemoryAndroidHardwareBufferANDROID(
    VkDevice device,
    const VkMemoryGetAndroidHardwareBufferInfoANDROID* pInfo,
    struct AHardwareBuffer** pBuffer);
```

- `device` is the logical device that created the device memory being exported.
- `pInfo` is a pointer to a `VkMemoryGetAndroidHardwareBufferInfoANDROID` structure containing parameters of the export operation.
- `pBuffer` will return an Android hardware buffer referencing the payload of the device memory object.

Each call to `vkGetMemoryAndroidHardwareBufferANDROID` **must** return an Android hardware buffer with a new reference acquired in addition to the reference held by the `VkDeviceMemory`. To avoid leaking resources, the application **must** release the reference by calling `AHardwareBuffer_release` when it is no longer needed. When called with the same handle in `VkMemoryGetAndroidHardwareBufferInfoANDROID::memory`, `vkGetMemoryAndroidHardwareBufferANDROID` **must** return the same Android hardware buffer object. If the device memory was created by importing an Android hardware buffer, `vkGetMemoryAndroidHardwareBufferANDROID` **must** return that same Android hardware buffer object.
Valid Usage (Implicit)

- VUID-vkGetMemoryAndroidHardwareBufferANDROID-device-parameter
  device must be a valid VkDevice handle

- VUID-vkGetMemoryAndroidHardwareBufferANDROID-pInfo-parameter
  pInfo must be a valid pointer to a valid VkMemoryGetAndroidHardwareBufferInfoANDROID structure

- VUID-vkGetMemoryAndroidHardwareBufferANDROID-pBuffer-parameter
  pBuffer must be a valid pointer to a valid pointer to an AHardwareBuffer value

Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_TOO_MANY_OBJECTS
- VK_ERROR_OUT_OF_HOST_MEMORY

The VkMemoryGetAndroidHardwareBufferInfoANDROID structure is defined as:

```c
// Provided by VK_ANDROID_external_memory_android_hardware_buffer
typedef struct VkMemoryGetAndroidHardwareBufferInfoANDROID {
    VkStructureType sType;
    const void* pNext;
    VkDeviceMemory memory;
} VkMemoryGetAndroidHardwareBufferInfoANDROID;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- memory is the memory object from which the Android hardware buffer will be exported.

Valid Usage

- VUID-VkMemoryGetAndroidHardwareBufferInfoANDROID-handleTypes-01882
  VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID must have been included in VkExportMemoryAllocateInfo::handleTypes when memory was created

- VUID-VkMemoryGetAndroidHardwareBufferInfoANDROID-pNext-01883
  If the pNext chain of the VkMemoryAllocateInfo used to allocate memory included a VkMemoryDedicatedAllocateInfo with non-NULL image member, then that image must already be bound to memory
Valid Usage (Implicit)

- VUID-VkMemoryGetAndroidHardwareBufferInfoANDROID-sType-sType
  sType must be VK_STRUCTURE_TYPE_MEMORY_GET_ANDROID_HARDWARE_BUFFER_INFO_ANDROID

- VUID-VkMemoryGetAndroidHardwareBufferInfoANDROID-pNext-pNext
  pNext must be NULL

- VUID-VkMemoryGetAndroidHardwareBufferInfoANDROID-memory-parameter
  memory must be a valid VkDeviceMemory handle

To determine the memory parameters to use when importing an Android hardware buffer, call:

```c
// Provided by VK_ANDROID_external_memory_android_hardware_buffer
VkResult vkGetAndroidHardwareBufferPropertiesANDROID(
    VkDevice device, const struct AHardwareBuffer* buffer,
    VkAndroidHardwareBufferPropertiesANDROID* pProperties);
```

- device is the logical device that will be importing buffer.
- buffer is the Android hardware buffer which will be imported.
- pProperties is a pointer to a VkAndroidHardwareBufferPropertiesANDROID structure in which the properties of buffer are returned.

Valid Usage

- VUID-vkGetAndroidHardwareBufferPropertiesANDROID-buffer-01884
  buffer must be a valid Android hardware buffer object with at least one of the AHARDWAREBUFFER_USAGE_GPU_* flags in its AHardwareBuffer_Desc::usage

Valid Usage (Implicit)

- VUID-vkGetAndroidHardwareBufferPropertiesANDROID-device-parameter
  device must be a valid VkDevice handle

- VUID-vkGetAndroidHardwareBufferPropertiesANDROID-buffer-parameter
  buffer must be a valid pointer to a valid AHardwareBuffer value

- VUID-vkGetAndroidHardwareBufferPropertiesANDROID-pProperties-parameter
  pProperties must be a valid pointer to a VkAndroidHardwareBufferPropertiesANDROID structure
Return Codes

Success
• VK_SUCCESS

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_INVALID_EXTERNAL_HANDLE_KHR

The `VkAndroidHardwareBufferPropertiesANDROID` structure returned is defined as:

```c
// Provided by VK_ANDROID_external_memory_android_hardware_buffer
typedef struct VkAndroidHardwareBufferPropertiesANDROID {
    VkStructureType sType;
    void* pNext;
    VkDeviceSize allocationSize;
    uint32_t memoryTypeBits;
} VkAndroidHardwareBufferPropertiesANDROID;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `allocationSize` is the size of the external memory
- `memoryTypeBits` is a bitmask containing one bit set for every memory type which the specified Android hardware buffer can be imported as.

Valid Usage (Implicit)

- VUID-VkAndroidHardwareBufferPropertiesANDROID-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_ANDROIDEH_HARDWARE_BUFFER_PROPERTIES_ANDROID`

- VUID-VkAndroidHardwareBufferPropertiesANDROID-pNext-pNext
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either NULL or a pointer to a valid instance of `VkAndroidHardwareBufferFormatProperties2ANDROID` or `VkAndroidHardwareBufferFormatPropertiesANDROID`

- VUID-VkAndroidHardwareBufferPropertiesANDROID-sType-unique
  The `sType` value of each struct in the `pNext` chain must be unique

To obtain format properties of an Android hardware buffer, include a `VkAndroidHardwareBufferFormatPropertiesANDROID` structure in the `pNext` chain of the `VkAndroidHardwareBufferPropertiesANDROID` structure passed to `vkGetAndroidHardwareBufferPropertiesANDROID`. This structure is defined as:

```c
// Provided by VK_ANDROID_external_memory_android_hardware_buffer
```
typedef struct VkAndroidHardwareBufferFormatPropertiesANDROID {
    VkStructureType sType;
    void* pNext;
    VkFormat format;
    uint64_t externalFormat;
    VkFormatFeatureFlags formatFeatures;
    VkComponentMapping samplerYcbcrConversionComponents;
    VkSamplerYcbcrModelConversion suggestedYcbcrModel;
    VkSamplerYcbcrRange suggestedYcbcrRange;
    VkChromaLocation suggestedXChromaOffset;
    VkChromaLocation suggestedYChromaOffset;
} VkAndroidHardwareBufferFormatPropertiesANDROID;

• **sType** is a VkStructureType value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.
• **format** is the Vulkan format corresponding to the Android hardware buffer’s format, or
  VK_FORMAT_UNDEFINED if there is not an equivalent Vulkan format.
• **externalFormat** is an implementation-defined external format identifier for use with
  VkExternalFormatANDROID. It **must** not be zero.
• **formatFeatures** describes the capabilities of this external format when used with an image
  bound to memory imported from buffer.
• **samplerYcbcrConversionComponents** is the component swizzle that **should** be used in
  VkSamplerYcbcrConversionCreateInfo.
• **suggestedYcbcrModel** is a suggested color model to use in the
  VkSamplerYcbcrConversionCreateInfo.
• **suggestedYcbcrRange** is a suggested numerical value range to use in
  VkSamplerYcbcrConversionCreateInfo.
• **suggestedXChromaOffset** is a suggested X chroma offset to use in
  VkSamplerYcbcrConversionCreateInfo.
• **suggestedYChromaOffset** is a suggested Y chroma offset to use in
  VkSamplerYcbcrConversionCreateInfo.

If the Android hardware buffer has one of the formats listed in the Format Equivalence table, then
**format** **must** have the equivalent Vulkan format listed in the table. Otherwise, **format** **may** be
VK_FORMAT_UNDEFINED, indicating the Android hardware buffer **can** only be used with an external
format.

The **formatFeatures** member **must** include VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT and at least one of
VK_FORMAT_FEATURE_MIDPOINT_CHROMA_SAMPLES_BIT or VK_FORMAT_FEATURE_COSITED_CHROMA_SAMPLES_BIT, and
**should** include VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT and
VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_LINEAR_FILTER_BIT.

---

**Note**
The **formatFeatures** member only indicates the features available when using an
external-format image created from the Android hardware buffer. Images from
Android hardware buffers with a format other than VK_FORMAT_UNDEFINED are subject to the format capabilities obtained from vkGetPhysicalDeviceFormatProperties2, and vkGetPhysicalDeviceImageFormatProperties2 with appropriate parameters. These sets of features are independent of each other, e.g. the external format will support sampler Y’CbCr conversion even if the non-external format does not, and writing to non-external format images is possible but writing to external format images is not.

Android hardware buffers with the same external format must have the same support for VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT, VK_FORMAT_FEATURE_MIDPOINT_CHROMA_SAMPLES_BIT, VK_FORMAT_FEATURE_COSITED_CHROMA_SAMPLES_BIT, VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_LINEAR_FILTER_BIT, VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_SEPARATE_RECONSTRUCTION_FILTER_BIT, and VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_FORCEABLE_BIT in formatFeatures. Other format features may differ between Android hardware buffers that have the same external format. This allows applications to use the same VkSamplerYcbcrConversion object (and samplers and pipelines created from them) for any Android hardware buffers that have the same external format.

If format is not VK_FORMAT_UNDEFINED, then the value of samplerYcbcrConversionComponents must be valid when used as the components member of VkSamplerYcbcrConversionCreateInfo with that format. If format is VK_FORMAT_UNDEFINED, all members of samplerYcbcrConversionComponents must be the identity swizzle.

Implementations may not always be able to determine the color model, numerical range, or chroma offsets of the image contents, so the values in VkAndroidHardwareBufferFormatPropertiesANDROID are only suggestions. Applications should treat these values as sensible defaults to use in the absence of more reliable information obtained through some other means. If the underlying physical device is also usable via OpenGL ES with the GL_OES_EGL_image_external extension, the implementation should suggest values that will produce similar sampled values as would be obtained by sampling the same external image via samplerExternalOES in OpenGL ES using equivalent sampler parameters.

Note
Since GL_OES_EGL_image_external does not require the same sampling and conversion calculations as Vulkan does, achieving identical results between APIs may not be possible on some implementations.

Valid Usage (Implicit)

- VUID-VkAndroidHardwareBufferFormatPropertiesANDROID-sType-sType
  sType must be VK_STRUCTURE_TYPE_ANDROID_HARDWARE_BUFFER_FORMAT_PROPERTIESANDROID

The format properties of an Android hardware buffer can be obtained by including a VkAndroidHardwareBufferFormatProperties2ANDROID structure in the pNext chain of the VkAndroidHardwareBufferPropertiesANDROID structure passed to
vkGetAndroidHardwareBufferPropertiesANDROID. This structure is defined as:

```c
typedef struct VkAndroidHardwareBufferFormatProperties2ANDROID {
    VkStructureType sType;
    void* pNext;
    VkFormat format;
    uint64_t externalFormat;
    VkFormatFeatureFlags2 formatFeatures;
    VkComponentMapping samplerYcbcrConversionComponents;
    VkSamplerYcbcrModelConversion suggestedYcbcrModel;
    VkSamplerYcbcrRange suggestedYcbcrRange;
    VkChromaLocation suggestedXChromaOffset;
    VkChromaLocation suggestedYChromaOffset;
} VkAndroidHardwareBufferFormatProperties2ANDROID;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `format` is the Vulkan format corresponding to the Android hardware buffer’s format, or `VK_FORMAT_UNDEFINED` if there is not an equivalent Vulkan format.
- `externalFormat` is an implementation-defined external format identifier for use with `VkExternalFormatANDROID`. It must not be zero.
- `formatFeatures` describes the capabilities of this external format when used with an image bound to memory imported from `buffer`.
- `samplerYcbcrConversionComponents` is the component swizzle that should be used in `VkSamplerYcbcrConversionCreateInfo`.
- `suggestedYcbcrModel` is a suggested color model to use in the `VkSamplerYcbcrConversionCreateInfo`.
- `suggestedYcbcrRange` is a suggested numerical value range to use in `VkSamplerYcbcrConversionCreateInfo`.
- `suggestedXChromaOffset` is a suggested X chroma offset to use in `VkSamplerYcbcrConversionCreateInfo`.
- `suggestedYChromaOffset` is a suggested Y chroma offset to use in `VkSamplerYcbcrConversionCreateInfo`.

The bits reported in `formatFeatures` must include the bits reported in the corresponding fields of `VkAndroidHardwareBufferFormatPropertiesANDROID::formatFeatures`.

**Valid Usage (Implicit)**

- VUID-VkAndroidHardwareBufferFormatProperties2ANDROID-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_ANDROID_HARDWARE_BUFFER_FORMAT_PROPERTIES_2_ANDROID`. 

11.2.8. Remote Device External Memory

To export an address representing the payload of a Vulkan device memory object accessible by remote devices, call:

```c
VkResult vkGetMemoryRemoteAddressNV(
    VkDevice device,
    const VkMemoryGetRemoteAddressInfoNV* pMemoryGetRemoteAddressInfo,
    VkRemoteAddressNV* pAddress);
```

- `device` is the logical device that created the device memory being exported.
- `pMemoryGetRemoteAddressInfo` is a pointer to a `VkMemoryGetRemoteAddressInfoNV` structure containing parameters of the export operation.
- `pAddress` is a pointer to a `VkRemoteAddressNV` value in which an address representing the payload of the device memory object is returned.

More communication may be required between the kernel-mode drivers of the devices involved. This information is out of scope of this documentation and should be requested from the vendors of the devices.

**Valid Usage (Implicit)**

- VUID-vkGetMemoryRemoteAddressNV-device-parameter `device` must be a valid `VkDevice` handle
- VUID-vkGetMemoryRemoteAddressNV-pMemoryGetRemoteAddressInfo-parameter `pMemoryGetRemoteAddressInfo` must be a valid pointer to a valid `VkMemoryGetRemoteAddressInfoNV` structure
- VUID-vkGetMemoryRemoteAddressNV-pAddress-parameter `pAddress` must be a valid pointer to a `VkRemoteAddressNV` value

**Return Codes**

- **Success**
  - `VK_SUCCESS`
- **Failure**
  - `VK_ERROR_INVALID_EXTERNAL_HANDLE`

The `VkMemoryGetRemoteAddressInfoNV` structure is defined as:

```c
typedef struct VkMemoryGetRemoteAddressInfoNV {
    VkStructureType sType;
} VkMemoryGetRemoteAddressInfoNV;
```
const void* pNext;
VkDeviceMemory memory;
VkExternalMemoryHandleTypeFlagBits handleType;
} VkMemoryGetRemoteAddressInfoNV;

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **memory** is the memory object from which the remote accessible address will be exported.
- **handleType** is the type of handle requested.

**Valid Usage**

- VUID-VkMemoryGetRemoteAddressInfoNV-handleType-04966
  handleType must have been included in VkExportMemoryAllocateInfo::handleTypes when memory was created

**Valid Usage (Implicit)**

- VUID-VkMemoryGetRemoteAddressInfoNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_MEMORY_GET_REMOTE_ADDRESS_INFO_NV
- VUID-VkMemoryGetRemoteAddressInfoNV-pNext-pNext
  pNext must be NULL
- VUID-VkMemoryGetRemoteAddressInfoNV-memory-parameter
  memory must be a valid VkDeviceMemory handle
- VUID-VkMemoryGetRemoteAddressInfoNV-handleType-parameter
  handleType must be a valid VkExternalMemoryHandleTypeFlagBits value

**VkRemoteAddressNV** represents an address of a memory object accessible by remote devices, as returned in vkGetMemoryRemoteAddressNV::pAddress.

// Provided by VK_NV_external_memory_rdma
typedef void* VkRemoteAddressNV;

### 11.2.9. Fuchsia External Memory

On Fuchsia, when allocating memory that may be imported from another device, process or Vulkan instance, add a VkImportMemoryZirconHandleInfoFUCHSIA structure to the pNext chain of the VkMemoryAllocateInfo structure.

External memory on Fuchsia is imported and exported using VMO handles of type zx_handle_t. VMO handles to external memory are canonically obtained from Fuchsia's Sysmem service or from syscalls such as zx_vmo_create(). VMO handles for import can also be obtained by exporting them from another Vulkan instance as described in exporting fuchsia device memory.
Importing VMO handles to the Vulkan instance transfers ownership of the handle to the instance from the application. The application must not perform any operations on the handle after successful import.

Applications can import the same underlying memory into multiple instances of Vulkan, into the same instance from which it was exported, and multiple times into a given Vulkan instance. In all cases, each import operation must create a distinct VkDeviceMemory object.

### Importing Fuchsia External Memory

The VkImportMemoryZirconHandleInfoFUCHSIA structure is defined as:

```c
// Provided by VK_FUCHSIA_external_memory
typedef struct VkImportMemoryZirconHandleInfoFUCHSIA {
    VkStructureType sType;
    const void* pNext;
    VkExternalMemoryHandleTypeFlagBits handleType;
    zx_handle_t handle;
} VkImportMemoryZirconHandleInfoFUCHSIA;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `handleType` is a VkExternalMemoryHandleTypeFlagBits value specifying the type of `handle`.
- `handle` is a `zx_handle_t` (Zircon) handle to the external memory.

#### Valid Usage

- VUID-VkImportMemoryZirconHandleInfoFUCHSIA-handlerType-04771
  handleType must be `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ZIRCON_VMO_BIT_FUCHSIA`
- VUID-VkImportMemoryZirconHandleInfoFUCHSIA-handle-04772
  `handle` must be a valid VMO handle

#### Valid Usage ( Implicit )

- VUID-VkImportMemoryZirconHandleInfoFUCHSIA-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_IMPORT_MEMORY_ZIRCON_HANDLE_INFO_FUCHSIA`
- VUID-VkImportMemoryZirconHandleInfoFUCHSIA-handlerType-parameter
  If `handleType` is not 0, `handleType` must be a valid `VkExternalMemoryHandleTypeFlagBits` value

To obtain the memoryTypeIndex for the VkMemoryAllocateInfo structure, call vkGetMemoryZirconHandlePropertiesFUCHSIA:

```c
// Provided by VK_FUCHSIA_external_memory
```
VkResult vkGetMemoryZirconHandlePropertiesFUCHSIA(
    VkDevice device,
    VkExternalMemoryHandleTypeFlagBits handleType,
    zx_handle_t zirconHandle,
    VkMemoryZirconHandlePropertiesFUCHSIA* pMemoryZirconHandleProperties);

- **device** is the VkDevice.
- **handleType** is a VkExternalMemoryHandleTypeFlagBits value specifying the type of zirconHandle.
- **zirconHandle** is a zx_handle_t (Zircon) handle to the external resource.
- **pMemoryZirconHandleProperties** is a pointer to a VkMemoryZirconHandlePropertiesFUCHSIA structure in which the result will be stored.

### Valid Usage

- VUID-vkGetMemoryZirconHandlePropertiesFUCHSIA-handleType-04773
  - **handleType** must be VK_EXTERNAL_MEMORY_HANDLE_TYPE_ZIRCON_VMO_BIT_FUCHSIA
- VUID-vkGetMemoryZirconHandlePropertiesFUCHSIA-zirconHandle-04774
  - **zirconHandle** must reference a valid VMO

### Valid Usage (Implicit)

- VUID-vkGetMemoryZirconHandlePropertiesFUCHSIA-device-parameter
  - **device** must be a valid VkDevice handle
- VUID-vkGetMemoryZirconHandlePropertiesFUCHSIA-handleType-parameter
  - **handleType** must be a valid VkExternalMemoryHandleTypeFlagBits value
- VUID-vkGetMemoryZirconHandlePropertiesFUCHSIA-pMemoryZirconHandleProperties-parameter
  - **pMemoryZirconHandleProperties** must be a valid pointer to a VkMemoryZirconHandlePropertiesFUCHSIA structure

### Return Codes

- **Success**
  - VK_SUCCESS
- **Failure**
  - VK_ERROR_INVALID_EXTERNAL_HANDLE

The VkMemoryZirconHandlePropertiesFUCHSIA structure is defined as:

```c
// Provided by VK_FUCHSIA_external_memory
typedef struct VkMemoryZirconHandlePropertiesFUCHSIA {
```
VkStructureType sType;
void* pNext;
uint32_t memoryTypeBits;
} VkMemoryZirconHandlePropertiesFUCHSIA;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **memoryTypeBits** a bitmask containing one bit set for every memory type which the specified handle can be imported as.

### Valid Usage (Implicit)

- VUID-VkMemoryZirconHandlePropertiesFUCHSIA-sType-sType
  
  *sType* **must** be `VK_STRUCTURE_TYPE_MEMORY_ZIRCON_HANDLE_PROPERTIES_FUCHSIA`

- VUID-VkMemoryZirconHandlePropertiesFUCHSIA-pNext-pNext
  
  *pNext* **must** be `NULL`

With `pMemoryZirconHandleProperties` now successfully populated by `vkGetMemoryZirconHandlePropertiesFUCHSIA`, assign the `VkMemoryAllocateInfo` `memoryTypeIndex` field to a memory type which has a bit set in the `VkMemoryZirconHandlePropertiesFUCHSIA` `memoryTypeBits` field.

### Exporting Fuchsia Device Memory

Similar to importing, exporting a VMO handle from Vulkan transfers ownership of the handle from the Vulkan instance to the application. The application is responsible for closing the handle with `zx_handle_close()` when it is no longer in use.

To export device memory as a Zircon handle that can be used by another instance, device, or process, the handle to the `VkDeviceMemory` must be retrieved using `vkGetMemoryZirconHandleFUCHSIA`:

```c
// Provided by VK_FUCHSIA_external_memory
VkResult vkGetMemoryZirconHandleFUCHSIA(
    VkDevice device,
    const VkMemoryGetZirconHandleInfoFUCHSIA* pGetZirconHandleInfo,
    zx_handle_t* pZirconHandle);
```

- **device** is the `VkDevice`.
- **pGetZirconHandleInfo** is a pointer to a `VkMemoryGetZirconHandleInfoFUCHSIA` structure.
- **pZirconHandle** is a pointer to a `zx_handle_t` which holds the resulting Zircon handle.
Valid Usage (Implicit)

- VUID-vkGetMemoryZirconHandleFUCHSIA-device-parameter
device must be a valid VkDevice handle

- VUID-vkGetMemoryZirconHandleFUCHSIA-pGetZirconHandleInfo-parameter
pGetZirconHandleInfo must be a valid pointer to a valid VkMemoryGetZirconHandleInfoFUCHSIA structure

- VUID-vkGetMemoryZirconHandleFUCHSIA-pZirconHandle-parameter
pZirconHandle must be a valid pointer to a zx_handle_t value

Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_TOO_MANY_OBJECTS
- VK_ERROR_OUT_OF_HOST_MEMORY

VkMemoryGetZirconHandleInfoFUCHSIA is defined as:

```c
// Provided by VK_FUCHSIA_external_memory
typedef struct VkMemoryGetZirconHandleInfoFUCHSIA {
    VkStructureType sType;
    const void* pNext;
    VkDeviceMemory memory;
    VkExternalMemoryHandleTypeFlagBits handleType;
} VkMemoryGetZirconHandleInfoFUCHSIA;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- memory the VkDeviceMemory being exported.
- handleType is a VkExternalMemoryHandleTypeFlagBits value specifying the type of the handle pointed to by vkGetMemoryZirconHandleFUCHSIA::pZirconHandle.

Valid Usage

- VUID-VkMemoryGetZirconHandleInfoFUCHSIA-handleType-04775
handleType must be VK_EXTERNAL_MEMORY_HANDLE_TYPE_ZIRCON_VMO_BIT_FUCHSIA

- VUID-VkMemoryGetZirconHandleInfoFUCHSIA-handleType-04776
handleType must have been included in the handleTypes field of the VkExportMemoryAllocateInfo structure when the external memory was allocated
Valid Usage (Implicit)

- VUID-VkMemoryGetZirconHandleInfoFUCHSIA-sType-sType
  sType must be VK_STRUCTURE_TYPE_MEMORY_GET_ZIRCON_HANDLE_INFO_FUCHSIA

- VUID-VkMemoryGetZirconHandleInfoFUCHSIA-pNext-pNext
  pNext must be NULL

- VUID-VkMemoryGetZirconHandleInfoFUCHSIA-memory-parameter
  memory must be a valid VkDeviceMemory handle

- VUID-VkMemoryGetZirconHandleInfoFUCHSIA-handleType-parameter
  handleType must be a valid VkExternalMemoryHandleTypeFlagBits value

With the result pZirconHandle now obtained, the memory properties for the handle can be retrieved using vkGetMemoryZirconHandlePropertiesFUCHSIA as documented above substituting the dereferenced, retrieved pZirconHandle in for the zirconHandle argument.

11.2.10. Metal Objects

A Vulkan implementation that is layered on top of Metal on Apple device platform, and implements the VK_EXT_metal_objects extension, supports the ability to import and export the underlying Metal objects associated with specific Vulkan objects.

The underlying Metal objects associated with certain Vulkan objects can be exported from those Vulkan objects using the pNext chain of the VkExportMetalObjectsInfoEXT parameter of the vkExportMetalObjectsEXT command.

An VkDeviceMemory object can be allocated on an existing MTLBuffer object, by including the MTLBuffer object in a VkImportMetalBufferInfoEXT structure in the pNext chain of the VkMemoryAllocateInfo structure in the vkAllocateMemory command.

A new VkImage object can be created on an existing IOSurface object, or one or more existing Metal MTLTexture objects, by including those Metal objects in either VkImportMetalIOSurfaceInfoEXT or VkImportMetalTextureInfoEXT structures in the pNext chain of the VkImageCreateInfo structure in the vkCreateImage command.

To export Metal objects from Vulkan objects, the app must first indicate the intention to do so during the creation of the Vulkan object, by including one or more VkExportMetalObjectCreateInfoEXT structures in the pNext chain of the VkInstanceCreateInfo, VkMemoryAllocateInfo, VkImageCreateInfo, VkImageViewCreateInfo, VkBufferViewCreateInfo, VkSemaphoreCreateInfo, or VkEventCreateInfo, in the corresponding Vulkan object creation command.

The VkExportMetalObjectCreateInfoEXT structure is defined as:

```c
// Provided by VK_EXT_metal_objects
typedef struct VkExportMetalObjectCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
} VkExportMetalObjectCreateInfoEXT;
```
VkExportMetalObjectTypeFlagBitsEXT  exportObjectType;
} VkExportMetalObjectCreateInfoEXT;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **exportObjectType** is a `VkExportMetalObjectTypeFlagBitsEXT` indicating the type of Metal object that the application may request to be exported from the Vulkan object.

### Valid Usage (Implicit)

- **VUID-VkExportMetalObjectCreateInfoEXT-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_EXPORT_METAL_OBJECT_CREATE_INFO_EXT`
- **VUID-VkExportMetalObjectCreateInfoEXT-exportObjectType-parameter**
  - If `exportObjectType` is not `0`, `exportObjectType` must be a valid `VkExportMetalObjectTypeFlagBitsEXT` value

Bits which indicate the types of Metal objects that may be exported from a corresponding Vulkan object are:

```cpp
// Provided by VK_EXT_metal_objects
typedef enum VkExportMetalObjectTypeFlagBitsEXT {
    VK_EXPORT_METAL_OBJECT_TYPE_METAL_DEVICE_BIT_EXT = 0x00000001,
    VK_EXPORT_METAL_OBJECT_TYPE_METAL_COMMAND_QUEUE_BIT_EXT = 0x00000002,
    VK_EXPORT_METAL_OBJECT_TYPE_METAL_BUFFER_BIT_EXT = 0x00000004,
    VK_EXPORT_METAL_OBJECT_TYPE_METAL_TEXTURE_BIT_EXT = 0x00000008,
    VK_EXPORT_METAL_OBJECT_TYPE_METAL_IOSURFACE_BIT_EXT = 0x00000010,
    VK_EXPORT_METAL_OBJECT_TYPE_METAL_SHARED_EVENT_BIT_EXT = 0x00000020,
} VkExportMetalObjectTypeFlagBitsEXT;
```

- **VK_EXPORT_METAL_OBJECT_TYPE_METAL_DEVICE_BIT_EXT** indicates a Metal `MTLDevice` may be exported.
- **VK_EXPORT_METAL_OBJECT_TYPE_METAL_COMMAND_QUEUE_BIT_EXT** indicates a Metal `MTLCommandQueue` may be exported.
- **VK_EXPORT_METAL_OBJECT_TYPE_METAL_BUFFER_BIT_EXT** indicates a Metal `MTLBuffer` may be exported.
- **VK_EXPORT_METAL_OBJECT_TYPE_METAL_TEXTURE_BIT_EXT** indicates a Metal `MTLTexture` may be exported.
- **VK_EXPORT_METAL_OBJECT_TYPE_METAL_IOSURFACE_BIT_EXT** indicates a Metal `IOSurface` may be exported.
- **VK_EXPORT_METAL_OBJECT_TYPE_METAL_SHARED_EVENT_BIT_EXT** indicates a Metal `MTLSharedEvent` may be exported.

```cpp
// Provided by VK_EXT_metal_objects
typedef VkFlags VkExportMetalObjectTypeFlagsEXT;
```
VkExportMetalObjectTypeFlagsEXT is a bitmask type for setting a mask of zero or more VkExportMetalObjectTypeFlagBitsEXT.

To export Metal objects that underlie Vulkan objects, call:

```c
// Provided by VK_EXT_metal_objects
void vkExportMetalObjectsEXT(
    VkDevice device,
    VkExportMetalObjectsInfoEXT* pMetalObjectsInfo);
```

- `device` is the device that created the Vulkan objects.
- `pMetalObjectsInfo` is a pointer to a VkExportMetalObjectsInfoEXT structure whose `pNext` chain contains structures, each identifying a Vulkan object and providing a pointer through which the Metal object will be returned.

**Valid Usage (Implicit)**

- VUID-vkExportMetalObjectsEXT-device-parameter
  `device` must be a valid VkDevice handle
- VUID-vkExportMetalObjectsEXT-pMetalObjectsInfo-parameter
  `pMetalObjectsInfo` must be a valid pointer to a VkExportMetalObjectsInfoEXT structure

The VkExportMetalObjectsInfoEXT structure is defined as:

```c
// Provided by VK_EXT_metal_objects
typedef struct VkExportMetalObjectsInfoEXT {
    VkStructureType sType;
    const void* pNext;
} VkExportMetalObjectsInfoEXT;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.

**Valid Usage**

- VUID-VkExportMetalObjectsInfoEXT-pNext-06791
  If the `pNext` chain includes a VkExportMetalDeviceInfoEXT structure, the VkInstance must have been created with VK_EXPORT_METAL_OBJECT_TYPE_METAL_DEVICE_BIT_EXT in the exportObjectType member of a VkExportMetalObjectCreateInfoEXT structure in the `pNext` chain of the VkInstanceCreateInfo structure in the vkCreateInstance command
- VUID-VkExportMetalObjectsInfoEXT-pNext-06792
  If the `pNext` chain includes a VkExportMetalCommandQueueInfoEXT structure, the VkInstance must have been created with VK_EXPORT_METAL_OBJECT_TYPE_METAL_COMMAND_QUEUE_BIT_EXT in the exportObjectType
member of a VkExportMetalObjectCreateInfoEXT structure in the pNext chain of the VkInstanceCreateInfo structure in the vkCreateInstance command

- VUID-VkExportMetalObjectsInfoEXT-pNext-06793
  If the pNext chain includes a VkExportMetalBufferInfoEXT structure, the VkDeviceMemory in its memory member must have been allocated with VK_EXPORT_METAL_OBJECT_TYPE_METAL_BUFFER_BIT_EXT in the exportObjectType member of a VkExportMetalObjectCreateInfoEXT structure in the pNext chain of the VkMemoryAllocateInfo structure in the vkAllocateMemory command

- VUID-VkExportMetalObjectsInfoEXT-pNext-06794
  If the pNext chain includes a VkExportMetalTextureInfoEXT structure, exactly one of its image, imageView, or bufferView members must not be VK_NULL_HANDLE

- VUID-VkExportMetalObjectsInfoEXT-pNext-06795
  If the pNext chain includes a VkExportMetalTextureInfoEXT structure, and its image member is not VK_NULL_HANDLE, the VkImage in its image member must have been created with VK_EXPORT_METAL_OBJECT_TYPE_METAL_TEXTURE_BIT_EXT in the exportObjectType member of a VkExportMetalObjectCreateInfoEXT structure in the pNext chain of the VkImageCreateInfo structure in the vkCreateImage command

- VUID-VkExportMetalObjectsInfoEXT-pNext-06796
  If the pNext chain includes a VkExportMetalTextureInfoEXT structure, and its imageView member is not VK_NULL_HANDLE, the VkImageView in its imageView member must have been created with VK_EXPORT_METAL_OBJECT_TYPE_METAL_TEXTURE_BIT_EXT in the exportObjectType member of a VkExportMetalObjectCreateInfoEXT structure in the pNext chain of the VkImageViewCreateInfo structure in the vkCreateImageView command

- VUID-VkExportMetalObjectsInfoEXT-pNext-06797
  If the pNext chain includes a VkExportMetalTextureInfoEXT structure, and its bufferView member is not VK_NULL_HANDLE, the VkBufferView in its bufferView member must have been created with VK_EXPORT_METAL_OBJECT_TYPE_METAL_TEXTURE_BIT_EXT in the exportObjectType member of a VkExportMetalObjectCreateInfoEXT structure in the pNext chain of the VkBufferViewCreateInfo structure in the vkCreateBufferView command

- VUID-VkExportMetalObjectsInfoEXT-pNext-06798
  If the pNext chain includes a VkExportMetalTextureInfoEXT structure, and if either its image or imageView member is not VK_NULL_HANDLE, then plane must be VK_IMAGE_ASPECT_PLANE_0_BIT, VK_IMAGE_ASPECT_PLANE_1_BIT, or VK_IMAGE_ASPECT_PLANE_2_BIT

- VUID-VkExportMetalObjectsInfoEXT-pNext-06799
  If the pNext chain includes a VkExportMetalTextureInfoEXT structure, and if the VkImage in its image member does not have a multi-planar format, then its plane member must be VK_IMAGE_ASPECT_PLANE_0_BIT

- VUID-VkExportMetalObjectsInfoEXT-pNext-06800
  If the pNext chain includes a VkExportMetalTextureInfoEXT structure, and if the VkImage in its image member has a multi-planar format with only two planes, then its plane member must not be VK_IMAGE_ASPECT_PLANE_2_BIT

- VUID-VkExportMetalObjectsInfoEXT-pNext-06801
  If the pNext chain includes a VkExportMetalTextureInfoEXT structure, and if the VkImageView in its imageView member does not have a multi-planar format, then its plane
member **must** be `VK_IMAGE_ASPECT_PLANE_0_BIT`

- **VUID-VkExportMetalObjectsInfoEXT-pNext-06802**
  If the `pNext` chain includes a `VkExportMetalTextureInfoEXT` structure, and if the `VkImageView` in its `imageView` member has a multi-planar format with only two planes, then its `plane` member **must** not be `VK_IMAGE_ASPECT_PLANE_2_BIT`

- **VUID-VkExportMetalObjectsInfoEXT-pNext-06803**
  If the `pNext` chain includes a `VkExportMetalIOSurfaceInfoEXT` structure, and if the `VkImageView` in its `imageView` member has a multi-planar format with only two planes, then its `plane` member **must** not be `VK_IMAGE_ASPECT_PLANE_2_BIT`

- **VUID-VkExportMetalObjectsInfoEXT-pNext-06804**
  If the `pNext` chain includes a `VkExportMetalSharedEventInfoEXT` structure, exactly one of its `semaphore` or `event` members **must** not be `VK_NULL_HANDLE`

- **VUID-VkExportMetalObjectsInfoEXT-pNext-06805**
  If the `pNext` chain includes a `VkExportMetalSharedEventInfoEXT` structure, and its `semaphore` member is not `VK_NULL_HANDLE`, the `VkSemaphore` in its `semaphore` member **must** have been created with `VK_EXPORT_METAL_OBJECT_TYPE_METAL_SHARED_EVENT_BIT_EXT` in the `exportObjectType` member of a `VkExportMetalObjectCreateInfoEXT` structure in the `pNext` chain of the `VkSemaphoreCreateInfo` structure in the `vkCreateSemaphore` command

- **VUID-VkExportMetalObjectsInfoEXT-pNext-06806**
  If the `pNext` chain includes a `VkExportMetalSharedEventInfoEXT` structure, and its `event` member is not `VK_NULL_HANDLE`, the `VkEvent` in its `event` member **must** have been created with `VK_EXPORT_METAL_OBJECT_TYPE_METAL_SHARED_EVENT_BIT_EXT` in the `exportObjectType` member of a `VkExportMetalObjectCreateInfoEXT` structure in the `pNext` chain of the `VkEventCreateInfo` structure in the `vkCreateEvent` command

**Valid Usage (Implicit)**

- **VUID-VkExportMetalObjectsInfoEXT-sType-sType**
  The `sType` value of each struct in the `pNext` chain **must** be unique, with the exception of structures of type `VkExportMetalBufferInfoEXT`, `VkExportMetalCommandQueueInfoEXT`, `VkExportMetalDeviceInfoEXT`, `VkExportMetalIOSurfaceInfoEXT`, `VkExportMetalSharedEventInfoEXT`, or `VkExportMetalTextureInfoEXT`

- **VUID-VkExportMetalObjectsInfoEXT-pNext-pNext**
  Each `pNext` member of any structure (including this one) in the `pNext` chain **must** be either `NULL` or a pointer to a valid instance of `VkExportMetalBufferInfoEXT`, `VkExportMetalCommandQueueInfoEXT`, `VkExportMetalDeviceInfoEXT`, `VkExportMetalIOSurfaceInfoEXT`, `VkExportMetalSharedEventInfoEXT`, or `VkExportMetalTextureInfoEXT`
To export the Metal `MTLDevice` object underlying the `VkPhysicalDevice` associated with a `VkDevice` object, include a `VkExportMetalDeviceInfoEXT` structure in the `pNext` chain of the `pMetalObjectsInfo` parameter of a `vkExportMetalObjectsEXT` call.

The `VkExportMetalDeviceInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_metal_objects
typedef struct VkExportMetalDeviceInfoEXT {
    VkStructureType sType;
    const void* pNext;
    MTLDevice_id mtlDevice;
} VkExportMetalDeviceInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `mtlDevice` is the Metal `id<MTLDevice>` object underlying the `VkPhysicalDevice` associated with the `VkDevice` object identified in the call. The implementation will return the `MTLDevice` in this member, or it will return `NULL` if no `MTLDevice` could be found underlying the `VkPhysicalDevice` object.

**Valid Usage ( Implicit )**

- VUID-VkExportMetalDeviceInfoEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_EXPORT_METAL_DEVICE_INFO_EXT`

The type `id<MTLDevice>` is defined in Apple’s Metal framework, but to remove an unnecessary compile time dependency, an incomplete type definition of `MTLDevice_id` is provided in the Vulkan headers:

```c
// Provided by VK_EXT_metal_objects
#ifndef __OBJC__
@protocol MTLDevice;`
typedef id<MTLDevice> MTLDevice_id;
#else
    typedef void* MTLDevice_id;
#endif
```

To export the Metal `MTLCommandQueue` object underlying a `VkQueue` object, include a `VkExportMetalCommandQueueInfoEXT` structure in the `pNext` chain of the `pMetalObjectsInfo` parameter of a `vkExportMetalObjectsEXT` call.

The `VkExportMetalCommandQueueInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_metal_objects
typedef struct VkExportMetalCommandQueueInfoEXT {
```
VkStructureType sType;
const void* pNext;
VkQueue queue;
MTLCommandQueue_id mtlCommandQueue;
} VkExportMetalCommandQueueInfoEXT;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• queue is a VkQueue.
• mtlCommandQueue is the Metal id<MTLCommandQueue> object underlying the VkQueue object in queue. The implementation will return the MTLCommandQueue in this member, or it will return NULL if no MTLCommandQueue could be found underlying the VkQueue object.

Valid Usage (Implicit)

• VUID-VkExportMetalCommandQueueInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_EXPORT_METAL_COMMAND_QUEUE_INFO_EXT
• VUID-VkExportMetalCommandQueueInfoEXT-queue-parameter
  queue must be a valid VkQueue handle

The type id<MTLCommandQueue> is defined in Apple's Metal framework, but to remove an unnecessary compile time dependency, an incomplete type definition of MTLCommandQueue_id is provided in the Vulkan headers:

// Provided by VK_EXT_metal_objects
#ifdef __OBJC__
@protocol MTLCommandQueue;
typedef id<MTLCommandQueue> MTLCommandQueue_id;
#else
typedef void* MTLCommandQueue_id;
#endif

To export the Metal MTLBuffer object underlying a VkDeviceMemory object, include a VkExportMetalBufferInfoEXT structure in the pNext chain of the pMetalObjectsInfo parameter of a vkExportMetalObjectsEXT call.

The VkExportMetalBufferInfoEXT structure is defined as:

typedef struct VkExportMetalBufferInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkDeviceMemory memory;
    MTLBuffer_id mtlBuffer;
}
VkExportMetalBufferInfoEXT;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **memory** is a `VkDeviceMemory`.
- **mtlBuffer** is the Metal `id<MTLBuffer>` object underlying the `VkDeviceMemory` object in `memory`. The implementation will return the `MTLBuffer` in this member, or it will return `NULL` if no `MTLBuffer` could be found underlying the `VkDeviceMemory` object.

### Valid Usage (Implicit)

- VUID-VkExportMetalBufferInfoEXT-sType-sType
  - **sType** must be `VK_STRUCTURE_TYPE_EXPORT_METAL_BUFFER_INFO_EXT`
- VUID-VkExportMetalBufferInfoEXT-memory-parameter
  - **memory** must be a valid `VkDeviceMemory` handle

To import a Metal `MTLBuffer` object to underlie a `VkDeviceMemory` object, include a `VkImportMetalBufferInfoEXT` structure in the `pNext` chain of the `VkMemoryAllocateInfo` structure in a `vkAllocateMemory` command.

The `VkImportMetalBufferInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_metal_objects
typedef struct VkImportMetalBufferInfoEXT {
    VkStructureType sType;
    const void* pNext;
    MTLBuffer_id mtlBuffer;
} VkImportMetalBufferInfoEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **mtlBuffer** is the Metal `id<MTLBuffer>` object that is to underlie the `VkDeviceMemory`.

The app **must** ensure that the configuration of the `id<MTLBuffer>` object is compatible with the configuration of the `VkDeviceMemory`. Failure to do so results in undefined behavior.

### Valid Usage (Implicit)

- VUID-VkImportMetalBufferInfoEXT-sType-sType
  - **sType** must be `VK_STRUCTURE_TYPE_IMPORT_METAL_BUFFER_INFO_EXT`

The type `id<MTLBuffer>` is defined in Apple's Metal framework, but to remove an unnecessary compile-time dependency, an incomplete type definition of `MTLBuffer_id` is provided in the Vulkan
To export a Metal MTLTexture object underlying a VkImage, VkImageView, or VkBufferView object, include a VkExportMetalTextureInfoEXT structure in the pNext chain of the pMetalObjectsInfo parameter of a vkExportMetalObjectsEXT call.

The VkExportMetalTextureInfoEXT structure is defined as:

```c
typedef struct VkExportMetalTextureInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkImage image;
    VkImageView imageView;
    VkBufferView bufferView;
    VkImageAspectFlagBits plane;
    MTLTexture_id mtlTexture;
} VkExportMetalTextureInfoEXT;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **image** is VK_NULL_HANDLE or a VkImage.
- **imageView** is VK_NULL_HANDLE or a VkImageView.
- **bufferView** is VK_NULL_HANDLE or a VkBufferView.
- **plane** indicates the plane of a multi-planar VkImage or VkImageView.
- **mtlTexture** is the Metal id<MTLTexture> object underlying the VkImage, VkImageView, or VkBufferView object in image, imageView, or bufferView, respectively, at the plane indicated in aspectMask. The implementation will return the MTLTexture in this member, or it will return NULL if no MTLTexture could be found underlying the VkImage, VkImageView, or VkBufferView object, at the plane indicated in aspectMask.

**Valid Usage (Implicit)**

- VUID-VkExportMetalTextureInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_EXPORT_METAL_TEXTURE_INFO_EXT
- VUID-VkExportMetalTextureInfoEXT-image-parameter
If `image` is not `VK_NULL_HANDLE`, `image` must be a valid `VkImage` handle

- VUID-VkExportMetalTextureInfoEXT-imageView-parameter
  If `imageView` is not `VK_NULL_HANDLE`, `imageView` must be a valid `VkImageView` handle

- VUID-VkExportMetalTextureInfoEXT-bufferView-parameter
  If `bufferView` is not `VK_NULL_HANDLE`, `bufferView` must be a valid `VkBufferView` handle

- VUID-VkExportMetalTextureInfoEXT-plane-parameter
  `plane` must be a valid `VkImageAspectFlagBits` value

- VUID-VkExportMetalTextureInfoEXT-commonparent
  Each of `bufferView`, `image`, and `imageView` that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same `VkDevice`

To import one or more existing Metal `MTLTexture` objects to underlie a `VkImage` object, include one or more `VkImportMetalTextureInfoEXT` structures in the `pNext` chain of the `VkImageCreateInfo` structure in a `vkCreateImage` command.

The `VkImportMetalTextureInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_metal_objects
typedef struct VkImportMetalTextureInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkImageAspectFlagBits plane;
    MTLTexture_id mtlTexture;
} VkImportMetalTextureInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `plane` indicates the plane of the `VkImage` that the `id<MTLTexture>` object should be attached to.
- `mtlTexture` is a the Metal `id<MTLTexture>` object that is to underlie the `VkImage` plane.

The `pNext` chain must include one `VkImportMetalTextureInfoEXT` structure for each plane in the `VkImage`. The app must ensure that the configuration of the Metal `id<MTLTexture>` objects are compatible with the configuration of the `VkImage`. Failure to do so results in undefined behavior.

### Valid Usage (Implicit)

- VUID-VkImportMetalTextureInfoEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_IMPORT_Metal_TEXTURE_INFO_EXT`

- VUID-VkImportMetalTextureInfoEXT-plane-parameter
  `plane` must be a valid `VkImageAspectFlagBits` value

The type `id<MTLTexture>` is defined in Apple’s Metal framework, but to remove an unnecessary compile time dependency, an incomplete type definition of `MTLTexture_id` is provided in the
To export the Metal `IOSurfaceRef` object underlying a `VkImage` object, include a `VkExportMetalIOSurfaceInfoEXT` structure in the `pNext` chain of the `pMetalObjectsInfo` parameter of a `vkExportMetalObjectsEXT` call.

The `VkExportMetalIOSurfaceInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_metal_objects
typedef struct VkExportMetalIOSurfaceInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkImage image;
    IOSurfaceRef ioSurface;
} VkExportMetalIOSurfaceInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `image` is a `VkImage`.
- `ioSurface` is the Metal `IOSurfaceRef` object underlying the `VkImage` object in `image`. The implementation will return the `IOSurfaceRef` in this member, or it will return `NULL` if no `IOSurfaceRef` could be found underlying the `VkImage` object.

**Valid Usage (Implicit)**

- VUID-VkExportMetalIOSurfaceInfoEXT-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_EXPORT_METAL_IO_SURFACE_INFO_EXT`

- VUID-VkExportMetalIOSurfaceInfoEXT-image-parameter
  
  `image` must be a valid `VkImage` handle

To import, or create, a Metal `IOSurfaceRef` object to underlie a `VkImage` object, include a `VkImportMetalIOSurfaceInfoEXT` structure in the `pNext` chain of the `VkImageCreateInfo` structure in a `vkCreateImage` command.

The `VkImportMetalIOSurfaceInfoEXT` structure is defined as:
typedef struct VkImportMetalIOSurfaceInfoEXT {
    VkStructureType sType;
    const void* pNext;
    IOSurfaceRef ioSurface;
} VkImportMetalIOSurfaceInfoEXT;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `ioSurface` is `VK_NULL_HANDLE` or the Metal `IOSurfaceRef` object that is to underlie the `VkImage`.

If `ioSurface` is not `VK_NULL_HANDLE`, it will be used to underlie the `VkImage`. If `ioSurface` is `VK_NULL_HANDLE`, the implementation will create a new `IOSurface` to underlie the `VkImage`.

If provided, the app must ensure that the configuration of the `IOSurfaceRef` object is compatible with the configuration of the `VkImage`. Failure to do so results in undefined behavior.

**Valid Usage (Implicit)**

- VUID-VkImportMetalIOSurfaceInfoEXT-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_IMPORT_METAL_IO_SURFACE_INFO_EXT`

The type `IOSurfaceRef` is defined in Apple’s CoreGraphics framework, but to remove an unnecessary compile time dependency, an incomplete type definition of `IOSurfaceRef` is provided in the Vulkan headers:

```c
typedef struct __IOSurface* IOSurfaceRef;
```

To export the Metal `MTLSharedEvent` object underlying a `VkSemaphore` or `VkEvent` object, include a `VkExportMetalSharedEventInfoEXT` structure in the `pNext` chain of the `pMetalObjectsInfo` parameter of a `vkExportMetalObjectsEXT` call.

The `VkExportMetalSharedEventInfoEXT` structure is defined as:

```c
typedef struct VkExportMetalSharedEventInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkSemaphore semaphore;
    VkEvent event;
    MTLSharedEvent_id mtlSharedEvent;
} VkExportMetalSharedEventInfoEXT;
```
sType is a VkStructureType value identifying this structure.

pNext is NULL or a pointer to a structure extending this structure.

semaphore is VK_NULL_HANDLE or a VkSemaphore.

event is VK_NULL_HANDLE or a VkEvent.

mtlSharedEvent is the Metal id<MTLSharedEvent> object underlying the VkSemaphore or VkEvent object in semaphore or event, respectively. The implementation will return the MTLSharedEvent in this member, or it will return NULL if no MTLSharedEvent could be found underlying the VkSemaphore or VkEvent object.

Valid Usage (Implicit)

- VUID-VkExportMetalSharedEventInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_EXPORT_METAL_SHARED_EVENT_INFO_EXT

- VUID-VkExportMetalSharedEventInfoEXT-semaphore-parameter
  If semaphore is not VK_NULL_HANDLE, semaphore must be a valid VkSemaphore handle

- VUID-VkExportMetalSharedEventInfoEXT-event-parameter
  If event is not VK_NULL_HANDLE, event must be a valid VkEvent handle

- VUID-VkExportMetalSharedEventInfoEXT-commonparent
  Both of event, and semaphore that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice

To import a Metal id<MTLSharedEvent> object to underlie a VkSemaphore or VkEvent object, include a VkImportMetalSharedEventInfoEXT structure in the pNext chain of the VkSemaphoreCreateInfo or VkEventCreateInfo structure in a vkCreateSemaphore or vkCreateEvent command, respectively.

The VkImportMetalSharedEventInfoEXT structure is defined as:

```c
// Provided by VK_EXT_metal_objects
typedef structVkImportMetalSharedEventInfoEXT {
    VkStructureType sType;
    const void* pNext;
    MTLSharedEvent_id mtlSharedEvent;
} VkImportMetalSharedEventInfoEXT;
```

- sType is a VkStructureType value identifying this structure.

- pNext is NULL or a pointer to a structure extending this structure.

- mtlSharedEvent is the Metal id<MTLSharedEvent> object that is to underlie the VkSemaphore or VkEvent.

If the pNext chain of the VkSemaphoreCreateInfo structure includes both VkImportMetalSharedEventInfoEXT and VkSemaphoreTypeCreateInfo, the signaledValue property of the imported id<MTLSharedEvent> object will be set to initialValue of VkSemaphoreTypeCreateInfo.
Valid Usage (Implicit)

- VUID-VkImportMetalSharedEventInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_IMPORT_METAL_SHARED_EVENT_INFO_EXT

The type `id<MTLSharedEvent>` is defined in Apple's Metal framework, but to remove an unnecessary compile time dependency, an incomplete type definition of `MTLSharedEvent_id` is provided in the Vulkan headers:

```cpp
// Provided by VK_EXT_metal_objects
#ifdef __OBJC__
@protocol MTLSharedEvent;
typedef id<MTLSharedEvent> MTLSharedEvent_id;
#else
typedef void* MTLSharedEvent_id;
#endif
```

### 11.2.11. QNX Screen Buffer External Memory

To import memory created outside of the current Vulkan instance from a QNX Screen buffer, add a `VkImportScreenBufferInfoQNX` structure to the `pNext` chain of the `VkMemoryAllocateInfo` structure. The `VkImportScreenBufferInfoQNX` structure is defined as:

```cpp
// Provided by VK_QNX_external_memory_screen_buffer
typedef struct VkImportScreenBufferInfoQNX {
    VkStructureType sType;
    const void* pNext;
    struct _screen_buffer* buffer;
} VkImportScreenBufferInfoQNX;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **buffer** is a pointer to a `struct _screen_buffer`, the QNX Screen buffer to import

The implementation may not acquire a reference to the imported Screen buffer. Therefore, the application must ensure that the object referred to by `buffer` stays valid as long as the device memory to which it is imported is being used.

Valid Usage

- VUID-VkImportScreenBufferInfoQNX-buffer-08966
  If `buffer` is not NULL, QNX Screen Buffers must be supported for import, as reported by `VkExternalImageFormatProperties` or `VkExternalBufferProperties`
- VUID-VkImportScreenBufferInfoQNX-buffer-08967
**Valid Usage (Implicit)**

- **VUID-VkImportScreenBufferInfoQNX-sType-sType**
  
  `sType` **must** be `VK_STRUCTURE_TYPE_IMPORT_SCREEN_BUFFER_INFO_QNX`

To determine the memory parameters to use when importing a QNX Screen buffer, call:

```c
// Provided by VK_QNX_external_memory_screen_buffer
VkResult vkGetScreenBufferPropertiesQNX(
    VkDevice device,
    const struct _screen_buffer* buffer,
    VkScreenBufferPropertiesQNX* pProperties);
```

- **device** is the logical device that will be importing `buffer`.
- **buffer** is the QNX Screen buffer which will be imported.
- **pProperties** is a pointer to a `VkScreenBufferPropertiesQNX` structure in which the properties of `buffer` are returned.

**Valid Usage**

- **VUID-vkGetScreenBufferPropertiesQNX-buffer-08968**
  
  `buffer` **must** be a **valid QNX Screen buffer**

**Valid Usage (Implicit)**

- **VUID-vkGetScreenBufferPropertiesQNX-device-parameter**
  
  `device` **must** be a valid `VkDevice` handle

- **VUID-vkGetScreenBufferPropertiesQNX-buffer-parameter**
  
  `buffer` **must** be a valid pointer to a valid `struct _screen_buffer` value

- **VUID-vkGetScreenBufferPropertiesQNX-pProperties-parameter**
  
  `pProperties` **must** be a valid pointer to a `VkScreenBufferPropertiesQNX` structure

**Return Codes**

**Success**

- **VK_SUCCESS**

**Failure**

- **VK_ERROR_OUT_OF_HOST_MEMORY**
The `VkScreenBufferPropertiesQNX` structure returned is defined as:

```c
// Provided by VK_QNX_external_memory_screen_buffer
typedef struct VkScreenBufferPropertiesQNX {
    VkStructureType sType;
    void* pNext;
    VkDeviceSize allocationSize;
    uint32_t memoryTypeBits;
} VkScreenBufferPropertiesQNX;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `allocationSize` is the size of the external memory.
- `memoryTypeBits` is a bitmask containing one bit set for every memory type which the specified Screen buffer can be imported as.

**Valid Usage (Implicit)**

- VUID-VkScreenBufferPropertiesQNX-sType-sType
  sType must be `VK_STRUCTURE_TYPE_SCREEN_BUFFER_PROPERTIES_QNX`
- VUID-VkScreenBufferPropertiesQNX-pNext-pNext
  pNext must be `NULL` or a pointer to a valid instance of `VkScreenBufferFormatPropertiesQNX`
- VUID-VkScreenBufferPropertiesQNX-sType-unique
  The sType value of each struct in the pNext chain must be unique

To obtain format properties of a QNX Screen buffer, include a `VkScreenBufferFormatPropertiesQNX` structure in the `pNext` chain of the `VkScreenBufferPropertiesQNX` structure passed to `vkGetScreenBufferPropertiesQNX`. This structure is defined as:

```c
// Provided by VK_QNX_external_memory_screen_buffer
typedef struct VkScreenBufferFormatPropertiesQNX {
    VkStructureType sType;
    void* pNext;
    VkFormat format;
    uint64_t externalFormat;
    uint64_t screenUsage;
    VkFormatFeatureFlags formatFeatures;
    VkComponentMapping samplerYcbcrConversionComponents;
    VkSamplerYcbcrModelConversion suggestedYcbcrModel;
    VkSamplerYcbcrRange suggestedYcbcrRange;
    VkChromaLocation suggestedXChromaOffset;
} VkScreenBufferFormatPropertiesQNX;
```
• **sType** is a *VkStructureType* value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **format** is the Vulkan format corresponding to the Screen buffer's format or `VK_FORMAT_UNDEFINED` if there is not an equivalent Vulkan format.

• **externalFormat** is an implementation-defined external format identifier for use with `VkExternalFormatQNX`. It must not be zero.

• **screenUsage** is an implementation-defined external usage identifier for the QNX Screen buffer.

• **formatFeatures** describes the capabilities of this external format when used with an image bound to memory imported from `buffer`.

• **samplerYcbcrConversionComponents** is the component swizzle that should be used in `VkSamplerYcbcrConversionCreateInfo`.

• **suggestedYcbcrModel** is a suggested color model to use in `VkSamplerYcbcrConversionCreateInfo`.

• **suggestedYcbcrRange** is a suggested numerical value range to use in `VkSamplerYcbcrConversionCreateInfo`.

• **suggestedXChromaOffset** is a suggested X chroma offset to use in `VkSamplerYcbcrConversionCreateInfo`.

• **suggestedYChromaOffset** is a suggested Y chroma offset to use in `VkSamplerYcbcrConversionCreateInfo`.

If the QNX Screen buffer has one of the formats listed in the [QNX Screen Format Equivalence table](#), then **format** must have the equivalent Vulkan format listed in the table. Otherwise, **format** may be `VK_FORMAT_UNDEFINED`, indicating the QNX Screen buffer can only be used with an external format. The **formatFeatures** member must include `VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT` and should include `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT` and `VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_LINEAR_FILTER_BIT`.

### Valid Usage (Implicit)

- **VUID-VkScreenBufferFormatPropertiesQNX-sType-sType**
  
  **sType** must be `VK_STRUCTURE_TYPE_SCREEN_BUFFER_FORMAT_PROPERTIES_QNX`.

### 11.2.12. Device Group Memory Allocations

If the **pNext** chain of `VkMemoryAllocateInfo` includes a `VkMemoryAllocateFlagsInfo` structure, then that structure includes flags and a device mask controlling how many instances of the memory will be allocated.

The `VkMemoryAllocateFlagsInfo` structure is defined as:
typedef struct VkMemoryAllocateFlagsInfo {
    VkStructureType sType;
    const void* pNext;
    VkMemoryAllocateFlags flags;
    uint32_t deviceMask;
} VkMemoryAllocateFlagsInfo;

or the equivalent

// Provided by VK_KHR_device_group
typedef VkMemoryAllocateFlagsInfo VkMemoryAllocateFlagsInfoKHR;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is a bitmask of `VkMemoryAllocateFlagBits` controlling the allocation.
- **deviceMask** is a mask of physical devices in the logical device, indicating that memory **must** be allocated on each device in the mask, if `VK_MEMORY_ALLOCATE_DEVICE_MASK_BIT` is set in **flags**.

If `VK_MEMORY_ALLOCATE_DEVICE_MASK_BIT` is not set, the number of instances allocated depends on whether `VK_MEMORY_HEAP_MULTI_INSTANCE_BIT` is set in the memory heap. If `VK_MEMORY_HEAP_MULTI_INSTANCE_BIT` is set, then memory is allocated for every physical device in the logical device (as if `deviceMask` has bits set for all device indices). If `VK_MEMORY_HEAP_MULTI_INSTANCE_BIT` is not set, then a single instance of memory is allocated (as if `deviceMask` is set to one).

On some implementations, allocations from a multi-instance heap **may** consume memory on all physical devices even if the `deviceMask` excludes some devices. If `VkPhysicalDeviceGroupProperties::subsetAllocation` is `VK_TRUE`, then memory is only consumed for the devices in the device mask.

**Note**

In practice, most allocations on a multi-instance heap will be allocated across all physical devices. Unicast allocation support is an optional optimization for a minority of allocations.

**Valid Usage**

- VUID-VkMemoryAllocateFlagsInfo-deviceMask-00675
  If `VK_MEMORY_ALLOCATE_DEVICE_MASK_BIT` is set, `deviceMask` **must** be a valid device mask
- VUID-VkMemoryAllocateFlagsInfo-deviceMask-00676
  If `VK_MEMORY_ALLOCATE_DEVICE_MASK_BIT` is set, `deviceMask` **must** not be zero
Valid Usage (Implicit)

- **VUID-VkMemoryAllocateFlagsInfo-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_FLAGS_INFO`

- **VUID-VkMemoryAllocateFlagsInfo-flags-parameter**
  - `flags` must be a valid combination of `VkMemoryAllocateFlagBits` values

Bits which **can** be set in `VkMemoryAllocateFlagsInfo::flags`, controlling device memory allocation, are:

```c
// Provided by VK_VERSION_1_1
typedef enum VkMemoryAllocateFlagBits {
    VK_MEMORY_ALLOCATE_DEVICE_MASK_BIT = 0x00000001,
    // Provided by VK_VERSION_1_2
    VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT = 0x00000002,
    // Provided by VK_VERSION_1_2
    VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT = 0x00000004,
    // Provided by VK_KHR_device_group
    VK_MEMORY_ALLOCATE_DEVICE_MASK_BIT_KHR = VK_MEMORY_ALLOCATE_DEVICE_MASK_BIT,
    // Provided by VK_KHR_buffer_device_address
    VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT_KHR = VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT,
    // Provided by VK_KHR_buffer_device_address
    VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT_KHR = VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT,
} VkMemoryAllocateFlagBits;
```

or the equivalent

```c
// Provided by VK_KHR_device_group
typedef VkMemoryAllocateFlagBits VkMemoryAllocateFlagBitsKHR;
```

- **VK_MEMORY_ALLOCATE_DEVICE_MASK_BIT** specifies that memory will be allocated for the devices in `VkMemoryAllocateFlagsInfo::deviceMask`.

- **VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT** specifies that the memory **can** be attached to a buffer object created with the `VK_BUFFER_USAGE_SHADER_DEVICE_ADDRESS_BIT` bit set in `usage`, and that the memory handle **can** be used to retrieve an opaque address via `vkGetDeviceMemoryOpaqueCaptureAddress`.

- **VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT** specifies that the memory's address **can** be saved and reused on a subsequent run (e.g. for trace capture and replay), see `VkBufferOpaqueCaptureAddressCreateInfo` for more detail.

```c
// Provided by VK_VERSION_1_1
typedef VkFlags VkMemoryAllocateFlags;
```
or the equivalent

```c
// Provided by VK_KHR_device_group
typedef VkMemoryAllocateFlags VkMemoryAllocateFlagsKHR;
```

`VkMemoryAllocateFlags` is a bitmask type for setting a mask of zero or more `VkMemoryAllocateFlagBits`.

### 11.2.13. Opaque Capture Address Allocation

To request a specific device address for a memory allocation, add a `VkMemoryOpaqueCaptureAddressAllocateInfo` structure to the `pNext` chain of the `VkMemoryAllocateInfo` structure. The `VkMemoryOpaqueCaptureAddressAllocateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkMemoryOpaqueCaptureAddressAllocateInfo {
    VkStructureType sType;
    const void* pNext;
    uint64_t opaqueCaptureAddress;
} VkMemoryOpaqueCaptureAddressAllocateInfo;
```

or the equivalent

```c
// Provided by VK_KHR_buffer_device_address
typedef VkMemoryOpaqueCaptureAddressAllocateInfo VkMemoryOpaqueCaptureAddressAllocateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `opaqueCaptureAddress` is the opaque capture address requested for the memory allocation.

If `opaqueCaptureAddress` is zero, no specific address is requested.

If `opaqueCaptureAddress` is not zero, it **should** be an address retrieved from `vkGetDeviceMemoryOpaqueCaptureAddress` on an identically created memory allocation on the same implementation.

**Note**

In most cases, it is expected that a non-zero `opaqueAddress` is an address retrieved from `vkGetDeviceMemoryOpaqueCaptureAddress` on an identically created memory allocation. If this is not the case, it is likely that `VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS` errors will occur.

This is, however, not a strict requirement because trace capture/replay tools may
need to adjust memory allocation parameters for imported memory.

If this structure is not present, it is as if `opaqueCaptureAddress` is zero.

**Valid Usage (Implicit)**

- VUID-VkMemoryOpaqueCaptureAddressAllocateInfo-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_MEMORY_OPAQUE_CAPTURE_ADDRESS_ALLOCATE_INFO`

11.2.14. Freeing Device Memory

To free a memory object, call:

```c
// Provided by VK_VERSION_1_0
void vkFreeMemory(  
    VkDevice device,  
    VkDeviceMemory memory,  
    const VkAllocationCallbacks* pAllocator);
```

- `device` is the logical device that owns the memory.
- `memory` is the `VkDeviceMemory` object to be freed.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

Before freeing a memory object, an application must ensure the memory object is no longer in use by the device — for example by command buffers in the pending state. Memory can be freed whilst still bound to resources, but those resources must not be used afterwards. Freeing a memory object releases the reference it held, if any, to its payload. If there are still any bound images or buffers, the memory object’s payload may not be immediately released by the implementation, but must be released by the time all bound images and buffers have been destroyed. Once all references to a payload are released, it is returned to the heap from which it was allocated.

How memory objects are bound to Images and Buffers is described in detail in the Resource Memory Association section.

If a memory object is mapped at the time it is freed, it is implicitly unmapped.

**Note**

As described below, host writes are not implicitly flushed when the memory object is unmapped, but the implementation must guarantee that writes that have not been flushed do not affect any other memory.

**Valid Usage**

- VUID-vkFreeMemory-memory-00677
  
  All submitted commands that refer to `memory` (via images or buffers) must have completed

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### Valid Usage (Implicit)

- **VUID-vkFreeMemory-device-parameter**
  
  *device must be a valid *VkDevice* handle*

- **VUID-vkFreeMemory-memory-parameter**

  *If memory is not VK_NULL_HANDLE, memory must be a valid *VkDeviceMemory* handle*

- **VUID-vkFreeMemory-pAllocator-parameter**

  *If pAllocator is not NULL, pAllocator must be a valid pointer to a valid *VkAllocationCallbacks* structure*

- **VUID-vkFreeMemory-memory-parent**

  *If memory is a valid handle, it must have been created, allocated, or retrieved from device*

### Host Synchronization

- Host access to memory must be externally synchronized

### 11.2.15. Host Access to Device Memory Objects

Memory objects created with *vkAllocateMemory* are not directly host accessible.

Memory objects created with the memory property *VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT* are considered *mappable*. Memory objects must be mappable in order to be successfully mapped on the host.

To retrieve a host virtual address pointer to a region of a mappable memory object, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkMapMemory(  
    VkDevice device,  
    VkDeviceMemory memory,  
    VkDeviceSize offset,  
    VkDeviceSize size,  
    VkMemoryMapFlags flags,  
    void** ppData);
```

- **device** is the logical device that owns the memory.
- **memory** is the *VkDeviceMemory* object to be mapped.
- **offset** is a zero-based byte offset from the beginning of the memory object.
- **size** is the size of the memory range to map, or *VK_WHOLE_SIZE* to map from offset to the end of the allocation.
• **flags** is reserved for future use.

• **pData** is a pointer to a `void*` variable in which a host-accessible pointer to the beginning of the mapped range is returned. This pointer minus **offset must** be aligned to at least `VkPhysicalDeviceLimits::minMemoryMapAlignment`.

After a successful call to `vkMapMemory` the memory object **memory** is considered to be currently **host mapped**.

**Note**

It is an application error to call `vkMapMemory` on a memory object that is already **host mapped**.

**Note**

`vkMapMemory` will fail if the implementation is unable to allocate an appropriately sized contiguous virtual address range, e.g. due to virtual address space fragmentation or platform limits. In such cases, `vkMapMemory` must return `VK_ERROR_MEMORY_MAP_FAILED`. The application can improve the likelihood of success by reducing the size of the mapped range and/or removing unneeded mappings using `vkUnmapMemory`.

`vkMapMemory` does not check whether the device memory is currently in use before returning the host-accessible pointer. The application must guarantee that any previously submitted command that writes to this range has completed before the host reads from or writes to that range, and that any previously submitted command that reads from that range has completed before the host writes to that region (see here for details on fulfilling such a guarantee). If the device memory was allocated without the `VK_MEMORY_PROPERTY_HOST_COHERENT_BIT` set, these guarantees must be made for an extended range: the application must round down the start of the range to the nearest multiple of `VkPhysicalDeviceLimits::nonCoherentAtomSize`, and round the end of the range up to the nearest multiple of `VkPhysicalDeviceLimits::nonCoherentAtomSize`.

While a range of device memory is host mapped, the application is responsible for synchronizing both device and host access to that memory range.

**Note**

It is important for the application developer to become meticulously familiar with all of the mechanisms described in the chapter on **Synchronization and Cache Control** as they are crucial to maintaining memory access ordering.

Calling `vkMapMemory` is equivalent to calling `vkMapMemory2KHR` with an empty **pNext** chain.

---

**Valid Usage**

- VUID-vkMapMemory-memory-00678
  **memory** must not be currently host mapped

- VUID-vkMapMemory-offset-00679
  **offset** must be less than the size of **memory**
If `size` is not equal to `VK_WHOLE_SIZE`, `size` must be greater than 0.

If `size` is not equal to `VK_WHOLE_SIZE`, `size` must be less than or equal to the size of the memory minus offset.

`memory` must have been created with a memory type that reports `VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT`.

`memory` must not have been allocated with multiple instances.

### Valid Usage (Implicit)

- `device` must be a valid `VkDevice` handle
- `memory` must be a valid `VkDeviceMemory` handle
- `flags` must be 0
- `ppData` must be a valid pointer to a pointer value
- `memory` must have been created, allocated, or retrieved from `device`

### Host Synchronization

Host access to `memory` must be externally synchronized.

### Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_MEMORY_MAP_FAILED`

// Provided by VK_VERSION_1_0
typedef VkFlags VkMemoryMapFlags;

VkMemoryMapFlags is a bitmask type for setting a mask, but is currently reserved for future use.

Alternatively, to retrieve a host virtual address pointer to a region of a mappable memory object, call:

```
// Provided by VK_KHR_map_memory2
VkResult vkMapMemory2KHR(
    VkDevice device,
    const VkMemoryMapInfoKHR* pMemoryMapInfo,
    void** ppData);
```

- **device** is the logical device that owns the memory.
- **pMemoryMapInfo** is a pointer to a VkMemoryMapInfoKHR structure describing parameters of the map.
- **ppData** is a pointer to a void * variable in which is returned a host-accessible pointer to the beginning of the mapped range. This pointer minus VkMemoryMapInfoKHR::offset must be aligned to at least VkPhysicalDeviceLimits::minMemoryMapAlignment.

This function behaves identically to vkMapMemory except that it gets its parameters via an extensible structure pointer rather than directly as function arguments.

### Valid Usage (Implicit)

- VUID-vkMapMemory2KHR-device-parameter
  
  device must be a valid VkDevice handle

- VUID-vkMapMemory2KHR-pMemoryMapInfo-parameter
  
  pMemoryMapInfo must be a valid pointer to a valid VkMemoryMapInfoKHR structure

- VUID-vkMapMemory2KHR-ppData-parameter
  
  ppData must be a valid pointer to a pointer value

### Return Codes

**Success**

- VK_SUCCESS

**Failure**

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_MEMORY_MAP_FAILED

The VkMemoryMapInfoKHR structure is defined as:
// Provided by VK_KHR_map_memory2

typedef struct VkMemoryMapInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkMemoryMapFlags flags;
    VkDeviceMemory memory;
    VkDeviceSize offset;
    VkDeviceSize size;
} VkMemoryMapInfoKHR;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **memory** is the `VkDeviceMemory` object to be mapped.
- **offset** is a zero-based byte offset from the beginning of the memory object.
- **size** is the size of the memory range to map, or `VK_WHOLE_SIZE` to map from `offset` to the end of the allocation.

### Valid Usage

- VUID-VkMemoryMapInfoKHR-memory-07958
  memory must not be currently host mapped
- VUID-VkMemoryMapInfoKHR-offset-07959
  offset must be less than the size of memory
- VUID-VkMemoryMapInfoKHR-size-07960
  If size is not equal to `VK_WHOLE_SIZE`, size must be greater than 0
- VUID-VkMemoryMapInfoKHR-size-07961
  If size is not equal to `VK_WHOLE_SIZE`, size must be less than or equal to the size of the memory minus offset
- VUID-VkMemoryMapInfoKHR-memory-07962
  memory must have been created with a memory type that reports `VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT`
- VUID-VkMemoryMapInfoKHR-memory-07963
  memory must not have been allocated with multiple instances

### Valid Usage (Implicit)

- VUID-VkMemoryMapInfoKHR-sType-sType
  sType must be `VK_STRUCTURE_TYPE_MEMORY_MAP_INFO_KHR`
- VUID-VkMemoryMapInfoKHR-pNext-pNext
  pNext must be `NULL`
Host Synchronization

- Host access to memory must be externally synchronized

Two commands are provided to enable applications to work with non-coherent memory allocations: `vkFlushMappedMemoryRanges` and `vkInvalidateMappedMemoryRanges`.

**Note**
If the memory object was created with the `VK_MEMORY_PROPERTY_HOST_COHERENT_BIT` set, `vkFlushMappedMemoryRanges` and `vkInvalidateMappedMemoryRanges` are unnecessary and may have a performance cost. However, availability and visibility operations still need to be managed on the device. See the description of host access types for more information.

**Note**
While memory objects imported from a handle type of `VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_ALLOCATION_BIT_EXT` or `VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_MAPPED_FOREIGN_MEMORY_BIT_EXT` are inherently mapped to host address space, they are not considered to be host mapped device memory unless they are explicitly host mapped using `vkMapMemory`. That means flushing or invalidating host caches with respect to host accesses performed on such memory through the original host pointer specified at import time is the responsibility of the application and must be performed with appropriate synchronization primitives provided by the platform which are outside the scope of Vulkan. `vkFlushMappedMemoryRanges` and `vkInvalidateMappedMemoryRanges`, however, can still be used on such memory objects to synchronize host accesses performed through the host pointer of the host mapped device memory range returned by `vkMapMemory`.

After a successful call to `vkMapMemory` or `vkMapMemory2KHR` the memory object memory is considered to be currently host mapped.

To flush ranges of non-coherent memory from the host caches, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkFlushMappedMemoryRanges(
    VkDevice device,
    uint32_t memoryRangeCount,
    const VkMappedMemoryRange* pMemoryRanges);
```
device is the logical device that owns the memory ranges.

memoryRangeCount is the length of the pMemoryRanges array.

pMemoryRanges is a pointer to an array of VkMappedMemoryRange structures describing the memory ranges to flush.

vkFlushMappedMemoryRanges guarantees that host writes to the memory ranges described by pMemoryRanges are made available to the host memory domain, such that they can be made available to the device memory domain via memory domain operations using the VK_ACCESS_HOST_WRITE_BIT access type.

Within each range described by pMemoryRanges, each set of nonCoherentAtomSize bytes in that range is flushed if any byte in that set has been written by the host since it was first host mapped, or the last time it was flushed. If pMemoryRanges includes sets of nonCoherentAtomSize bytes where no bytes have been written by the host, those bytes must not be flushed.

Unmapping non-coherent memory does not implicitly flush the host mapped memory, and host writes that have not been flushed may not ever be visible to the device. However, implementations must ensure that writes that have not been flushed do not become visible to any other memory.

Note
The above guarantee avoids a potential memory corruption in scenarios where host writes to a mapped memory object have not been flushed before the memory is unmapped (or freed), and the virtual address range is subsequently reused for a different mapping (or memory allocation).

Valid Usage (Implicit)

- VUID-vkFlushMappedMemoryRanges-device-parameter device must be a valid VkDevice handle
- VUID-vkFlushMappedMemoryRanges-pMemoryRanges-parameter pMemoryRanges must be a valid pointer to an array of memoryRangeCount valid VkMappedMemoryRange structures
- VUID-vkFlushMappedMemoryRanges-memoryRangeCount-arraylength memoryRangeCount must be greater than 0

Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
To invalidate ranges of non-coherent memory from the host caches, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkInvalidateMappedMemoryRanges(
    VkDevice device,
    uint32_t memoryRangeCount,
    const VkMappedMemoryRange* pMemoryRanges);
```

- `device` is the logical device that owns the memory ranges.
- `memoryRangeCount` is the length of the `pMemoryRanges` array.
- `pMemoryRanges` is a pointer to an array of `VkMappedMemoryRange` structures describing the memory ranges to invalidate.

`vkInvalidateMappedMemoryRanges` guarantees that device writes to the memory ranges described by `pMemoryRanges`, which have been made available to the host memory domain using the `VK_ACCESS_HOST_WRITE_BIT` and `VK_ACCESS_HOST_READ_BIT` access types, are made visible to the host. If a range of non-coherent memory is written by the host and then invalidated without first being flushed, its contents are undefined.

Within each range described by `pMemoryRanges`, each set of `nonCoherentAtomSize` bytes in that range is invalidated if any byte in that set has been written by the device since it was first host mapped, or the last time it was invalidated.

**Note**

Mapping non-coherent memory does not implicitly invalidate that memory.

### Valid Usage (Implicit)

- VUID-vkInvalidateMappedMemoryRanges-device-parameter `device` **must** be a valid `VkDevice` handle
- VUID-vkInvalidateMappedMemoryRanges-pMemoryRanges-parameter `pMemoryRanges` **must** be a valid pointer to an array of `memoryRangeCount` valid `VkMappedMemoryRange` structures
- VUID-vkInvalidateMappedMemoryRanges-memoryRangeCount-arraylength `memoryRangeCount` **must** be greater than 0

### Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
The `VkMappedMemoryRange` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkMappedMemoryRange {
    VkStructureType sType;
    const void* pNext;
    VkDeviceMemory memory;
    VkDeviceSize offset;
    VkDeviceSize size;
} VkMappedMemoryRange;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `memory` is the memory object to which this range belongs.
- `offset` is the zero-based byte offset from the beginning of the memory object.
- `size` is either the size of range, or `VK_WHOLE_SIZE` to affect the range from `offset` to the end of the current mapping of the allocation.

### Valid Usage

- **VUID-VkMappedMemoryRange-memory-00684**
  - `memory` must be currently host mapped

- **VUID-VkMappedMemoryRange-size-00685**
  - If `size` is not equal to `VK_WHOLE_SIZE`, `offset` and `size` must specify a range contained within the currently mapped range of `memory`

- **VUID-VkMappedMemoryRange-size-00686**
  - If `size` is equal to `VK_WHOLE_SIZE`, `offset` must be within the currently mapped range of `memory`

- **VUID-VkMappedMemoryRange-size-00687**
  - `offset` must be a multiple of `VkPhysicalDeviceLimits::nonCoherentAtomSize`

- **VUID-VkMappedMemoryRange-size-01389**
  - If `size` is equal to `VK_WHOLE_SIZE`, the end of the current mapping of `memory` must either be a multiple of `VkPhysicalDeviceLimits::nonCoherentAtomSize` bytes from the beginning of the memory object, or be equal to the end of the memory object

- **VUID-VkMappedMemoryRange-size-01390**
  - If `size` is not equal to `VK_WHOLE_SIZE`, `size` must either be a multiple of `VkPhysicalDeviceLimits::nonCoherentAtomSize`, or `offset` plus `size` must equal the size of `memory`

### Valid Usage (Implicit)

- **VUID-VkMappedMemoryRange-sType-sType**
sType \textbf{must} be \textit{VK_STRUCTURE_TYPE_MAPPED_MEMORY_RANGE}

- VUID-VkMappedMemoryRange-pNext-pNext
  \textit{pNext} \textbf{must} be \textit{NULL}

- VUID-VkMappedMemoryRange-memory-parameter
  \textit{memory} \textbf{must} be a valid \textit{VkDeviceMemory} handle

To unmap a memory object once host access to it is no longer needed by the application, call:

\begin{verbatim}
// Provided by VK_VERSION_1_0
void vkUnmapMemory(
    VkDevice device,
    VkDeviceMemory memory);
\end{verbatim}

- \textit{device} is the logical device that owns the memory.
- \textit{memory} is the memory object to be unmapped.

Calling \textit{vkUnmapMemory} is equivalent to calling \textit{vkUnmapMemory2KHR} with an empty \textit{pNext} chain and the flags parameter set to zero.

### Valid Usage

- VUID-vkUnmapMemory-memory-00689
  \textit{memory} \textbf{must} be currently host mapped

### Valid Usage (Implicit)

- VUID-vkUnmapMemory-device-parameter
  \textit{device} \textbf{must} be a valid \textit{VkDevice} handle

- VUID-vkUnmapMemory-memory-parameter
  \textit{memory} \textbf{must} be a valid \textit{VkDeviceMemory} handle

- VUID-vkUnmapMemory-memory-parent
  \textit{memory} \textbf{must} have been created, allocated, or retrieved from \textit{device}

### Host Synchronization

- Host access to \textit{memory} \textbf{must} be externally synchronized

Alternatively, to unmap a memory object once host access to it is no longer needed by the application, call:

\begin{verbatim}
// Provided by VK_KHR_map_memory2
\end{verbatim}
VkResult vkUnmapMemory2KHR(
    VkDevice device,
    const VkMemoryUnmapInfoKHR* pMemoryUnmapInfo);

- **device** is the logical device that owns the memory.
- **pMemoryUnmapInfo** is a pointer to a VkMemoryUnmapInfoKHR structure describing parameters of the unmap.

This function behaves identically to vkUnmapMemory except that it gets its parameters via an extensible structure pointer rather than directly as function arguments.

**Valid Usage (Implicit)**

- VUID-vkUnmapMemory2KHR-device-parameter
  
  **device** must be a valid VkDevice handle

- VUID-vkUnmapMemory2KHR-pMemoryUnmapInfo-parameter
  
  **pMemoryUnmapInfo** must be a valid pointer to a valid VkMemoryUnmapInfoKHR structure

**Return Codes**

**Success**

- VK_SUCCESS

The VkMemoryUnmapInfoKHR structure is defined as:

```c
// Provided by VK_KHR_map_memory2
typedef struct VkMemoryUnmapInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkMemoryUnmapFlagsKHR flags;
    VkDeviceMemory memory;
} VkMemoryUnmapInfoKHR;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **memory** is the VkDeviceMemory object to be unmapped.

**Valid Usage**

- VUID-VkMemoryUnmapInfoKHR-memory-07964
  
  **memory** must be currently host mapped
Valid Usage (Implicit)

- VUID-VkMemoryUnmapInfoKHR-sType-sType
  \textit{sType} \textbf{must} be \texttt{VK_STRUCTURE_TYPE_MEMORY_UNMAP_INFO_KHR}

- VUID-VkMemoryUnmapInfoKHR-pNext-pNext
  \textit{pNext} \textbf{must} be \texttt{NULL}

- VUID-VkMemoryUnmapInfoKHR-flags-zerobitmask
  \textit{flags} \textbf{must} be \texttt{0}

- VUID-VkMemoryUnmapInfoKHR-memory-parameter
  \textit{memory} \textbf{must} be a valid \texttt{VkDeviceMemory} handle

Host Synchronization

- Host access to \textit{memory} \textbf{must} be externally synchronized

// Provided by VK_KHR_map_memory2
typedef VkFlags VkMemoryUnmapFlagsKHR;

\texttt{VkMemoryMapFlagsKHR} is a bitmask type for setting a mask, but is currently reserved for future use.

11.2.16. Lazily Allocated Memory

If the memory object is allocated from a heap with the \texttt{VK_MEMORY_PROPERTY_LAZILY_ALLOCATED_BIT} bit set, that object's backing memory \textbf{may} be provided by the implementation lazily. The actual committed size of the memory \textbf{may} initially be as small as zero (or as large as the requested size), and monotonically increases as additional memory is needed.

A memory type with this flag set is only allowed to be bound to a \texttt{VkImage} whose usage flags include \texttt{VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT}.

\textbf{Note}

Using lazily allocated memory objects for framebuffer attachments that are not needed once a render pass instance has completed \textbf{may} allow some implementations to never allocate memory for such attachments.

To determine the amount of lazily-allocated memory that is currently committed for a memory object, call:

// Provided by VK_VERSION_1_0
\textbf{void} vkGetDeviceMemoryCommitment(
  VkDevice device,
  VkDeviceMemory memory,
  VkDeviceSize* pCommittedMemoryInBytes);

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• device is the logical device that owns the memory.
• memory is the memory object being queried.
• pCommittedMemoryInBytes is a pointer to a VkDeviceSize value in which the number of bytes currently committed is returned, on success.

The implementation may update the commitment at any time, and the value returned by this query may be out of date.

The implementation guarantees to allocate any committed memory from the heapIndex indicated by the memory type that the memory object was created with.

Valid Usage

• VUID-vkGetDeviceMemoryCommitment-memory-00690
  memory must have been created with a memory type that reports VK_MEMORY_PROPERTY_LAZILY_ALLOCATED_BIT

Valid Usage (Implicit)

• VUID-vkGetDeviceMemoryCommitment-device-parameter
device must be a valid VkDevice handle

• VUID-vkGetDeviceMemoryCommitment-memory-parameter
  memory must be a valid VkDeviceMemory handle

• VUID-vkGetDeviceMemoryCommitment-pCommittedMemoryInBytes-parameter
  pCommittedMemoryInBytes must be a valid pointer to a VkDeviceSize value

• VUID-vkGetDeviceMemoryCommitment-memory-parent
  memory must have been created, allocated, or retrieved from device

11.2.17. Protected Memory

Protected memory divides device memory into protected device memory and unprotected device memory.

Protected memory adds the following concepts:

• Memory:
  ◦ Unprotected device memory, which can be visible to the device and can be visible to the host
  ◦ Protected device memory, which can be visible to the device but must not be visible to the host

• Resources:
  ◦ Unprotected images and unprotected buffers, to which unprotected memory can be bound
  ◦ Protected images and protected buffers, to which protected memory can be bound
• Command buffers:
  ◦ Unprotected command buffers, which can be submitted to a device queue to execute unprotected queue operations
  ◦ Protected command buffers, which can be submitted to a protected-capable device queue to execute protected queue operations

• Device queues:
  ◦ Unprotected device queues, to which unprotected command buffers can be submitted
  ◦ Protected-capable device queues, to which unprotected command buffers or protected command buffers can be submitted

• Queue submissions
  ◦ Unprotected queue submissions, through which unprotected command buffers can be submitted
  ◦ Protected queue submissions, through which protected command buffers can be submitted

• Queue operations
  ◦ Unprotected queue operations
  ◦ Protected queue operations

Note
When the protectedMemory feature is enabled, all pipelines may be recorded in either protected or unprotected command buffers (or both), which may incur an extra cost on some implementations. This can be mitigated by enabling the pipelineProtectedAccess feature, in which case pipelines created with VK_PIPELINE_CREATE_PROTECTED_ACCESS_ONLY_BIT_EXT may only be recorded in protected command buffers, and pipelines created with VK_PIPELINE_CREATE_NO_PROTECTED_ACCESS_BIT_EXT may only be recorded in unprotected command buffers.

Protected Memory Access Rules

If VkPhysicalDeviceProtectedMemoryProperties::protectedNoFault is VK_FALSE, applications must not perform any of the following operations:

• Write to unprotected memory within protected queue operations.
• Access protected memory within protected queue operations other than in framebuffer-space pipeline stages, the compute shader stage, or the transfer stage.
• Perform a query within protected queue operations.

If VkPhysicalDeviceProtectedMemoryProperties::protectedNoFault is VK_TRUE, these operations are valid, but reads will return undefined values, and writes will either be dropped or store undefined values.

Additionally, indirect operations must not be performed within protected queue operations.
Whether these operations are valid or not, or if any other invalid usage is performed, the implementation \textit{must} guarantee that:

- Protected device memory \textit{must} never be visible to the host.
- Values written to unprotected device memory \textit{must} not be a function of values from protected memory.

11.2.18. External Memory Handle Types

Android Hardware Buffer

Android's NDK defines \texttt{AHardwareBuffer} objects, which represent device memory that is shareable across processes and that \texttt{can} be accessed by a variety of media APIs and the hardware used to implement them. These Android hardware buffer objects \texttt{may} be imported into \texttt{VkDeviceMemory} objects for access via Vulkan, or exported from Vulkan. An \texttt{VkImage} or \texttt{VkBuffer} \texttt{can} be bound to the imported or exported \texttt{VkDeviceMemory} object if it is created with \texttt{VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID}.

To remove an unnecessary compile time dependency, an incomplete type definition of \texttt{AHardwareBuffer} is provided in the Vulkan headers:

```c
// Provided by VKANDROID_EXTERNAL_MEMORY_ANDROID_HARDWARE_BUFFER
struct AHardwareBuffer;
```

The actual \texttt{AHardwareBuffer} type is defined in Android NDK headers.

\textbf{Note}

The NDK format, usage, and size/dimensions of an \texttt{AHardwareBuffer} object can be obtained with the \texttt{AHardwareBuffer\_describe} function. While Android hardware buffers can be imported to or exported from Vulkan without using that function, valid usage and implementation behavior is defined in terms of the \texttt{AHardwareBuffer\_Desc} properties it returns.

Android hardware buffer objects are reference-counted using Android NDK functions outside of the scope of this specification. A \texttt{VkDeviceMemory} imported from an Android hardware buffer or that \texttt{can} be exported to an Android hardware buffer \textit{must} acquire a reference to its \texttt{AHardwareBuffer} object, and \textit{must} release this reference when the device memory is freed. During the host execution of a Vulkan command that has an Android hardware buffer as a parameter (including indirect parameters via \texttt{pNext} chains), the application \textit{must} not decrement the Android hardware buffer's reference count to zero.

Android hardware buffers \texttt{can} be mapped and unmapped for CPU access using the NDK functions. These lock and unlock APIs are considered to acquire and release ownership of the Android hardware buffer, and applications \textit{must} follow the rules described in \textbf{External Resource Sharing} to transfer ownership between the Vulkan instance and these native APIs.

Android hardware buffers \texttt{can} be shared with external APIs and Vulkan instances on the same
device, and also with foreign devices. When transferring ownership of the Android hardware buffer, the external and foreign special queue families described in Queue Family Ownership Transfer are not identical. All APIs which produce or consume Android hardware buffers are considered to use foreign devices, except OpenGL ES contexts and Vulkan logical devices that have matching device and driver UUIDs. Implementations may treat a transfer to or from the foreign queue family as if it were a transfer to or from the external queue family when the Android hardware buffer's usage only permits it to be used on the same physical device.

**Android Hardware Buffer Optimal Usages**

Vulkan buffer and image usage flags do not correspond exactly to Android hardware buffer usage flags. When allocating Android hardware buffers with non-Vulkan APIs, if any AHWARDBUFFER_USAGE_GPU_* usage bits are included, by default the allocator must allocate the memory in such a way that it supports Vulkan usages and creation flags in the usage equivalence table which do not have Android hardware buffer equivalents.

An VkAndroidHardwareBufferUsageANDROID structure can be included in the pNext chain of a VkImageFormatProperties2 structure passed to vkGetPhysicalDeviceImageFormatProperties2 to obtain optimal Android hardware buffer usage flags for specific Vulkan resource creation parameters. Some usage flags returned by these commands are required based on the input parameters, but additional vendor-specific usage flags (AHWARDBUFFER_USAGE_VENDOR_*) may also be returned. Any Android hardware buffer allocated with these vendor-specific usage flags and imported to Vulkan must only be bound to resources created with parameters that are a subset of the parameters used to obtain the Android hardware buffer usage, since the memory may have been allocated in a way incompatible with other parameters. If an Android hardware buffer is successfully allocated with additional non-vendor-specific usage flags in addition to the recommended usage, it must support being used in the same ways as an Android hardware buffer allocated with only the recommended usage, and also in ways indicated by the additional usage.

**Android Hardware Buffer External Formats**

Android hardware buffers may represent images using implementation-specific formats, layouts, color models, etc., which do not have Vulkan equivalents. Such external formats are commonly used by external image sources such as video decoders or cameras. Vulkan can import Android hardware buffers that have external formats, but since the image contents are in an undiscoverable and possibly proprietary representation, images with external formats must only be used as sampled images, must only be sampled with a sampler that has YC_{b}C_{r} conversion enabled, and must have optimal tiling.

Images that will be backed by an Android hardware buffer can use an external format by setting VkImageCreateInfo::format to VK_FORMAT_UNDEFINED and including a VkExternalFormatANDROID structure in the pNext chain. Images can be created with an external format even if the Android hardware buffer has a format which has an equivalent Vulkan format to enable consistent handling of images from sources that might use either category of format. However, all images created with an external format are subject to the valid usage requirements associated with external formats, even if the Android hardware buffer's format has a Vulkan equivalent. The external format of an Android hardware buffer can be obtained by passing a VkAndroidHardwareBufferFormatPropertiesANDROID structure to vkGetAndroidHardwareBufferPropertiesANDROID.
Android Hardware Buffer Image Resources

Android hardware buffers have intrinsic width, height, format, and usage properties, so Vulkan images bound to memory imported from an Android hardware buffer must use dedicated allocations: `VkMemoryDedicatedRequirements::requiresDedicatedAllocation` must be VK_TRUE for images created with `VkExternalMemoryImageCreateInfo::handleTypes` that includes `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID`. When creating an image that will be bound to an imported Android hardware buffer, the image creation parameters must be equivalent to the `AHardwareBuffer` properties as described by the valid usage of `VkMemoryAllocateInfo`. Similarly, device memory allocated for a dedicated image must not be exported to an Android hardware buffer until it has been bound to that image, and the implementation must return an Android hardware buffer with properties derived from the image:

- The width and height members of `AHardwareBuffer_Desc` must be the same as the width and height members of `VkImageCreateInfo::extent`, respectively.
- The layers member of `AHardwareBuffer_Desc` must be the same as the arrayLayers member of `VkImageCreateInfo`.
- The format member of `AHardwareBuffer_Desc` must be equivalent to `VkImageCreateInfo::format` as defined by `AHardwareBuffer Format Equivalence`.
- The usage member of `AHardwareBuffer_Desc` must include bits corresponding to bits included in `VkImageCreateInfo::usage` and `VkImageCreateInfo::flags` where such a correspondence exists according to `AHardwareBuffer Usage Equivalence`. It may also include additional usage bits, including vendor-specific usages. Presence of vendor usage bits may make the Android hardware buffer only usable in ways indicated by the image creation parameters, even when used outside Vulkan, in a similar way that allocating the Android hardware buffer with usage returned in `VkAndroidHardwareBufferUsageANDROID` does.

Implementations may support fewer combinations of image creation parameters for images with Android hardware buffer external handle type than for non-external images. Support for a given set of parameters can be determined by passing `VkExternalImageFormatProperties` to `vkGetPhysicalDeviceImageFormatProperties2` with `handleType` set to `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID`. Any Android hardware buffer successfully allocated outside Vulkan with usage that includes `AHARDWAREBUFFER_USAGE_GPU_*` must be supported when using equivalent Vulkan image parameters. If a given choice of image parameters are supported for import, they can also be used to create an image and memory that will be exported to an Android hardware buffer.

### Table 13. AHardwareBuffer Format Equivalence

<table>
<thead>
<tr>
<th>AHardwareBuffer Format</th>
<th>Vulkan Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHWARDBUFFER_FORMAT_R8G8B8A8_UNORM</td>
<td>VK_FORMAT_R8G8B8A8_UNORM</td>
</tr>
<tr>
<td>AHWARDBUFFER_FORMAT_R8G8B8X8_UNORM</td>
<td>VK_FORMAT_R8G8B8A8_UNORM</td>
</tr>
<tr>
<td>AHWARDBUFFER_FORMAT_R8G8B8_UNORM</td>
<td>VK_FORMAT_R8G8B8_UNORM</td>
</tr>
<tr>
<td>AHWARDBUFFER_FORMAT_R5G6B5_UNORM</td>
<td>VK_FORMAT_A2B10G10R10_UNORM_PACK32</td>
</tr>
<tr>
<td>AHWARDBUFFER_FORMAT_R16G16B16A16_FLOAT</td>
<td>VK_FORMAT_R16G16B16A16_SFLOAT</td>
</tr>
<tr>
<td>AHWARDBUFFER_FORMAT_R10G10B10A2_UNORM</td>
<td>VK_FORMAT_R10G10B10A2_UNORM</td>
</tr>
</tbody>
</table>

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### AHardwareBuffer Format vs. Vulkan Format

<table>
<thead>
<tr>
<th>AHardwareBuffer Format</th>
<th>Vulkan Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHARDWAREBUFFER_FORMAT_D16_UNORM</td>
<td>VK_FORMAT_D16_UNORM</td>
</tr>
<tr>
<td>AHARDWAREBUFFER_FORMAT_D24_UNORM</td>
<td>VK_FORMAT_X8_D24_UNORM_PACK32</td>
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<tr>
<td>AHARDWAREBUFFER_FORMAT_D24_UNORM_S8_UINT</td>
<td>VK_FORMAT_D24_UNORM_S8_UINT</td>
</tr>
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<td>AHARDWAREBUFFER_FORMAT_D32_FLOAT</td>
<td>VK_FORMAT_D32_SFLOAT</td>
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<td>AHARDWAREBUFFER_FORMAT_D32_FLOAT_S8_UINT</td>
<td>VK_FORMAT_D32_SFLOAT_S8_UINT</td>
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<tr>
<td>AHARDWAREBUFFER_FORMAT_S8_UINT</td>
<td>VK_FORMAT_S8_UINT</td>
</tr>
</tbody>
</table>

### Table 14. AHardwareBuffer Usage Equivalence

<table>
<thead>
<tr>
<th>AHardwareBuffer Usage</th>
<th>Vulkan Usage or Creation Flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>VK_IMAGE_USAGE_TRANSFER_SRC_BIT</td>
</tr>
<tr>
<td>None</td>
<td>VK_IMAGE_USAGE_TRANSFER_DST_BIT</td>
</tr>
<tr>
<td>AHARDWAREBUFFER_USAGE_GPU_SAMPLED_IMAGE</td>
<td>VK_IMAGE_USAGE_SAMPLED_BIT</td>
</tr>
<tr>
<td>AHARDWAREBUFFER_USAGE_GPU_SAMPLED_IMAGE</td>
<td>VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT</td>
</tr>
<tr>
<td>AHARDWAREBUFFER_USAGE_GPU_FRAMEBUFFER</td>
<td>VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT</td>
</tr>
<tr>
<td>AHARDWAREBUFFER_USAGE_GPU_FRAMEBUFFER</td>
<td>VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT</td>
</tr>
<tr>
<td>AHARDWAREBUFFER_USAGE_GPU_CUBE_MAP</td>
<td>VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT</td>
</tr>
<tr>
<td>AHARDWAREBUFFER_USAGE_GPU_MIPMAP_COMPLETE</td>
<td>None</td>
</tr>
<tr>
<td>AHARDWAREBUFFER_USAGE_PROTECTED_CONTENT</td>
<td>VK_IMAGE_CREATE_PROTECTED_BIT</td>
</tr>
<tr>
<td>None</td>
<td>VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT</td>
</tr>
<tr>
<td>None</td>
<td>VK_IMAGE_CREATE_EXTENDED_USAGE_BIT</td>
</tr>
<tr>
<td>AHARDWAREBUFFER_USAGE_GPU_DATA_BUFFER</td>
<td>VK_IMAGE_USAGE_STORAGE_BIT</td>
</tr>
</tbody>
</table>

1. **Vulkan does not differentiate between** **AHARDWAREBUFFER_FORMAT_R8G8B8A8_UNORM** **and** **AHARDWAREBUFFER_FORMAT_R8G8B8X8_UNORM**: they both behave as **VK_FORMAT_R8G8B8A8_UNORM**. After an external entity writes to a **AHARDWAREBUFFER_FORMAT_R8G8B8X8_UNORM** Android hardware buffer, the values read by Vulkan from the X/A component are undefined. To emulate the traditional behavior of the X component during sampling or blending, applications should use **VK_COMPONENT_SWIZZLE_ONE** in image view component mappings and **VK_BLEND_FACTOR_ONE** in color blend factors. There is no way to avoid copying these undefined values when copying from such an image to another image or buffer.

2. The **AHARDWAREBUFFER_USAGE_GPU_MIPMAP_COMPLETE** flag does not correspond to a Vulkan image usage or creation flag. Instead, its presence indicates that the Android hardware buffer contains a complete mipmap chain, and its absence indicates that the Android hardware buffer contains only a single mip level.

3. Only image usages valid for the format are valid. It would be invalid to take a Android Hardware Buffer with a format of **AHARDWAREBUFFER_FORMAT_R8G8B8A8_UNORM** that has a
AHARDWAREBUFFER_USAGE_GPU_FRAMEBUFFER usage and try to create an image with
VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT.

4

In combination with a hardware buffer format other than BLOB.

Note
When using VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT with Android hardware buffer images, applications should use VkImageFormatListCreateInfo to inform the implementation which view formats will be used with the image. For some common sets of format, this allows some implementations to provide significantly better performance when accessing the image via Vulkan.

Android Hardware Buffer Buffer Resources

Android hardware buffers with a format of AHARDWAREBUFFER_FORMAT_BLOB and usage that includes AHARDWAREBUFFER_USAGE_GPU_DATA_BUFFER can be used as the backing store for VkBuffer objects. Such Android hardware buffers have a size in bytes specified by their width; height and layers are both 1.

Unlike images, buffer resources backed by Android hardware buffers do not require dedicated allocations.

Exported AHardwareBuffer objects that do not have dedicated images must have a format of AHARDWAREBUFFER_FORMAT_BLOB, usage must include AHARDWAREBUFFER_USAGE_GPU_DATA_BUFFER, width must equal the device memory allocation size, and height and layers must be 1.

QNX Screen Buffer

The QNX SDP defines _screen_buffer objects, which represent a buffer that the QNX Screen graphics subsystem can use directly in its windowing system APIs. More specifically, a Screen buffer is an area of memory that stores pixel data. It can be attached to Screen windows, streams, or pixmaps. These QNX Screen buffer objects may be imported into VkDeviceMemory objects for access via Vulkan. An VkImage or VkBuffer can be bound to the imported VkDeviceMemory object if it is created with VK_EXTERNAL_MEMORY_HANDLE_TYPE_SCREEN_BUFFER_BIT_QNX.

_struct_ _screen_ _buffer is strongly typed, so naming the handle type is redundant. The internal layout and therefore size of a struct _screen_buffer image may depend on native usage flags that do not have corresponding Vulkan counterparts.

QNX Screen Buffer Validity

The design of Screen in the QNX SDP makes it difficult to determine the validity of objects from outside of Screen. Therefore, applications must ensure that QNX Screen buffer objects provided used in various Vulkan interfaces are ones created explicitly with QNX Screen APIs. See QNX SDP documentation for more information.

A VkDeviceMemory imported from a QNX Screen buffer has no way to acquire a reference to its _screen_buffer object. Therefore, during the host execution of a Vulkan command that has a QNX Screen buffer as a parameter (including indirect parameters via pNext chains), the application must
ensure that the QNX Screen buffer resource remains valid.

Generally, for a _screen_buffer object to be valid for use within a Vulkan implementation, the buffer object **should** have a _screen_buffer::SCREEN_PROPERTY_USAGE that includes at least one of: SCREEN_USAGE_VULKAN, SCREEN_USAGE_OPENGL_ES2, SCREEN_USAGE_OPENGL_ES3, or SCREEN_USAGE_NATIVE. The exact Screen-native usage flags required depends on the Vulkan implementation, and QNX Screen itself will not necessarily enforce these requirements. Note that Screen-native usage flags are in no way related to usage flags in the Vulkan specification.

**QNX Screen Buffer External Formats**

QNX Screen buffers **may** represent images using implementation-specific formats, layouts, color models, etc., which do not have Vulkan equivalents. Such external formats are commonly used by external image sources such as video decoders or cameras. Vulkan **can** import QNX Screen buffers that have external formats, but since the image contents are in an undiscoverable and possibly proprietary representation, images with external formats **must** only be used as sampled images, **must** only be sampled with a sampler that has Y′C_bC_r conversion enabled, and **must** have optimal tiling.

Images that will be backed by a QNX Screen buffer **can** use an external format by setting VkImageCreateInfo::format to VK_FORMAT_UNDEFINED and including a VkExternalFormatQNX structure in the pNext chain. Images **can** be created with an external format even if the QNX Screen buffer has a format which has an equivalent Vulkan format to enable consistent handling of images from sources that might use either category of format. The external format of a QNX Screen buffer **can** be obtained by passing a VkScreenBufferFormatPropertiesQNX structure to vkGetScreenBufferPropertiesQNX.

**QNX Screen Buffer Image Resources**

QNX Screen buffers have intrinsic width, height, format, and usage properties, so Vulkan images bound to memory imported from a QNX Screen buffer **must** use dedicated allocations: VkMemoryDedicatedRequirements::requiresDedicatedAllocation **must** be VK_TRUE for images created with VkExternalMemoryImageCreateInfo::handleTypes that includes VK_EXTERNAL_MEMORY_HANDLE_TYPE_SCREEN_BUFFER_BIT_QNX. When creating an image that will be bound to an imported QNX Screen buffer, the image creation parameters **must** be equivalent to the _screen_buffer properties as described by the valid usage of VkMemoryAllocateInfo.

**Table 15. QNX Screen Buffer Format Equivalence**

<table>
<thead>
<tr>
<th>QNX Screen Format</th>
<th>Vulkan Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCREEN_FORMAT_RGBA8888</td>
<td>VK_FORMAT_B8G8R8A8_UNORM</td>
</tr>
<tr>
<td>SCREEN_FORMAT_RGBA8888 1</td>
<td>VK_FORMAT_B8G8R8A8_UNORM</td>
</tr>
<tr>
<td>SCREEN_FORMAT_RGBX8888</td>
<td>VK_FORMAT_B8G8R8A8_UNORM</td>
</tr>
<tr>
<td>SCREEN_FORMAT_BGRX8888 1</td>
<td>VK_FORMAT_B8G8R8A8_UNORM</td>
</tr>
<tr>
<td>SCREEN_FORMAT_RGBA1010102</td>
<td>VK_FORMAT_A2R10G10B10_UNORM_PACK32</td>
</tr>
<tr>
<td>SCREEN_FORMAT_RGBA1010102 1</td>
<td>VK_FORMAT_A2R10G10B10_UNORM_PACK32</td>
</tr>
<tr>
<td>SCREEN_FORMAT_BGRX1010102</td>
<td>VK_FORMAT_A2B10G10R10_UNORM_PACK32</td>
</tr>
</tbody>
</table>

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Vulkan does not differentiate between `SCREEN_FORMAT_RGBA8888` and `SCREEN_FORMAT_RGBX8888`: they both behave as `VK_FORMAT_R8G8B8A8_UNORM`. After an external entity writes to a `SCREEN_FORMAT_RGBX8888` QNX Screen buffer, the values read by Vulkan from the X/A component are undefined. To emulate the traditional behavior of the X component during sampling or blending, applications should use `VK_COMPONENT_SWIZZLE_ONE` in image view component mappings and `VK_BLEND_FACTOR_ONE` in color blend factors. There is no way to avoid copying these undefined values when copying from such an image to another image or buffer. The same behavior applies to the following pairs: `SCREEN_FORMAT_BGRA8888` and `SCREEN_FORMAT_BGRX8888`, `SCREEN_FORMAT_RGBA1010102` and `SCREEN_FORMAT_RGBX1010102`, `SCREEN_FORMAT_BGRA1010102` and `SCREEN_FORMAT_BGRX1010102`, `SCREEN_FORMAT_RGBA5551` and `SCREEN_FORMAT_RGBX5551`.

### 11.2.19. Peer Memory Features

Peermemory is memory that is allocated for a given physical device and then bound to a resource and accessed by a different physical device, in a logical device that represents multiple physical devices. Some ways of reading and writing peer memory may not be supported by a device.

To determine how peer memory can be accessed, call:

```c
// Provided by VK_VERSION_1_1
void vkGetDeviceGroupPeerMemoryFeatures(
    VkDevice device,
    uint32_t heapIndex,
    uint32_t localDeviceIndex,
    uint32_t remoteDeviceIndex,
    VkPeerMemoryFeatureFlags* pPeerMemoryFeatures);
```

or the equivalent command

```c
// Provided by VK_KHR_device_group
void vkGetDeviceGroupPeerMemoryFeaturesKHR(
    VkDevice device,
    uint32_t heapIndex,
    uint32_t localDeviceIndex,
    uint32_t remoteDeviceIndex,
    VkPeerMemoryFeatureFlags* pPeerMemoryFeatures);
```
• **device** is the logical device that owns the memory.

• **heapIndex** is the index of the memory heap from which the memory is allocated.

• **localDeviceIndex** is the device index of the physical device that performs the memory access.

• **remoteDeviceIndex** is the device index of the physical device that the memory is allocated for.

• **pPeerMemoryFeatures** is a pointer to a `VkPeerMemoryFeatureFlags` bitmask indicating which types of memory accesses are supported for the combination of heap, local, and remote devices.

---

### Valid Usage

- **VUID-vkGetDeviceGroupPeerMemoryFeatures-heapIndex-00691**
  heapIndex **must** be less than `memoryHeapCount`

- **VUID-vkGetDeviceGroupPeerMemoryFeatures-localDeviceIndex-00692**
  localDeviceIndex **must** be a valid device index

- **VUID-vkGetDeviceGroupPeerMemoryFeatures-remoteDeviceIndex-00693**
  remoteDeviceIndex **must** be a valid device index

- **VUID-vkGetDeviceGroupPeerMemoryFeatures-localDeviceIndex-00694**
  localDeviceIndex **must** not equal remoteDeviceIndex

---

### Valid Usage (Implicit)

- **VUID-vkGetDeviceGroupPeerMemoryFeatures-device-parameter**
  device **must** be a valid `VkDevice` handle

- **VUID-vkGetDeviceGroupPeerMemoryFeatures-pPeerMemoryFeatures-parameter**
  pPeerMemoryFeatures **must** be a valid pointer to a `VkPeerMemoryFeatureFlags` value

---

Bits which **may** be set in `vkGetDeviceGroupPeerMemoryFeatures::pPeerMemoryFeatures`, indicating supported peer memory features, are:

```c
// Provided by VK_VERSION_1_1
typedef enum VkPeerMemoryFeatureFlagBits {
    VK_PEER_MEMORY_FEATURE_COPY_SRC_BIT = 0x00000001,
    VK_PEER_MEMORY_FEATURE_COPY_DST_BIT = 0x00000002,
    VK_PEER_MEMORY_FEATURE_GENERIC_SRC_BIT = 0x00000004,
    VK_PEER_MEMORY_FEATURE_GENERIC_DST_BIT = 0x00000008,

    // Provided by VK_KHR_device_group
    VK_PEER_MEMORY_FEATURE_COPY_SRC_BIT_KHR = VK_PEER_MEMORY_FEATURE_COPY_SRC_BIT,
    VK_PEER_MEMORY_FEATURE_COPY_DST_BIT_KHR = VK_PEER_MEMORY_FEATURE_COPY_DST_BIT,
    VK_PEER_MEMORY_FEATURE_GENERIC_SRC_BIT_KHR = VK_PEER_MEMORY_FEATURE_GENERIC_SRC_BIT,
    VK_PEER_MEMORY_FEATURE_GENERIC_DST_BIT_KHR = VK_PEER_MEMORY_FEATURE_GENERIC_DST_BIT,
}
```
or the equivalent

// Provided by VK_KHR_device_group
typedef VkPeerMemoryFeatureFlagBits VkPeerMemoryFeatureFlagBitsKHR;

- **VK_PEER_MEMORY_FEATURE_COPY_SRC_BIT** specifies that the memory can be accessed as the source of any `vkCmdCopy*` command.
- **VK_PEER_MEMORY_FEATURE_COPY_DST_BIT** specifies that the memory can be accessed as the destination of any `vkCmdCopy*` command.
- **VK_PEER_MEMORY_FEATURE_GENERIC_SRC_BIT** specifies that the memory can be read as any memory access type.
- **VK_PEER_MEMORY_FEATURE_GENERIC_DST_BIT** specifies that the memory can be written as any memory access type. Shader atomics are considered to be writes.

<table>
<thead>
<tr>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>The peer memory features of a memory heap also apply to any accesses that may be performed during image layout transitions.</td>
</tr>
</tbody>
</table>

**VK_PEER_MEMORY_FEATURE_COPY_DST_BIT** must be supported for all host local heaps and for at least one device-local memory heap.

If a device does not support a peer memory feature, it is still valid to use a resource that includes both local and peer memory bindings with the corresponding access type as long as only the local bindings are actually accessed. For example, an application doing split-frame rendering would use framebuffer attachments that include both local and peer memory bindings, but would scissor the rendering to only update local memory.

// Provided by VK_VERSION_1_1
typedef VkFlags VkPeerMemoryFeatureFlags;

or the equivalent

// Provided by VK_KHR_device_group
typedef VkPeerMemoryFeatureFlags VkPeerMemoryFeatureFlagsKHR;

`VkPeerMemoryFeatureFlags` is a bitmask type for setting a mask of zero or more `VkPeerMemoryFeatureFlagBits`.

### 11.2.20. Opaque Capture Address Query

To query a 64-bit opaque capture address value from a memory object, call:
or the equivalent command

```c
// Provided by VK_KHR_buffer_device_address
uint64_t vkGetDeviceMemoryOpaqueCaptureAddressKHR(
  VkDevice device,
  const VkDeviceMemoryOpaqueCaptureAddressInfo* pInfo);
```

- `device` is the logical device that the memory object was allocated on.
- `pInfo` is a pointer to a `VkDeviceMemoryOpaqueCaptureAddressInfo` structure specifying the memory object to retrieve an address for.

The 64-bit return value is an opaque address representing the start of `pInfo->memory`.

If the memory object was allocated with a non-zero value of `VkMemoryOpaqueCaptureAddressAllocateInfo::opaqueCaptureAddress`, the return value must be the same address.

**Note**
The expected usage for these opaque addresses is only for trace capture/replay tools to store these addresses in a trace and subsequently specify them during replay.

**Valid Usage**

- **VUID-vkGetDeviceMemoryOpaqueCaptureAddress-None-03334**
  The `bufferDeviceAddress` feature must be enabled

- **VUID-vkGetDeviceMemoryOpaqueCaptureAddress-device-03335**
  If `device` was created with multiple physical devices, then the `bufferDeviceAddressMultiDevice` feature must be enabled

**Valid Usage (Implicit)**

- **VUID-vkGetDeviceMemoryOpaqueCaptureAddress-device-parameter**
  `device` must be a valid `VkDevice` handle

- **VUID-vkGetDeviceMemoryOpaqueCaptureAddress-pInfo-parameter**
  `pInfo` must be a valid pointer to a valid `VkDeviceMemoryOpaqueCaptureAddressInfo` structure
The `VkDeviceMemoryOpaqueCaptureAddressInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkDeviceMemoryOpaqueCaptureAddressInfo {
    VkStructureType sType;
    const void* pNext;
    VkDeviceMemory memory;
} VkDeviceMemoryOpaqueCaptureAddressInfo;
```

or the equivalent

```c
// Provided by VK_KHR_buffer_device_address
typedef VkDeviceMemoryOpaqueCaptureAddressInfo
VkDeviceMemoryOpaqueCaptureAddressInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `memory` specifies the memory whose address is being queried.

### Valid Usage

- VUID-VkDeviceMemoryOpaqueCaptureAddressInfo-memory-03336  
  `memory` must have been allocated with `VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT`

### Valid Usage (Implicit)

- VUID-VkDeviceMemoryOpaqueCaptureAddressInfo-sType-sType  
  `sType` must be `VK_STRUCTURE_TYPE_DEVICE_MEMORY_OPAQUE_CAPTURE_ADDRESS_INFO`

- VUID-VkDeviceMemoryOpaqueCaptureAddressInfo-pNext-pNext  
  `pNext` must be `NULL`

- VUID-VkDeviceMemoryOpaqueCaptureAddressInfo-memory-parameter  
  `memory` must be a valid `VkDeviceMemory` handle
Chapter 12. Resource Creation

Vulkan supports two primary resource types: buffers and images. Resources are views of memory with associated formatting and dimensionality. Buffers provide access to raw arrays of bytes, whereas images can be multidimensional and may have associated metadata.

Other resource types, such as acceleration structures and micromaps use buffers as the backing store for opaque data structures.

12.1. Buffers

Buffers represent linear arrays of data which are used for various purposes by binding them to a graphics or compute pipeline via descriptor sets or certain commands, or by directly specifying them as parameters to certain commands.

Buffers are represented by VkBuffer handles:

```cpp
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkBuffer)
```

To create buffers, call:

```cpp
// Provided by VK_VERSION_1_0
VkResult vkCreateBuffer(
    VkDevice device, // Logical device
    const VkBufferCreateInfo* pCreateInfo, // Pointer to VkBufferCreateInfo structure
    const VkAllocationCallbacks* pAllocator, // Controls host memory allocation
    VkBuffer* pBuffer // Pointer to VkBuffer handle in which the resulting buffer object is returned
);
```

- **device** is the logical device that creates the buffer object.
- **pCreateInfo** is a pointer to a VkBufferCreateInfo structure containing parameters affecting creation of the buffer.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
- **pBuffer** is a pointer to a VkBuffer handle in which the resulting buffer object is returned.

**Valid Usage**

- **VUID-vkCreateBuffer-flags-00911**
  If the flags member of pCreateInfo includes VK_BUFFER_CREATE_SPARSE_BINDING_BIT, creating this VkBuffer must not cause the total required sparse memory for all currently valid sparse resources on the device to exceed VkPhysicalDeviceLimits::sparseAddressSpaceSize.

- **VUID-vkCreateBuffer-pNext-06387**
  If using the VkBuffer for an import operation from a VkBufferCollectionFUCHSIA where a
**VkBufferCollectionBufferCreateInfoFUCHSIA** has been chained to **pNext**, **pCreateInfo** must match the **VkBufferConstraintsInfoFUCHSIA::createInfo** used when setting the constraints on the buffer collection with **vkSetBufferCollectionBufferConstraintsFUCHSIA**

### Valid Usage (Implicit)

- **VUID-vkCreateBuffer-device-parameter**
  
  device must be a valid **VkDevice** handle

- **VUID-vkCreateBuffer-pCreateInfo-parameter**
  
  pCreateInfo must be a valid pointer to a valid **VkBufferCreateInfo** structure

- **VUID-vkCreateBuffer-pAllocator-parameter**
  
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid **VkAllocationCallbacks** structure

- **VUID-vkCreateBuffer-pBuffer-parameter**
  
  pBuffer must be a valid pointer to a **VkBuffer** handle

### Return Codes

**Success**

- **VK_SUCCESS**

**Failure**

- **VK_ERROR_OUT_OF_HOST_MEMORY**
- **VK_ERROR_OUT_OF_DEVICE_MEMORY**
- **VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS_KHR**

The **VkBufferCreateInfo** structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkBufferCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkBufferCreateFlags flags;
    VkDeviceSize size;
    VkBufferUsageFlags usage;
    VkSharingMode sharingMode;
    uint32_t queueFamilyIndexCount;
    const uint32_t* pQueueFamilyIndices;
} VkBufferCreateInfo;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
• **flags** is a bitmask of **VkBufferCreateFlagBits** specifying additional parameters of the buffer.
• **size** is the size in bytes of the buffer to be created.
• **usage** is a bitmask of **VkBufferUsageFlagBits** specifying allowed usages of the buffer.
• **sharingMode** is a **VkSharingMode** value specifying the sharing mode of the buffer when it will be accessed by multiple queue families.

• **queueFamilyIndexCount** is the number of entries in the **pQueueFamilyIndices** array.
• **pQueueFamilyIndices** is a pointer to an array of queue families that will access this buffer. It is ignored if **sharingMode** is not **VK_SHARING_MODE_CONCURRENT**.

If a **VkBufferUsageFlags2CreateInfoKHR** structure is present in the **pNext** chain, **VkBufferUsageFlags2CreateInfoKHR::usage** from that structure is used instead of **usage** from this structure.

### Valid Usage

- **VUID-VkBufferCreateInfo-size-00912**
  - **size must** be greater than 0

- **VUID-VkBufferCreateInfo-sharingMode-00913**
  - If **sharingMode** is **VK_SHARING_MODE_CONCURRENT**, **pQueueFamilyIndices must** be a valid pointer to an array of **queueFamilyIndexCount** uint32_t values

- **VUID-VkBufferCreateInfo-sharingMode-00914**
  - If **sharingMode** is **VK_SHARING_MODE_CONCURRENT**, **queueFamilyIndexCount must** be greater than 1

- **VUID-VkBufferCreateInfo-sharingMode-01419**
  - If **sharingMode** is **VK_SHARING_MODE_CONCURRENT**, each element of **pQueueFamilyIndices must** be unique and **must** be less than **pQueueFamilyPropertyCount** returned by either **vkGetPhysicalDeviceQueueFamilyProperties** or **vkGetPhysicalDeviceQueueFamilyProperties2** for the **physicalDevice** that was used to create **device**

- **VUID-VkBufferCreateInfo-flags-00915**
  - If the **sparseBinding** feature is not enabled, **flags must** not contain **VK_BUFFER_CREATE_SPARSE_BINDING_BIT**

- **VUID-VkBufferCreateInfo-flags-00916**
  - If the **sparseResidencyBuffer** feature is not enabled, **flags must** not contain **VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT**

- **VUID-VkBufferCreateInfo-flags-00917**
  - If the **sparseResidencyAliased** feature is not enabled, **flags must** not contain **VK_BUFFER_CREATE_SPARSE_ALIASED_BIT**

- **VUID-VkBufferCreateInfo-flags-00918**
  - If **flags contains **VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT** or **VK_BUFFER_CREATE_SPARSE_ALIASED_BIT** it **must also** contain **VK_BUFFER_CREATE_SPARSE_BINDING_BIT**

- **VUID-VkBufferCreateInfo-pNext-00920**
If the `pNext` chain includes a `VkExternalMemoryBufferCreateInfo` structure, its `handleTypes` member must only contain bits that are also in `VkExternalBufferProperties::externalMemoryProperties.compatibleHandleTypes`, as returned by `vkGetPhysicalDeviceExternalBufferProperties` with `pExternalBufferInfo->handleType` equal to any one of the handle types specified in `VkExternalMemoryBufferCreateInfo::handleTypes`.

- VUID-VkBufferCreateInfo-flags-01887
  If the `protectedMemory` feature is not enabled, flags must not contain `VK_BUFFER_CREATE_PROTECTED_BIT`.

- VUID-VkBufferCreateInfo-None-01888
  If any of the bits `VK_BUFFER_CREATE_SPARSE_BINDING_BIT`, `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT`, or `VK_BUFFER_CREATE_SPARSE_ALIASED_BIT` are set, `VK_BUFFER_CREATE_PROTECTED_BIT` must not also be set.

- VUID-VkBufferCreateInfo-pNext-01571
  If the `pNext` chain includes a `VkDedicatedAllocationBufferCreateInfoNV` structure, and the `dedicatedAllocation` member of the chained structure is `VK_TRUE`, then flags must not include `VK_BUFFER_CREATE_SPARSE_BINDING_BIT`, `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT`, or `VK_BUFFER_CREATE_SPARSE_ALIASED_BIT`.

- VUID-VkBufferCreateInfo-deviceAddress-02604
  If `VkBufferDeviceAddressCreateInfoEXT::deviceAddress` is not zero, flags must include `VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT`.

- VUID-VkBufferCreateInfo-opaqueCaptureAddress-03337
  If `VkBufferOpaqueCaptureAddressCreateInfo::opaqueCaptureAddress` is not zero, flags must include `VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT`.

- VUID-VkBufferCreateInfo-flags-03338
  If flags includes `VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT`, the `bufferDeviceAddressCaptureReplay` or `bufferDeviceAddressCaptureReplayEXT` feature must be enabled.

- VUID-VkBufferCreateInfo-usage-04813
  If `usage` includes `VK_BUFFER_USAGE_VIDEO_DECODE_SRC_BIT_KHR` or `VK_BUFFER_USAGE_VIDEO_DECODE_DST_BIT_KHR`, then the `pNext` chain must include a `VkVideoProfileListInfoKHR` structure with `profileCount` greater than 0 and `pProfiles` including at least one `VkVideoProfileInfoKHR` structure with a `videoCodecOperation` member specifying a decode operation.

- VUID-VkBufferCreateInfo-usage-04814
  If `usage` includes `VK_BUFFER_USAGE_VIDEO_ENCODE_SRC_BIT_KHR` or `VK_BUFFER_USAGE_VIDEO_ENCODE_DST_BIT_KHR`, then the `pNext` chain must include a `VkVideoProfileListInfoKHR` structure with `profileCount` greater than 0 and `pProfiles` including at least one `VkVideoProfileInfoKHR` structure with a `videoCodecOperation` member specifying an encode operation.

- VUID-VkBufferCreateInfo-size-06409
  Size must be less than or equal to `VkPhysicalDeviceMaintenance4Properties::maxBufferSize`.

- VUID-VkBufferCreateInfo-usage-08097
  953
If `usage` includes `VK_BUFFER_USAGE_SAMPLER_DESCRIPTOR_BUFFER_BIT_EXT`, creating this `VkBuffer` must not cause the total required space for all currently valid buffers using this flag on the device to exceed `VkPhysicalDeviceDescriptorBufferPropertiesEXT::samplerDescriptorBufferAddressSpaceSize` or `VkPhysicalDeviceDescriptorBufferPropertiesEXT::descriptorBufferAddressSpaceSize`

- **VUID-VkBufferCreateInfo-usage-08098**
  If `usage` includes `VK_BUFFER_USAGE_RESOURCE_DESCRIPTOR_BUFFER_BIT_EXT`, creating this `VkBuffer` must not cause the total required space for all currently valid buffers using this flag on the device to exceed `VkPhysicalDeviceDescriptorBufferPropertiesEXT::resourceDescriptorBufferAddressSpaceSize` or `VkPhysicalDeviceDescriptorBufferPropertiesEXT::descriptorBufferAddressSpaceSize`

- **VUID-VkBufferCreateInfo-flags-08099**
  If `flags` includes `VK_BUFFER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT`, the `descriptorBufferCaptureReplay` feature must be enabled

- **VUID-VkBufferCreateInfo-pNext-08100**
  If the `pNext` chain includes a `VkOpaqueCaptureDescriptorDataCreateInfoEXT` structure, `flags` must contain `VK_BUFFER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT`

- **VUID-VkBufferCreateInfo-usage-08101**
  If `usage` includes `VK_BUFFER_USAGE_PUSH_DESCRIPTORS_DESCRIPTOR_BUFFER_BIT_EXT`, the `descriptorBufferPushDescriptors` feature must be enabled

- **VUID-VkBufferCreateInfo-usage-08102**
  If `usage` includes `VK_BUFFER_USAGE_PUSH_DESCRIPTORS_DESCRIPTOR_BUFFER_BIT_EXT`, `VkPhysicalDeviceDescriptorBufferPropertiesEXT::bufferlessPushDescriptors` must be `VK_FALSE`

- **VUID-VkBufferCreateInfo-usage-08103**
  If `usage` includes `VK_BUFFER_USAGE_PUSH_DESCRIPTORS_DESCRIPTOR_BUFFER_BIT_EXT`, `usage` must contain at least one of `VK_BUFFER_USAGE_RESOURCE_DESCRIPTOR_BUFFER_BIT_EXT` or `VK_BUFFER_USAGE_SAMPLER_DESCRIPTOR_BUFFER_BIT_EXT`

- **VUID-VkBufferCreateInfo-None-09205**
  If the `pNext` chain does not include a `VkBufferUsageFlags2CreateInfoKHR` structure, `usage` must be a valid combination of `VkBufferUsageFlagBits` values

- **VUID-VkBufferCreateInfo-None-09206**
  If the `pNext` chain does not include a `VkBufferUsageFlags2CreateInfoKHR` structure, `usage` must not be 0

---

**Valid Usage (Implicit)**

- **VUID-VkBufferCreateInfo-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_BUFFER_CREATE_INFO`

- **VUID-VkBufferCreateInfo-pNext-pNext**
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkBufferCollectionBufferCreateInfoFUCHSIA`, `VkBufferDeviceAddressCreateInfoEXT`, `VkBufferOpaqueCaptureAddressCreateInfo`, `VkBufferOpaqueCaptureAddressCreateInfo`
The `VkBufferUsageFlags2CreateInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_maintenance5
typedef struct VkBufferUsageFlags2CreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkBufferUsageFlags2KHR usage;
} VkBufferUsageFlags2CreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `usage` is a bitmask of `VkBufferUsageFlagBits2KHR` specifying allowed usages of the buffer.

If this structure is included in the `pNext` chain of a buffer creation structure, `usage` is used instead of the corresponding `usage` value passed in that creation structure, allowing additional usage flags to be specified. If this structure is included in the `pNext` chain of a buffer query structure, the usage flags of the buffer are returned in `usage` of this structure, and the usage flags representable in `usage` of the buffer query structure are also returned in that field.

**Valid Usage (Implicit)**

- `VUID-VkBufferUsageFlags2CreateInfoKHR-sType-sType` 
  `sType` must be `VK_STRUCTURE_TYPE_BUFFER_USAGE_FLAGS_2_CREATE_INFO_KHR`

- `VUID-VkBufferUsageFlags2CreateInfoKHR-usage-parameter` 
  `usage` must be a valid combination of `VkBufferUsageFlagBits2KHR` values

- `VUID-VkBufferUsageFlags2CreateInfoKHR-usage-requiredbitmask` 
  `usage` must not be 0

Bits which can be set in `VkBufferUsageFlags2CreateInfoKHR::usage`, specifying usage behavior of a buffer, are:

```c
// Provided by VK_KHR_maintenance5
// Flag bits for VkBufferUsageFlagBits2KHR
```
typedef VkFlags64 VkBufferUsageFlagBits2KHR;
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_TRANSFER_SRC_BIT_KHR = 0x00000001ULL;
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_TRANSFER_DST_BIT_KHR = 0x00000002ULL;
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_UNIFORM_TEXEL_BUFFER_BIT_KHR = 0x00000004ULL;
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_STORAGE_TEXEL_BUFFER_BIT_KHR = 0x00000008ULL;
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_UNIFORM_BUFFER_BIT_KHR = 0x00000010ULL;
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_STORAGE_BUFFER_BIT_KHR = 0x00000020ULL;
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_INDEX_BUFFER_BIT_KHR = 0x00000040ULL;
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_VERTEX_BUFFER_BIT_KHR = 0x00000080ULL;
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_INDIRECT_BUFFER_BIT_KHR = 0x00000100ULL;
// Provided by VK_KHR_maintenance5 with VK_AMDX_shader_enqueue
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_EXECUTION_GRAPH_SCRATCH_BIT_AMDX = 0x02000000ULL;
// Provided by VK_KHR_maintenance5 with VK_EXT_conditional_rendering
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_CONDITIONAL_RENDERING_BIT_EXT = 0x00000200ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_ray_tracing_pipeline
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_SHADER_BINDING_TABLE_BIT_KHR = 0x00000400ULL;
// Provided by VK_KHR_maintenance5 with VK_KHR_video_decode_queue
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_VIDEO_DECODE_SRC_BIT_KHR = 0x00002000ULL;
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_VIDEO_DECODE_DST_BIT_KHR = 0x00004000ULL;
#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_maintenance5 with VK_KHR_video_encode_queue
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_VIDEO_ENCODE_DST_BIT_KHR = 0x00008000ULL;
#endif
#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_maintenance5 with VK_KHR_video_encode_queue
static const VkBufferUsageFlagBits2KHR VK_BUFFER_USAGE_2_VIDEO_ENCODE_SRC_BIT_KHR = 0x00000100ULL;
#endif
#if 0
#else
#endif
VK_BUFFER_USAGE_2_TRANSFER_SRC_BIT_KHR specifies that the buffer can be used as the source of a transfer command (see the definition of VK_PIPELINE_STAGE_TRANSFER_BIT).

VK_BUFFER_USAGE_2TRANSFER_DST_BIT_KHR specifies that the buffer can be used as the destination of a transfer command.

VK_BUFFER_USAGE_2_UNIFORM_TEXEL_BUFFER_BIT_KHR specifies that the buffer can be used to create a VkBufferView suitable for occupying a VkDescriptorSet slot of type VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER.

VK_BUFFER_USAGE_2_STORAGE_TEXEL_BUFFER_BIT_KHR specifies that the buffer can be used to create a VkBufferView suitable for occupying a VkDescriptorSet slot of type VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER.

VK_BUFFER_USAGE_2_UNIFORM_BUFFER_BIT_KHR specifies that the buffer can be used in a VkDescriptorBufferInfo suitable for occupying a VkDescriptorSet slot either of type VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER or VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC.

VK_BUFFER_USAGE_2_STORAGE_BUFFER_BIT_KHR specifies that the buffer can be used in a VkDescriptorBufferInfo suitable for occupying a VkDescriptorSet slot either of type VK_DESCRIPTOR_TYPE_STORAGE_BUFFER or VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC.

VK_BUFFER_USAGE_2_INDEX_BUFFER_BIT_KHR specifies that the buffer is suitable for passing as the buffer parameter to vkCmdBindIndexBuffer2KHR and vkCmdBindIndexBuffer.
- **VK_BUFFER_USAGE_2_VERTEX_BUFFER_BIT_KHR** specifies that the buffer is suitable for passing as an element of the pBuffers array to `vkCmdBindVertexBuffers`.

- **VK_BUFFER_USAGE_2_INDIRECT_BUFFER_BIT_KHR** specifies that the buffer is suitable for passing as the buffer parameter to `vkCmdDrawIndirect`, `vkCmdDrawIndexedIndirect`, `vkCmdDrawMeshTasksIndirectNV`, `vkCmdDrawMeshTasksIndirectCountNV`, `vkCmdDrawMeshTasksIndirectEXT`, `vkCmdDrawMeshTasksIndirectCountEXT`, `vkCmdDrawClusterIndirectHUAWEI`, or `vkCmdDispatchIndirect`. It is also suitable for passing as the buffer member of `VkIndirectCommandsStreamNV`, or `sequencesCountBuffer` or `sequencesIndexBuffer` or `preprocessedBuffer` member of `VkGeneratedCommandsInfoNV`.

- **VK_BUFFER_USAGE_2_CONDITIONAL_RENDERING_BIT_EXT** specifies that the buffer is suitable for passing as the buffer parameter to `vkCmdBeginConditionalRenderingEXT`.

- **VK_BUFFER_USAGE_2_TRANSFORM_FEEDBACK_BUFFER_BIT_EXT** specifies that the buffer is suitable for using for binding as a transform feedback buffer with `vkCmdBindTransformFeedbackBuffersEXT`.

- **VK_BUFFER_USAGE_2_TRANSFORM_FEEDBACK_COUNTER_BUFFER_BIT_EXT** specifies that the buffer is suitable for using as a counter buffer with `vkCmdBeginTransformFeedbackEXT` and `vkCmdEndTransformFeedbackEXT`.

- **VK_BUFFER_USAGE_2_SAMPLER_DESCRIPTOR_BUFFER_BIT_EXT** specifies that the buffer is suitable to contain sampler and combined image sampler descriptors when bound as a descriptor buffer. Buffers containing combined image sampler descriptors must also specify **VK_BUFFER_USAGE_2_RESOURCE_DESCRIPTOR_BUFFER_BIT_EXT**.

- **VK_BUFFER_USAGE_2_RESOURCE_DESCRIPTOR_BUFFER_BIT_EXT** specifies that the buffer is suitable to contain resource descriptors when bound as a descriptor buffer.

- **VK_BUFFER_USAGE_2_PUSH_DESCRIPTORS_DESCRIPTOR_BUFFER_BIT_EXT** specifies that the buffer, when bound, can be used by the implementation to support push descriptors when using descriptor buffers.

- **VK_BUFFER_USAGE_2_RAY_TRACING_BIT_NV** specifies that the buffer is suitable for use in `vkCmdTraceRaysNV`.

- **VK_BUFFER_USAGE_2_SHADER_BINDING_TABLE_BIT_KHR** specifies that the buffer is suitable for use as a Shader Binding Table.

- **VK_BUFFER_USAGE_2_ACCELERATION_STRUCTURE_BUILD_INPUT_READ_ONLY_BIT_KHR** specifies that the buffer is suitable for use as a read-only input to an acceleration structure build.

- **VK_BUFFER_USAGE_2_ACCELERATION_STRUCTURE_STORAGE_BIT_KHR** specifies that the buffer is suitable for storage space for a `VkAccelerationStructureKHR`.

- **VK_BUFFER_USAGE_2_SHADER_DEVICE_ADDRESS_BIT_KHR** specifies that the buffer can be used to retrieve a buffer device address via `vkGetBufferDeviceAddress` and use that address to access the buffer’s memory from a shader.

- **VK_BUFFER_USAGE_2_VIDEO_DECODE_SRC_BIT_KHR** specifies that the buffer can be used as the source video bitstream buffer in a video decode operation.

- **VK_BUFFER_USAGE_2_VIDEO_DECODE_DST_BIT_KHR** is reserved for future use.

- **VK_BUFFER_USAGE_2_VIDEO_ENCODE_DST_BIT_KHR** specifies that the buffer can be used as the destination video bitstream buffer in a video encode operation.
• `VK_BUFFER_USAGE_2_VIDEO_ENCODE_SRC_BIT_KHR` is reserved for future use.

• `VK_BUFFER_USAGE_2_EXECUTION_GRAPH_SCRATCH_BIT_AMDX` specifies that the buffer can be used for as scratch memory for execution graph dispatch.

```c
// Provided by VK_KHR_maintenance5
typedef VkFlags64 VkBufferUsageFlags2KHR;
```

`VkBufferUsageFlags2KHR` is a bitmask type for setting a mask of zero or more `VkBufferUsageFlagBits2KHR`.

Bits which can be set in `VkBufferCreateInfo::usage`, specifying usage behavior of a buffer, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkVersion_1_0 VkBufferUsageFlagBits {
    VK_BUFFER_USAGE_TRANSFER_SRC_BIT = 0x00000001,
    VK_BUFFER_USAGE_TRANSFER_DST_BIT = 0x00000002,
    VK_BUFFER_USAGE_UNIFORM_TEXEL_BUFFER_BIT = 0x00000004,
    VK_BUFFER_USAGE_STORAGE_TEXEL_BUFFER_BIT = 0x00000008,
    VK_BUFFER_USAGE_UNIFORM_BUFFER_BIT = 0x00000010,
    VK_BUFFER_USAGE_STORAGE_BUFFER_BIT = 0x00000020,
    VK_BUFFER_USAGE_INDEX_BUFFER_BIT = 0x00000040,
    VK_BUFFER_USAGE_VERTEX_BUFFER_BIT = 0x00000080,
    VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT = 0x00000100,
    // Provided by VK_KHR_video_decode_queue
    VK_BUFFER_USAGE_VIDEO_DECODE_SRC_BIT_KHR = 0x00002000,
    VK_BUFFER_USAGE_VIDEO_DECODE_DST_BIT_KHR = 0x00004000,
    // Provided by VK_KHR_video_decode_queue
    VK_BUFFER_USAGE_SHADER_DEVICE_ADDRESS_BIT = 0x00020000,
    // Provided by VK_KHR_video_encode_queue
    VK_BUFFER_USAGE_VIDEO_ENCODE_DST_BIT_KHR = 0x00008000,
    #ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_KHR_shader_enqueue
    VK_BUFFER_USAGE_EXECUTION_GRAPH_SCRATCH_BIT_AMDX = 0x02000000,
    #endif
    // Provided by VK_KHR_acceleration_structure
    VK_BUFFER_USAGE_ACCELERATION_STRUCTURE_BUILD_INPUT_READ_ONLY_BIT_KHR = 0x00080000,
    VK_BUFFER_USAGE_ACCELERATION_STRUCTURE_STORAGE_BIT_KHR = 0x00100000,
    // Provided by VK_KHR_ray_tracing_pipeline
    VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR = 0x00000400,
    #ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_KHR_video_encode_queue
    VK_BUFFER_USAGE_VIDEO_ENCODE_DST_BIT_KHR = 0x00008000,
    #endif
};
```
• **VK_BUFFER_USAGE_TRANSFER_SRC_BIT** specifies that the buffer can be used as the source of a transfer command (see the definition of VK_PIPELINE_STAGE_TRANSFER_BIT).

• **VK_BUFFER_USAGE_TRANSFER_DST_BIT** specifies that the buffer can be used as the destination of a transfer command.

• **VK_BUFFER_USAGE_UNIFORM_TEXEL_BUFFER_BIT** specifies that the buffer can be used to create a VkBufferView suitable for occupying a VkDescriptorSet slot of type VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER.

• **VK_BUFFER_USAGE_STORAGE_TEXEL_BUFFER_BIT** specifies that the buffer can be used to create a VkBufferView suitable for occupying a VkDescriptorSet slot of type VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER.

• **VK_BUFFER_USAGE_UNIFORM_BUFFER_BIT** specifies that the buffer can be used in a VkDescriptorBufferInfo suitable for occupying a VkDescriptorSet slot either of type VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER or VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC.

• **VK_BUFFER_USAGE_STORAGE_BUFFER_BIT** specifies that the buffer can be used in a VkDescriptorBufferInfo suitable for occupying a VkDescriptorSet slot either of type VK_DESCRIPTOR_TYPE_STORAGE_BUFFER or VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC.

• **VK_BUFFER_USAGE_INDEX_BUFFER_BIT** specifies that the buffer is suitable for passing as the buffer parameter to vkCmdBindIndexBuffer2KHR and vkCmdBindIndexBuffer.

• **VK_BUFFER_USAGE_VERTEX_BUFFER_BIT** specifies that the buffer is suitable for passing as an element of the pBuffers array to vkCmdBindVertexBuffers.

• **VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT** specifies that the buffer is suitable for passing as the buffer parameter to vkCmdDrawIndirect, vkCmdDrawIndexedIndirect,
vkCmdDrawMeshTasksIndirectNV, vkCmdDrawMeshTasksIndirectCountNV, vkCmdDrawMeshTasksIndirectEXT, vkCmdDrawMeshTasksIndirectCountEXT, vkCmdDrawClusterIndirectHUAWEI, or vkCmdDispatchIndirect. It is also suitable for passing as the buffer member of VkIndirectCommandsStreamNV, or sequencesCountBuffer or sequencesIndexBuffer or preprocessedBuffer member of VkGeneratedCommandsInfoNV

• VK_BUFFER_USAGE_CONDITIONAL_RENDERING_BIT_EXT specifies that the buffer is suitable for passing as the buffer parameter to vkCmdBeginConditionalRenderingEXT.

• VK_BUFFER_USAGE_TRANSFORM_FEEDBACK_BUFFER_BIT_EXT specifies that the buffer is suitable for using for binding as a transform feedback buffer with vkCmdBindTransformFeedbackBuffersEXT.

• VK_BUFFER_USAGE_TRANSFORM_FEEDBACK_COUNTER_BUFFER_BIT_EXT specifies that the buffer is suitable for using as a counter buffer with vkCmdBeginTransformFeedbackEXT and vkCmdEndTransformFeedbackEXT.

• VK_BUFFER_USAGE_SAMPLER_DESCRIPTOR_BUFFER_BIT_EXT specifies that the buffer is suitable to contain sampler and combined image sampler descriptors when bound as a descriptor buffer. Buffers containing combined image sampler descriptors must also specify VK_BUFFER_USAGE_RESOURCE_DESCRIPTOR_BUFFER_BIT_EXT.

• VK_BUFFER_USAGE_RESOURCE_DESCRIPTOR_BUFFER_BIT_EXT specifies that the buffer is suitable to contain resource descriptors when bound as a descriptor buffer.

• VK_BUFFER_USAGE_PUSH_DESCRIPTORS_DESCRIPTOR_BUFFER_BIT_EXT specifies that the buffer, when bound, can be used by the implementation to support push descriptors when using descriptor buffers.

• VK_BUFFER_USAGE_RAY_TRACING_BIT_NV specifies that the buffer is suitable for use in vkCmdTraceRaysNV.

• VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR specifies that the buffer is suitable for use as a Shader Binding Table.

• VK_BUFFER_USAGE_ACCELERATION_STRUCTURE_BUILD_INPUT_READ_ONLY_BIT_KHR specifies that the buffer is suitable for use as a read-only input to an acceleration structure build.

• VK_BUFFER_USAGE_ACCELERATION_STRUCTURE_STORAGE_BIT_KHR specifies that the buffer is suitable for storage space for a VkAccelerationStructureKHR.

• VK_BUFFER_USAGE_SHADER_DEVICE_ADDRESS_BIT specifies that the buffer can be used to retrieve a buffer device address via vkGetBufferDeviceAddress and use that address to access the buffer’s memory from a shader.

• VK_BUFFER_USAGE_VIDEO_DECODE_SRC_BIT_KHR specifies that the buffer can be used as the source video bitstream buffer in a video decode operation.

• VK_BUFFER_USAGE_VIDEO_DECODE_DST_BIT_KHR is reserved for future use.

• VK_BUFFER_USAGE_VIDEO_ENCODE_DST_BIT_KHR specifies that the buffer can be used as the destination video bitstream buffer in a video encode operation.

• VK_BUFFER_USAGE_VIDEO_ENCODE_SRC_BIT_KHR is reserved for future use.

• VK_BUFFER_USAGE_EXECUTION_GRAPH_SCRATCH_BIT_AMD especifies that the buffer can be used for as scratch memory for execution graph dispatch.
typedef VkFlags VkBufferUsageFlags;

VkBufferUsageFlags is a bitmask type for setting a mask of zero or more VkBufferUsageFlagBits.

Bits which can be set in VkBufferCreateInfo::flags, specifying additional parameters of a buffer, are:

- **VK_BUFFER_CREATE_SPARSE_BINDING_BIT** specifies that the buffer will be backed using sparse memory binding.
- **VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT** specifies that the buffer can be partially backed using sparse memory binding. Buffers created with this flag must also be created with the VK_BUFFER_CREATE_SPARSE_BINDING_BIT flag.
- **VK_BUFFER_CREATE_SPARSE_ALIASED_BIT** specifies that the buffer will be backed using sparse memory binding with memory ranges that might also simultaneously be backing another buffer (or another portion of the same buffer). Buffers created with this flag must also be created with the VK_BUFFER_CREATE_SPARSE_BINDING_BIT flag.
- **VK_BUFFER_CREATE_PROTECTED_BIT** specifies that the buffer is a protected buffer.
- **VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT** specifies that the buffer’s address can be saved and reused on a subsequent run (e.g. for trace capture and replay), see VkBufferOpaqueCaptureAddressCreateInfo for more detail.
- **VK_BUFFER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT** specifies that the buffer can be used with descriptor buffers when capturing and replaying (e.g. for trace capture and replay), see VkOpaqueCaptureDescriptorDataCreateInfoEXT for more detail.

See Sparse Resource Features and Physical Device Features for details of the sparse memory features.
features supported on a device.

// Provided by VK_VERSION_1_0
typedef VkFlags VkBufferCreateFlags;

VkBufferCreateFlags is a bitmask type for setting a mask of zero or more VkBufferCreateFlagBits.

If the pNext chain includes a VkDedicatedAllocationBufferCreateInfoNV structure, then that structure includes an enable controlling whether the buffer will have a dedicated memory allocation bound to it.

The VkDedicatedAllocationBufferCreateInfoNV structure is defined as:

// Provided by VK_NV_dedicated_allocation
typedef struct VkDedicatedAllocationBufferCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkBool32 dedicatedAllocation;
} VkDedicatedAllocationBufferCreateInfoNV;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• dedicatedAllocation specifies whether the buffer will have a dedicated allocation bound to it.

Valid Usage (Implicit)

• VUID-VkDedicatedAllocationBufferCreateInfoNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_DEDICATED_ALLOCATION_BUFFER_CREATE_INFO_NV

To define a set of external memory handle types that may be used as backing store for a buffer, add a VkExternalMemoryBufferCreateInfo structure to the pNext chain of the VkBufferCreateInfo structure. The VkExternalMemoryBufferCreateInfo structure is defined as:

// Provided by VK_VERSION_1_1
typedef struct VkExternalMemoryBufferCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkExternalMemoryHandleTypeFlags handleTypes;
} VkExternalMemoryBufferCreateInfo;

or the equivalent

// Provided by VK_KHR_external_memory
typedef VkExternalMemoryBufferCreateInfo VkExternalMemoryBufferCreateInfoKHR;
A `VkExternalMemoryBufferCreateInfo` structure with a non-zero `handleTypes` field must be included in the creation parameters for a buffer that will be bound to memory that is either exported or imported.

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `handleTypes` is zero or a bitmask of `VkExternalMemoryHandleTypeFlagBits` specifying one or more external memory handle types.

### Valid Usage (Implicit)

- VUID-VkExternalMemoryBufferCreateInfo-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_BUFFER_CREATE_INFO`
- VUID-VkExternalMemoryBufferCreateInfo-handleTypes-parameter
  - `handleTypes` must be a valid combination of `VkExternalMemoryHandleTypeFlagBits` values

To request a specific device address for a buffer, add a `VkBufferOpaqueCaptureAddressCreateInfo` structure to the `pNext` chain of the `VkBufferCreateInfo` structure. The `VkBufferOpaqueCaptureAddressCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkBufferOpaqueCaptureAddressCreateInfo {
    VkStructureType sType;
    const void* pNext;
    uint64_t opaqueCaptureAddress;
} VkBufferOpaqueCaptureAddressCreateInfo;
```

or the equivalent

```c
// Provided by VK_KHR_buffer_device_address
typedef VkBufferOpaqueCaptureAddressCreateInfo VkBufferOpaqueCaptureAddressCreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `opaqueCaptureAddress` is the opaque capture address requested for the buffer.

If `opaqueCaptureAddress` is zero, no specific address is requested.

If `opaqueCaptureAddress` is not zero, then it should be an address retrieved from `vkGetBufferOpaqueCaptureAddress` for an identically created buffer on the same implementation.
If this structure is not present, it is as if `opaqueCaptureAddress` is zero.

Apps **should** avoid creating buffers with app-provided addresses and implementation-provided addresses in the same process, to reduce the likelihood of `VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS` errors.

**Note**

The expected usage for this is that a trace capture/replay tool will add the `VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT` flag to all buffers that use `VK_BUFFER_USAGE_SHADER_DEVICE_ADDRESS_BIT`, and during capture will save the queried opaque device addresses in the trace. During replay, the buffers will be created specifying the original address so any address values stored in the trace data will remain valid.

Implementations are expected to separate such buffers in the GPU address space so normal allocations will avoid using these addresses. Apps/tools should avoid mixing app-provided and implementation-provided addresses for buffers created with `VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT`, to avoid address space allocation conflicts.

---

**Valid Usage (Implicit)**

- `VUID-VkBufferOpaqueCaptureAddressCreateInfo-sType-sType`  
  `sType` **must** be `VK_STRUCTURE_TYPE_BUFFER_OPAQUE_CAPTURE_ADDRESS_CREATE_INFO`  

Alternatively, to request a specific device address for a buffer, add a `VkBufferDeviceAddressCreateInfoEXT` structure to the `pNext` chain of the `VkBufferCreateInfo` structure. The `VkBufferDeviceAddressCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_buffer_device_address
typedef struct VkBufferDeviceAddressCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkDeviceAddress deviceAddress;
} VkBufferDeviceAddressCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `deviceAddress` is the device address requested for the buffer.

If `deviceAddress` is zero, no specific address is requested.

If `deviceAddress` is not zero, then it **must** be an address retrieved from an identically created buffer on the same implementation. The buffer **must** also be bound to an identically created `VkDeviceMemory` object.
If this structure is not present, it is as if `deviceAddress` is zero.

Apps **should** avoid creating buffers with app-provided addresses and implementation-provided addresses in the same process, to reduce the likelihood of `VK_ERROR_INVALID_DEVICE_ADDRESS_EXT` errors.

### Valid Usage (Implicit)

- **VUID-VkBufferDeviceAddressCreateInfoEXT-sType-sType**
  
  `sType` **must** be `VK_STRUCTURE_TYPE_BUFFER_DEVICE_ADDRESS_CREATE_INFO_EXT`

The `VkBufferCollectionBufferCreateInfoFUCHSIA` structure is defined as:

```c
// Provided by VK_FUCHSIA_buffer_collection
typedef struct VkBufferCollectionBufferCreateInfoFUCHSIA {
    VkStructureType sType;
    const void* pNext;
    VkBufferCollectionFUCHSIA collection;
    uint32_t index;
} VkBufferCollectionBufferCreateInfoFUCHSIA;
```

- `sType` **is** a `VkStructureType` **value identifying this structure.**
- `pNext` **is** `NULL` or a pointer to a structure extending this structure
- `collection` **is** the `VkBufferCollectionFUCHSIA` **handle**
- `index` **is** the index of the buffer in the buffer collection from which the memory will be imported

### Valid Usage

- **VUID-VkBufferCollectionBufferCreateInfoFUCHSIA-index-06388**
  
  `index` **must** be less than `VkBufferCollectionPropertiesFUCHSIA::bufferCount`

### Valid Usage (Implicit)

- **VUID-VkBufferCollectionBufferCreateInfoFUCHSIA-sType-sType**
  
  `sType` **must** be `VK_STRUCTURE_TYPE_BUFFER_COLLECTION_BUFFER_CREATE_INFO_FUCHSIA`

- **VUID-VkBufferCollectionBufferCreateInfoFUCHSIA-collection-parameter**
  
  `collection` **must** be a valid `VkBufferCollectionFUCHSIA` **handle**

To destroy a buffer, call:

```c
// Provided by VK_VERSION_1_0
void vkDestroyBuffer(
    VkDevice device,
```
VkBuffer
const VkAllocationCallbacks* pAllocator);

- **device** is the logical device that destroys the buffer.
- **buffer** is the buffer to destroy.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.

**Valid Usage**

- VUID-vkDestroyBuffer-buffer-00922
  All submitted commands that refer to **buffer**, either directly or via a **VkBufferView**, **must** have completed execution
- VUID-vkDestroyBuffer-buffer-00923
  If **VkAllocationCallbacks** were provided when **buffer** was created, a compatible set of callbacks **must** be provided here
- VUID-vkDestroyBuffer-buffer-00924
  If no **VkAllocationCallbacks** were provided when **buffer** was created, **pAllocator** **must** be **NULL**

**Valid Usage (Implicit)**

- VUID-vkDestroyBuffer-device-parameter
  **device** **must** be a valid **VkDevice** handle
- VUID-vkDestroyBuffer-buffer-parameter
  If **buffer** is not **VK_NULL_HANDLE**, **buffer** **must** be a valid **VkBuffer** handle
- VUID-vkDestroyBuffer-pAllocator-parameter
  If **pAllocator** is not **NULL**, **pAllocator** **must** be a valid pointer to a valid **VkAllocationCallbacks** structure
- VUID-vkDestroyBuffer-buffer-parent
  If **buffer** is a valid handle, it **must** have been created, allocated, or retrieved from **device**

**Host Synchronization**

- Host access to **buffer** **must** be externally synchronized

**12.2. Buffer Views**

A **buffer view** represents a contiguous range of a buffer and a specific format to be used to interpret the data. Buffer views are used to enable shaders to access buffer contents using image operations. In order to create a valid buffer view, the **buffer** **must** have been created with at least one of the following usage flags:
Buffer views are represented by `VkBufferView` handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkBufferView)
```

To create a buffer view, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkCreateBufferView(
    VkDevice device,
    const VkBufferViewCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkBufferView* pView);
```

- `device` is the logical device that creates the buffer view.
- `pCreateInfo` is a pointer to a `VkBufferViewCreateInfo` structure containing parameters to be used to create the buffer view.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pView` is a pointer to a `VkBufferView` handle in which the resulting buffer view object is returned.

### Valid Usage (Implicit)

- `VUID-vkCreateBufferView-device-parameter`  
  `device` must be a valid `VkDevice` handle
- `VUID-vkCreateBufferView-pCreateInfo-parameter`  
  `pCreateInfo` must be a valid pointer to a valid `VkBufferViewCreateInfo` structure
- `VUID-vkCreateBufferView-pAllocator-parameter`  
  If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure
- `VUID-vkCreateBufferView-pView-parameter`  
  `pView` must be a valid pointer to a `VkBufferView` handle

### Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
The `VkBufferViewCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkBufferViewCreateInfo {
    VkStructureType           sType;
    const void*               pNext;
    VkBufferViewCreateFlags   flags;
    VkBuffer                  buffer;
    VkFormat                  format;
    VkDeviceSize              offset;
    VkDeviceSize              range;
} VkBufferViewCreateInfo;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **buffer** is a `VkBuffer` on which the view will be created.
- **format** is a `VkFormat` describing the format of the data elements in the buffer.
- **offset** is an offset in bytes from the base address of the buffer. Accesses to the buffer view from shaders use addressing that is relative to this starting offset.
- **range** is a size in bytes of the buffer view. If `range` is equal to `VK_WHOLE_SIZE`, the range from `offset` to the end of the buffer is used. If `VK_WHOLE_SIZE` is used and the remaining size of the buffer is not a multiple of the texel block size of `format`, the nearest smaller multiple is used.

The buffer view has a *buffer view usage* identifying which descriptor types can be created from it. This usage can be defined by including the `VkBufferUsageFlags2CreateInfoKHR` structure in the `pNext` chain, and specifying the `usage` value there. If this structure is not included, it is equal to the `VkBufferCreateInfo::usage` value used to create `buffer`.

**Valid Usage**

- **VUID-VkBufferViewCreateInfo-offset-00925**
  - `offset` must be less than the size of `buffer`

- **VUID-VkBufferViewCreateInfo-range-00928**
  - If `range` is not equal to `VK_WHOLE_SIZE`, `range` must be greater than 0

- **VUID-VkBufferViewCreateInfo-range-00929**
  - If `range` is not equal to `VK_WHOLE_SIZE`, `range` must be an integer multiple of the texel block size of `format`

- **VUID-VkBufferViewCreateInfo-range-00930**
  - If `range` is not equal to `VK_WHOLE_SIZE`, the number of texel buffer elements given by `(range / (texel block size) × (texels per block))` where texel block size and texels per block are as
defined in the **Compatible Formats** table for *format*, **must** be less than or equal to *VkPhysicalDeviceLimits::maxTexelBufferElements*

- **VUID-VkBufferViewCreateInfo-offset-00931**
  If *range* is not equal to *VK_WHOLE_SIZE*, the sum of *offset* and *range* **must** be less than or equal to the size of *buffer*.

- **VUID-VkBufferViewCreateInfo-range-04059**
  If *range* is equal to *VK_WHOLE_SIZE*, the number of texel buffer elements given by \( \lfloor (\text{size} - \text{offset}) / (\text{texel block size}) \rfloor \times (\text{texels per block}) \) where the size is the size of *buffer*, and texel block size and texels per block are as defined in the **Compatible Formats** table for *format*, **must** be less than or equal to *VkPhysicalDeviceLimits::maxTexelBufferElements*

- **VUID-VkBufferViewCreateInfo-buffer-00932**
  *buffer* **must** have been created with a *usage* value containing at least one of *VK_BUFFER_USAGE_UNIFORM_TEXEL_BUFFER_BIT* or *VK_BUFFER_USAGE_STORAGE_TEXEL_BUFFER_BIT*

- **VUID-VkBufferViewCreateInfo-format-08778**
  If the *buffer view usage* contains *VK_BUFFER_USAGE_UNIFORM_TEXEL_BUFFER_BIT*, then *format* **features** of *format** must** contain *VK_FORMAT_FEATURE_UNIFORM_TEXEL_BUFFER_BIT*

- **VUID-VkBufferViewCreateInfo-format-08779**
  If the *buffer view usage* contains *VK_BUFFER_USAGE_STORAGE_TEXEL_BUFFER_BIT*, then *format** features** of *format** must** contain *VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_BIT*

- **VUID-VkBufferViewCreateInfo-buffer-00935**
  If *buffer* is non-sparse then it **must** be bound completely and contiguously to a single *VkDeviceMemory* object

- **VUID-VkBufferViewCreateInfo-offset-02749**
  If the *texelBufferAlignment* feature is not enabled, *offset** must** be a multiple of *VkPhysicalDeviceLimits::minTexelBufferOffsetAlignment*

- **VUID-VkBufferViewCreateInfo-buffer-02750**
  If the *texelBufferAlignment* feature is enabled and if *buffer* was created with *usage* containing *VK_BUFFER_USAGE_STORAGE_TEXEL_BUFFER_BIT*, *offset** must** be a multiple of the lesser of *VkPhysicalDeviceTexelBufferAlignmentProperties::storageTexelBufferOffsetAlignmentBytes* or, if *VkPhysicalDeviceTexelBufferAlignmentProperties::storageTexelBufferOffsetSingleTexelAlignment* is *VK_TRUE*, the size of a texel of the requested *format*. If the size of a texel is a multiple of three bytes, then the size of a single component of *format* is used instead

- **VUID-VkBufferViewCreateInfo-buffer-02751**
  If the *texelBufferAlignment* feature is enabled and if *buffer* was created with *usage* containing *VK_BUFFER_USAGE_UNIFORM_TEXEL_BUFFER_BIT*, *offset** must** be a multiple of the lesser of *VkPhysicalDeviceTexelBufferAlignmentProperties::uniformTexelBufferOffsetAlignmentBytes* or, if *VkPhysicalDeviceTexelBufferAlignmentProperties::uniformTexelBufferOffsetSingleTexelAlignment* is *VK_TRUE*, the size of a texel of the requested *format*. If the size of a texel is a multiple of three bytes, then the size of a single component of *format* is used instead

- **VUID-VkBufferViewCreateInfo-pNext-06782**
  If the *pNext* chain includes a *VkExportMetalObjectCreateInfoEXT* structure, its *exportObjectType* member **must** be *VK_EXPORT_METAL_OBJECT_TYPE_METAL_TEXTURE_BIT_EXT*
• VUID-VkBufferViewCreateInfo-pNext-08780
  If the pNext chain includes a VkBufferUsageFlags2CreateInfoKHR, its usage must not contain any other bit than VK_BUFFER_USAGE_2_UNIFORM_TEXEL_BUFFER_BIT_KHR or VK_BUFFER_USAGE_2_STORAGE_TEXEL_BUFFER_BIT_KHR.

• VUID-VkBufferViewCreateInfo-pNext-08781
  If the pNext chain includes a VkBufferUsageFlags2CreateInfoKHR, its usage must be a subset of the VkBufferCreateInfo::usage specified or VkBufferUsageFlags2CreateInfoKHR::usage from VkBufferCreateInfo::pNext when creating buffer.

Valid Usage (Implicit)

• VUID-VkBufferViewCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_BUFFER_VIEW_CREATE_INFO.

• VUID-VkBufferViewCreateInfo-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkBufferUsageFlags2CreateInfoKHR or VkExportMetalObjectCreateInfoEXT.

• VUID-VkBufferViewCreateInfo-sType-unique
  The sType value of each struct in the pNext chain must be unique, with the exception of structures of type VkExportMetalObjectCreateInfoEXT.

• VUID-VkBufferViewCreateInfo-flags-zerobitmask
  flags must be 0.

• VUID-VkBufferViewCreateInfo-buffer-parameter
  buffer must be a valid VkBuffer handle.

• VUID-VkBufferViewCreateInfo-format-parameter
  format must be a valid VkFormat value.

// Provided by VK_VERSION_1_0
typedef VkFlags VkBufferViewCreateFlags;

VkBufferViewCreateFlags is a bitmask type for setting a mask, but is currently reserved for future use.

To destroy a buffer view, call:

// Provided by VK_VERSION_1_0
void vkDestroyBufferView(
    VkDevice device,
    VkBufferView bufferView,
    const VkAllocationCallbacks* pAllocator);
• `bufferView` is the buffer view to destroy.
• `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

### Valid Usage

- **VUID-vkDestroyBufferView-bufferView-00936**
  All submitted commands that refer to `bufferView` must have completed execution.

- **VUID-vkDestroyBufferView-bufferView-00937**
  If `VkAllocationCallbacks` were provided when `bufferView` was created, a compatible set of callbacks must be provided here.

- **VUID-vkDestroyBufferView-bufferView-00938**
  If no `VkAllocationCallbacks` were provided when `bufferView` was created, `pAllocator` must be `NULL`.

### Valid Usage (Implicit)

- **VUID-vkDestroyBufferView-device-parameter**
  `device` must be a valid `VkDevice` handle.

- **VUID-vkDestroyBufferView-bufferView-parameter**
  If `bufferView` is not `VK_NULL_HANDLE`, `bufferView` must be a valid `VkBufferView` handle.

- **VUID-vkDestroyBufferView-pAllocator-parameter**
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure.

- **VUID-vkDestroyBufferView-bufferView-parent**
  If `bufferView` is a valid handle, it must have been created, allocated, or retrieved from `device`.

### Host Synchronization

- Host access to `bufferView` must be externally synchronized.

### 12.2.1. Buffer View Format Features

Valid uses of a `VkBufferView` may depend on the buffer view's `format features`, defined below. Such constraints are documented in the affected valid usage statement.

- If Vulkan 1.3 is supported or the `VK_KHR_format_feature_flags2` extension is supported, then the buffer view's set of `format features` is the value of `VkFormatProperties3::bufferFeatures` found by calling `vkGetPhysicalDeviceFormatProperties2` on the same `format` as `VkBufferViewCreateInfo::format`. 
12.3. Images

Images represent multidimensional - up to 3 - arrays of data which can be used for various purposes (e.g. attachments, textures), by binding them to a graphics or compute pipeline via descriptor sets, or by directly specifying them as parameters to certain commands.

Images are represented by VkImage handles:

// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkImage)

To create images, call:

// Provided by VK_VERSION_1_0
VkResult vkCreateImage(
    VkDevice device,
    const VkImageCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkImage* pImage);

- device is the logical device that creates the image.
- pCreateInfo is a pointer to a VkImageCreateInfo structure containing parameters to be used to create the image.
- pAllocator controls host memory allocation as described in the Memory Allocation chapter.
- pImage is a pointer to a VkImage handle in which the resulting image object is returned.

Valid Usage

- VUID-vkCreateImage-flags-00939
  If the flags member of pCreateInfo includes VK_IMAGE_CREATE_SPARSE_BINDING_BIT, creating this VkImage must not cause the total required sparse memory for all currently valid sparse resources on the device to exceed VkPhysicalDeviceLimits::sparseAddressSpaceSize

- VUID-vkCreateImage-pNext-06389
  If a VkBufferCollectionImageCreateInfoFUCHSIA has been chained to pNext, pCreateInfo must match the Sysmem chosen VkImageCreateInfo excepting members VkImageCreateInfo::extent and VkImageCreateInfo::usage in the match criteria

Valid Usage (Implicit)

- VUID-vkCreateImage-device-parameter
device must be a valid VkDevice handle

- VUID-vkCreateImage-pCreateInfo-parameter
pCreateInfo must be a valid pointer to a valid VkImageCreateInfo structure
• **VUID-vkCreateImage-pAllocator-parameter**
  
  If `pAllocators` is not `NULL`, `pAllocators` must be a valid pointer to a valid `VkAllocationCallbacks` structure.

• **VUID-vkCreateImage-pImage-parameter**
  
  `pImage` must be a valid pointer to a `VkImage` handle.

**Return Codes**

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_COMPRESSION_EXHAUSTED_EXT`
- `VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS_KHR`

The `VkImageCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkImageCreateInfo {
    VkStructureType                  sType;
    const void*                      pNext;
    VkImageCreateFlags               flags;
    VkImageType                      imageType;
    VkFormat                          format;
    VkExtent3D                        extent;
    uint32_t                          mipLevels;
    uint32_t                          arrayLayers;
    VkSampleCountFlagBits            samples;
    VkImageTiling                     tiling;
    VkImageUsageFlags                usage;
    VkSharingMode                    sharingMode;
    uint32_t                          queueFamilyIndexCount;
    const uint32_t*                   pQueueFamilyIndices;
    VkImageLayout                     initialLayout;
} VkImageCreateInfo;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkImageCreateFlagBits` describing additional parameters of the image.
- `imageType` is a `VkImageType` value specifying the basic dimensionality of the image. Layers in array textures do not count as a dimension for the purposes of the image type.
• **format** is a *VkFormat* describing the format and type of the texel blocks that will be contained in the image.

• **extent** is a *VkExtent3D* describing the number of data elements in each dimension of the base level.

• **mipLevels** describes the number of levels of detail available for minified sampling of the image.

• **arrayLayers** is the number of layers in the image.

• **samples** is a *VkSampleCountFlagBits* value specifying the number of samples per texel.

• **tiling** is a *VkImageTiling* value specifying the tiling arrangement of the texel blocks in memory.

• **usage** is a bitmask of *VkImageUsageFlagBits* describing the intended usage of the image.

• **sharingMode** is a *VkSharingMode* value specifying the sharing mode of the image when it will be accessed by multiple queue families.

• **queueFamilyIndexCount** is the number of entries in the *pQueueFamilyIndices* array.

• **pQueueFamilyIndices** is a pointer to an array of queue families that will access this image. It is ignored if **sharingMode** is not *VK_SHARING_MODE_CONCURRENT*.

• **initialLayout** is a *VkImageLayout* value specifying the initial *VkImageLayout* of all image subresources of the image. See Image Layouts.

Images created with **tiling** equal to *VK_IMAGE_TILING_LINEAR* have further restrictions on their limits and capabilities compared to images created with **tiling** equal to *VK_IMAGE_TILING_OPTIMAL*. Creation of images with tiling *VK_IMAGE_TILING_LINEAR* **may not be supported** unless other parameters meet all of the constraints:

• **imageType** is *VK_IMAGE_TYPE_2D*

• **format** is not a depth/stencil format

• **mipLevels** is 1

• **arrayLayers** is 1

• **samples** is *VK_SAMPLE_COUNT_1_BIT*

• **usage** only includes *VK_IMAGE_USAGE_TRANSFER_SRC_BIT* and/or *VK_IMAGE_USAGE_TRANSFER_DST_BIT*

Images created with one of the formats that require a sampler Y’C_bC_r conversion, have further restrictions on their limits and capabilities compared to images created with other formats. Creation of images with a format requiring Y’C_bC_r conversion **may not be supported** unless other parameters meet all of the constraints:

• **imageType** is *VK_IMAGE_TYPE_2D*

• **mipLevels** is 1

• **arrayLayers** is 1, unless the *ycbcrImageArrays* feature is enabled, or otherwise indicated by *VkImageFormatProperties::maxArrayLayers*, as returned by *vkGetPhysicalDeviceImageFormatProperties*

• **samples** is *VK_SAMPLE_COUNT_1_BIT*

Implementations **may** support additional limits and capabilities beyond those listed above.
To determine the set of valid usage bits for a given format, call `vkGetPhysicalDeviceFormatProperties`.

If the size of the resultant image would exceed `maxResourceSize`, then `vkCreateImage` must fail and return `VK_ERROR_OUT_OF_DEVICE_MEMORY`. This failure may occur even when all image creation parameters satisfy their valid usage requirements.

If the implementation reports `VK_TRUE` in `VkPhysicalDeviceHostImageCopyPropertiesEXT::identicalMemoryTypeRequirements`, usage of `VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT` must not affect the memory type requirements of the image as described in Sparse Resource Memory Requirements and Resource Memory Association.

**Note**
For images created without `VK_IMAGE_CREATE_EXTENDED_USAGE_BIT` a usage bit is valid if it is supported for the format the image is created with.

For images created with `VK_IMAGE_CREATE_EXTENDED_USAGE_BIT` a usage bit is valid if it is supported for at least one of the formats a `VkImageView` created from the image can have (see Image Views for more detail).

**Image Creation Limits**

Valid values for some image creation parameters are limited by a numerical upper bound or by inclusion in a bitset. For example, `VkImageCreateInfo::arrayLayers` is limited by `imageCreateMaxArrayLayers`, defined below; and `VkImageCreateInfo::samples` is limited by `imageCreateSampleCounts`, also defined below.

Several limiting values are defined below, as well as assisting values from which the limiting values are derived. The limiting values are referenced by the relevant valid usage statements of `VkImageCreateInfo`.

- Let `uint64_t imageCreateDrmFormatModifiers[]` be the set of Linux DRM format modifiers that the resultant image may have.
  - If tiling is not `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`, then `imageCreateDrmFormatModifiers` is empty.
  - If `VkImageCreateInfo::pNext` contains `VkImageDrmFormatModifierExplicitCreateInfoEXT`, then `imageCreateDrmFormatModifiers` contains exactly one modifier, `VkImageDrmFormatModifierExplicitCreateInfoEXT::drmFormatModifier`.
  - If `VkImageCreateInfo::pNext` contains `VkImageDrmFormatModifierListCreateInfoEXT`, then `imageCreateDrmFormatModifiers` contains the entire array `VkImageDrmFormatModifierListCreateInfoEXT::pDrmFormatModifiers`.

- Let `VkBool32 imageCreateMaybeLinear` indicate if the resultant image may be linear.
  - If tiling is `VK_IMAGE_TILING_LINEAR`, then `imageCreateMaybeLinear` is `VK_TRUE`.
  - If tiling is `VK_IMAGE_TILING_OPTIMAL`, then `imageCreateMaybeLinear` is `VK_FALSE`.
If tiling is VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT, then imageCreateMaybeLinear is VK_TRUE if and only if imageCreateDrmFormatModifiers contains DRM_FORMAT_MOD_LINEAR.

Let VkFormatFeatureFlags imageCreateFormatFeatures be the set of valid format features available during image creation.

If tiling is VK_IMAGE_TILING_LINEAR, then imageCreateFormatFeatures is the value of VkFormatProperties::linearTilingFeatures found by calling vkGetPhysicalDeviceFormatProperties with parameter format equal to VkImageCreateInfo::format.

If tiling is VK_IMAGE_TILING_OPTIMAL, and if the pNext chain includes no VkExternalFormatANDROID or VkExternalFormatQNX structure with non-zero externalFormat, then imageCreateFormatFeatures is the value of VkFormatProperties::optimalTilingFeatures found by calling vkGetPhysicalDeviceFormatProperties with parameter format equal to VkImageCreateInfo::format.

If tiling is VK_IMAGE_TILING_OPTIMAL, and if the pNext chain includes a VkExternalFormatANDROID structure with non-zero externalFormat, then imageCreateFormatFeatures is the value of VkAndroidHardwareBufferFormatPropertiesANDROID::formatFeatures obtained by vkGetAndroidHardwareBufferPropertiesANDROID with a matching externalFormat value.

If tiling is VK_IMAGE_TILING_OPTIMAL, and if the pNext chain includes a VkExternalFormatQNX structure with non-zero externalFormat, then imageCreateFormatFeatures is the value of VkScreenBufferFormatPropertiesQNX::formatFeatures obtained by vkGetScreenBufferPropertiesQNX with a matching externalFormat value.

If the pNext chain includes a VkBufferCollectionImageCreateInfoFUCHSIA structure, then imageCreateFormatFeatures is the value of VkBufferCollectionPropertiesFUCHSIA::formatFeatures found by calling vkGetBufferCollectionPropertiesFUCHSIA with a parameter collection equal to VkBufferCollectionImageCreateInfoFUCHSIA::collection.

If tiling is VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT, then the value of imageCreateFormatFeatures is found by calling vkGetPhysicalDeviceFormatProperties2 with VkImageFormatProperties::format equal to VkImageCreateInfo::format and with VkDrmFormatModifierPropertiesListEXT chained into VkFormatProperties2; by collecting all members of the returned array VkDrmFormatModifierPropertiesListEXT::pDrmFormatModifierProperties whose drmFormatModifier belongs to imageCreateDrmFormatModifiers; and by taking the bitwise intersection, over the collected array members, of drmFormatModifierTilingFeatures. (The resultant imageCreateFormatFeatures may be empty).

Let VkImageFormatProperties2 imageCreateImageFormatPropertiesList[] be defined as follows.

If VkImageCreateInfo::pNext contains no VkExternalFormatANDROID or VkExternalFormatQNX structure with non-zero externalFormat, then imageCreateImageFormatPropertiesList is the list of structures obtained by calling vkGetPhysicalDeviceImageFormatProperties2, possibly multiple times, as follows:
The parameters `VkPhysicalDeviceImageFormatInfo2::format`, `imageType`, `tiling`, `usage`, and `flags` must be equal to those in `VkImageCreateInfo`.

If `VkImageCreateInfo::pNext` contains a `VkExternalMemoryImageCreateInfo` structure whose `handleTypes` is not 0, then `VkPhysicalDeviceImageFormatInfo2::pNext` must contain a `VkPhysicalDeviceExternalImageFormatInfo` structure whose `handleType` is not 0; and `vkGetPhysicalDeviceImageFormatProperties2` must be called for each handle type in `VkExternalMemoryImageCreateInfo::handleTypes`, successively setting `VkPhysicalDeviceExternalImageFormatInfo::handleType` on each call.

If `VkImageCreateInfo::pNext` contains no `VkExternalMemoryImageCreateInfo` structure, or contains a structure whose `handleTypes` is 0, then `VkPhysicalDeviceImageFormatInfo2::pNext` must either contain no `VkPhysicalDeviceExternalImageFormatInfo` structure, or contain a structure whose `handleType` is 0.

If `VkImageCreateInfo::pNext` contains a `VkVideoProfileListInfoKHR` structure then `VkPhysicalDeviceImageFormatInfo2::pNext` must also contain the same `VkVideoProfileListInfoKHR` structure on each call.

If `tiling` is `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`, then:

- `VkPhysicalDeviceImageFormatInfo2::pNext` must contain a `VkPhysicalDeviceImageDrmFormatModifierInfoEXT` structure where `sharingMode` is equal to `VkImageCreateInfo::sharingMode`;
- if `sharingMode` is `VK_SHARING_MODE_CONCURRENT`, then `queueFamilyIndexCount` and `pQueueFamilyIndices` must be equal to those in `VkImageCreateInfo`;
- if `flags` contains `VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT`, then the `VkImageFormatListCreateInfo` structure included in the `pNext` chain of `VkPhysicalDeviceImageFormatInfo2` must be equivalent to the one included in the `pNext` chain of `VkImageCreateInfo`;
- if `VkImageCreateInfo::pNext` contains a `VkImageCompressionControlEXT` structure, then the `VkPhysicalDeviceImageFormatInfo2::pNext` chain must contain an equivalent structure;
- `vkGetPhysicalDeviceImageFormatProperties2` must be called for each modifier in `imageCreateDrmFormatModifiers`, successively setting `VkPhysicalDeviceImageDrmFormatModifierInfoEXT::drmFormatModifier` on each call.

If `tiling` is not `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`, then `VkPhysicalDeviceImageFormatInfo2::pNext` must contain no `VkPhysicalDeviceImageDrmFormatModifierInfoEXT` structure.

If any call to `vkGetPhysicalDeviceImageFormatProperties2` returns an error, then `imageCreateImageFormatPropertiesList` is defined to be the empty list.

- If `VkImageCreateInfo::pNext` contains a `VkExternalFormatANDROID` structure with non-zero `externalFormat`, then `imageCreateImageFormatPropertiesList` contains a single element where:
  - `VkImageFormatProperties::maxMipLevels` is $\lceil \log_2(\max(extent.width, extent.height, 978) \rceil$. 
extent.depth)\[ + 1.

- \( \text{VkImageFormatProperties::maxArrayLayers} \) is \( \text{VkPhysicalDeviceLimits::maxImageArrayLayers} \).

- Each component of \( \text{VkImageFormatProperties::maxExtent} \) is \( \text{VkPhysicalDeviceLimits::maxImageDimension2D} \).

- \( \text{VkImageFormatProperties::sampleCounts} \) contains exactly \( \text{VK_SAMPLE_COUNT_1_BIT} \).

- Let \( \text{uint32_t imageCreateMaxMipLevels} \) be the minimum value of \( \text{VkImageFormatProperties::maxMipLevels} \) in \( \text{imageCreateImageFormatPropertiesList} \). The value is undefined if \( \text{imageCreateImageFormatPropertiesList} \) is empty.

- Let \( \text{uint32_t imageCreateMaxArrayLayers} \) be the minimum value of \( \text{VkImageFormatProperties::maxArrayLayers} \) in \( \text{imageCreateImageFormatPropertiesList} \). The value is undefined if \( \text{imageCreateImageFormatPropertiesList} \) is empty.

- Let \( \text{VkExtent3D imageCreateMaxExtent} \) be the component-wise minimum over all \( \text{VkImageFormatProperties::maxExtent} \) values in \( \text{imageCreateImageFormatPropertiesList} \). The value is undefined if \( \text{imageCreateImageFormatPropertiesList} \) is empty.

- Let \( \text{VkSampleCountFlags imageCreateSampleCounts} \) be the intersection of each \( \text{VkImageFormatProperties::sampleCounts} \) in \( \text{imageCreateImageFormatPropertiesList} \). The value is undefined if \( \text{imageCreateImageFormatPropertiesList} \) is empty.

- Let \( \text{VkVideoFormatPropertiesKHR videoFormatProperties[]} \) be defined as follows.
  - If \( \text{VkImageCreateInfo::pNext} \) contains a \( \text{VkVideoProfileListInfoKHR} \) structure, then \( \text{videoFormatProperties} \) is the list of structures obtained by calling \( \text{vkGetPhysicalDeviceVideoFormatPropertiesKHR} \) with \( \text{VkPhysicalDeviceVideoFormatInfoKHR::imageUsage} \) equal to the \( \text{usage} \) member of \( \text{VkImageCreateInfo} \) and \( \text{VkPhysicalDeviceVideoFormatInfoKHR::pNext} \) containing the same \( \text{VkVideoProfileListInfoKHR} \) structure chained to \( \text{VkImageCreateInfo} \).
  - If \( \text{VkImageCreateInfo::pNext} \) contains no \( \text{VkVideoProfileListInfoKHR} \) structure, then \( \text{videoFormatProperties} \) is an empty list.

- Let \( \text{VkBool32 supportedVideoFormat} \) indicate if the image parameters are supported by the specified video profiles.
  - \( \text{supportedVideoFormat} \) is \( \text{VK_TRUE} \) if there exists an element in the \( \text{videoFormatProperties} \) list for which all of the following conditions are true:
    - \( \text{VkImageCreateInfo::format} \) equals \( \text{VkVideoFormatPropertiesKHR::format} \).
    - \( \text{VkImageCreateInfo::flags} \) only contains bits also set in \( \text{VkVideoFormatPropertiesKHR::imageCreateFlags} \).
    - \( \text{VkImageCreateInfo::imageType} \) equals \( \text{VkVideoFormatPropertiesKHR::imageType} \).
    - \( \text{VkImageCreateInfo::tiling} \) equals \( \text{VkVideoFormatPropertiesKHR::imageTiling} \).
    - \( \text{VkImageCreateInfo::usage} \) only contains bits also set in \( \text{VkVideoFormatPropertiesKHR::imageUsageFlags} \).
  - Otherwise \( \text{supportedVideoFormat} \) is \( \text{VK_FALSE} \).
Valid Usage

- **VUID-VkImageCreateInfo-imageCreateMaxMipLevels-02251**
  Each of the following values (as described in Image Creation Limits) must not be undefined: `imageCreateMaxMipLevels`, `imageCreateMaxArrayLayers`, `imageCreateMaxExtent`, and `imageCreateSampleCounts`.

- **VUID-VkImageCreateInfo-sharingMode-00941**
  If `sharingMode` is `VK_SHARING_MODE_CONCURRENT`, `pQueueFamilyIndices` must be a valid pointer to an array of `queueFamilyIndexCount uint32_t` values.

- **VUID-VkImageCreateInfo-sharingMode-00942**
  If `sharingMode` is `VK_SHARING_MODE_CONCURRENT`, `queueFamilyIndexCount` must be greater than 1.

- **VUID-VkImageCreateInfo-sharingMode-01420**
  If `sharingMode` is `VK_SHARING_MODE_CONCURRENT`, each element of `pQueueFamilyIndices` must be unique and must be less than `pQueueFamilyPropertyCount` returned by either `vkGetPhysicalDeviceQueueFamilyProperties` or `vkGetPhysicalDeviceQueueFamilyProperties2` for the physicalDevice that was used to create device.

- **VUID-VkImageCreateInfo-pNext-01974**
  If the `pNext` chain includes a `VkExternalFormatANDROID` structure, and its `externalFormat` member is non-zero the format must be `VK_FORMAT_UNDEFINED`.

- **VUID-VkImageCreateInfo-pNext-01975**
  If the `pNext` chain does not include a `VkExternalFormatANDROID` structure, or does and its `externalFormat` member is 0, the format must not be `VK_FORMAT_UNDEFINED`.

- **VUID-VkImageCreateInfo-extent-00944**
  `extent.width` must be greater than 0.

- **VUID-VkImageCreateInfo-extent-00945**
  `extent.height` must be greater than 0.

- **VUID-VkImageCreateInfo-extent-00946**
  `extent.depth` must be greater than 0.

- **VUID-VkImageCreateInfo-mipLevels-00947**
  `mipLevels` must be greater than 0.

- **VUID-VkImageCreateInfo-arrayLayers-00948**
  `arrayLayers` must be greater than 0.

- **VUID-VkImageCreateInfo-flags-00949**
  If `flags` contains `VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT`, `imageType` must be `VK_IMAGE_TYPE_2D`.

- **VUID-VkImageCreateInfo-flags-08865**
  If `flags` contains `VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT`, `extent.width` and `extent.height` must be equal.

- **VUID-VkImageCreateInfo-flags-08866**
  If `flags` contains `VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT`, `arrayLayers` must be greater than
• VUID-VkImageCreateInfo-flags-02557
  If flags contains VK_IMAGE_USAGE_FRAGMENT_DENSITY_MAP_BIT_EXT, imageType must be VK_IMAGE_TYPE_2D

• VUID-VkImageCreateInfo-flags-00950
  If flags contains VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT, imageType must be VK_IMAGE_TYPE_3D

• VUID-VkImageCreateInfo-flags-07755
  If flags contains VK_IMAGE_CREATE_2D_VIEW_COMPATIBLE_BIT_EXT, imageType must be VK_IMAGE_TYPE_3D

• VUID-VkImageCreateInfo-extent-02252
  extent.width must be less than or equal to imageCreateMaxExtent.width (as defined in Image Creation Limits)

• VUID-VkImageCreateInfo-extent-02253
  extent.height must be less than or equal to imageCreateMaxExtent.height (as defined in Image Creation Limits)

• VUID-VkImageCreateInfo-extent-02254
  extent.depth must be less than or equal to imageCreateMaxExtent.depth (as defined in Image Creation Limits)

• VUID-VkImageCreateInfo-imageType-00956
  If imageType is VK_IMAGE_TYPE_1D, both extent.height and extent.depth must be 1

• VUID-VkImageCreateInfo-imageType-00957
  If imageType is VK_IMAGE_TYPE_2D, extent.depth must be 1

• VUID-VkImageCreateInfo-mipLevels-00958
  mipLevels must be less than or equal to the number of levels in the complete mipmap chain based on extent.width, extent.height, and extent.depth

• VUID-VkImageCreateInfo-mipLevels-02255
  mipLevels must be less than or equal to imageCreateMaxMipLevels (as defined in Image Creation Limits)

• VUID-VkImageCreateInfo-arrayLayers-02256
  arrayLayers must be less than or equal to imageCreateMaxArrayLayers (as defined in Image Creation Limits)

• VUID-VkImageCreateInfo-imageType-00961
  If imageType is VK_IMAGE_TYPE_3D, arrayLayers must be 1

• VUID-VkImageCreateInfo-samples-02257
  If samples is not VK_SAMPLE_COUNT_1_BIT, then imageType must be VK_IMAGE_TYPE_2D, flags must not contain VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT, mipLevels must be equal to 1, and imageCreateMaybeLinear (as defined in Image Creation Limits) must be VK_FALSE,

• VUID-VkImageCreateInfo-samples-02558
  If samples is not VK_SAMPLE_COUNT_1_BIT, usage must not contain VK_IMAGE_USAGE_FRAGMENT_DENSITY_MAP_BIT_EXT

• VUID-VkImageCreateInfo-usage-00963
If usage includes VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT, then bits other than VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT, VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT, and VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT must not be set

- VUID-VkImageCreateInfo-usage-00964
  If usage includes VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT, VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT, VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT, or VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT, extent.width must be less than or equal to VkPhysicalDeviceLimits::maxFramebufferWidth

- VUID-VkImageCreateInfo-usage-00965
  If usage includes VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT, VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT, VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT, or VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT, extent.height must be less than or equal to VkPhysicalDeviceLimits::maxFramebufferHeight

- VUID-VkImageCreateInfo-fragmentDensityMapOffset-06514
  If the fragmentDensityMapOffset feature is not enabled and usage includes VK_IMAGE_USAGE_FRAGMENT_DENSITY_MAP_BIT_EXT, extent.width must be less than or equal to \( \frac{\text{maxFramebufferWidth}}{\text{minFragmentDensityTexelSize.width}} \)

- VUID-VkImageCreateInfo-fragmentDensityMapOffset-06515
  If the fragmentDensityMapOffset feature is not enabled and usage includes VK_IMAGE_USAGE_FRAGMENT_DENSITY_MAP_BIT_EXT, extent.height must be less than or equal to \( \frac{\text{maxFramebufferHeight}}{\text{minFragmentDensityTexelSize.height}} \)

- VUID-VkImageCreateInfo-usage-00966
  If usage includes VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT, usage must also contain at least one of VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT, VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT, or VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT

- VUID-VkImageCreateInfo-samples-02258
  samples must be a bit value that is set in imageCreateSampleCounts (as defined in Image Creation Limits)

- VUID-VkImageCreateInfo-usage-00968
  If the shaderStorageImageMultisample feature is not enabled, and usage contains VK_IMAGE_USAGE_STORAGE_BIT, samples must be VK_SAMPLE_COUNT_1_BIT

- VUID-VkImageCreateInfo-flags-00969
  If the sparseBinding feature is not enabled, flags must not contain VK_IMAGE_CREATE_SPARSE_BINDING_BIT

- VUID-VkImageCreateInfo-flags-01924
  If the sparseResidencyAliased feature is not enabled, flags must not contain VK_IMAGE_CREATE_SPARSE_ALIASED_BIT

- VUID-VkImageCreateInfo-tiling-04121
  If tiling is VK_IMAGE_TILING_LINEAR, flags must not contain VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT

- VUID-VkImageCreateInfo-imageType-00970
  If imageType is VK_IMAGE_TYPE_1D, flags must not contain VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT
• VUID-VkImageCreateInfo-imageType-00971
  If the `sparseResidencyImage2D` feature is not enabled, and `imageType` is `VK_IMAGE_TYPE_2D`, `flags` must not contain `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`.

• VUID-VkImageCreateInfo-imageType-00972
  If the `sparseResidencyImage3D` feature is not enabled, and `imageType` is `VK_IMAGE_TYPE_3D`, `flags` must not contain `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`.

• VUID-VkImageCreateInfo-imageType-00973
  If the `sparseResidency2Samples` feature is not enabled, `imageType` is `VK_IMAGE_TYPE_2D`, and `samples` is `VK_SAMPLE_COUNT_2_BIT`, `flags` must not contain `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`.

• VUID-VkImageCreateInfo-imageType-00974
  If the `sparseResidency4Samples` feature is not enabled, `imageType` is `VK_IMAGE_TYPE_2D`, and `samples` is `VK_SAMPLE_COUNT_4_BIT`, `flags` must not contain `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`.

• VUID-VkImageCreateInfo-imageType-00975
  If the `sparseResidency8Samples` feature is not enabled, `imageType` is `VK_IMAGE_TYPE_2D`, and `samples` is `VK_SAMPLE_COUNT_8_BIT`, `flags` must not contain `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`.

• VUID-VkImageCreateInfo-imageType-00976
  If the `sparseResidency16Samples` feature is not enabled, `imageType` is `VK_IMAGE_TYPE_2D`, and `samples` is `VK_SAMPLE_COUNT_16_BIT`, `flags` must not contain `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`.

• VUID-VkImageCreateInfo-flags-00987
  If `flags` contains `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` or `VK_IMAGE_CREATE_SPARSE_ALIASED_BIT`, it must also contain `VK_IMAGE_CREATE_SPARSE_BINDING_BIT`.

• VUID-VkImageCreateInfo-None-01925
  If any of the bits `VK_IMAGE_CREATE_SPARSE_BINDING_BIT`, `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`, or `VK_IMAGE_CREATE_SPARSE_ALIASED_BIT` are set, `VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT` must not also be set.

• VUID-VkImageCreateInfo-flags-01890
  If the `protectedMemory` feature is not enabled, `flags` must not contain `VK_IMAGE_CREATE_PROTECTED_BIT`.

• VUID-VkImageCreateInfo-None-01891
  If any of the bits `VK_IMAGE_CREATE_SPARSE_BINDING_BIT`, `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`, or `VK_IMAGE_CREATE_SPARSE_ALIASED_BIT` are set, `VK_IMAGE_CREATE_PROTECTED_BIT` must not also be set.

• VUID-VkImageCreateInfo-pNext-00988
  If the `pNext` chain includes a `VkExternalMemoryImageCreateInfoNV` structure, it must not contain a `VkExternalMemoryImageCreateInfo` structure.

• VUID-VkImageCreateInfo-pNext-00990
  If the `pNext` chain includes a `VkExternalMemoryImageCreateInfo` structure, its `handleTypes` member must only contain bits that are also in `VkExternalImageFormatProperties`.
externalMemoryProperties.compatibleHandleTypes, as returned by vkGetPhysicalDeviceImageFormatProperties2 with format, imageType, tiling, usage, and flags equal to those in this structure, and with a VkPhysicalDeviceExternalImageFormatInfo structure included in the pNext chain, with a handleType equal to any one of the handle types specified in VkExternalMemoryImageCreateInfo::handleTypes

- VUID-VkImageCreateInfo-pNext-00991
  If the pNext chain includes a VkExternalMemoryImageCreateInfoNV structure, its handleTypes member must only contain bits that are also in externalMemoryProperties.compatibleHandleTypes, as returned by vkGetPhysicalDeviceExternalImageFormatPropertiesNV with format, imageType, tiling, usage, and flags equal to those in this structure, and with externalHandleType equal to any one of the handle types specified in VkExternalMemoryImageCreateInfoNV::handleTypes

- VUID-VkImageCreateInfo-physicalDeviceCount-01421
  If the logical device was created with VkDeviceGroupDeviceCreateInfo::physicalDeviceCount equal to 1, flags must not contain VK_IMAGE_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT

- VUID-VkImageCreateInfo-flags-02259
  If flags contains VK_IMAGE_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT, then mipLevels must be one, arrayLayers must be one, imageType must be VK_IMAGE_TYPE_2D, and imageCreateMaybeLinear (as defined in Image Creation Limits) must be VK_FALSE

- VUID-VkImageCreateInfo-flags-01572
  If flags contains VK_IMAGE_CREATE_BLOCK_TEXEL_VIEW_COMPATIBLE_BIT, then format must be a compressed image format

- VUID-VkImageCreateInfo-flags-01573
  If flags contains VK_IMAGE_CREATE_BLOCK_TEXEL_VIEW_COMPATIBLE_BIT, then flags must also contain VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT

- VUID-VkImageCreateInfo-initialLayout-00993
  initialLayout must be VK_IMAGE_LAYOUT_UNDEFINED or VK_IMAGE_LAYOUT_PREINITIALIZED

- VUID-VkImageCreateInfo-pNext-01443
  If the pNext chain includes a VkExternalMemoryImageCreateInfo or VkExternalMemoryImageCreateInfoNV structure whose handleTypes member is not 0, initialLayout must be VK_IMAGE_LAYOUT_UNDEFINED

- VUID-VkImageCreateInfo-format-06410
  If the image format is one of the formats that require a sampler Y’C_bC_R conversion, mipLevels must be 1

- VUID-VkImageCreateInfo-format-06411
  If the image format is one of the formats that require a sampler Y’C_bC_R conversion, samples must be VK_SAMPLE_COUNT_1_BIT

- VUID-VkImageCreateInfo-format-06412
  If the image format is one of the formats that require a sampler Y’C_bC_R conversion, imageType must be VK_IMAGE_TYPE_2D
If `format` is a *multi-planar* format, and if `imageCreateFormatFeatures` (as defined in Image Creation Limits) does not contain `VK_FORMAT_FEATURE_DISJOINT_BIT`, then `flags` must not contain `VK_IMAGE_CREATE_DISJOINT_BIT`.

If `format` is not a *multi-planar* format, and `flags` does not include `VK_IMAGE_CREATE_ALIAS_BIT`, `flags` must not contain `VK_IMAGE_CREATE_DISJOINT_BIT`.

If `format` has a _422 or _420 suffix, `width` must be a multiple of 2.

If `format` has a _420 suffix, `height` must be a multiple of 2.

If `tiling` is `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`, then the `pNext` chain must include exactly one of `VkImageDrmFormatModifierListCreateInfoEXT` or `VkImageDrmFormatModifierExplicitCreateInfoEXT` structures.

If the `pNext` chain includes a `VkImageDrmFormatModifierListCreateInfoEXT` or `VkImageDrmFormatModifierExplicitCreateInfoEXT` structure, then `tiling` must be `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`.

If `tiling` is `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT` and `flags` contains `VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT`, then the `pNext` chain must include a `VkImageFormatListCreateInfo` structure with non-zero `viewFormatCount`.

If `flags` contains `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` format must be a depth or depth/stencil format.

If the `pNext` chain includes a `VkExternalMemoryImageCreateInfo` structure whose `handleTypes` member includes `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID`, `imageType` must be `VK_IMAGE_TYPE_2D`.

If the `pNext` chain includes a `VkExternalFormatANDROID` structure whose `externalFormat` member is not 0, `flags` must not include `VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT`.

If the `pNext` chain includes a `VkExternalFormatANDROID` structure whose `externalFormat` member is not 0, `usage` must not include any usages except `VK_IMAGE_USAGE_SAMPLED_BIT`.
If the pNext chain includes a VkExternalFormatANDROID structure whose externalFormat member is not 0, tiling must be VK_IMAGE_TILING_OPTIMAL

If the pNext chain includes a VkExternalMemoryImageCreateInfo structure whose handleTypes member includes VK_EXTERNAL_MEMORY_HANDLE_TYPE_SCREEN_BUFFER_BIT_QNX, imageType must be VK_IMAGE_TYPE_2D

If the pNext chain includes a VkExternalMemoryImageCreateInfo structure whose handleTypes member includes VK_EXTERNAL_MEMORY_HANDLE_TYPE_SCREEN_BUFFER_BIT_QNX, mipLevels must either be 1 or equal to the number of levels in the complete mipmap chain based on extent.width, extent.height, and extent.depth

If the pNext chain includes a VkExternalFormatQNX structure whose externalFormat member is not 0, flags must not include VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT

If the pNext chain includes a VkExternalFormatQNX structure whose externalFormat member is not 0, usage must not include any usages except VK_IMAGE_USAGE_SAMPLED_BIT

If the pNext chain includes a VkExternalFormatQNX structure whose externalFormat member is not 0, tiling must be VK_IMAGE_TILING_OPTIMAL

If format is a depth-stencil format, usage includes VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT, and the pNext chain includes a VkImageStencilUsageCreateInfo structure, then its VkImageStencilUsageCreateInfo::stencilUsage member must also include VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT

If format is a depth-stencil format, usage does not include VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT, and the pNext chain includes a VkImageStencilUsageCreateInfo structure, then its VkImageStencilUsageCreateInfo::stencilUsage member must also not include VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT

If format is a depth-stencil format, usage includes VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT, and the pNext chain includes a VkImageStencilUsageCreateInfo structure, then its VkImageStencilUsageCreateInfo::stencilUsage member must also include VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT

If format is a depth-stencil format, usage does not include VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT, and the pNext chain includes a VkImageStencilUsageCreateInfo structure, then its VkImageStencilUsageCreateInfo::stencilUsage member must also not include VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT

If Format is a depth-stencil format and the pNext chain includes a
VkImageStencilUsageCreateInfo structure with its stencilUsage member including VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT, extent.width must be less than or equal to VkPhysicalDeviceLimits::maxFramebufferWidth

- VUID-VkImageCreateInfo-format-02537
  If format is a depth-stencil format and the pNext chain includes a VkImageStencilUsageCreateInfo structure with its stencilUsage member including VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT, extent.height must be less than or equal to VkPhysicalDeviceLimits::maxFramebufferHeight

- VUID-VkImageCreateInfo-format-02538
  If the shaderStorageImageMultisample feature is not enabled, format is a depth-stencil format and the pNext chain includes a VkImageStencilUsageCreateInfo structure with its stencilUsage including VK_IMAGE_USAGE_STORAGE_BIT, samples must be VK_SAMPLE_COUNT_1_BIT

- VUID-VkImageCreateInfo-flags-02050
  If flags contains VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV, imageType must be VK_IMAGE_TYPE_2D or VK_IMAGE_TYPE_3D

- VUID-VkImageCreateInfo-flags-02051
  If flags contains VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV, it must not contain VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT and the format must not be a depth/stencil format

- VUID-VkImageCreateInfo-flags-02052
  If flags contains VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV and imageType is VK_IMAGE_TYPE_2D, extent.width and extent.height must be greater than 1

- VUID-VkImageCreateInfo-flags-02053
  If flags contains VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV and imageType is VK_IMAGE_TYPE_3D, extent.width, extent.height, and extent.depth must be greater than 1

- VUID-VkImageCreateInfo-imageType-02082
  If usage includes VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR, imageType must be VK_IMAGE_TYPE_2D

- VUID-VkImageCreateInfo-samples-02083
  If usage includes VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR, samples must be VK_SAMPLE_COUNT_1_BIT

- VUID-VkImageCreateInfo-shadingRateImage-07727
  If the shadingRateImage feature is enabled and usage includes VK_IMAGE_USAGE_SHADING_RATE_IMAGE_BIT_NV, tiling must be VK_IMAGE_TILING_OPTIMAL

- VUID-VkImageCreateInfo-flags-02565
  If flags contains VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT, tiling must be VK_IMAGE_TILING_OPTIMAL

- VUID-VkImageCreateInfo-flags-02566
  If flags contains VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT, imageType must be VK_IMAGE_TYPE_2D

- VUID-VkImageCreateInfo-flags-02567
  If flags contains VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT, flags must not contain VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT

- VUID-VkImageCreateInfo-flags-02568
If `flags` contains `VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT`, `mipLevels` must be 1

- VUID-VkImageCreateInfo-usage-04992
  If `usage` includes `VK_IMAGE_USAGE_INVOCATION_MASK_BIT_HUAWEI`, tiling must be `VK_IMAGE_TILING_LINEAR`

- VUID-VkImageCreateInfo-imageView2DOn3DImage-04459
  If the `VK_KHR_portability_subset` extension is enabled, and `VkPhysicalDevicePortabilitySubsetFeaturesKHR::imageView2DOn3DImage` is `VK_FALSE`, `flags` must not contain `VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT`

- VUID-VkImageCreateInfo-multisampleArrayImage-04460
  If the `VK_KHR_portability_subset` extension is enabled, and `VkPhysicalDevicePortabilitySubsetFeaturesKHR::multisampleArrayImage` is `VK_FALSE`, and `samples` is not `VK_SAMPLE_COUNT_1_BIT`, then `arrayLayers` must be 1

- VUID-VkImageCreateInfo-pNext-06722
  If a `VkImageFormatListCreateInfo` structure was included in the `pNext` chain and `VkImageFormatListCreateInfo::viewFormatCount` is not zero, then each format in `VkImageFormatListCreateInfo::pViewFormats` must either be compatible with the `format` as described in the compatibility table or, if `flags` contains `VK_IMAGE_CREATE_BLOCK_TEXEL_VIEW_COMPATIBLE_BIT`, be an uncompressed format that is size-compatible with `format`

- VUID-VkImageCreateInfo-flags-04738
  If `flags` does not contain `VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT` and the `pNext` chain includes a `VkImageFormatListCreateInfo` structure, then `VkImageFormatListCreateInfo::viewFormatCount` must be 0 or 1

- VUID-VkImageCreateInfo-usage-04815
  If `usage` includes `VK_IMAGE_USAGE_VIDEO_DECODE_SRC_BIT_KHR`, `VK_IMAGE_USAGE_VIDEO_DECODE_DST_BIT_KHR`, or `VK_IMAGE_USAGE_VIDEO_DECODE_DPB_BIT_KHR`, then the `pNext` chain must include a `VkVideoProfileListInfoKHR` structure with `profileCount` greater than 0 and `pProfiles` including at least one `VkVideoProfileInfoKHR` structure with a `videoCodecOperation` member specifying a decode operation

- VUID-VkImageCreateInfo-usage-04816
  If `usage` includes `VK_IMAGE_USAGE_VIDEO_ENCODE_SRC_BIT_KHR`, `VK_IMAGE_USAGE_VIDEO_ENCODE_DST_BIT_KHR`, or `VK_IMAGE_USAGE_VIDEO_ENCODE_DPB_BIT_KHR`, then the `pNext` chain must include a `VkVideoProfileListInfoKHR` structure with `profileCount` greater than 0 and `pProfiles` including at least one `VkVideoProfileInfoKHR` structure with a `videoCodecOperation` member specifying an encode operation

- VUID-VkImageCreateInfo-pNext-06811
  If the `pNext` chain includes a `VkVideoProfileListInfoKHR` structure with `profileCount` greater than 0, then `supportedVideoFormat` must be `VK_TRUE`

- VUID-VkImageCreateInfo-pNext-06390
  If the `VkImage` is to be used to import memory from a `VkBufferCollectionFUCHSIA`, a `VkBufferCollectionImageCreateInfoFUCHSIA` structure must be chained to `pNext`

- VUID-VkImageCreateInfo-multisampledRenderToSingleSampled-06882
  If the `multisampledRenderToSingleSampled` feature is not enabled, `flags` must not contain `VK_IMAGE_CREATE_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_BIT_EXT`
• **VUID-VkImageCreateInfo-flags-06883**
  If `flags` contains `VK_IMAGE_CREATE_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_BIT_EXT`, `samples` must be `VK_SAMPLE_COUNT_1_BIT`.

• **VUID-VkImageCreateInfo-pNext-06743**
  If the `pNext` chain includes a `VkImageCompressionControlEXT` structure, `format` is a multi-planar format, and `VkImageCompressionControlEXT::flags` includes `VK_IMAGE_COMPRESSION_FIXED_RATE_EXPLICIT_EXT`, then `VkImageCompressionControlEXT::compressionControlPlaneCount` must be equal to the number of planes in `format`.

• **VUID-VkImageCreateInfo-pNext-06744**
  If the `pNext` chain includes a `VkImageCompressionControlEXT` structure, `format` is not a multi-planar format, and `VkImageCompressionControlEXT::flags` includes `VK_IMAGE_COMPRESSION_FIXED_RATE_EXPLICIT_EXT`, then `VkImageCompressionControlEXT::compressionControlPlaneCount` must be 1.

• **VUID-VkImageCreateInfo-pNext-06746**
  If the `pNext` chain includes a `VkImageCompressionControlEXT` structure, it must not contain a `VkImageDrmFormatModifierExplicitCreateInfoEXT` structure.

• **VUID-VkImageCreateInfo-flags-08104**
  If `flags` includes `VK_IMAGE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT`, the `descriptorBufferCaptureReplay` feature must be enabled.

• **VUID-VkImageCreateInfo-pNext-08105**
  If the `pNext` chain includes a `VkOpaqueCaptureDescriptorDataCreateInfoEXT` structure, `flags` must contain `VK_IMAGE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT`.

• **VUID-VkImageCreateInfo-pNext-06783**
  If the `pNext` chain includes a `VkExportMetalObjectCreateInfoEXT` structure, its `exportObjectType` member must be either `VK_EXPORT_METAL_OBJECT_TYPE_METAL_TEXTURE_BIT_EXT` or `VK_EXPORT_METAL_OBJECT_TYPE_METAL_IOSURFACE_BIT_EXT`.

• **VUID-VkImageCreateInfo-pNext-06784**
  If the `pNext` chain includes a `VkImportMetalTextureInfoEXT` structure its `plane` member must be `VK_IMAGE_ASPECT_PLANE_0_BIT`, `VK_IMAGE_ASPECT_PLANE_1_BIT`, or `VK_IMAGE_ASPECT_PLANE_2_BIT`.

• **VUID-VkImageCreateInfo-pNext-06785**
  If the `pNext` chain includes a `VkImportMetalTextureInfoEXT` structure and the image does not have a multi-planar format, then `VkImportMetalTextureInfoEXT::plane` must be `VK_IMAGE_ASPECT_PLANE_0_BIT`.

• **VUID-VkImageCreateInfo-pNext-06786**
  If the `pNext` chain includes a `VkImportMetalTextureInfoEXT` structure and the image has a multi-planar format with only two planes, then `VkImportMetalTextureInfoEXT::plane` must not be `VK_IMAGE_ASPECT_PLANE_2_BIT`.

• **VUID-VkImageCreateInfo-imageCreateInfoFormatFeatures-09048**
  If `imageCreateInfoFormatFeatures` (as defined in Image Creation Limits) does not contain `VK_FORMAT_FEATURE_2_HOST_IMAGE_TRANSFER_BIT_EXT`, then `usage` must not contain `VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT`. 
Valid Usage (Implicit)

- VUID-VkImageCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO

- VUID-VkImageCreateInfo-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkBufferCollectionImageCreateInfoFUCHSIA, VkDedicatedAllocationImageCreateInfoNV, VkExportMetalObjectCreateInfoEXT, VkExternalFormatANDROID, VkExternalFormatQNX, VkExternalMemoryImageCreateInfo, VkExternalMemoryImageCreateInfoNV, VkImageCompressionControlEXT, VkImageDrmFormatModifierExplicitCreateInfoEXT, VkImageDrmFormatModifierListCreateInfoEXT, VkImageStencilUsageCreateInfo, VkImageSwapchainCreateInfoKHR, VkImportMetalIOSurfaceInfoEXT, VkImportMetalTextureInfoEXT, VkOpaqueCaptureDescriptorDataCreateInfoEXT, VkOpticalFlowImageFormatInfoNV, or VkVideoProfileListInfoKHR

- VUID-VkImageCreateInfo-sType-unique
  The sType value of each struct in the pNext chain must be unique, with the exception of structures of type VkExportMetalObjectCreateInfoEXT or VkImportMetalTextureInfoEXT

- VUID-VkImageCreateInfo-flags-parameter
  flags must be a valid combination of VkImageCreateFlagBits values

- VUID-VkImageCreateInfo-imageType-parameter
  imageType must be a valid VkImageType value

- VUID-VkImageCreateInfo-format-parameter
  format must be a valid VkFormat value

- VUID-VkImageCreateInfo-samples-parameter
  samples must be a valid VkSampleCountFlagBits value

- VUID-VkImageCreateInfo-tiling-parameter
  tiling must be a valid VkImageTiling value

- VUID-VkImageCreateInfo-usage-parameter
  usage must be a valid combination of VkImageUsageFlagBits values

- VUID-VkImageCreateInfo-usage-requiredbitmask
  usage must not be 0

- VUID-VkImageCreateInfo-sharingMode-parameter
  sharingMode must be a valid VkSharingMode value

- VUID-VkImageCreateInfo-initialLayout-parameter
  initialLayout must be a valid VkImageLayout value

The VkBufferCollectionImageCreateInfoFUCHSIA structure is defined as:

```c
// Provided by VK_FUCHSIA_buffer_collection
typedef struct VkBufferCollectionImageCreateInfoFUCHSIA {
```
VkBufferCollectionImageCreateInfoFUCHSIA:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **collection** is the `VkBufferCollectionFUCHSIA` handle.
- **index** is the index of the buffer in the buffer collection from which the memory will be imported.

**Valid Usage**

- VUID-VkBufferCollectionImageCreateInfoFUCHSIA-index-06391
  - **index** must be less than `VkBufferCollectionPropertiesFUCHSIA::bufferCount`.

**Valid Usage (Implicit)**

- VUID-VkBufferCollectionImageCreateInfoFUCHSIA-sType-sType
  - **sType** must be `VK_STRUCTURE_TYPE_BUFFER_COLLECTION_IMAGE_CREATE_INFO_FUCHSIA`.
- VUID-VkBufferCollectionImageCreateInfoFUCHSIA-collection-parameter
  - **collection** must be a valid `VkBufferCollectionFUCHSIA` handle.

The `VkImageStencilUsageCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkImageStencilUsageCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkImageUsageFlags stencilUsage;
} VkImageStencilUsageCreateInfo;
```

or the equivalent:

```c
// Provided by VK_EXT_separate_stencil_usage
typedef VkImageStencilUsageCreateInfo VkImageStencilUsageCreateInfoEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **stencilUsage** is a bitmask of `VkImageUsageFlagBits` describing the intended usage of the stencil aspect of the image.
If the `pNext` chain of `VkImageCreateInfo` includes a `VkImageStencilUsageCreateInfo` structure, then that structure includes the usage flags specific to the stencil aspect of the image for an image with a depth-stencil format.

This structure specifies image usages which only apply to the stencil aspect of a depth/stencil format image. When this structure is included in the `pNext` chain of `VkImageCreateInfo`, the stencil aspect of the image **must** only be used as specified by `stencilUsage`. When this structure is not included in the `pNext` chain of `VkImageCreateInfo`, the stencil aspect of an image **must** only be used as specified by `VkImageCreateInfo::usage`. Use of other aspects of an image are unaffected by this structure.

This structure **can** also be included in the `pNext` chain of `VkPhysicalDeviceImageFormatInfo2` to query additional capabilities specific to image creation parameter combinations including a separate set of usage flags for the stencil aspect of the image using `vkGetPhysicalDeviceImageFormatProperties2`. When this structure is not included in the `pNext` chain of `VkPhysicalDeviceImageFormatInfo2` then the implicit value of `stencilUsage` matches that of `VkPhysicalDeviceImageFormatInfo2::usage`.

**Valid Usage**

- VUID-VkImageStencilUsageCreateInfo-stencilUsage-02539
  
  If `stencilUsage` includes `VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT`, it **must** not include bits other than `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT` or `VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT`

**Valid Usage (Implicit)**

- VUID-VkImageStencilUsageCreateInfo-sType-sType
  
  `sType` **must** be `VK_STRUCTURE_TYPE_IMAGE_STENCIL_USAGE_CREATE_INFO`

- VUID-VkImageStencilUsageCreateInfo-stencilUsage-parameter
  
  `stencilUsage` **must** be a valid combination of `VkImageUsageFlagBits` values

- VUID-VkImageStencilUsageCreateInfo-stencilUsage-requiredbitmask
  
  `stencilUsage` **must** not be 0

If the `pNext` chain includes a `VkDedicatedAllocationImageCreateInfoNV` structure, then that structure includes an enable controlling whether the image will have a dedicated memory allocation bound to it.

The `VkDedicatedAllocationImageCreateInfoNV` structure is defined as:

```c
// Provided by VK_NV_dedicated_allocation
typedef struct VkDedicatedAllocationImageCreateInfoNV {
  VkStructureType sType;
  const void* pNext;
  VkBool32 dedicatedAllocation;
} VkDedicatedAllocationImageCreateInfoNV;
```
sType is a VkStructureType value identifying this structure.

pNext is NULL or a pointer to a structure extending this structure.

dedicatedAllocation specifies whether the image will have a dedicated allocation bound to it.

Note
Using a dedicated allocation for color and depth/stencil attachments or other large images may improve performance on some devices.

Valid Usage

• VUID-VkDedicatedAllocationImageCreateInfoNV-dedicatedAllocation-00994
  If dedicatedAllocation is VK_TRUE, VkImageCreateInfo::flags must not include
  VK_IMAGE_CREATE_SPARSE_BINDING_BIT, VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT, or
  VK_IMAGE_CREATE_SPARSE_ALIASED_BIT

Valid Usage (Implicit)

• VUID-VkDedicatedAllocationImageCreateInfoNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_DEDICATED_ALLOCATION_IMAGE_CREATE_INFO_NV

To define a set of external memory handle types that may be used as backing store for an image, add a VkExternalMemoryImageCreateInfo structure to the pNext chain of the VkImageCreateInfo structure. The VkExternalMemoryImageCreateInfo structure is defined as:

// Provided by VK_VERSION_1_1
typedef struct VkExternalMemoryImageCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkExternalMemoryHandleTypeFlags handleTypes;
} VkExternalMemoryImageCreateInfo;

or the equivalent

// Provided by VK_KHR_external_memory
typedef VkExternalMemoryImageCreateInfo VkExternalMemoryImageCreateInfoKHR;

Note
A VkExternalMemoryImageCreateInfo structure with a non-zero handleTypes field must be included in the creation parameters for an image that will be bound to memory that is either exported or imported.
• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **handleTypes** is zero or a bitmask of `VkExternalMemoryHandleTypeFlagBits` specifying one or more external memory handle types.

---

**Valid Usage (Implicit)**

- VUID-VkExternalMemoryImageCreateInfo-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_IMAGE_CREATE_INFO`.

- VUID-VkExternalMemoryImageCreateInfo-handleTypes-parameter
  
  `handleTypes` must be a valid combination of `VkExternalMemoryHandleTypeFlagBits` values.

If the `pNext` chain includes a `VkExternalMemoryImageCreateInfoNV` structure, then that structure defines a set of external memory handle types that may be used as backing store for the image.

The `VkExternalMemoryImageCreateInfoNV` structure is defined as:

```c
// Provided by VK_NV_external_memory
typedef struct VkExternalMemoryImageCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkExternalMemoryHandleTypeFlagsNV handleTypes;
} VkExternalMemoryImageCreateInfoNV;
```

• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **handleTypes** is zero or a bitmask of `VkExternalMemoryHandleTypeFlagBitsNV` specifying one or more external memory handle types.

---

**Valid Usage (Implicit)**

- VUID-VkExternalMemoryImageCreateInfoNV-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_IMAGE_CREATE_INFO_NV`.

- VUID-VkExternalMemoryImageCreateInfoNV-handleTypes-parameter
  
  `handleTypes` must be a valid combination of `VkExternalMemoryHandleTypeFlagBitsNV` values.

To create an image with an external format, add a `VkExternalFormatANDROID` structure in the `pNext` chain of `VkImageCreateInfo`. `VkExternalFormatANDROID` is defined as:

```c
// Provided by VK_ANDROID_external_memory_android_hardware_buffer
typedef struct VkExternalFormatANDROID {
```
VkExternalFormatANDROID;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `externalFormat` is an implementation-defined identifier for the external format.

If `externalFormat` is zero, the effect is as if the `VkExternalFormatANDROID` structure was not present. Otherwise, the `image` will have the specified external format.

### Valid Usage

- VUID-VkExternalFormatANDROID-externalFormat-01894
  
  `externalFormat` must be 0 or a value returned in the `externalFormat` member of `VkAndroidHardwareBufferFormatPropertiesANDROID` by an earlier call to `vkGetAndroidHardwareBufferPropertiesANDROID`.

### Valid Usage (Implicit)

- VUID-VkExternalFormatANDROID-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_EXTERNAL_FORMAT_ANDROID`.

To create an image with a QNX Screen external format, add a `VkExternalFormatQNX` structure in the `pNext` chain of `VkImageCreateInfo`. `VkExternalFormatQNX` is defined as:

```c
// Provided by VK_QNX_external_memory_screen_buffer
typedef struct VkExternalFormatQNX {
    VkStructureType sType;
    void* pNext;
    uint64_t externalFormat;
} VkExternalFormatQNX;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `externalFormat` is an implementation-defined identifier for the external format.

If `externalFormat` is zero, the effect is as if the `VkExternalFormatQNX` structure was not present. Otherwise, the `image` will have the specified external format.

### Valid Usage

- VUID-VkExternalFormatQNX-externalFormat-08956
externalFormat must be 0 or a value returned in the externalFormat member of VkScreenBufferFormatPropertiesQNX by an earlier call to vkGetScreenBufferPropertiesQNX

Valid Usage (Implicit)

- VUID-VkExternalFormatQNX-sType-sType
  sType must be VK_STRUCTURE_TYPE_EXTERNAL_FORMAT_QNX

If the pNext chain of VkImageCreateInfo includes a VkImageSwapchainCreateInfoKHR structure, then that structure includes a swapchain handle indicating that the image will be bound to memory from that swapchain.

The VkImageSwapchainCreateInfoKHR structure is defined as:

```c
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with VK_KHR_swapchain
typedef struct VkImageSwapchainCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkSwapchainKHR swapchain;
} VkImageSwapchainCreateInfoKHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- swapchain is VK_NULL_HANDLE or a handle of a swapchain that the image will be bound to.

Valid Usage

- VUID-VkImageSwapchainCreateInfoKHR-swapchain-00995
  If swapchain is not VK_NULL_HANDLE, the fields of VkImageCreateInfo must match the implied image creation parameters of the swapchain

Valid Usage (Implicit)

- VUID-VkImageSwapchainCreateInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_IMAGE_SWAPCHAIN_CREATE_INFO_KHR
- VUID-VkImageSwapchainCreateInfoKHR-swapchain-parameter
  If swapchain is not VK_NULL_HANDLE, swapchain must be a valid VkSwapchainKHR handle

If the pNext chain of VkImageCreateInfo includes a VkImageFormatListCreateInfo structure, then that structure contains a list of all formats that can be used when creating views of this image.
The `VkImageFormatListCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkImageFormatListCreateInfo {
    VkStructureType sType;
    const void*pNext;
    uint32_t viewFormatCount;
    const VkFormat*pViewFormats;
} VkImageFormatListCreateInfo;
```

or the equivalent

```c
// Provided by VK_KHR_image_format_list
typedef VkImageFormatListCreateInfo VkImageFormatListCreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `viewFormatCount` is the number of entries in the `pViewFormats` array.
- `pViewFormats` is a pointer to an array of `VkFormat` values specifying all formats which can be used when creating views of this image.

If `viewFormatCount` is zero, `pViewFormats` is ignored and the image is created as if the `VkImageFormatListCreateInfo` structure were not included in the `pNext` chain of `VkImageCreateInfo`.

**Valid Usage (Implicit)**

- `VUID-VkImageFormatListCreateInfo-sType-sType` `sType` must be `VK_STRUCTURE_TYPE_IMAGE_FORMAT_LIST_CREATE_INFO`
- `VUID-VkImageFormatListCreateInfo-pViewFormats-parameter` If `viewFormatCount` is not 0, `pViewFormats` must be a valid pointer to an array of `viewFormatCount` valid `VkFormat` values

If the `pNext` chain of `VkImageCreateInfo` includes a `VkImageDrmFormatModifierListCreateInfoEXT` structure, then the image will be created with one of the Linux DRM format modifiers listed in the structure. The choice of modifier is implementation-dependent.

The `VkImageDrmFormatModifierListCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_image_drm_format_modifier
typedef struct VkImageDrmFormatModifierListCreateInfoEXT {
    VkStructureType sType;
    const void*pNext;
    uint32_t drmFormatModifierCount;
    const uint64_t*pDrmFormatModifiers;
} VkImageDrmFormatModifierListCreateInfoEXT;
```
VkImageDrmFormatModifierListCreateInfoEXT;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **drmFormatModifierCount** is the length of the `pDrmFormatModifiers` array.
- **pDrmFormatModifiers** is a pointer to an array of Linux DRM format modifiers.

**Valid Usage**

- VUID-VkImageDrmFormatModifierListCreateInfoEXT-pDrmFormatModifiers-02263
  Each modifier in `pDrmFormatModifiers` must be compatible with the parameters in `VkImageCreateInfo` and its `pNext` chain, as determined by querying `VkPhysicalDeviceImageFormatInfo2` extended with `VkPhysicalDeviceImageDrmFormatModifierInfoEXT`

**Valid Usage (Implicit)**

- VUID-VkImageDrmFormatModifierListCreateInfoEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_IMAGE_DRM_FORMAT_MODIFIER_LIST_CREATE_INFO_EXT`

- VUID-VkImageDrmFormatModifierListCreateInfoEXT-pDrmFormatModifiers-parameter
  `pDrmFormatModifiers` must be a valid pointer to an array of `drmFormatModifierCount` `uint64_t` values

- VUID-VkImageDrmFormatModifierListCreateInfoEXT-drmFormatModifierCount-arraylength
  `drmFormatModifierCount` must be greater than 0

If the `pNext` chain of `VkImageCreateInfo` includes a `VkImageDrmFormatModifierExplicitCreateInfoEXT` structure, then the image will be created with the Linux DRM format modifier and memory layout defined by the structure.

The `VkImageDrmFormatModifierExplicitCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_image_drm_format_modifier
typedef struct VkImageDrmFormatModifierExplicitCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    uint64_t drmFormatModifier;
    uint32_t drmFormatModifierPlaneCount;
    const VkSubresourceLayout* pPlaneLayouts;
} VkImageDrmFormatModifierExplicitCreateInfoEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
• `drmFormatModifier` is the *Linux DRM format modifier* with which the image will be created.
• `drmFormatModifierPlaneCount` is the number of *memory planes* in the image (as reported by `VkDrmFormatModifierPropertiesEXT`) as well as the length of the `pPlaneLayouts` array.
• `pPlaneLayouts` is a pointer to an array of `VkSubresourceLayout` structures describing the image’s *memory planes*.

The $i^{th}$ member of `pPlaneLayouts` describes the layout of the image’s $i^{th}$ *memory plane* (that is, `VK_IMAGE_ASPECT_MEMORY_PLANE_i_BIT_EXT`). In each element of `pPlaneLayouts`, the implementation must ignore `size`. The implementation calculates the size of each plane, which the application can query with `vkGetImageSubresourceLayout`.

When creating an image with `VkImageDrmFormatModifierExplicitCreateInfoEXT`, it is the application’s responsibility to satisfy all valid usage requirements. However, the implementation must validate that the provided `pPlaneLayouts`, when combined with the provided `drmFormatModifier` and other creation parameters in `VkImageCreateInfo` and its `pNext` chain, produce a valid image. (This validation is necessarily implementation-dependent and outside the scope of Vulkan, and therefore not described by valid usage requirements). If this validation fails, then `vkCreateImage` returns `VK_ERROR_INVALID_DRM_FORMAT_MODIFIER_PLANE_LAYOUT_EXT`.

---

### Valid Usage

- **VUID-VkImageDrmFormatModifierExplicitCreateInfoEXT-drmFormatModifier-02264**
  - `drmFormatModifier` must be compatible with the parameters in `VkImageCreateInfo` and its `pNext` chain, as determined by querying `VkPhysicalDeviceImageFormatInfo2` extended with `VkPhysicalDeviceImageDrmFormatModifierInfoEXT`.

- **VUID-VkImageDrmFormatModifierExplicitCreateInfoEXT-drmFormatModifierPlaneCount-02265**
  - `drmFormatModifierPlaneCount` must be equal to the `VkDrmFormatModifierPropertiesEXT::drmFormatModifierPlaneCount` associated with `VkImageCreateInfo::format` and `drmFormatModifier`, as found by querying `VkDrmFormatModifierPropertiesListEXT`.

- **VUID-VkImageDrmFormatModifierExplicitCreateInfoEXT-size-02267**
  - For each element of `pPlaneLayouts`, `size` must be 0.

- **VUID-VkImageDrmFormatModifierExplicitCreateInfoEXT-arrayPitch-02268**
  - For each element of `pPlaneLayouts`, `arrayPitch` must be 0 if `VkImageCreateInfo::arrayLayers` is 1.

- **VUID-VkImageDrmFormatModifierExplicitCreateInfoEXT-depthPitch-02269**
  - For each element of `pPlaneLayouts`, `depthPitch` must be 0 if `VkImageCreateInfo::extent.depth` is 1.

---

### Valid Usage (Implicit)

- **VUID-VkImageDrmFormatModifierExplicitCreateInfoEXT-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_IMAGE_DRM_FORMAT_MODIFIER_EXPLICIT_CREATE_INFO_EXT`.

- **VUID-VkImageDrmFormatModifierExplicitCreateInfoEXT-pPlaneLayouts-parameter**
**pPlaneLayouts** must be a valid pointer to an array of `drmFormatModifierPlaneCount VkSubresourceLayout` structures

- VUID-VkImageDrmFormatModifierExplicitCreateInfoEXT-drmFormatModifierPlaneCount-arraylength
  `drmFormatModifierPlaneCount` must be greater than 0

If the `pNext` list of `VkImageCreateInfo` includes a `VkImageCompressionControlEXT` structure, then that structure describes compression controls for this image.

The `VkImageCompressionControlEXT` structure is defined as:

```c
// Provided by VK_EXT_image_compression_control
typedef struct VkImageCompressionControlEXT {
    VkStructureType sType;
    const void* pNext;
    VkImageCompressionFlagsEXT flags;
    uint32_t compressionControlPlaneCount;
    VkImageCompressionFixedRateFlagsEXT* pFixedRateFlags;
} VkImageCompressionControlEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkImageCompressionFlagBitsEXT` describing compression controls for the image.
- `compressionControlPlaneCount` is the number of entries in the `pFixedRateFlags` array.
- `pFixedRateFlags` is `NULL` or a pointer to an array of `VkImageCompressionFixedRateFlagsEXT` bitfields describing allowed fixed-rate compression rates of each image plane. It is ignored if `flags` does not include `VK_IMAGE_COMPRESSION_FIXED_RATE_EXPLICIT_EXT`.

If enabled, fixed-rate compression is done in an implementation-defined manner and may be applied at block granularity. In that case, a write to an individual texel may modify the value of other texels in the same block.

### Valid Usage

- VUID-VkImageCompressionControlEXT-flags-06747
  `flags` must be one of `VK_IMAGE_COMPRESSION_DEFAULT_EXT`, `VK_IMAGE_COMPRESSION_FIXED_RATE_DEFAULT_EXT`, `VK_IMAGE_COMPRESSION_FIXED_RATE_EXPLICIT_EXT`, or `VK_IMAGE_COMPRESSION_DISABLED_EXT`

- VUID-VkImageCompressionControlEXT-flags-06748
  If `flags` includes `VK_IMAGE_COMPRESSION_FIXED_RATE_EXPLICIT_EXT`, `pFixedRateFlags` must not be `NULL`
Valid Usage (Implicit)

- VUID-VkImageCompressionControlEXT-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_IMAGE_COMPRESSION_CONTROL_EXT`

Note

Some combinations of compression properties may not be supported. For example, some implementations may not support different fixed-rate compression rates per plane of a multi-planar format and will not be able to enable fixed-rate compression for any plane if the requested rates differ.

Possible values of `VkImageCompressionControlEXT::flags`, specifying compression controls for an image, are:

```cpp
// Provided by VK_EXT_image_compression_control
typedef enum VkImageCompressionFlagBitsEXT {
    VK_IMAGE_COMPRESSION_DEFAULT_EXT = 0,
    VK_IMAGE_COMPRESSION_FIXED_RATE_DEFAULT_EXT = 0x00000001,
    VK_IMAGE_COMPRESSION_FIXED_RATE_EXPLICIT_EXT = 0x00000002,
    VK_IMAGE_COMPRESSION_DISABLED_EXT = 0x00000004,
} VkImageCompressionFlagBitsEXT;
```

- `VK_IMAGE_COMPRESSION_DEFAULT_EXT` specifies that the default image compression setting is used. Implementations must not apply fixed-rate compression.
- `VK_IMAGE_COMPRESSION_FIXED_RATE_DEFAULT_EXT` specifies that the implementation may choose any supported fixed-rate compression setting in an implementation-defined manner based on the properties of the image.
- `VK_IMAGE_COMPRESSION_FIXED_RATE_EXPLICIT_EXT` specifies that fixed-rate compression may be used and that the allowed compression rates are specified by `VkImageCompressionControlEXT::pFixedRateFlags`.
- `VK_IMAGE_COMPRESSION_DISABLED_EXT` specifies that all lossless and fixed-rate compression should be disabled.

If `VkImageCompressionControlEXT::flags` is `VK_IMAGE_COMPRESSION_FIXED_RATE_EXPLICIT_EXT`, then the i<sup>th</sup> member of the `pFixedRateFlags` array specifies the allowed compression rates for the image’s i<sup>th</sup> plane.

Note

If `VK_IMAGE_COMPRESSION_DISABLED_EXT` is included in `VkImageCompressionControlEXT::flags`, both lossless and fixed-rate compression will be disabled. This is likely to have a negative impact on performance and is only intended to be used for debugging purposes.
**typedef** VkFlags VkImageCompressionFlagsEXT;

**VkImageCompressionFlagsEXT** is a bitmask type for setting a mask of zero or more **VkImageCompressionFlagBitsEXT**.

// Provided by VK_EXT_image_compression_control
typedef VkFlags VkImageCompressionFixedRateFlagsEXT;

**VkImageCompressionFixedRateFlagsEXT** is a bitmask type for setting a mask of zero or more **VkImageCompressionFixedRateFlagBitsEXT**.

Bits which **can** be set in **VkImageCompressionControlEXT::pFixedRateFlags**, specifying allowed compression rates for an image plane, are:

// Provided by VK_EXT_image_compression_control
typedef enum VkImageCompressionFixedRateFlagBitsEXT {
    VK_IMAGE_COMPRESSION_FIXED_RATE_NONE_EXT = 0,
    VK_IMAGE_COMPRESSION_FIXED_RATE_1BPC_BIT_EXT = 0x00000001,
    VK_IMAGE_COMPRESSION_FIXED_RATE_2BPC_BIT_EXT = 0x00000002,
    VK_IMAGE_COMPRESSION_FIXED_RATE_3BPC_BIT_EXT = 0x00000004,
    VK_IMAGE_COMPRESSION_FIXED_RATE_4BPC_BIT_EXT = 0x00000008,
    VK_IMAGE_COMPRESSION_FIXED_RATE_5BPC_BIT_EXT = 0x00000010,
    VK_IMAGE_COMPRESSION_FIXED_RATE_6BPC_BIT_EXT = 0x00000020,
    VK_IMAGE_COMPRESSION_FIXED_RATE_7BPC_BIT_EXT = 0x00000040,
    VK_IMAGE_COMPRESSION_FIXED_RATE_8BPC_BIT_EXT = 0x00000080,
    VK_IMAGE_COMPRESSION_FIXED_RATE_9BPC_BIT_EXT = 0x00000100,
    VK_IMAGE_COMPRESSION_FIXED_RATE_10BPC_BIT_EXT = 0x00000200,
    VK_IMAGE_COMPRESSION_FIXED_RATE_11BPC_BIT_EXT = 0x00000400,
    VK_IMAGE_COMPRESSION_FIXED_RATE_12BPC_BIT_EXT = 0x00000800,
    VK_IMAGE_COMPRESSION_FIXED_RATE_13BPC_BIT_EXT = 0x00001000,
    VK_IMAGE_COMPRESSION_FIXED_RATE_14BPC_BIT_EXT = 0x00002000,
    VK_IMAGE_COMPRESSION_FIXED_RATE_15BPC_BIT_EXT = 0x00004000,
    VK_IMAGE_COMPRESSION_FIXED_RATE_16BPC_BIT_EXT = 0x00008000,
    VK_IMAGE_COMPRESSION_FIXED_RATE_17BPC_BIT_EXT = 0x00010000,
    VK_IMAGE_COMPRESSION_FIXED_RATE_18BPC_BIT_EXT = 0x00020000,
    VK_IMAGE_COMPRESSION_FIXED_RATE_19BPC_BIT_EXT = 0x00040000,
    VK_IMAGE_COMPRESSION_FIXED_RATE_20BPC_BIT_EXT = 0x00080000,
    VK_IMAGE_COMPRESSION_FIXED_RATE_21BPC_BIT_EXT = 0x00100000,
    VK_IMAGE_COMPRESSION_FIXED_RATE_22BPC_BIT_EXT = 0x00200000,
    VK_IMAGE_COMPRESSION_FIXED_RATE_23BPC_BIT_EXT = 0x00400000,
    VK_IMAGE_COMPRESSION_FIXED_RATE_24BPC_BIT_EXT = 0x00800000,
} VkImageCompressionFixedRateFlagBitsEXT;

- **VK_IMAGE_COMPRESSION_FIXED_RATE_NONE_EXT** specifies that fixed-rate compression **must** not be used.
- **VK_IMAGE_COMPRESSION_FIXED_RATE_1BPC_BIT_EXT** specifies that fixed-rate compression with a bitrate of [1,2) bits per component **may** be used.
• **VK_IMAGE_COMPRESSION_FIXED_RATE_2BPC_BIT_EXT** specifies that fixed-rate compression with a bitrate of [2,3) bits per component may be used.

• **VK_IMAGE_COMPRESSION_FIXED_RATE_3BPC_BIT_EXT** specifies that fixed-rate compression with a bitrate of [3,4) bits per component may be used.

• **VK_IMAGE_COMPRESSION_FIXED_RATE_4BPC_BIT_EXT** specifies that fixed-rate compression with a bitrate of [4,5) bits per component may be used.

• **VK_IMAGE_COMPRESSION_FIXED_RATE_5BPC_BIT_EXT** specifies that fixed-rate compression with a bitrate of [5,6) bits per component may be used.

• **VK_IMAGE_COMPRESSION_FIXED_RATE_6BPC_BIT_EXT** specifies that fixed-rate compression with a bitrate of [6,7) bits per component may be used.

• **VK_IMAGE_COMPRESSION_FIXED_RATE_7BPC_BIT_EXT** specifies that fixed-rate compression with a bitrate of [7,8) bits per component may be used.

• **VK_IMAGE_COMPRESSION_FIXED_RATE_8BPC_BIT_EXT** specifies that fixed-rate compression with a bitrate of [8,9) bits per component may be used.

• **VK_IMAGE_COMPRESSION_FIXED_RATE_9BPC_BIT_EXT** specifies that fixed-rate compression with a bitrate of [9,10) bits per component may be used.

• **VK_IMAGE_COMPRESSION_FIXED_RATE_10BPC_BIT_EXT** specifies that fixed-rate compression with a bitrate of [10,11) bits per component may be used.

• **VK_IMAGE_COMPRESSION_FIXED_RATE_11BPC_BIT_EXT** specifies that fixed-rate compression with a bitrate of [11,12) bits per component may be used.

• **VK_IMAGE_COMPRESSION_FIXED_RATE_12BPC_BIT_EXT** specifies that fixed-rate compression with a bitrate of at least 12 bits per component may be used.

If the format has a different bit rate for different components, **VkImageCompressionControlEXT**::pFixedRateFlags describes the rate of the component with the largest number of bits assigned to it, scaled pro rata. For example, to request that a **VK_FORMAT_A2R10G10B10_UNORM_PACK32** format be stored at a rate of 8 bits per pixel, use **VK_IMAGE_COMPRESSION_FIXED_RATE_2BPC_BIT_EXT** (10 bits for the largest component, stored at quarter the original size, 2.5 bits, rounded down).

If flags includes **VK_IMAGE_COMPRESSION_FIXED_RATE_EXPLICIT_EXT**, and multiple bits are set in **VkImageCompressionControlEXT**::pFixedRateFlags for a plane, implementations should apply the lowest allowed bitrate that is supported.

---

**Note**

The choice of “bits per component” terminology was chosen so that the same compression rate describes the same degree of compression applied to formats that differ only in the number of components. For example, **VK_FORMAT_R8G8_UNORM** compressed to half its original size is a rate of 4 bits per component, 8 bits per pixel. **VK_FORMAT_R8G8B8A8_UNORM** compressed to half its original size is 4 bits per component, 16 bits per pixel. Both of these cases can be requested with **VK_IMAGE_COMPRESSION_FIXED_RATE_4BPC_BIT_EXT**.

To query the compression properties of an image, add a **VkImageCompressionPropertiesEXT** structure to the pNext chain of the **VkSubresourceLayout2EXT** structure in a call to
vkGetImageSubresourceLayout2KHR or vkGetImageSubresourceLayout2EXT.

To determine the compression rates that are supported for a given image format, add a VkImageCompressionPropertiesEXT structure to the pNext chain of the VkImageFormatProperties2 structure in a call to vkGetPhysicalDeviceImageFormatProperties2.

Note
Since fixed-rate compression is disabled by default, the VkImageCompressionPropertiesEXT structure passed to vkGetPhysicalDeviceImageFormatProperties2 will not indicate any fixed-rate compression support unless a VkImageCompressionControlEXT structure is also included in the pNext chain of the VkPhysicalDeviceImageFormatInfo2 structure passed to the same command.

The VkImageCompressionPropertiesEXT structure is defined as:

```
// Provided by VK_EXT_image_compression_control
typedef struct VkImageCompressionPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    VkImageCompressionFlagsEXT imageCompressionFlags;
    VkImageCompressionFixedRateFlagsEXT imageCompressionFixedRateFlags;
} VkImageCompressionPropertiesEXT;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **imageCompressionFlags** returns a value describing the compression controls that apply to the image. The value will be either VK_IMAGE_COMPRESSION_DEFAULT_EXT to indicate no fixed-rate compression, VK_IMAGE_COMPRESSION_FIXED_RATE_EXPLICIT_EXT to indicate fixed-rate compression, or VK_IMAGE_COMPRESSION_DISABLED_EXT to indicate no compression.
- **imageCompressionFixedRateFlags** returns a VkImageCompressionFixedRateFlagsEXT value describing the compression rates that apply to the specified aspect of the image.

Valid Usage (Implicit)

- VUID-VkImageCompressionPropertiesEXT-sType-sType
  
  **sType** must be VK_STRUCTURE_TYPE_IMAGE_COMPRESSION_PROPERTIES_EXT

Bits which **can** be set in

- VkImageViewUsageCreateInfo::usage
- VkImageStencilUsageCreateInfo::stencilUsage
- VkImageCreateInfo::usage

specify intended usage of an image, and are:
typedef enum VkImageUsageFlagBits {
    VK_IMAGE_USAGE_TRANSFER_SRC_BIT = 0x00000001,
    VK_IMAGE_USAGE_TRANSFER_DST_BIT = 0x00000002,
    VK_IMAGE_USAGE_SAMPLED_BIT = 0x00000004,
    VK_IMAGE_USAGE_STORAGE_BIT = 0x00000008,
    VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT = 0x00000010,
    VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT = 0x00000020,
    VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT = 0x00000040,
    VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT = 0x00000080,
    // Provided by VK_KHR_video_decode_queue
    VK_IMAGE_USAGE_VIDEO_DECODE_DST_BIT_KHR = 0x00000400,
    // Provided by VK_KHR_video_decode_queue
    VK_IMAGE_USAGE_VIDEO_DECODE_SRC_BIT_KHR = 0x00000800,
    // Provided by VK_KHR_video_decode_queue
    VK_IMAGE_USAGE_VIDEO_DECODE_DPB_BIT_KHR = 0x00001000,
    // Provided by VK_EXT_fragment_density_map
    VK_IMAGE_USAGE_FRAGMENT_DENSITY_MAP_BIT_EXT = 0x00000200,
    // Provided by VK_KHR_fragment_shading_rate
    VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR = 0x00000100,
    // Provided by VK_EXT_host_image_copy
    VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT = 0x00400000,
    #ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_KHR_video_encode_queue
    VK_IMAGE_USAGE_VIDEO_ENCODE_DST_BIT_KHR = 0x00002000,
    #endif
    #ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_KHR_video_encode_queue
    VK_IMAGE_USAGE_VIDEO_ENCODE_SRC_BIT_KHR = 0x00004000,
    #endif
    #ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_KHR_video_encode_queue
    VK_IMAGE_USAGE_VIDEO_ENCODE_DPB_BIT_KHR = 0x00008000,
    #endif
    // Provided by VK_EXT_attachment_feedback_loop_layout
    VK_IMAGE_USAGE_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT = 0x00080000,
    // Provided by VK_HUAWEI_invocation_mask
    VK_IMAGE_USAGE_INVOCATION_MASK_BIT_HUAWEI = 0x00040000,
    // Provided by VK_QCOM_image_processing
    VK_IMAGE_USAGE_SAMPLE_WEIGHT_BIT_QCOM = 0x00100000,
    // Provided by VK_QCOM_image_processing
    VK_IMAGE_USAGE_SAMPLE_BLOCK_MATCH_BIT_QCOM = 0x00200000,
    // Provided by VK_NV_shading_rate_image
    VK_IMAGE_USAGE_SHADING_RATE_IMAGE_BIT_NV =
    VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR,
} VkImageUsageFlagBits;

- **VK_IMAGE_USAGE_TRANSFER_SRC_BIT** specifies that the image can be used as the source of a transfer command.
VK_IMAGE_USAGE_TRANSFER_DST_BIT specifies that the image can be used as the destination of a transfer command.

VK_IMAGE_USAGE_SAMPLED_BIT specifies that the image can be used to create a VkImageView suitable for occupying a VkDescriptorSet slot either of type VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE or VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER, and be sampled by a shader.

VK_IMAGE_USAGE_STORAGE_BIT specifies that the image can be used to create a VkImageView suitable for occupying a VkDescriptorSet slot of type VK_DESCRIPTOR_TYPE_STORAGE_IMAGE.

VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT specifies that the image can be used to create a VkImageView suitable for use as a color or resolve attachment in a VkFramebuffer.

VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT specifies that the image can be used to create a VkImageView suitable for use as a depth/stencil or depth/stencil resolve attachment in a VkFramebuffer.

VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT specifies that implementations may support using memory allocations with the VK_MEMORY_PROPERTY_LAZILY_ALLOCATED_BIT to back an image with this usage. This bit can be set for any image that can be used to create a VkImageView suitable for use as a color, resolve, depth/stencil, or input attachment.

VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT specifies that the image can be used to create a VkImageView suitable for occupying VkDescriptorSet slot of type VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT; be read from a shader as an input attachment; and be used as an input attachment in a framebuffer.

VK_IMAGE_USAGE_FRAGMENT_DENSITY_MAP_BIT_EXT specifies that the image can be used to create a VkImageView suitable for use as a fragment density map image.

VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR specifies that the image can be used to create a VkImageView suitable for use as a fragment shading rate attachment or shading rate image.

VK_IMAGE_USAGE_VIDEO_DECODE_DST_BIT_KHR specifies that the image can be used as a decode output picture in a video decode operation.

VK_IMAGE_USAGE_VIDEO_DECODE_SRC_BIT_KHR is reserved for future use.

VK_IMAGE_USAGE_VIDEO_DECODE_DPB_BIT_KHR specifies that the image can be used as an output reconstructed picture or an input reference picture in a video decode operation.

VK_IMAGE_USAGE_VIDEO_ENCODE_DST_BIT_KHR is reserved for future use.

VK_IMAGE_USAGE_VIDEO_ENCODE_SRC_BIT_KHR specifies that the image can be used as an encode input picture in a video encode operation.

VK_IMAGE_USAGE_VIDEO_ENCODE_DPB_BIT_KHR specifies that the image can be used as an output reconstructed picture or an input reference picture in a video encode operation.

VK_IMAGE_USAGE_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT specifies that the image can be transitioned to the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT layout to be used as a color or depth/stencil attachment in a VkFramebuffer and/or as a read-only input resource in a shader (sampled image, combined image sampler or input attachment) in the same render pass.

VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT specifies that the image can be used with host copy commands and host layout transitions.
typedef VkFlags VkImageUsageFlags;

VkImageUsageFlags is a bitmask type for setting a mask of zero or more VkImageUsageFlagBits.

When creating a VkImageView one of the following VkImageUsageFlagBits must be set:

- VK_IMAGE_USAGE_SAMPLED_BIT
- VK_IMAGE_USAGE_STORAGE_BIT
- VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT
- VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT
- VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT
- VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT
- VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR
- VK_IMAGE_USAGE_FRAGMENT_DENSITY_MAP_BIT_EXT
- VK_IMAGE_USAGE_VIDEO_DECODE_DST_BIT_KHR
- VK_IMAGE_USAGE_VIDEO_DECODE_DPB_BIT_KHR
- VK_IMAGE_USAGE_VIDEO_ENCODE_SRC_BIT_KHR
- VK_IMAGE_USAGE_VIDEO_ENCODE_DPB_BIT_KHR
- VK_IMAGE_USAGE_SAMPLE_WEIGHT_BIT_QCOM
- VK_IMAGE_USAGE_SAMPLE_BLOCK_MATCH_BIT_QCOM

Bits which can be set in VkImageCreateInfo::flags, specifying additional parameters of an image, are:

typedef enum VkImageCreateFlagBits {
    VK_IMAGE_CREATE_SPARSE_BINDING_BIT = 0x00000001,
    VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT = 0x00000002,
    VK_IMAGE_CREATE_SPARSE_ALIASED_BIT = 0x00000004,
    VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT = 0x00000008,
    VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT = 0x00000010,
    // Provided by VK_VERSION_1_1
    VK_IMAGE_CREATE_ALIAS_BIT = 0x00000400,
    // Provided by VK_VERSION_1_1
    VK_IMAGE_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT = 0x00000040,
    // Provided by VK_VERSION_1_1
    VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT = 0x00000020,
    // Provided by VK_VERSION_1_1
    VK_IMAGE_CREATE_BLOCK_TEXEL_VIEW_COMPATIBLE_BIT = 0x00000080,
    // Provided by VK_VERSION_1_1
    VK_IMAGE_CREATE_EXTENDED_USAGE_BIT = 0x00000100,
    // Provided by VK_VERSION_1_1
    1007
}
<table>
<thead>
<tr>
<th>VK_IMAGE_CREATE_FLAG_BITS</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_IMAGE_CREATE_PROTECTED_BIT</td>
<td>Provides protection for the image data.</td>
</tr>
<tr>
<td>VK_IMAGE_CREATE_DISJOINT_BIT</td>
<td>Indicates that the image is not shared with any other image.</td>
</tr>
<tr>
<td>VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV</td>
<td>Provides corner sampling for the image.</td>
</tr>
<tr>
<td>VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT</td>
<td>Enables sampling for the image's depth.</td>
</tr>
<tr>
<td>VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT</td>
<td>Enables subsampling for the image.</td>
</tr>
<tr>
<td>VK_IMAGE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT</td>
<td>Enables capturing and replaying for descriptor buffers.</td>
</tr>
<tr>
<td>VK_IMAGE_CREATE_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_BIT_EXT</td>
<td>Enables rendering to a single sample.</td>
</tr>
<tr>
<td>VK_IMAGE_CREATE_2D_VIEW_COMPATIBLE_BIT_EXT</td>
<td>Enables creating 2D views of 3D images.</td>
</tr>
<tr>
<td>VK_IMAGE_CREATE_FRAGMENT_DENSITY_MAP_OFFSET_BIT_QCOM</td>
<td>Enables fragment density map offset for images.</td>
</tr>
<tr>
<td>VK_IMAGE_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT_KHR</td>
<td>Enables creating VkImageViews with different formats.</td>
</tr>
<tr>
<td>VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT_KHR</td>
<td>Enables creating 2D arrays with different formats.</td>
</tr>
<tr>
<td>VK_IMAGE_CREATE_BLOCK_TEXEL_VIEW_COMPATIBLE_BIT_KHR</td>
<td>Enables creating block texel views with different formats.</td>
</tr>
<tr>
<td>VK_IMAGE_CREATE_EXTENDED_USAGE_BIT_KHR</td>
<td>Enables using the image for extended usage.</td>
</tr>
<tr>
<td>VK_IMAGE_CREATE_DISJOINT_BIT_KHR</td>
<td>Indicates that the image is not shared with any other image.</td>
</tr>
<tr>
<td>VK_IMAGE_CREATE_ALIAS_BIT_KHR</td>
<td>Enables creating VkImageViews with different formats.</td>
</tr>
</tbody>
</table>

- **VK_IMAGE_CREATE_SPARSE_BINDING_BIT** specifies that the image will be backed using sparse memory binding.
- **VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT** specifies that the image can be partially backed using sparse memory binding. Images created with this flag must also be created with the **VK_IMAGE_CREATE_SPARSE_BINDING_BIT** flag.
- **VK_IMAGE_CREATE_SPARSE_ALIASED_BIT** specifies that the image will be backed using sparse memory binding with memory ranges that might also simultaneously be backing another image (or another portion of the same image). Images created with this flag must also be created with the **VK_IMAGE_CREATE_SPARSE_BINDING_BIT** flag.
- **VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT** specifies that the image can be used to create a VkImageView with a different format from the image. For multi-planar formats, **VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT** specifies that a VkImageView can be created of a plane of the image.
- **VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT** specifies that the image can be used to create a VkImageView with a different format from the image.
VkImageView of type VK_IMAGE_VIEW_TYPE_CUBE or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY.

- **VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT** specifies that the image can be used to create a VkImageView of type VK_IMAGE_VIEW_TYPE_2D or VK_IMAGE_VIEW_TYPE_2D_ARRAY.

- **VK_IMAGE_CREATE_2D_VIEW_COMPATIBLE_BIT_EXT** specifies that the image can be used to create a VkImageView of type VK_IMAGE_VIEW_TYPE_2D.

- **VK_IMAGE_CREATE_PROTECTED_BIT** specifies that the image is a protected image.

- **VK_IMAGE_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT** specifies that the image can be used with a non-zero value of the splitInstanceBindRegionCount member of a VkBindImageMemoryDeviceGroupInfo structure passed into vkBindImageMemory2. This flag also has the effect of making the image use the standard sparse image block dimensions.

- **VK_IMAGE_CREATE_BLOCK_TEXEL_VIEW_COMPATIBLE_BIT** specifies that the image having a compressed format can be used to create a VkImageView with an uncompressed format where each texel in the image view corresponds to a compressed texel block of the image.

- **VK_IMAGE_CREATE_EXTENDED_USAGE_BIT** specifies that the image can be created with usage flags that are not supported for the format the image is created with but are supported for at least one format a VkImageView created from the image can have.

- **VK_IMAGE_CREATE_DISJOINT_BIT** specifies that an image with a multi-planar format must have each plane separately bound to memory, rather than having a single memory binding for the whole image; the presence of this bit distinguishes a disjoint image from an image without this bit set.

- **VK_IMAGE_CREATE_ALIAS_BIT** specifies that two images created with the same creation parameters and aliased to the same memory can interpret the contents of the memory consistently with each other, subject to the rules described in the Memory Aliasing section. This flag further specifies that each plane of a disjoint image can share an in-memory non-linear representation with single-plane images, and that a single-plane image can share an in-memory non-linear representation with a plane of a multi-planar disjoint image, according to the rules in Compatible formats of planes of multi-planar formats. If the pNext chain includes a VkExternalMemoryImageCreateInfo or VkExternalMemoryImageCreateInfoNV structure whose handleTypes member is not 0, it is as if VK_IMAGE_CREATE_ALIAS_BIT is set.

- **VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT** specifies that an image with a depth or depth/stencil format can be used with custom sample locations when used as a depth/stencil attachment.

- **VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV** specifies that the image is a corner-sampled image.

- **VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT** specifies that an image can be in a subsampled format which may be more optimal when written as an attachment by a render pass that has a fragment density map attachment. Accessing a subsampled image has additional considerations:
  - Image data read as an image sampler will have undefined values if the sampler was not created with flags containing VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT or was not sampled through the use of a combined image sampler with an immutable sampler in VkDescriptorSetLayoutBinding.
  - Image data read with an input attachment will have undefined values if the contents were not written as an attachment in an earlier subpass of the same render pass.
Image data read as an image sampler in the fragment shader will be additionally be read by the device during VK_PIPELINE_STAGE_VERTEX_SHADER_BIT if VkPhysicalDeviceFragmentDensityMap2PropertiesEXT::subsampledCoarseReconstructionEarlyAccess is VK_TRUE and the sampler was created with flags containing VK_SAMPLER_CREATE_SUBSAMPLED_COARSE_RECONSTRUCTION_BIT_EXT.

Image data read with load operations are resampled to the fragment density of the render pass if VkPhysicalDeviceFragmentDensityMap2PropertiesEXT::subsampledLoads is VK_TRUE. Otherwise, values of image data are undefined.

Image contents outside of the render area take on undefined values if the image is stored as a render pass attachment.

- **VK_IMAGE_CREATE_FRAGMENT_DENSITY_MAP_OFFSET_BIT_QCOM** specifies that an image can be used in a render pass with non-zero fragment density map offsets. In a render pass with non-zero offsets, fragment density map attachments, input attachments, color attachments, depth/stencil attachment, resolve attachments, and preserve attachments must be created with VK_IMAGE_CREATE_FRAGMENT_DENSITY_MAP_OFFSET_BIT_QCOM.

- **VK_IMAGE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT** specifies that the image can be used with descriptor buffers when capturing and replaying (e.g. for trace capture and replay), see VkOpaqueCaptureDescriptorDataCreateInfoEXT for more detail.

- **VK_IMAGE_CREATE_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_BIT_EXT** specifies that an image can be used with multisampled rendering as a single-sampled framebuffer attachment.

See Sparse Resource Features and Sparse Physical Device Features for more details.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkImageCreateFlags;

VkImageCreateFlags is a bitmask type for setting a mask of zero or more VkImageCreateFlagBits.

Possible values of VkImageCreateInfo::imageType, specifying the basic dimensionality of an image, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkImageType {
    VK_IMAGE_TYPE_1D = 0,
    VK_IMAGE_TYPE_2D = 1,
    VK_IMAGE_TYPE_3D = 2,
} VkImageType;
```

- **VK_IMAGE_TYPE_1D** specifies a one-dimensional image.
- **VK_IMAGE_TYPE_2D** specifies a two-dimensional image.
- **VK_IMAGE_TYPE_3D** specifies a three-dimensional image.

Possible values of VkImageCreateInfo::tiling, specifying the tiling arrangement of texel blocks in an image, are:
typedef enum VkImageTiling {
    VK_IMAGE_TILING_OPTIMAL = 0,
    VK_IMAGE_TILING_LINEAR = 1,
    VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT = 1000158000,
} VkImageTiling;

- **VK_IMAGE_TILING_OPTIMAL** specifies optimal tiling (texels are laid out in an implementation-dependent arrangement, for more efficient memory access).
- **VK_IMAGE_TILING_LINEAR** specifies linear tiling (texels are laid out in memory in row-major order, possibly with some padding on each row).
- **VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT** indicates that the image's tiling is defined by a Linux DRM format modifier. The modifier is specified at image creation with VkImageDrmFormatModifierListCreateInfoEXT or VkImageDrmFormatModifierExplicitCreateInfoEXT, and can be queried with vkGetImageDrmFormatModifierPropertiesEXT.

To query the memory layout of an image subresource, call:

```c
// Provided by VK_VERSION_1_0
void vkGetImageSubresourceLayout(
    VkDevice device,
    VkImage image,
    const VkImageSubresource* pSubresource,
    VkSubresourceLayout* pLayout);
```

- **device** is the logical device that owns the image.
- **image** is the image whose layout is being queried.
- **pSubresource** is a pointer to a VkImageSubresource structure selecting a specific image subresource from the image.
- **pLayout** is a pointer to a VkSubresourceLayout structure in which the layout is returned.

If the image is **linear**, then the returned layout is valid for **host access**.

If the image's tiling is **VK_IMAGE_TILING_LINEAR** and its format is a **multi-planar format**, then vkGetImageSubresourceLayout describes one **format plane** of the image. If the image's tiling is **VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT**, then vkGetImageSubresourceLayout describes one **memory plane** of the image. If the image's tiling is **VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT** and the image is **non-linear**, then the returned layout has an implementation-dependent meaning; the vendor of the image's DRM format modifier may provide documentation that explains how to interpret the returned layout.

vkGetImageSubresourceLayout is invariant for the lifetime of a single image. However, the subresource layout of images in Android hardware buffer or QNX Screen buffer external memory...
is not known until the image has been bound to memory, so applications must not call `vkGetImageSubresourceLayout` for such an image before it has been bound.

**Valid Usage**

- VUID-vkGetImageSubresourceLayout-image-07790
  image must have been created with tiling equal to `VK_IMAGE_TILING_LINEAR` or `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`

- VUID-vkGetImageSubresourceLayout-aspectMask-00997
  The `aspectMask` member of `pSubresource` must only have a single bit set

- VUID-vkGetImageSubresourceLayout-mipLevel-01716
  The `mipLevel` member of `pSubresource` must be less than the `mipLevels` specified in `VkImageCreateInfo` when image was created

- VUID-vkGetImageSubresourceLayout-arrayLayer-01717
  The `arrayLayer` member of `pSubresource` must be less than the `arrayLayers` specified in `VkImageCreateInfo` when image was created

- VUID-vkGetImageSubresourceLayout-format-08886
  If format of the image is a color format, tiling of the image is `VK_IMAGE_TILING_LINEAR` or `VK_IMAGE_TILING_OPTIMAL`, and does not have a multi-planar image format, the `aspectMask` member of `pSubresource` must be `VK_IMAGE_ASPECT_COLOR_BIT`

- VUID-vkGetImageSubresourceLayout-format-04462
  If format of the image has a depth component, the `aspectMask` member of `pSubresource` must contain `VK_IMAGE_ASPECT_DEPTH_BIT`

- VUID-vkGetImageSubresourceLayout-format-04463
  If format of the image has a stencil component, the `aspectMask` member of `pSubresource` must contain `VK_IMAGE_ASPECT_STENCIL_BIT`

- VUID-vkGetImageSubresourceLayout-format-04464
  If format of the image does not contain a stencil or depth component, the `aspectMask` member of `pSubresource` must not contain `VK_IMAGE_ASPECT_DEPTH_BIT` or `VK_IMAGE_ASPECT_STENCIL_BIT`

- VUID-vkGetImageSubresourceLayout-tiling-08717
  If the tiling of the image is `VK_IMAGE_TILING_LINEAR` and has a multi-planar image format, then the `aspectMask` member of `pSubresource` must be a single valid multi-planar aspect mask bit

- VUID-vkGetImageSubresourceLayout-image-01895
  If image was created with the `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID` external memory handle type, then image must be bound to memory

- VUID-vkGetImageSubresourceLayout-tiling-02271
  If the tiling of the image is `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`, then the `aspectMask` member of `pSubresource` must be `VK_IMAGE_ASPECT_MEMORY_PLANE_i_BIT_EXT` and the index `i` must be less than the `VkDrmFormatModifierPropertiesEXT::drmFormatModifierPlaneCount` associated with the image’s format and `VkImageDrmFormatModifierPropertiesEXT`
Valid Usage (Implicit)

- VUID-vkGetImageSubresourceLayout-device-parameter
device must be a valid VkDevice handle
- VUID-vkGetImageSubresourceLayout-image-parameter
image must be a valid VkImage handle
- VUID-vkGetImageSubresourceLayout-pSubresource-parameter
pSubresource must be a valid pointer to a valid VkImageSubresource structure
- VUID-vkGetImageSubresourceLayout-pLayout-parameter
pLayout must be a valid pointer to a VkSubresourceLayout structure
- VUID-vkGetImageSubresourceLayout-image-parent
image must have been created, allocated, or retrieved from device

The VkImageSubresource structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkImageSubresource {
    VkImageAspectFlags aspectMask;
    uint32_t mipLevel;
    uint32_t arrayLayer;
} VkImageSubresource;
```

- aspectMask is a VkImageAspectFlags value selecting the image aspect.
- mipLevel selects the mipmap level.
- arrayLayer selects the array layer.

Valid Usage (Implicit)

- VUID-VkImageSubresource-aspectMask-parameter
aspectMask must be a valid combination of VkImageAspectFlagBits values
- VUID-VkImageSubresource-aspectMask-requiredbitmask
aspectMask must not be 0

Information about the layout of the image subresource is returned in a VkSubresourceLayout structure:

```c
// Provided by VK_VERSION_1_0
typedef struct VkSubresourceLayout {
    VkDeviceSize offset;
    VkDeviceSize size;
} VkSubresourceLayout;
```
VkDeviceSize rowPitch;
VkDeviceSize arrayPitch;
VkDeviceSize depthPitch;
} VkSubresourceLayout;

- **offset** is the byte offset from the start of the image or the plane where the image subresource begins.

- **size** is the size in bytes of the image subresource. **size** includes any extra memory that is required based on **rowPitch**.

- **rowPitch** describes the number of bytes between each row of texels in an image.

- **arrayPitch** describes the number of bytes between each array layer of an image.

- **depthPitch** describes the number of bytes between each slice of 3D image.

If the image is **linear**, then **rowPitch**, **arrayPitch** and **depthPitch** describe the layout of the image subresource in linear memory. For uncompressed formats, **rowPitch** is the number of bytes between texels with the same x coordinate in adjacent rows (y coordinates differ by one). **arrayPitch** is the number of bytes between texels with the same x and y coordinate in adjacent array layers of the image (array layer values differ by one). **depthPitch** is the number of bytes between texels with the same x and y coordinate in adjacent slices of a 3D image (z coordinates differ by one). Expressed as an addressing formula, the starting byte of a texel in the image subresource has address:

```
// (x,y,z,layer) are in texel coordinates
address(x,y,z,layer) = layer*arrayPitch + z*depthPitch + y*rowPitch + x*elementSize + offset
```

For compressed formats, the **rowPitch** is the number of bytes between compressed texel blocks in adjacent rows. **arrayPitch** is the number of bytes between compressed texel blocks in adjacent array layers. **depthPitch** is the number of bytes between compressed texel blocks in adjacent slices of a 3D image.

```
// (x,y,z,layer) are in compressed texel block coordinates
address(x,y,z,layer) = layer*arrayPitch + z*depthPitch + y*rowPitch + x
*compressedTexelBlockByteSize + offset;
```

The value of **arrayPitch** is undefined for images that were not created as arrays. **depthPitch** is defined only for 3D images.

If the image has a **single-plane** color format and its tiling is **VK_IMAGE_TILING_LINEAR**, then the **aspectMask** member of **VkImageSubresource** **must** be **VK_IMAGE_ASPECT_COLOR_BIT**.

If the image has a depth/stencil format and its tiling is **VK_IMAGE_TILING_LINEAR**, then **aspectMask** **must** be either **VK_IMAGE_ASPECT_DEPTH_BIT** or **VK_IMAGE_ASPECT_STENCIL_BIT**. On implementations that store depth and stencil aspects separately, querying each of these image subresource layouts will return a different **offset** and **size** representing the region of memory used for that aspect. On implementations that store depth and stencil aspects interleaved, the same **offset** and **size** are
returned and represent the interleaved memory allocation.

If the image has a multi-planar format and its tiling is VK_IMAGE_TILING_LINEAR, then the aspectMask member of VkImageSubresource must be VK_IMAGE_ASPECT_PLANE_0_BIT, VK_IMAGE_ASPECT_PLANE_1_BIT, or (for 3-plane formats only) VK_IMAGE_ASPECT_PLANE_2_BIT. Querying each of these image subresource layouts will return a different offset and size representing the region of memory used for that plane. If the image is disjoint, then the offset is relative to the base address of the plane. If the image is non-disjoint, then the offset is relative to the base address of the image.

If the image’s tiling is VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT, then the aspectMask member of VkImageSubresource must be one of VK_IMAGE_ASPECT_MEMORY_PLANE_i_BIT_EXT, where the maximum allowed plane index i is defined by the VkDrmFormatModifierPropertiesEXT::drmFormatModifierPlaneCount associated with the image’s VkImageCreateInfo::format and modifier. The memory range used by the subresource is described by offset and size. If the image is disjoint, then the offset is relative to the base address of the memory plane. If the image is non-disjoint, then the offset is relative to the base address of the image. If the image is non-linear, then rowPitch, arrayPitch, and depthPitch have an implementation-dependent meaning.

To query the memory layout of an image subresource, call:

```c
// Provided by VK_KHR_maintenance5
void vkGetImageSubresourceLayout2KHR(
    VkDevice device,
    VkImage image,
    const VkImageSubresource2KHR* pSubresource,
    VkSubresourceLayout2KHR* pLayout);
```

or the equivalent command

```c
// Provided by VK_EXT_host_image_copy, VK_EXT_image_compression_control
void vkGetImageSubresourceLayout2EXT(
    VkDevice device,
    VkImage image,
    const VkImageSubresource2KHR* pSubresource,
    VkSubresourceLayout2KHR* pLayout);
```

- device is the logical device that owns the image.
- image is the image whose layout is being queried.
- pSubresource is a pointer to a VkImageSubresource2KHR structure selecting a specific image for the image subresource.
- pLayout is a pointer to a VkSubresourceLayout2KHR structure in which the layout is returned.

vkGetImageSubresourceLayout2KHR behaves similarly to vkGetImageSubresourceLayout, with the ability to specify extended inputs via chained input structures, and to return extended information via chained output structures.

It is legal to call vkGetImageSubresourceLayout2KHR with a image created with tiling equal to
**VK_IMAGE_TILING_OPTIMAL**, but the members of `VkSubresourceLayout2KHR::subresourceLayout` will have undefined values in this case.

**Note**

Structures chained from `VkImageSubresource2KHR::pNext` will also be updated when `tiling` is equal to **VK_IMAGE_TILING_OPTIMAL**.

---

**Valid Usage**

- **VUID-vkGetImageSubresourceLayout2KHR-aspectMask-00997**
  The `aspectMask` member of `pSubresource must` only have a single bit set

- **VUID-vkGetImageSubresourceLayout2KHR-mipLevel-01716**
  The `mipLevel` member of `pSubresource must` be less than the `mipLevels` specified in `VkImageCreateInfo` when `image` was created

- **VUID-vkGetImageSubresourceLayout2KHR-arrayLayer-01717**
  The `arrayLayer` member of `pSubresource must` be less than the `arrayLayers` specified in `VkImageCreateInfo` when `image` was created

- **VUID-vkGetImageSubresourceLayout2KHR-format-08886**
  If `format` of the `image` is a color format, `tiling` of the `image` is **VK_IMAGE_TILING_LINEAR** or **VK_IMAGE_TILING_OPTIMAL**, and does not have a multi-planar image format, the `aspectMask` member of `pSubresource must` be **VK_IMAGE_ASPECT_COLOR_BIT**

- **VUID-vkGetImageSubresourceLayout2KHR-format-04462**
  If `format` of the `image` has a depth component, the `aspectMask` member of `pSubresource must` contain **VK_IMAGE_ASPECT_DEPTH_BIT**

- **VUID-vkGetImageSubresourceLayout2KHR-format-04463**
  If `format` of the `image` has a stencil component, the `aspectMask` member of `pSubresource must` contain **VK_IMAGE_ASPECT_STENCIL_BIT**

- **VUID-vkGetImageSubresourceLayout2KHR-format-04464**
  If `format` of the `image` does not contain a stencil or depth component, the `aspectMask` member of `pSubresource must` not contain **VK_IMAGE_ASPECT_DEPTH_BIT** or **VK_IMAGE_ASPECT_STENCIL_BIT**

- **VUID-vkGetImageSubresourceLayout2KHR-tiling-08717**
  If the `tiling` of the `image` is **VK_IMAGE_TILING_LINEAR** and has a multi-planar image format, then the `aspectMask` member of `pSubresource must` be a single valid multi-planar aspect mask bit

- **VUID-vkGetImageSubresourceLayout2KHR-image-01895**
  If `image` was created with the **VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID** external memory handle type, then `image must` be bound to memory

- **VUID-vkGetImageSubresourceLayout2KHR-tiling-02271**
  If the `tiling` of the `image` is **VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT**, then the `aspectMask` member of `pSubresource must` be **VK_IMAGE_ASPECT_MEMORY_PLANE_i_BIT_EXT** and the index `i must` be less than the `VkDrmFormatModifierPropertiesEXT::drmFormatModifierPlaneCount`
associated with the image's format and VkImageDrmFormatModifierPropertiesEXT::drmFormatModifier

## Valid Usage (Implicit)

- **VUID-vkGetImageSubresourceLayout2KHR-device-parameter**
  
  device must be a valid VkDevice handle

- **VUID-vkGetImageSubresourceLayout2KHR-image-parameter**
  
  image must be a valid VkImage handle

- **VUID-vkGetImageSubresourceLayout2KHR-pSubresource-parameter**
  
  pSubresource must be a valid pointer to a valid VkImageSubresource2KHR structure

- **VUID-vkGetImageSubresourceLayout2KHR-pLayout-parameter**
  
  pLayout must be a valid pointer to a VkSubresourceLayout2KHR structure

- **VUID-vkGetImageSubresourceLayout2KHR-image-parent**
  
  image must have been created, allocated, or retrieved from device

The **VkImageSubresource2KHR** structure is defined as:

```c
// Provided by VK_KHR_maintenance5
typedef struct VkImageSubresource2KHR {
    VkStructureType sType;
    void* pNext;
    VkImageSubresource imageSubresource;
} VkImageSubresource2KHR;
```

or the equivalent

```c
// Provided by VK_EXT_host_image_copy, VK_EXT_image_compression_control
typedef VkImageSubresource2KHR VkImageSubresource2EXT;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **imageSubresource** is a VkImageSubresource structure.

## Valid Usage (Implicit)

- **VUID-VkImageSubresource2KHR-sType-sType**
  
  sType must be VK_STRUCTURE_TYPE_IMAGE_SUBRESOURCE_2_KHR

- **VUID-VkImageSubresource2KHR-pNext-pNext**
  
  pNext must be NULL

- **VUID-VkImageSubresource2KHR-imageSubresource-parameter**
**imageSubresource** must be a valid **VkImageSubresource** structure

Information about the layout of the image subresource is returned in a **VkSubresourceLayout2KHR** structure:

```c
// Provided by VK_KHR_maintenance5
typedef struct VkSubresourceLayout2KHR {
    VkStructureType sType;
    void* pNext;
    VkSubresourceLayout subresourceLayout;
} VkSubresourceLayout2KHR;
```

or the equivalent

```c
// Provided by VK_EXT_host_image_copy, VK_EXT_image_compression_control
typedef VkSubresourceLayout2KHR VkSubresourceLayout2EXT;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **subresourceLayout** is a **VkSubresourceLayout** structure.

### Valid Usage (Implicit)

- **VUID-VkSubresourceLayout2KHR-sType-sType**
  
  * **sType** must be **VK_STRUCTURE_TYPE_SUBRESOURCE_LAYOUT_2_KHR**

- **VUID-VkSubresourceLayout2KHR-pNext-pNext**
  
  Each **pNext** member of any structure (including this one) in the **pNext** chain must be either NULL or a pointer to a valid instance of **VkImageCompressionPropertiesEXT** or **VkSubresourceHostMemcpySizeEXT**

- **VUID-VkSubresourceLayout2KHR-sType-unique**
  
  The **sType** value of each struct in the **pNext** chain must be unique

To query the memory size needed to copy to or from an image using **vkCopyMemoryToImageEXT** or **vkCopyImageToMemoryEXT** when the **VK_HOST_IMAGE_COPY_MEMCPY_EXT** flag is specified, add a **VkSubresourceHostMemcpySizeEXT** structure to the **pNext** chain of the **VkSubresourceLayout2EXT** structure in a call to **vkGetImageSubresourceLayout2EXT**.

The **VkSubresourceHostMemcpySizeEXT** structure is defined as:

```c
// Provided by VK_EXT_host_image_copy
typedef struct VkSubresourceHostMemcpySizeEXT {
    VkStructureType sType;
    void* pNext;
    VkDeviceSize size;
} VkSubresourceHostMemcpySizeEXT;
```
• **sType** is a **VkStructureType** value identifying this structure.
• **pNext** is **NULL** or a pointer to a structure extending this structure.
• **size** is the size in bytes of the image subresource.

### Valid Usage (Implicit)

- VUID-VkSubresourceHostMemcpySizeEXT-sType-sType
  sType **must** be **VK_STRUCTURE_TYPE_SUBRESOURCE_HOST_MEMCPY_SIZE_EXT**

To query the memory layout of an image subresource, without an image object, call:

```c
// Provided by VK_KHR_maintenance5
void vkGetDeviceImageSubresourceLayoutKHR(
  VkDevice device,
  const VkDeviceImageSubresourceInfoKHR* pInfo,
  VkSubresourceLayout2KHR* pLayout);
```

- **device** is the logical device that owns the image.
- **pInfo** is a pointer to a **VkDeviceImageSubresourceInfoKHR** structure containing parameters required for the subresource layout query.
- **pLayout** is a pointer to a **VkSubresourceLayout2KHR** structure in which the layout is returned.

vkGetDeviceImageSubresourceLayoutKHR behaves similarly to vkGetImageSubresourceLayout2KHR, but uses a **VkImageCreateInfo** structure to specify the image rather than a **VkImage** object.

### Valid Usage (Implicit)

- VUID-vkGetDeviceImageSubresourceLayoutKHR-device-parameter
device **must** be a valid **VkDevice** handle
- VUID-vkGetDeviceImageSubresourceLayoutKHR-pInfo-parameter
  pInfo **must** be a valid pointer to a valid **VkDeviceImageSubresourceInfoKHR** structure
- VUID-vkGetDeviceImageSubresourceLayoutKHR-pLayout-parameter
  pLayout **must** be a valid pointer to a **VkSubresourceLayout2KHR** structure

The **VkDeviceImageSubresourceInfoKHR** structure is defined as:

```c
// Provided by VK_KHR_maintenance5
typedef struct VkDeviceImageSubresourceInfoKHR {
  VkStructureType sType;
  const void* pNext;
  const VkImageCreateInfo* pCreateInfo;
} VkDeviceImageSubresourceInfoKHR;
```
*const VkImageSubresource2KHR* pSubresource;
} VkDeviceImageSubresourceInfoKHR;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `pCreateInfo` is a pointer to a `VkImageCreateInfo` structure containing parameters affecting creation of the image to query.
- `pSubresource` `pSubresource` is a pointer to a `VkImageSubresource2KHR` structure selecting a specific image subresource for the query.

**Valid Usage**

- VUID-VkDeviceImageSubresourceInfoKHR-aspectMask-00997
  The `aspectMask` member of `pSubresource` must only have a single bit set

- VUID-VkDeviceImageSubresourceInfoKHR-mipLevel-01716
  The `mipLevel` member of `pSubresource` must be less than the `mipLevels` specified in `VkImageCreateInfo` when image was created

- VUID-VkDeviceImageSubresourceInfoKHR-arrayLayer-01717
  The `arrayLayer` member of `pSubresource` must be less than the `arrayLayers` specified in `VkImageCreateInfo` when image was created

- VUID-VkDeviceImageSubresourceInfoKHR-format-08886
  If format of the image is a color format, tiling of the image is `VK_IMAGE_TILING_LINEAR` or `VK_IMAGE_TILING_OPTIMAL`, and does not have a multi-planar image format, the `aspectMask` member of `pSubresource` must be `VK_IMAGE_ASPECT_COLOR_BIT`

- VUID-VkDeviceImageSubresourceInfoKHR-format-04462
  If format of the image has a depth component, the `aspectMask` member of `pSubresource` must contain `VK_IMAGE_ASPECT_DEPTH_BIT`

- VUID-VkDeviceImageSubresourceInfoKHR-format-04463
  If format of the image has a stencil component, the `aspectMask` member of `pSubresource` must contain `VK_IMAGE_ASPECT_STENCIL_BIT`

- VUID-VkDeviceImageSubresourceInfoKHR-format-04464
  If format of the image does not contain a stencil or depth component, the `aspectMask` member of `pSubresource` must not contain `VK_IMAGE_ASPECT_DEPTH_BIT` or `VK_IMAGE_ASPECT_STENCIL_BIT`

- VUID-VkDeviceImageSubresourceInfoKHR-tiling-08717
  If the tiling of the image is `VK_IMAGE_TILING_LINEAR` and has a multi-planar image format, then the `aspectMask` member of `pSubresource` must be a single valid multi-planar aspect mask bit

- VUID-VkDeviceImageSubresourceInfoKHR-image-01895
  If image was created with the `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID` external memory handle type, then image must be bound to memory
If the tiling of the image is VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT, then the aspectMask member of pSubresource must be VK_IMAGE_ASPECT_MEMORY_PLANE_0_BIT_EXT and the index i must be less than the VkDrmFormatModifierPropertiesEXT::drmFormatModifierPlaneCount associated with the image's format and VkImageDrmFormatModifierPropertiesEXT::drmFormatModifier.

Valid Usage (Implicit)

- VUID-VkDeviceImageSubresourceInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_DEVICE_IMAGE_SUBRESOURCE_INFO_KHR
- VUID-VkDeviceImageSubresourceInfoKHR-pNext-pNext
  pNext must be NULL
- VUID-VkDeviceImageSubresourceInfoKHR-pCreateInfo-parameter
  pCreateInfo must be a valid pointer to a valid VkImageCreateInfo structure
- VUID-VkDeviceImageSubresourceInfoKHR-pSubresource-parameter
  pSubresource must be a valid pointer to a valid VkImageSubresource2KHR structure

If an image was created with VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT, then the image has a Linux DRM format modifier. To query the modifier, call:

```c
// Provided by VK_EXT_image_drm_format_modifier
VkResult vkGetImageDrmFormatModifierPropertiesEXT(
    VkDevice device,
    VkImage image,
    VkImageDrmFormatModifierPropertiesEXT* pProperties);
```

- device is the logical device that owns the image.
- image is the queried image.
- pProperties is a pointer to a VkImageDrmFormatModifierPropertiesEXT structure in which properties of the image's DRM format modifier are returned.

Valid Usage

- VUID-vkGetImageDrmFormatModifierPropertiesEXT-image-02272
  image must have been created with tiling equal to VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT

Valid Usage (Implicit)

- VUID-vkGetImageDrmFormatModifierPropertiesEXT-device-parameter
  device must be a valid VkDevice handle
Return Codes

Success
• VK_SUCCESS

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY

The `VkImageDrmFormatModifierPropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_image_drm_format_modifier
typedef struct VkImageDrmFormatModifierPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    uint64_t drmFormatModifier;
} VkImageDrmFormatModifierPropertiesEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `drmFormatModifier` returns the image's Linux DRM format modifier.

If the `image` was created with `VkImageDrmFormatModifierListCreateInfoEXT`, then the returned `drmFormatModifier` must belong to the list of modifiers provided at time of image creation in `VkImageDrmFormatModifierListCreateInfoEXT::pDrmFormatModifiers`. If the `image` was created with `VkImageDrmFormatModifierExplicitCreateInfoEXT`, then the returned `drmFormatModifier` must be the modifier provided at time of image creation in `VkImageDrmFormatModifierExplicitCreateInfoEXT::drmFormatModifier`.

Valid Usage (Implicit)

- VUID-VkImageDrmFormatModifierPropertiesEXT-sType-sType `sType` must be `VK_STRUCTURE_TYPE_IMAGE_DRM_FORMAT_MODIFIER_PROPERTIES_EXT`
- VUID-VkImageDrmFormatModifierPropertiesEXT-pNext-pNext `pNext` must be `NULL`
To destroy an image, call:

```c
// Provided by VK_VERSION_1_0
void vkDestroyImage(
    VkDevice device,        // Provided by VK_VERSION_1_0
    VkImage image,          // Provided by VK_VERSION_1_0
    const VkAllocationCallbacks* pAllocator);
```

- `device` is the logical device that destroys the image.
- `image` is the image to destroy.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

### Valid Usage

- **VUID-vkDestroyImage-image-01000**
  All submitted commands that refer to `image`, either directly or via a `VkImageView`, **must** have completed execution
- **VUID-vkDestroyImage-image-01001**
  If `VkAllocationCallbacks` were provided when `image` was created, a compatible set of callbacks **must** be provided here
- **VUID-vkDestroyImage-image-01002**
  If no `VkAllocationCallbacks` were provided when `image` was created, `pAllocator` **must** be `NULL`
- **VUID-vkDestroyImage-image-04882**
  `image` **must** not have been acquired from `vkGetSwapchainImagesKHR`

### Valid Usage (Implicit)

- **VUID-vkDestroyImage-device-parameter**
  `device` **must** be a valid `VkDevice` handle
- **VUID-vkDestroyImage-image-parameter**
  If `image` is not `VK_NULL_HANDLE`, `image` **must** be a valid `VkImage` handle
- **VUID-vkDestroyImage-pAllocator-parameter**
  If `pAllocator` is not `NULL`, `pAllocator` **must** be a valid pointer to a valid `VkAllocationCallbacks` structure
- **VUID-vkDestroyImage-image-parent**
  If `image` is a valid handle, it **must** have been created, allocated, or retrieved from `device`

### Host Synchronization

- Host access to `image` **must** be externally synchronized
12.3.1. Image Format Features

Valid uses of a VkImage may depend on the image’s format features, defined below. Such constraints are documented in the affected valid usage statement.

- If the image was created with VK_IMAGE_TILING_LINEAR, then its set of format features is the value of VkFormatProperties::linearTilingFeatures found by calling vkGetPhysicalDeviceFormatProperties on the same format as VkImageCreateInfo::format.
- If the image was created with VK_IMAGE_TILING_OPTIMAL, but without an Android hardware buffer external format, or a QNX Screen Buffer external format or an VkBufferCollectionImageCreateInfoFUCHSIA, then its set of format features is the value of VkFormatProperties::optimalTilingFeatures found by calling vkGetPhysicalDeviceFormatProperties on the same format as VkImageCreateInfo::format.
- If the image was created with an Android hardware buffer external format, then its set of format features is the value of VkAndroidHardwareBufferFormatPropertiesANDROID::formatFeatures found by calling vkGetAndroidHardwareBufferPropertiesANDROID on the Android hardware buffer that was imported to the VkDeviceMemory to which the image is bound.
- If the image was created with an QNX Screen buffer external format, then its set of format features is the value of VkScreenBufferFormatPropertiesQNX::formatFeatures found by calling vkGetScreenBufferPropertiesQNX on the QNX Screen buffer that was imported to the VkDeviceMemory to which the image is bound.
- If the image was created with VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT, then:
  - The image’s DRM format modifier is the value of VkImageDrmFormatModifierPropertiesEXT::drmFormatModifier found by calling vkGetImageDrmFormatModifierPropertiesEXT.
  - Let VkDrmFormatModifierPropertiesListEXT::pDrmFormatModifierProperties be the array found by calling vkGetPhysicalDeviceFormatProperties2 on the same format as VkImageCreateInfo::format.
  - Let VkDrmFormatModifierPropertiesEXT prop be the array element whose drmFormatModifier member is the value of the image’s DRM format modifier.
  - Then the image’s set of format features is the value of prop::drmFormatModifierTilingFeatures.

12.3.2. Corner-Sampled Images

A corner-sampled image is an image where unnormalized texel coordinates are centered on integer values rather than half-integer values.

A corner-sampled image has a number of differences compared to conventional texture image:

- Texels are centered on integer coordinates. See Unnormalized Texel Coordinate Operations.
- Normalized coordinates are scaled using coord × (dim - 1) rather than coord × dim, where dim is the size of one dimension of the image. See normalized texel coordinate transform.
- Partial derivatives are scaled using coord × (dim - 1) rather than coord × dim. See Scale Factor Operation.
• Calculation of the next higher LOD size goes according to $\lceil \text{dim} / 2 \rceil$ rather than $\lfloor \text{dim} / 2 \rfloor$. See Image Mip Level Sizing.

• The minimum level size is 2x2 for 2D images and 2x2x2 for 3D images. See Image Mip Level Sizing.

Corner-sampling is only supported for 2D and 3D images. When sampling a corner-sampled image, the sampler addressing mode must be VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE. Corner-sampled images are not supported as cube maps or depth/stencil images.

12.3.3. Image Mip Level Sizing

A complete mipmap chain is the full set of mip levels, from the largest mip level provided, down to the minimum mip level size.

Conventional Images

For conventional images, the dimensions of each successive mip level, $n+1$, are:

$$\text{width}_{n+1} = \max(\lceil \text{width}_n/2 \rceil, 1)$$

$$\text{height}_{n+1} = \max(\lceil \text{height}_n/2 \rceil, 1)$$

$$\text{depth}_{n+1} = \max(\lceil \text{depth}_n/2 \rceil, 1)$$

where $\text{width}_n$, $\text{height}_n$, and $\text{depth}_n$ are the dimensions of the next larger mip level, $n$.

The minimum mip level size is:

• 1 for one-dimensional images,
• 1x1 for two-dimensional images, and
• 1x1x1 for three-dimensional images.

The number of levels in a complete mipmap chain is:

$$\lceil \log_2(\max(\text{width}_0, \text{height}_0, \text{depth}_0)) \rceil + 1$$

where $\text{width}_0$, $\text{height}_0$, and $\text{depth}_0$ are the dimensions of the largest (most detailed) mip level, 0.

Corner-Sampled Images

For corner-sampled images, the dimensions of each successive mip level, $n+1$, are:

$$\text{width}_{n+1} = \max(\lceil \text{width}_n/2 \rceil, 2)$$
\[ \text{height}_{n+1} = \max(\lceil \text{height}_n/2 \rceil, 2) \]

\[ \text{depth}_{n+1} = \max(\lceil \text{depth}_n/2 \rceil, 2) \]

where \( \text{width}_n, \text{height}_n, \) and \( \text{depth}_n \) are the dimensions of the next larger mip level, \( n \).

The minimum mip level size is:

- 2x2 for two-dimensional images, and
- 2x2x2 for three-dimensional images.

The number of levels in a complete mipmap chain is:

\[ \lceil \log_2(\max(\text{width}_0, \text{height}_0, \text{depth}_0)) \rceil \]

where \( \text{width}_0, \text{height}_0, \) and \( \text{depth}_0 \) are the dimensions of the largest (most detailed) mip level, \( 0 \).

### 12.4. Image Layouts

Images are stored in implementation-dependent opaque layouts in memory. Each layout has limitations on what kinds of operations are supported for image subresources using the layout. At any given time, the data representing an image subresource in memory exists in a particular layout which is determined by the most recent layout transition that was performed on that image subresource. Applications have control over which layout each image subresource uses, and can transition an image subresource from one layout to another. Transitions can happen with an image memory barrier, included as part of a \text{vkCmdPipelineBarrier} or a \text{vkCmdWaitEvents} command buffer command (see \text{Image Memory Barriers}), or as part of a subpass dependency within a render pass (see \text{VkSubpassDependency}).

Image layout is per-image subresource. Separate image subresources of the same image can be in different layouts at the same time, with the exception that depth and stencil aspects of a given image subresource can only be in different layouts if the \text{separateDepthStencilLayouts} feature is enabled.

\[ \textbf{Note} \]

Each layout may offer optimal performance for a specific usage of image memory. For example, an image with a layout of \text{VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL} may provide optimal performance for use as a color attachment, but be unsupported for use in transfer commands. Applications can transition an image subresource from one layout to another in order to achieve optimal performance when the image subresource is used for multiple kinds of operations. After initialization, applications need not use any layout other than the general layout, though this may produce suboptimal performance on some implementations.

Upon creation, all image subresources of an image are initially in the same layout, where that
layout is selected by the `VkImageCreateInfo::initialLayout` member. The `initialLayout` must be either `VK_IMAGE_LAYOUT_UNDEFINED` or `VK_IMAGE_LAYOUT_PREINITIALIZED`. If it is `VK_IMAGE_LAYOUT_PREINITIALIZED`, then the image data can be preinitialized by the host while using this layout, and the transition away from this layout will preserve that data. If it is `VK_IMAGE_LAYOUT_UNDEFINED`, then the contents of the data are considered to be undefined, and the transition away from this layout is not guaranteed to preserve that data. For either of these initial layouts, any image subresources must be transitioned to another layout before they are accessed by the device.

Host access to image memory is only well-defined for linear images and for image subresources of those images which are currently in either the `VK_IMAGE_LAYOUT_PREINITIALIZED` or `VK_IMAGE_LAYOUT_GENERAL` layout. Calling `vkGetImageSubresourceLayout` for a linear image returns a subresource layout mapping that is valid for either of those image layouts.

The set of image layouts consists of:

```c
// Provided by VK_VERSION_1_0
typedef enum VkImageLayout {
    VK_IMAGE_LAYOUT_UNDEFINED = 0,
    VK_IMAGE_LAYOUT_GENERAL = 1,
    VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL = 2,
    VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL = 3,
    VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL = 4,
    VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL = 5,
    VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL = 6,
    VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL = 7,
    VK_IMAGE_LAYOUT_PREINITIALIZED = 8,
    // Provided by VK_VERSION_1_1
    VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL = 1000117000,
    // Provided by VK_VERSION_1_1
    VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL = 1000117001,
    // Provided by VK_VERSION_1_2
    VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL = 1000241000,
    // Provided by VK_VERSION_1_2
    VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL = 1000241001,
    // Provided by VK_VERSION_1_2
    VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL = 1000241002,
    // Provided by VK_VERSION_1_2
    VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL = 1000241003,
    // Provided by VK_VERSION_1_3
    VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL = 1000314000,
    // Provided by VK_KHR_swapchain
    VK_IMAGE_LAYOUT_PRESENT_SRC_KHR = 1000001002,
    // Provided by VK_KHR_video_decode_queue
    VK_IMAGE_LAYOUT_VIDEO_DECODE_DST_KHR = 1000024000,
    // Provided by VK_KHR_video_decode_queue
    VK_IMAGE_LAYOUT_VIDEO_DECODE_SRC_KHR = 1000024001,
    // Provided by VK_KHR_video_decode_queue
};
```
The type(s) of device access supported by each layout are:
• **VK_IMAGE_LAYOUT_UNDEFINED** specifies that the layout is unknown. Image memory cannot be transitioned into this layout. This layout can be used as the initialLayout member of VkImageCreateInfo. This layout can be used in place of the current image layout in a layout transition, but doing so will cause the contents of the image's memory to be undefined.

• **VK_IMAGE_LAYOUT_PREINITIALIZED** specifies that an image's memory is in a defined layout and can be populated by data, but that it has not yet been initialized by the driver. Image memory cannot be transitioned into this layout. This layout can be used as the initialLayout member of VkImageCreateInfo. This layout is intended to be used as the initial layout for an image whose contents are written by the host, and hence the data can be written to memory immediately, without first executing a layout transition. Currently, **VK_IMAGE_LAYOUT_PREINITIALIZED** is only useful with linear images because there is not a standard layout defined for **VK_IMAGE_TILING_OPTIMAL** images.

• **VK_IMAGE_LAYOUT_GENERAL** supports all types of device access.

• **VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL** specifies a layout that must only be used with attachment accesses in the graphics pipeline.

• **VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL** specifies a layout allowing read only access as an attachment, or in shaders as a sampled image, combined image/sampler, or input attachment.

• **VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL** must only be used as a color or resolve attachment in a VkFramebuffer. This layout is valid only for image subresources of images created with the VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT usage bit enabled.

• **VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL** specifies a layout for both the depth and stencil aspects of a depth/stencil format image allowing read and write access as a depth/stencil attachment. It is equivalent to **VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL** and **VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL**.

• **VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL** specifies a layout for both the depth and stencil aspects of a depth/stencil format image allowing read only access as a depth/stencil attachment or in shaders as a sampled image, combined image/sampler, or input attachment. It is equivalent to **VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL** and **VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL**.

• **VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL** specifies a layout for depth/stencil format images allowing read and write access to the stencil aspect as a stencil attachment, and read only access to the depth aspect as a depth attachment or in shaders as a sampled image, combined image/sampler, or input attachment. It is equivalent to **VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY** and **VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_STENCIL_READ_ONLY**.

• **VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY** specifies a layout for depth/stencil format images allowing read and write access to the depth aspect as a depth attachment, and read only access to the stencil aspect as a stencil attachment or in shaders as a sampled image, combined image/sampler, or input attachment. It is equivalent to **VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY** and **VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_STENCIL_READ_ONLY**.

• **VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY** specifies a layout for the depth aspect of a depth/stencil format image allowing read and write access as a depth attachment.

• **VK_IMAGE_LAYOUT_DEPTH_READ_ONLY**(OPTIMAL) specifies a layout for the depth aspect of a depth/stencil format image allowing read-only access as a depth attachment or in shaders as a depth attachment.
• **VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL** specifies a layout for the stencil aspect of a depth/stencil format image allowing read and write access as a stencil attachment.

• **VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL** specifies a layout for the stencil aspect of a depth/stencil format image allowing read-only access as a stencil attachment or in shaders as a sampled image, combined image/sampler, or input attachment.

• **VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL** specifies a layout allowing read-only access in a shader as a sampled image, combined image/sampler, or input attachment. This layout is valid only for image subresources of images created with the **VK_IMAGE_USAGE_SAMPLED_BIT** or **VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT** usage bits enabled.

• **VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL** must only be used as a source image of a transfer command (see the definition of **VK_PIPELINE_STAGE_TRANSFER_BIT**). This layout is valid only for image subresources of images created with the **VK_IMAGE_USAGE_TRANSFER_SRC_BIT** usage bit enabled.

• **VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL** must only be used as a destination image of a transfer command. This layout is valid only for image subresources of images created with the **VK_IMAGE_USAGE_TRANSFER_DST_BIT** usage bit enabled.

• **VK_IMAGE_LAYOUT_PRESENT_SRC_KHR** must only be used for presenting a presentable image for display.

• **VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR** is valid only for shared presentable images, and must be used for any usage the image supports.

• **VK_IMAGE_LAYOUT_FRAGMENT_SHADING_RATE_ATTACHMENT_OPTIMAL_KHR** must only be used as a fragment shading rate attachment or shading rate image. This layout is valid only for image subresources of images created with the **VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR** usage bit enabled.

• **VK_IMAGE_LAYOUT_FRAGMENT_DENSITY_MAP_OPTIMAL_EXT** must only be used as a fragment density map attachment in a **VkRenderPass**. This layout is valid only for image subresources of images created with the **VK_IMAGE_USAGE_FRAGMENT_DENSITY_MAP_BIT_EXT** usage bit enabled.

• **VK_IMAGE_LAYOUT_VIDEO_DECODE_DST_KHR** must only be used as a decode output picture in a video decode operation. This layout is valid only for image subresources of images created with the **VK_IMAGE_USAGE_VIDEO_DECODE_DST_BIT_KHR** usage bit enabled.

• **VK_IMAGE_LAYOUT_VIDEO_DECODE_SRC_KHR** is reserved for future use.

• **VK_IMAGE_LAYOUT_VIDEO_ENCODE_DST_KHR** is reserved for future use.

• **VK_IMAGE_LAYOUT_VIDEO_ENCODE_SRC_KHR** must only be used as an encode input picture in a video encode operation. This layout is valid only for image subresources of images created with the **VK_IMAGE_USAGE_VIDEO_ENCODE_SRC_BIT_KHR** usage bit enabled.

• **VK_IMAGE_LAYOUT_VIDEO_ENCODE_DPB_KHR** must only be used as an output reconstructed picture or an input reference picture in a video encode operation. This layout is valid only for image subresources of images created with the **VK_IMAGE_USAGE_VIDEO_ENCODE_DPB_BIT_KHR** usage bit enabled.
subresources of images created with the `VK_IMAGE_USAGEVIDEO_ENCODE_DPB_BIT_KHR` usage bit enabled.

- **VK_IMAGE_LAYOUTATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT** must only be used as either a color attachment or depth/stencil attachment in a `VkFramebuffer` and/or read-only access in a shader as a sampled image, combined image/sampler, or input attachment. This layout is valid only for image subresources of images created with the `VK_IMAGE_USAGE_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` usage bit enabled and either the `VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT` or `VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT` and either the `VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT` or `VK_IMAGE_USAGE_SAMPLED_BIT` usage bits enabled.

The layout of each image subresource is not a state of the image subresource itself, but is rather a property of how the data in memory is organized, and thus for each mechanism of accessing an image in the API the application must specify a parameter or structure member that indicates which image layout the image subresource(s) are considered to be in when the image will be accessed. For transfer commands, this is a parameter to the command (see Clear Commands and Copy Commands). For use as a framebuffer attachment, this is a member in the substructures of the `VkRenderPassCreateInfo` (see Render Pass). For use in a descriptor set, this is a member in the `VkDescriptorImageInfo` structure (see Descriptor Set Updates).

### 12.4.1. Image Layout Matching Rules

At the time that any command buffer command accessing an image executes on any queue, the layouts of the image subresources that are accessed must all match exactly the layout specified via the API controlling those accesses, except in case of accesses to an image with a depth/stencil format performed through descriptors referring to only a single aspect of the image, where the following relaxed matching rules apply:

- Descriptors referring just to the depth aspect of a depth/stencil image only need to match in the image layout of the depth aspect, thus `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL` and `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL` are considered to match.
- Descriptors referring just to the stencil aspect of a depth/stencil image only need to match in the image layout of the stencil aspect, thus `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL` and `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL` are considered to match.

When performing a layout transition on an image subresource, the old layout value must either equal the current layout of the image subresource (at the time the transition executes), or else be `VK_IMAGE_LAYOUT_UNDEFINED` (implying that the contents of the image subresource need not be preserved). The new layout used in a transition must not be `VK_IMAGE_LAYOUT_UNDEFINED` or `VK_IMAGE_LAYOUT_PREINITIALIZED`.

The image layout of each image subresource of a depth/stencil image created with `VK_IMAGE_CREATESAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` is dependent on the last sample locations used to render to the image subresource as a depth/stencil attachment, thus applications must provide the same sample locations that were last used to render to the given image subresource whenever a layout transition of the image subresource happens, otherwise the contents of the depth aspect of the image subresource become undefined.

In addition, depth reads from a depth/stencil attachment referring to an image subresource range
of a depth/stencil image created with `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` using different sample locations than what have been last used to perform depth writes to the image subresources of the same image subresource range return undefined values.

Similarly, depth writes to a depth/stencil attachment referring to an image subresource range of a depth/stencil image created with `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` using different sample locations than what have been last used to perform depth writes to the image subresources of the same image subresource range make the contents of the depth aspect of those image subresources undefined.

### 12.5. Image Views

Image objects are not directly accessed by pipeline shaders for reading or writing image data. Instead, image views representing contiguous ranges of the image subresources and containing additional metadata are used for that purpose. Views must be created on images of compatible types, and must represent a valid subset of image subresources.

Image views are represented by `VkImageView` handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkImageView)
```

`VK_REMAINING_ARRAY_LAYERS` is a special constant value used for image views to indicate that all remaining array layers in an image after the base layer should be included in the view.

```c
#define VK_REMAINING_ARRAY_LAYERS (~0U)
```

`VK_REMAINING_MIP_LEVELS` is a special constant value used for image views to indicate that all remaining mipmap levels in an image after the base level should be included in the view.

```c
#define VK_REMAINING_MIP_LEVELS (~0U)
```

The types of image views that can be created are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkImageViewType {
    VK_IMAGE_VIEW_TYPE_1D = 0,
    VK_IMAGE_VIEW_TYPE_2D = 1,
    VK_IMAGE_VIEW_TYPE_3D = 2,
    VK_IMAGE_VIEW_TYPE_CUBE = 3,
    VK_IMAGE_VIEW_TYPE_1D_ARRAY = 4,
    VK_IMAGE_VIEW_TYPE_2D_ARRAY = 5,
    VK_IMAGE_VIEW_TYPE_CUBE_ARRAY = 6,
} VkImageViewType;
```
To create an image view, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkCreateImageView(
    VkDevice device,
    const VkImageViewCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkImageView* pView);
```

- `device` is the logical device that creates the image view.
- `pCreateInfo` is a pointer to a `VkImageViewCreateInfo` structure containing parameters to be used to create the image view.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pView` is a pointer to a `VkImageView` handle in which the resulting image view object is returned.

### Valid Usage

- VUID-vkCreateImageView-image-09179
  `VkImageViewCreateInfo::image` must have been created from `device`

### Valid Usage (Implicit)

- VUID-vkCreateImageView-device-parameter
  `device` must be a valid `VkDevice` handle
- VUID-vkCreateImageView-pCreateInfo-parameter
  `pCreateInfo` must be a valid pointer to a valid `VkImageViewCreateInfo` structure
- VUID-vkCreateImageView-pAllocator-parameter
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure
- VUID-vkCreateImageView-pView-parameter
  `pView` must be a valid pointer to a `VkImageView` handle

### Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS_KHR`
The `VkImageViewCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkImageViewCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkImageViewCreateFlags flags;
    VkImage image;
    VkImageViewType viewType;
    VkFormat format;
    VkComponentMapping components;
    VkImageSubresourceRange subresourceRange;
} VkImageViewCreateInfo;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkImageViewCreateFlagBits` specifying additional parameters of the image view.
- `image` is a `VkImage` on which the view will be created.
- `viewType` is a `VkImageViewType` value specifying the type of the image view.
- `format` is a `VkFormat` specifying the format and type used to interpret texel blocks of the image.
- `components` is a `VkComponentMapping` structure specifying a remapping of color components (or of depth or stencil components after they have been converted into color components).
- `subresourceRange` is a `VkImageSubresourceRange` structure selecting the set of mipmap levels and array layers to be accessible to the view.

Some of the `image` creation parameters are inherited by the view. In particular, image view creation inherits the implicit parameter `usage` specifying the allowed usages of the image view that, by default, takes the value of the corresponding `usage` parameter specified in `VkImageCreateInfo` at image creation time. The implicit `usage` can be overridden by adding a `VkImageViewUsageCreateInfo` structure to the `pNext` chain, but the view usage must be a subset of the image usage. If `image` has a depth-stencil format and was created with a `VkImageStencilUsageCreateInfo` structure included in the `pNext` chain of `VkImageCreateInfo`, the usage is calculated based on the `subresource.aspectMask` provided:

- If `aspectMask` includes only `VK_IMAGE_ASPECT_STENCIL_BIT`, the implicit `usage` is equal to `VkImageStencilUsageCreateInfo::stencilUsage`.
- If `aspectMask` includes only `VK_IMAGE_ASPECT_DEPTH_BIT`, the implicit `usage` is equal to `VkImageCreateInfo::usage`.
- If both aspects are included in `aspectMask`, the implicit `usage` is equal to the intersection of `VkImageCreateInfo::usage` and `VkImageStencilUsageCreateInfo::stencilUsage`.

If `image` is a 3D image, its Z range can be restricted to a subset by adding a `VkImageViewSlicedCreateInfoEXT` to the `pNext` chain.
If `image` was created with the `VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT` flag, and if the `format` of the image is not multi-planar, `format` can be different from the image's format, but if `image` was created without the `VK_IMAGE_CREATE_BLOCK_TEXEL_VIEW_COMPATIBLE_BIT` flag and they are not equal they must be compatible. Image format compatibility is defined in the Format Compatibility Classes section. Views of compatible formats will have the same mapping between texel coordinates and memory locations irrespective of the `format`, with only the interpretation of the bit pattern changing.

If `image` was created with a multi-planar format, and the image view's `aspectMask` is one of `VK_IMAGE_ASPECT_PLANE_0_BIT`, `VK_IMAGE_ASPECT_PLANE_1_BIT` or `VK_IMAGE_ASPECT_PLANE_2_BIT`, the view's aspect mask is considered to be equivalent to `VK_IMAGE_ASPECT_COLOR_BIT` when used as a framebuffer attachment.

---

**Note**

Values intended to be used with one view format may not be exactly preserved when written or read through a different format. For example, an integer value that happens to have the bit pattern of a floating point denorm or NaN may be flushed or canonicalized when written or read through a view with a floating point format. Similarly, a value written through a signed normalized format that has a bit pattern exactly equal to \(-2^b\) may be changed to \(-2^b + 1\) as described in Conversion from Normalized Fixed-Point to Floating-Point.

If `image` was created with the `VK_IMAGE_CREATE_BLOCK_TEXEL_VIEW_COMPATIBLE_BIT` flag, `format` must be compatible with the image's format as described above; or `must` be an uncompressed format, in which case it must be size-compatible with the image's format. In this case, the resulting image view's texel dimensions equal the dimensions of the selected mip level divided by the compressed texel block size and rounded up.

The `VkComponentMapping components` member describes a remapping from components of the image to components of the vector returned by shader image instructions. This remapping must be the identity swizzle for storage image descriptors, input attachment descriptors, framebuffer attachments, and any `VkImageView` used with a combined image sampler that enables sampler Y’C₇C₅R conversion.

If the image view is to be used with a sampler which supports sampler Y’C₇C₅R conversion, an identically defined object of type `VkSamplerYcbcrConversion` to that used to create the sampler must be passed to `vkCreateImage` in a `VkSamplerYcbcrConversionInfo` included in the `pNext` chain of `VkImageViewCreateInfo`. Conversely, if a `VkSamplerYcbcrConversion` object is passed to `vkCreateImageView`, an identically defined `VkSamplerYcbcrConversion` object must be used when sampling the image.

If the image has a multi-planar format, `subresourceRange.aspectMask` is `VK_IMAGE_ASPECT_COLOR_BIT`, and `usage` includes `VK_IMAGE_USAGE_SAMPLED_BIT`, then the `format` must be identical to the image `format` and the sampler to be used with the image view must enable sampler Y’C₇C₅R conversion.

When such an image is used in a video coding operation, the sampler Y’C₇C₅R conversion has no effect.

If `image` was created with the `VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT` and the image has a multi-planar format, and if `subresourceRange.aspectMask` is `VK_IMAGE_ASPECT_PLANE_0_BIT`,
VK_IMAGE_ASPECT_PLANE_1_BIT, or VK_IMAGE_ASPECT_PLANE_2_BIT, format must be compatible with the corresponding plane of the image, and the sampler to be used with the image view must not enable sampler Y'CbCr conversion. The width and height of the single-plane image view must be derived from the multi-planar image's dimensions in the manner listed for plane compatibility for the plane.

Any view of an image plane will have the same mapping between texel coordinates and memory locations as used by the components of the color aspect, subject to the formulae relating texel coordinates to lower-resolution planes as described in Chroma Reconstruction. That is, if an R or B plane has a reduced resolution relative to the G plane of the multi-planar image, the image view operates using the \((u_{plane}, v_{plane})\) unnormalized coordinates of the reduced-resolution plane, and these coordinates access the same memory locations as the \((u_{color}, v_{color})\) unnormalized coordinates of the color aspect for which chroma reconstruction operations operate on the same \((u_{plane}, v_{plane})\) or \((i_{plane}, j_{plane})\) coordinates.

### Table 16. Image type and image view type compatibility requirements

<table>
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<td>VK_IMAGE_TYPE_2D</td>
</tr>
<tr>
<td>VK_IMAGE_VIEW_TYPE_3D</td>
<td>VK_IMAGE_TYPE_3D</td>
</tr>
</tbody>
</table>

### Valid Usage

- VUID-VkImageViewCreateInfo-image-01003
  If image was not created with VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT then viewType must not be VK_IMAGE_VIEW_TYPE_CUBE or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

- VUID-VkImageViewCreateInfo-viewType-01004
  If the imageCubeArray feature is not enabled, viewType must not be VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

- VUID-VkImageViewCreateInfo-image-06723
  If image was created with VK_IMAGE_TYPE_3D but without VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT set then viewType must not be VK_IMAGE_VIEW_TYPE_2D_ARRAY

- VUID-VkImageViewCreateInfo-image-06728
  If image was created with VK_IMAGE_TYPE_3D but without VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT or VK_IMAGE_CREATE_2D_VIEW_COMPATIBLE_BIT_EXT set, then viewType must not be VK_IMAGE_VIEW_TYPE_2D

- VUID-VkImageViewCreateInfo-image-04970
  If image was created with VK_IMAGE_TYPE_3D and viewType is VK_IMAGE_VIEW_TYPE_2D or VK_IMAGE_VIEW_TYPE_2D_ARRAY then subresourceRange.levelCount must be 1
• VUID-VkImageViewCreateInfo-image-04971
  If image was created with VK_IMAGE_TYPE_3D and viewType is VK_IMAGE_VIEW_TYPE_2D or VK_IMAGE_VIEW_TYPE_2D_ARRAY then VkImageCreateInfo::flags must not contain any of VK_IMAGE_CREATE_SPARSE_BINDING_BIT, VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT, and VK_IMAGE_CREATE_SPARSE_ALIASED_BIT

• VUID-VkImageViewCreateInfo-image-04972
  If image was created with a samples value not equal to VK_SAMPLE_COUNT_1_BIT then viewType must be either VK_IMAGE_VIEW_TYPE_2D or VK_IMAGE_VIEW_TYPE_2D_ARRAY

• VUID-VkImageViewCreateInfo-image-04441
  image must have been created with a usage value containing at least one of the usages defined in the valid image usage list for image views

• VUID-VkImageViewCreateInfo-None-02273
  The format features of the resultant image view must contain at least one bit

• VUID-VkImageViewCreateInfo-usage-02274
  If usage contains VK_IMAGE_USAGE_SAMPLED_BIT, then the format features of the resultant image view must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT

• VUID-VkImageViewCreateInfo-usage-02275
  If usage contains VK_IMAGE_USAGE_STORAGE_BIT, then the image view's format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_BIT

• VUID-VkImageViewCreateInfo-usage-08931
  If usage contains VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT, then the image view's format features must contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT or VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV

• VUID-VkImageViewCreateInfo-usage-02277
  If usage contains VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT, then the image view's format features must contain VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT

• VUID-VkImageViewCreateInfo-usage-08932
  If usage contains VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT, then the image view's format features must contain at least one of VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT, VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT or VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV

• VUID-VkImageViewCreateInfo-subresourceRange-01478
  subresourceRange.baseMipLevel must be less than the mipLevels specified in VkImageCreateInfo when image was created

• VUID-VkImageViewCreateInfo-subresourceRange-01718
  If subresourceRange.levelCount is not VK_REMAINING_MIP_LEVELS, subresourceRange.baseMipLevel + subresourceRange.levelCount must be less than or equal to the mipLevels specified in VkImageCreateInfo when image was created

• VUID-VkImageViewCreateInfo-image-02571
  If image was created with usage containing VK_IMAGE_USAGE_FRAGMENT_DENSITY_MAP_BIT_EXT, subresourceRange.levelCount must be 1

• VUID-VkImageViewCreateInfo-image-06724
  If image is not a 3D image created with VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT or
VK_IMAGE_CREATE_2D_VIEW_COMPATIBLE_BIT_EXT set, or viewType is not VK_IMAGE_VIEW_TYPE_2D or VK_IMAGE_VIEW_TYPE_2D_ARRAY, subresourceRange.baseArrayLayer must be less than the arrayLayers specified in VkImageCreateInfo when image was created

• VUID-VkImageViewCreateInfo-subresourceRange-06725
  If subresourceRange.layerCount is not VK_REMAINING_ARRAY_LAYERS, image is not a 3D image created with VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT or VK_IMAGE_CREATE_2D_VIEW_COMPATIBLE_BIT_EXT set, or viewType is not VK_IMAGE_VIEW_TYPE_2D or VK_IMAGE_VIEW_TYPE_2D_ARRAY, subresourceRange.layerCount must be non-zero and subresourceRange.baseArrayLayer + subresourceRange.layerCount must be less than or equal to the arrayLayers specified in VkImageCreateInfo when image was created

• VUID-VkImageViewCreateInfo-image-02724
  If image is a 3D image created with VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT set, and viewType is VK_IMAGE_VIEW_TYPE_2D or VK_IMAGE_VIEW_TYPE_2D_ARRAY, subresourceRange.baseArrayLayer must be less than the depth computed from baseMipLevel and extent.depth specified in VkImageCreateInfo when image was created, according to the formula defined in Image Mip Level Sizing

• VUID-VkImageViewCreateInfo-subresourceRange-02725
  If subresourceRange.layerCount is not VK_REMAINING_ARRAY_LAYERS, image is a 3D image created with VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT set, and viewType is VK_IMAGE_VIEW_TYPE_2D or VK_IMAGE_VIEW_TYPE_2D_ARRAY, subresourceRange.layerCount must be non-zero and subresourceRange.baseArrayLayer + subresourceRange.layerCount must be less than or equal to the depth computed from baseMipLevel and extent.depth specified in VkImageCreateInfo when image was created, according to the formula defined in Image Mip Level Sizing

• VUID-VkImageViewCreateInfo-image-01761
  If image was created with the VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT flag, but without the VK_IMAGE_CREATE_BLOCK_TEXEL_VIEW_COMPATIBLE_BIT flag, and if the format of the image is not a multi-planar format, format must be compatible with the format used to create image, as defined in Format Compatibility Classes

• VUID-VkImageViewCreateInfo-image-01583
  If image was created with the VK_IMAGE_CREATE_BLOCK_TEXEL_VIEW_COMPATIBLE_BIT flag, format must be compatible with, or must be an un compressed format that is size-compatible with, the format used to create image

• VUID-VkImageViewCreateInfo-image-07072
  If image was created with the VK_IMAGE_CREATE_BLOCK_TEXEL_VIEW_COMPATIBLE_BIT flag and format is a non-compressed format, the levelCount and layerCount members of subresourceRange must both be 1

• VUID-VkImageViewCreateInfo-pNext-01585
  If a VkImageFormatListCreateInfo structure was included in the pNext chain of the VkImageCreateInfo structure used when creating image and VkImageFormatListCreateInfo::viewFormatCount is not zero then format must be one of the formats in VkImageFormatListCreateInfo::pViewFormats

• VUID-VkImageViewCreateInfo-image-01586
  If image was created with the VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT flag, if the format of the image is a multi-planar format, and if subresourceRange.aspectMask is one of the multi-
planar aspect mask bits, then format must be compatible with the VkFormat for the plane of the image format indicated by subresourceRange.aspectMask, as defined in Compatible formats of planes of multi-planar formats

- VUID-VkImageViewCreateInfo-subresourceRange-07818
  subresourceRange.aspectMask must only have at most 1 valid multi-planar aspect mask bit

- VUID-VkImageViewCreateInfo-image-01762
  If image was not created with the VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT flag, or if the format of the image is a multi-planar format and if subresourceRange.aspectMask is VK_IMAGE_ASPECT_COLOR_BIT, format must be identical to the format used to create image

- VUID-VkImageViewCreateInfo-format-06415
  If the image view requires a sampler Y’C’bC’r conversion and usage contains VK_IMAGE_USAGE_SAMPLED_BIT, then the pNext chain must include a VkSamplerYcbcrConversionInfo structure with a conversion value other than VK_NULL_HANDLE

- VUID-VkImageViewCreateInfo-format-04714
  If format has a _422 or _420 suffix then image must have been created with a width that is a multiple of 2

- VUID-VkImageViewCreateInfo-format-04715
  If format has a _420 suffix then image must have been created with a height that is a multiple of 2

- VUID-VkImageViewCreateInfo-pNext-01970
  If the pNext chain includes a VkSamplerYcbcrConversionInfo structure with a conversion value other than VK_NULL_HANDLE, all members of components must have the identity swizzle

- VUID-VkImageViewCreateInfo-pNext-06658
  If the pNext chain includes a VkSamplerYcbcrConversionInfo structure with a conversion value other than VK_NULL_HANDLE, format must be the same used in VkSamplerYcbcrConversionCreateInfo::format

- VUID-VkImageViewCreateInfo-image-01020
  If image is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-VkImageViewCreateInfo-subResourceRange-01021
  viewType must be compatible with the type of image as shown in the view type compatibility table

- VUID-VkImageViewCreateInfo-image-02399
  If image has an Android external format, format must be VK_FORMAT_UNDEFINED

- VUID-VkImageViewCreateInfo-image-02400
  If image has an Android external format, the pNext chain must include a VkSamplerYcbcrConversionInfo structure with a conversion object created with the same external format as image

- VUID-VkImageViewCreateInfo-image-02401
  If image has an Android external format, all members of components must be the identity swizzle
If image has an QNX Screen external format, format must be VK_FORMAT_UNDEFINED

If image has an QNX Screen external format, the pNext chain must include a VkSamplerYcbcrConversionInfo structure with a conversion object created with the same external format as image

If image has an QNX Screen external format, all members of components must be the identity swizzle

If image was created with usage containing VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR, viewType must be VK_IMAGE_VIEW_TYPE_2D or VK_IMAGE_VIEW_TYPE_2D_ARRAY

If the shadingRateImage feature is enabled, and If image was created with usage containing VK_IMAGE_USAGE_SHADING_RATE_IMAGE_BIT_NV, format must be VK_FORMAT_R8_UINT

If the attachmentFragmentShadingRate feature is enabled, and the usage for the image view includes VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR, then the image view's format features must contain VK_FORMAT_FEATURE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

If the attachmentFragmentShadingRate feature is enabled, the usage for the image view includes VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR, and layeredShadingRateAttachments is VK_FALSE, subresourceRange.layerCount must be 1

If flags does not contain VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DYNAMIC_BIT_EXT and

If image was created with flags containing VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT and usage containing VK_IMAGE_USAGE_SAMPLED_BIT, subresourceRange.layerCount must be less than or equal to VkPhysicalDeviceFragmentDensityMap2PropertiesEXT::maxSubsampledArrayLayers

If flags contains VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DEFERRED_BIT_EXT, flags must not contain VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DYNAMIC_BIT_EXT

If flags contains VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DEFERRED_BIT_EXT, flags must not contain VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DYNAMIC_BIT_EXT

If flags contains VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DEFERRED_BIT_EXT, flags must not contain VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DYNAMIC_BIT_EXT

If flags contains VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DEFERRED_BIT_EXT, flags must not contain VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DYNAMIC_BIT_EXT

If image was created with flags containing VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT and usage containing VK_IMAGE_USAGE_SAMPLED_BIT, subresourceRange.layerCount must be less than or equal to VkPhysicalDeviceFragmentDensityMap2PropertiesEXT::maxSubsampledArrayLayers
image was created with usage containing VK_IMAGE_USAGE_FRAGMENT_DENSITY_MAP_BIT_EXT, its flags must not contain any of VK_IMAGE_CREATE_PROTECTED_BIT, VK_IMAGE_CREATE_SPARSE_BINDING_BIT, VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT, or VK_IMAGE_CREATE_SPARSE_ALIASED_BIT

- VUID-VkImageViewCreateInfo-pNext-02662
  If the pNext chain includes a VkImageViewUsageCreateInfo structure, and image was not created with a VkImageStencilUsageCreateInfo structure included in the pNext chain of VkImageCreateInfo, its usage member must not include any bits that were not set in the usage member of the VkImageCreateInfo structure used to create image

- VUID-VkImageViewCreateInfo-pNext-02663
  If the pNext chain includes a VkImageViewUsageCreateInfo structure, image was created with a VkImageStencilUsageCreateInfo structure included in the pNext chain of VkImageCreateInfo, and subresourceRange.aspectMask includes VK_IMAGE_ASPECT_STENCIL_BIT, the usage member of the VkImageViewUsageCreateInfo structure must not include any bits that were not set in the usage member of the VkImageStencilUsageCreateInfo structure used to create image

- VUID-VkImageViewCreateInfo-pNext-02664
  If the pNext chain includes a VkImageViewUsageCreateInfo structure, image was created with a VkImageStencilUsageCreateInfo structure included in the pNext chain of VkImageCreateInfo, and subresourceRange.aspectMask includes bits other than VK_IMAGE_ASPECT_STENCIL_BIT, the usage member of the VkImageViewUsageCreateInfo structure must not include any bits that were not set in the usage member of the VkImageStencilUsageCreateInfo structure used to create image

- VUID-VkImageViewCreateInfo-imageViewType-04973
  If viewType is VK_IMAGE_VIEW_TYPE_1D, VK_IMAGE_VIEW_TYPE_2D, or VK_IMAGE_VIEW_TYPE_3D; and subresourceRange.layerCount is not VK_REMAINING_ARRAY_LAYERS, then subresourceRange.layerCount must be 1

- VUID-VkImageViewCreateInfo-imageViewType-04974
  If viewType is VK_IMAGE_VIEW_TYPE_1D, VK_IMAGE_VIEW_TYPE_2D, or VK_IMAGE_VIEW_TYPE_3D; and subresourceRange.layerCount is VK_REMAINING_ARRAY_LAYERS, then the remaining number of layers must be 1

- VUID-VkImageViewCreateInfo-viewType-02960
  If viewType is VK_IMAGE_VIEW_TYPE_CUBE and subresourceRange.layerCount is not VK_REMAINING_ARRAY_LAYERS, subresourceRange.layerCount must be 6

- VUID-VkImageViewCreateInfo-viewType-02961
  If viewType is VK_IMAGE_VIEW_TYPE_CUBE_ARRAY and subresourceRange.layerCount is not VK_REMAINING_ARRAY_LAYERS, subresourceRange.layerCount must be a multiple of 6

- VUID-VkImageViewCreateInfo-viewType-02962
  If viewType is VK_IMAGE_VIEW_TYPE_CUBE and subresourceRange.layerCount is VK_REMAINING_ARRAY_LAYERS, the remaining number of layers must be 6

- VUID-VkImageViewCreateInfo-viewType-02963
  If viewType is VK_IMAGE_VIEW_TYPE_CUBE_ARRAY and subresourceRange.layerCount is VK_REMAINING_ARRAY_LAYERS, the remaining number of layers must be a multiple of 6

- VUID-VkImageViewCreateInfo-imageViewFormatSwizzle-04465
If the `VK_KHR_portability_subset` extension is enabled, and `VkPhysicalDevicePortabilitySubsetFeaturesKHR::imageViewFormatSwizzle` is `VK_FALSE`, all elements of components must have the identity swizzle.

- **VUID-VkImageViewCreateInfo-imageViewFormatReinterpretation-04466**
  If the `VK_KHR_portability_subset` extension is enabled, and `VkPhysicalDevicePortabilitySubsetFeaturesKHR::imageViewFormatReinterpretation` is `VK_FALSE`, the `VkFormat` in format must not contain a different number of components, or a different number of bits in each component, than the format of the `VkImage` in `image`.

- **VUID-VkImageViewCreateInfo-flags-08106**
  If flags includes `VK_IMAGE_VIEW_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT`, the descriptorBufferCaptureReplay feature must be enabled.

- **VUID-VkImageViewCreateInfo-pNext-06787**
  If the `pNext` chain includes a `VkExportMetalObjectCreateInfoEXT` structure, its `exportObjectType` member must be `VK_EXPORT_METAL_OBJECT_TYPE_METAL_TEXTURE_BIT_EXT`.

- **VUID-VkImageViewCreateInfo-pNext-06944**
  If the `pNext` chain includes `VkImageViewSampleWeightCreateInfoQCOM` structure, then textureSampleWeighted feature must be enabled.

- **VUID-VkImageViewCreateInfo-pNext-06945**
  If the `pNext` chain includes `VkImageViewSampleWeightCreateInfoQCOM` structure, then image must have been created with usage containing `VK_IMAGE_USAGE_SAMPLE_WEIGHT_BIT_QCOM`.

- **VUID-VkImageViewCreateInfo-pNext-06946**
  If the `pNext` chain includes `VkImageViewSampleWeightCreateInfoQCOM` structure, then components must be `VK_COMPONENT_SWIZZLE_IDENTITY` for all components.

- **VUID-VkImageViewCreateInfo-pNext-06947**
  If the `pNext` chain includes `VkImageViewSampleWeightCreateInfoQCOM` structure, then `subresourceRange.aspectMask` must be `VK_IMAGE_ASPECT_COLOR_BIT`.

- **VUID-VkImageViewCreateInfo-pNext-06948**
  If the `pNext` chain includes `VkImageViewSampleWeightCreateInfoQCOM` structure, then `subresourceRange.levelCount` must be 1.

- **VUID-VkImageViewCreateInfo-pNext-06949**
  If the `pNext` chain includes `VkImageViewSampleWeightCreateInfoQCOM` structure, then
viewType must be VK_IMAGE_VIEW_TYPE_1D_ARRAY or VK_IMAGE_VIEW_TYPE_2D_ARRAY

• VUID-VkImageViewCreateInfo-pNext-06950
  If the pNext chain includes VkImageViewSampleWeightCreateInfoQCOM structure and if viewType is VK_IMAGE_VIEW_TYPE_1D_ARRAY, then image must have been created with imageType VK_IMAGE_TYPE_1D

• VUID-VkImageViewCreateInfo-pNext-06951
  If the pNext chain includes VkImageViewSampleWeightCreateInfoQCOM structure and viewType is VK_IMAGE_VIEW_TYPE_1D_ARRAY, then subresourceRange.layerCount must be equal to 2

• VUID-VkImageViewCreateInfo-pNext-06952
  If the pNext chain includes VkImageViewSampleWeightCreateInfoQCOM structure and viewType is VK_IMAGE_VIEW_TYPE_1D_ARRAY, then image must have been created with width equal to or greater than (numPhases × max(align(filterSize.width, 4), filterSize.height))

• VUID-VkImageViewCreateInfo-pNext-06953
  If the pNext chain includes VkImageViewSampleWeightCreateInfoQCOM structure and if viewType is VK_IMAGE_VIEW_TYPE_2D_ARRAY, then image must have been created with imageType VK_IMAGE_TYPE_2D

• VUID-VkImageViewCreateInfo-pNext-06954
  If the pNext chain includes VkImageViewSampleWeightCreateInfoQCOM structure and viewType is VK_IMAGE_VIEW_TYPE_2D_ARRAY, then subresourceRange.layerCount must be equal or greater than numPhases

• VUID-VkImageViewCreateInfo-pNext-06955
  If the pNext chain includes VkImageViewSampleWeightCreateInfoQCOM structure and viewType is VK_IMAGE_VIEW_TYPE_2D_ARRAY, then image must have been created with width equal to or greater than filterSize.width

• VUID-VkImageViewCreateInfo-pNext-06956
  If the pNext chain includes VkImageViewSampleWeightCreateInfoQCOM structure and viewType is VK_IMAGE_VIEW_TYPE_2D_ARRAY, then image must have been created with height equal to or greater than filterSize.height

• VUID-VkImageViewCreateInfo-pNext-06957
  If the pNext chain includes VkImageViewSampleWeightCreateInfoQCOM structure then VkImageViewSampleWeightCreateInfoQCOM::filterSize.height must be less than or equal to VkPhysicalDeviceImageProcessingPropertiesQCOM::maxWeightFilterDimension.height

Valid Usage (Implicit)

• VUID-VkImageViewCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_IMAGE_VIEW_CREATE_INFO

• VUID-VkImageViewCreateInfo-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkExportMetalObjectCreateInfoEXT, VkImageViewASTCDecodeModeEXT, VkImageViewMinLodCreateInfoEXT,
VkImageViewSampleWeightCreateInfoQCOM, VkImageViewSlicedCreateInfoEXT, VkImageViewUsageCreateInfo, VkOpaqueCaptureDescriptorDataCreateInfoEXT, or VkSamplerYcbcrConversionInfo

- **VUID-VkImageViewCreateInfo-sType-unique**
  The `sType` value of each struct in the `pNext` chain **must** be unique, with the exception of structures of type `VkExportMetalObjectCreateInfoEXT`

- **VUID-VkImageViewCreateInfo-flags-parameter**
  `flags` **must** be a valid combination of `VkImageViewCreateFlagBits` values

- **VUID-VkImageViewCreateInfo-image-parameter**
  `image` **must** be a valid `VkImage` handle

- **VUID-VkImageViewCreateInfo-viewType-parameter**
  `viewType` **must** be a valid `VkImageViewType` value

- **VUID-VkImageViewCreateInfo-format-parameter**
  `format` **must** be a valid `VkFormat` value

- **VUID-VkImageViewCreateInfo-components-parameter**
  `components` **must** be a valid `VkComponentMapping` structure

- **VUID-VkImageViewCreateInfo-subresourceRange-parameter**
  `subresourceRange` **must** be a valid `VkImageSubresourceRange` structure

Bits which **can** be set in `VkImageViewCreateInfo::flags`, specifying additional parameters of an image view, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkImageViewCreateFlagBits {
    // Provided by VK_EXT_fragment_density_map
    VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DYNAMIC_BIT_EXT = 0x00000001,
    // Provided by VK_EXT_descriptor_buffer
    VK_IMAGE_VIEW_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT = 0x00000004,
    // Provided by VK_EXT_fragment_density_map2
    VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DEFERRED_BIT_EXT = 0x00000002,
} VkImageViewCreateFlagBits;
```

- **VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DYNAMIC_BIT_EXT** specifies that the fragment density map will be read by device during `VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT`

- **VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DEFERRED_BIT_EXT** specifies that the fragment density map will be read by the host during `vkEndCommandBuffer` for the primary command buffer that the render pass is recorded into

- **VK_IMAGE_VIEW_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT** specifies that the image view **can** be used with descriptor buffers when capturing and replaying (e.g. for trace capture and replay), see `VkOpaqueCaptureDescriptorDataCreateInfoEXT` for more detail.

```c
// Provided by VK_VERSION_1_0
```
typedef VkFlags VkImageViewCreateFlags;

VkImageViewCreateFlags is a bitmask type for setting a mask of zero or more VkImageViewCreateFlagBits.

The set of usages for the created image view can be restricted compared to the parent image’s usage flags by adding a VkImageViewUsageCreateInfo structure to the pNext chain of VkImageViewCreateInfo.

The VkImageViewUsageCreateInfo structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkImageViewUsageCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkImageUsageFlags usage;
} VkImageViewUsageCreateInfo;
```

or the equivalent

```c
// Provided by VK_KHR_maintenance2
typedef VkImageViewUsageCreateInfo VkImageViewUsageCreateInfoKHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- usage is a bitmask of VkImageUsageFlagBits specifying allowed usages of the image view.

When this structure is chained to VkImageViewCreateInfo the usage field overrides the implicit usage parameter inherited from image creation time and its value is used instead for the purposes of determining the valid usage conditions of VkImageViewCreateInfo.

Valid Usage (Implicit)

- VUID-VkImageViewUsageCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_IMAGE_VIEW_USAGE_CREATE_INFO
- VUID-VkImageViewUsageCreateInfo-usage-parameter
  usage must be a valid combination of VkImageUsageFlagBits values
- VUID-VkImageViewUsageCreateInfo-usage-requiredbitmask
  usage must not be 0

The range of 3D slices for the created image view can be restricted to a subset of the parent image’s Z range by adding a VkImageViewSlicedCreateInfoEXT structure to the pNext chain of VkImageViewCreateInfo.
The `VkImageViewSlicedCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_image_sliced_view_of_3d
typedef struct VkImageViewSlicedCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    uint32_t sliceOffset;
    uint32_t sliceCount;
} VkImageViewSlicedCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `sliceOffset` is the Z-offset for the first 3D slice accessible to the image view.
- `sliceCount` is the number of 3D slices accessible to the image view.

When this structure is chained to `VkImageViewCreateInfo` the `sliceOffset` field is treated as a Z-offset for the sliced view and `sliceCount` specifies the range. Shader accesses using a Z coordinate of 0 will access the depth slice corresponding to `sliceOffset` in the image, and in a shader, the maximum in-bounds Z coordinate for the view is `sliceCount - 1`.

A sliced 3D view must only be used with a single mip level. The slice coordinates are integer coordinates within the `subresourceRange.baseMipLevel` used to create the image view.

The effective view depth is equal to `extent.depth` used to create the `image` for this view adjusted by `subresourceRange.baseMipLevel` as specified in `Image Mip Level Sizing`.

Shader access to this image view is only affected by `VkImageViewSlicedCreateInfoEXT` if it uses a descriptor of type `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE`. For access using any other descriptor type, the contents of `VkImageViewSlicedCreateInfoEXT` are ignored; instead, `sliceOffset` is treated as being equal to 0, and `sliceCount` is treated as being equal to `VK_REMAINING_3D_SLICES_EXT`.

### Valid Usage

- **VUID-VkImageViewSlicedCreateInfoEXT-sliceOffset-07867**
  - `sliceOffset` must be less than the effective view depth as specified in `Image Mip Level Sizing`.

- **VUID-VkImageViewSlicedCreateInfoEXT-sliceCount-07868**
  - If `sliceCount` is not `VK_REMAINING_3D_SLICES_EXT`, it must be non-zero and `sliceOffset + sliceCount` must be less than or equal to the effective view depth as specified in `Image Mip Level Sizing`.

- **VUID-VkImageViewSlicedCreateInfoEXT-image-07869**
  - `image` must have been created with `imageType` equal to `VK_IMAGE_TYPE_3D`.

- **VUID-VkImageViewSlicedCreateInfoEXT-viewType-07909**
  - `viewType` must be `VK_IMAGE_VIEW_TYPE_3D`.

- **VUID-VkImageViewSlicedCreateInfoEXT-None-07870**
The image view must reference exactly 1 mip level

- VUID-VkImageViewSlicedCreateInfoEXT-None-07871

The imageSlicedViewOf3D feature must be enabled on the device

## Valid Usage (Implicit)

- VUID-VkImageViewSlicedCreateInfoEXT-sType-sType

  sType must be VK_STRUCTURE_TYPE_IMAGE_VIEW_SLICED_CREATE_INFO_EXT

**VK_REMAINING_3D_SLICES_EXT** is a special constant value used for VkImageViewSlicedCreateInfoEXT::sliceCount to indicate that all remaining 3D slices in an image after the first slice offset specified should be included in the view.

```cpp
#define VK_REMAINING_3D_SLICES_EXT        (~0U)
```

The **VkImageSubresourceRange** structure is defined as:

```cpp
// Provided by VK_VERSION_1_0
typedef struct VkImageSubresourceRange {  
    VkImageAspectFlags aspectMask;  
    uint32_t baseMipLevel;  
    uint32_t levelCount;  
    uint32_t baseArrayLayer;  
    uint32_t layerCount;  
} VkImageSubresourceRange;
```

- **aspectMask** is a bitmask of VkImageAspectFlagBits specifying which aspect(s) of the image are included in the view.
- **baseMipLevel** is the first mipmap level accessible to the view.
- **levelCount** is the number of mipmap levels (starting from baseMipLevel) accessible to the view.
- **baseArrayLayer** is the first array layer accessible to the view.
- **layerCount** is the number of array layers (starting from baseArrayLayer) accessible to the view.

The number of mipmap levels and array layers must be a subset of the image subresources in the image. If an application wants to use all mip levels or layers in an image after the first slice offset specified, it can set levelCount and layerCount to the special values VK_REMAINING_MIP_LEVELS and VK_REMAINING_ARRAY_LAYERS without knowing the exact number of mip levels or layers.

For cube and cube array image views, the layers of the image view starting at baseArrayLayer correspond to faces in the order +X, -X, +Y, -Y, +Z, -Z. For cube arrays, each set of six sequential layers is a single cube, so the number of cube maps in a cube map array view is layerCount / 6, and image array layer (baseArrayLayer + i) is face index (i mod 6) of cube i / 6. If the number of layers in the view, whether set explicitly in layerCount or implied by VK_REMAINING_ARRAY_LAYERS, is not a
multiple of 6, the last cube map in the array must not be accessed.

aspectMask must be only VK_IMAGE_ASPECT_COLOR_BIT, VK_IMAGE_ASPECT_DEPTH_BIT or VK_IMAGE_ASPECT_STENCIL_BIT if format is a color, depth-only or stencil-only format, respectively, except if format is a multi-planar format. If using a depth/stencil format with both depth and stencil components, aspectMask must include at least one of VK_IMAGE_ASPECT_DEPTH_BIT and VK_IMAGE_ASPECT_STENCIL_BIT, and can include both.

When the VkImageSubresourceRange structure is used to select a subset of the slices of a 3D image’s mip level in order to create a 2D or 2D array image view of a 3D image created with VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT, baseArrayLayer and layerCount specify the first slice index and the number of slices to include in the created image view. Such an image view can be used as a framebuffer attachment that refers only to the specified range of slices of the selected mip level. However, any layout transitions performed on such an attachment view during a render pass instance still apply to the entire subresource referenced which includes all the slices of the selected mip level.

When using an image view of a depth/stencil image to populate a descriptor set (e.g. for sampling in the shader, or for use as an input attachment), the aspectMask must only include one bit, which selects whether the image view is used for depth reads (i.e. using a floating-point sampler or input attachment in the shader) or stencil reads (i.e. using an unsigned integer sampler or input attachment in the shader). When an image view of a depth/stencil image is used as a depth/stencil framebuffer attachment, the aspectMask is ignored and both depth and stencil image subresources are used.

When creating a VkImageView, if sampler Y’C_bC_r conversion is enabled in the sampler, the aspectMask of a subresourceRange used by the VkImageView must be VK_IMAGE_ASPECT_COLOR_BIT.

When creating a VkImageView, if sampler Y’C_bC_r conversion is not enabled in the sampler and the image format is multi-planar, the image must have been created with VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT, and the aspectMask of the VkImageView’s subresourceRange must be VK_IMAGE_ASPECT_PLANE_0_BIT, VK_IMAGE_ASPECT_PLANE_1_BIT or VK_IMAGE_ASPECT_PLANE_2_BIT.

Valid Usage

- VUID-VkImageSubresourceRange-levelCount-01720
  If levelCount is not VK_REMAINING_MIP_LEVELS, it must be greater than 0

- VUID-VkImageSubresourceRange-layerCount-01721
  If layerCount is not VK_REMAINING_ARRAY_LAYERS, it must be greater than 0

- VUID-VkImageSubresourceRange-aspectMask-01670
  If aspectMask includes VK_IMAGE_ASPECT_COLOR_BIT, then it must not include any of VK_IMAGE_ASPECT_PLANE_0_BIT, VK_IMAGE_ASPECT_PLANE_1_BIT, or VK_IMAGE_ASPECT_PLANE_2_BIT

- VUID-VkImageSubresourceRange-aspectMask-02278
  aspectMask must not include VK_IMAGE_ASPECT_MEMORY_PLANE_i_BIT_EXT for any index i
Valid Usage (Implicit)

- VUID-VkImageSubresourceRange-aspectMask-parameter
  aspectMask must be a valid combination of VkImageAspectFlagBits values
- VUID-VkImageSubresourceRange-aspectMask-requiredbitmask
  aspectMask must not be \(0\)

Bits which can be set in an aspect mask to specify aspects of an image for purposes such as identifying a subresource, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkImageAspectFlagBits {
    VK_IMAGE_ASPECT_COLOR_BIT = 0x00000001,
    VK_IMAGE_ASPECT_DEPTH_BIT = 0x00000002,
    VK_IMAGE_ASPECT_STENCIL_BIT = 0x00000004,
    VK_IMAGE_ASPECT_METADATA_BIT = 0x00000008,
    // Provided by VK_VERSION_1_1
    VK_IMAGE_ASPECT_PLANE_0_BIT = 0x00000010,
    // Provided by VK_VERSION_1_1
    VK_IMAGE_ASPECT_PLANE_1_BIT = 0x00000020,
    // Provided by VK_VERSION_1_1
    VK_IMAGE_ASPECT_PLANE_2_BIT = 0x00000040,
    // Provided by VK_VERSION_1_3
    VK_IMAGE_ASPECT_NONE = 0,
    // Provided by VK_EXT_image_drm_format_modifier
    VK_IMAGE_ASPECT_MEMORY_PLANE_0_BIT_EXT = 0x00000080,
    // Provided by VK_EXT_image_drm_format_modifier
    VK_IMAGE_ASPECT_MEMORY_PLANE_1_BIT_EXT = 0x00000100,
    // Provided by VK_EXT_image_drm_format_modifier
    VK_IMAGE_ASPECT_MEMORY_PLANE_2_BIT_EXT = 0x00000200,
    // Provided by VK_EXT_image_drm_format_modifier
    VK_IMAGE_ASPECT_MEMORY_PLANE_3_BIT_EXT = 0x00000400,
    // Provided by VK_KHR_sampler_ycbcr_conversion
    VK_IMAGE_ASPECT_PLANE_0_BIT_KHR = VK_IMAGE_ASPECT_PLANE_0_BIT,
    // Provided by VK_KHR_sampler_ycbcr_conversion
    VK_IMAGE_ASPECT_PLANE_1_BIT_KHR = VK_IMAGE_ASPECT_PLANE_1_BIT,
    // Provided by VK_KHR_sampler_ycbcr_conversion
    VK_IMAGE_ASPECT_PLANE_2_BIT_KHR = VK_IMAGE_ASPECT_PLANE_2_BIT,
    // Provided by VK_KHR_maintenance4
    VK_IMAGE_ASPECT_NONE_KHR = VK_IMAGE_ASPECT_NONE,
} VkImageAspectFlagBits;
```

- \(VK_IMAGE_ASPECT_NONE\) specifies no image aspect, or the image aspect is not applicable.
- \(VK_IMAGE_ASPECT_COLOR_BIT\) specifies the color aspect.
- \(VK_IMAGE_ASPECT_DEPTH_BIT\) specifies the depth aspect.
- \(VK_IMAGE_ASPECT_STENCIL_BIT\) specifies the stencil aspect.
• VK_IMAGE_ASPECT_METADATA_BIT specifies the metadata aspect used for sparse resource operations.
• VK_IMAGE_ASPECT_PLANE_0_BIT specifies plane 0 of a multi-planar image format.
• VK_IMAGE_ASPECT_PLANE_1_BIT specifies plane 1 of a multi-planar image format.
• VK_IMAGE_ASPECT_PLANE_2_BIT specifies plane 2 of a multi-planar image format.
• VK_IMAGE_ASPECT_MEMORY_PLANE_0_BIT_EXT specifies memory plane 0.
• VK_IMAGE_ASPECT_MEMORY_PLANE_1_BIT_EXT specifies memory plane 1.
• VK_IMAGE_ASPECT_MEMORY_PLANE_2_BIT_EXT specifies memory plane 2.
• VK_IMAGE_ASPECT_MEMORY_PLANE_3_BIT_EXT specifies memory plane 3.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkImageAspectFlags;
```

VkImageAspectFlags is a bitmask type for setting a mask of zero or more VkImageAspectFlagBits.

The VkComponentMapping structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkComponentMapping {
    VkComponentSwizzle r;
    VkComponentSwizzle g;
    VkComponentSwizzle b;
    VkComponentSwizzle a;
} VkComponentMapping;
```

• r is a VkComponentSwizzle specifying the component value placed in the R component of the output vector.
• g is a VkComponentSwizzle specifying the component value placed in the G component of the output vector.
• b is a VkComponentSwizzle specifying the component value placed in the B component of the output vector.
• a is a VkComponentSwizzle specifying the component value placed in the A component of the output vector.

### Valid Usage (Implicit)

- VUID-VkComponentMapping-r-parameter
  r must be a valid VkComponentSwizzle value
- VUID-VkComponentMapping-g-parameter
  g must be a valid VkComponentSwizzle value
- VUID-VkComponentMapping-b-parameter
  b must be a valid VkComponentSwizzle value
Possible values of the members of `VkComponentMapping`, specifying the component values placed in each component of the output vector, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkComponentSwizzle {
    VK_COMPONENT_SWIZZLE_IDENTITY = 0,
    VK_COMPONENT_SWIZZLE_ZERO = 1,
    VK_COMPONENT_SWIZZLE_ONE = 2,
    VK_COMPONENT_SWIZZLE_R = 3,
    VK_COMPONENT_SWIZZLE_G = 4,
    VK_COMPONENT_SWIZZLE_B = 5,
    VK_COMPONENT_SWIZZLE_A = 6,
} VkComponentSwizzle;
```

- `VK_COMPONENT_SWIZZLE_IDENTITY` specifies that the component is set to the identity swizzle.
- `VK_COMPONENT_SWIZZLE_ZERO` specifies that the component is set to zero.
- `VK_COMPONENT_SWIZZLE_ONE` specifies that the component is set to either 1 or 1.0, depending on whether the type of the image view format is integer or floating-point respectively, as determined by the `Format Definition` section for each `VkFormat`.
- `VK_COMPONENT_SWIZZLE_R` specifies that the component is set to the value of the R component of the image.
- `VK_COMPONENT_SWIZZLE_G` specifies that the component is set to the value of the G component of the image.
- `VK_COMPONENT_SWIZZLE_B` specifies that the component is set to the value of the B component of the image.
- `VK_COMPONENT_SWIZZLE_A` specifies that the component is set to the value of the A component of the image.

Setting the identity swizzle on a component is equivalent to setting the identity mapping on that component. That is:

<table>
<thead>
<tr>
<th>Component</th>
<th>Identity Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>components.r</td>
<td>VK_COMPONENT_SWIZZLE_R</td>
</tr>
<tr>
<td>components.g</td>
<td>VK_COMPONENT_SWIZZLE_G</td>
</tr>
<tr>
<td>components.b</td>
<td>VK_COMPONENT_SWIZZLE_B</td>
</tr>
<tr>
<td>components.a</td>
<td>VK_COMPONENT_SWIZZLE_A</td>
</tr>
</tbody>
</table>

If the `pNext` chain includes a `VkImageViewASTCDecodeModeEXT` structure, then that structure includes a parameter specifying the decode mode for image views using ASTC compressed formats.
The `VkImageViewASTCDecodeModeEXT` structure is defined as:

```c
// Provided by VK_EXT_astc_decode_mode
typedef struct VkImageViewASTCDecodeModeEXT {
    VkStructureType sType;
    const void* pNext;
    VkFormat decodeMode;
} VkImageViewASTCDecodeModeEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **decodeMode** is the intermediate format used to decode ASTC compressed formats.

### Valid Usage

- VUID-VkImageViewASTCDecodeModeEXT-decodeMode-02230
  `decodeMode` must be one of `VK_FORMAT_R16G16B16A16_SFLOAT`, `VK_FORMAT_R8G8B8A8_UNORM`, or `VK_FORMAT_E5B9G9R9_UFLOAT_PACK32`

- VUID-VkImageViewASTCDecodeModeEXT-decodeMode-02231
  If the `decodeModeSharedExponent` feature is not enabled, `decodeMode` must not be `VK_FORMAT_E5B9G9R9_UFLOAT_PACK32`

- VUID-VkImageViewASTCDecodeModeEXT-decodeMode-02232
  If `decodeMode` is `VK_FORMAT_R8G8B8A8_UNORM` the image view must not include blocks using any of the ASTC HDR modes

- VUID-VkImageViewASTCDecodeModeEXT-format-04084
  `format` of the image view must be one of the ASTC Compressed Image Formats

If `format` uses sRGB encoding then the `decodeMode` has no effect.

### Valid Usage (Implicit)

- VUID-VkImageViewASTCDecodeModeEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_IMAGE_VIEW_ASTC_DECODE_MODE_EXT`

- VUID-VkImageViewASTCDecodeModeEXT-decodeMode-parameter
  `decodeMode` must be a valid `VkFormat` value

If the `pNext` chain includes a `VkImageViewSampleWeightCreateInfoQCOM` structure, then that structure includes a parameter specifying the parameters for weight image views used in weight image sampling.

The `VkImageViewSampleWeightCreateInfoQCOM` structure is defined as:

```c
// Provided by VK_QCOM_image_processing
```
typedef struct VkImageViewSampleWeightCreateInfoQCOM {
    VkStructureType sType;
    const void* pNext;
    VkOffset2D filterCenter;
    VkExtent2D filterSize;
    uint32_t numPhases;
} VkImageViewSampleWeightCreateInfoQCOM;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `filterCenter` is a `VkOffset2D` describing the location of the weight filter origin.
- `filterSize` is a `VkExtent2D` specifying weight filter dimensions.
- `numPhases` is number of sub-pixel filter phases.

The `filterCenter` specifies the origin or center of the filter kernel, as described in Weight Sampling Operation. The `numPhases` describes the number of sub-pixel filter phases as described in Weight Sampling Phases.

**Valid Usage**

- VUID-VkImageViewSampleWeightCreateInfoQCOM-filterSize-06958
  `filterSize.width` must be less than or equal to `VkPhysicalDeviceImageProcessingPropertiesQCOM::maxWeightFilterDimension.width`

- VUID-VkImageViewSampleWeightCreateInfoQCOM-filterSize-06959
  `filterSize.height` must be less than or equal to `VkPhysicalDeviceImageProcessingPropertiesQCOM::maxWeightFilterDimension.height`

- VUID-VkImageViewSampleWeightCreateInfoQCOM-filterCenter-06960
  `filterCenter.x` must be less than or equal to `(filterSize.width - 1)`

- VUID-VkImageViewSampleWeightCreateInfoQCOM-filterCenter-06961
  `filterCenter.y` must be less than or equal to `(filterSize.height - 1)`

- VUID-VkImageViewSampleWeightCreateInfoQCOM-numPhases-06962
  `numPhases` must be a power of two squared value (i.e., 1, 4, 16, 64, 256, etc.)

- VUID-VkImageViewSampleWeightCreateInfoQCOM-numPhases-06963
  `numPhases` must be less than or equal to `VkPhysicalDeviceImageProcessingPropertiesQCOM::maxWeightFilterPhases`

**Valid Usage (Implicit)**

- VUID-VkImageViewSampleWeightCreateInfoQCOM-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_IMAGE_VIEW_SAMPLE_WEIGHT_CREATE_INFO_QCOM`

To destroy an image view, call:
```c
void vkDestroyImageView(
    VkDevice device,
    VkImageView imageView,
    const VkAllocationCallbacks* pAllocator);
```

- `device` is the logical device that destroys the image view.
- `imageView` is the image view to destroy.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

### Valid Usage

- VUID-vkDestroyImageView-imageView-01026
  All submitted commands that refer to `imageView` must have completed execution.

- VUID-vkDestroyImageView-imageView-01027
  If `VkAllocationCallbacks` were provided when `imageView` was created, a compatible set of callbacks must be provided here.

- VUID-vkDestroyImageView-imageView-01028
  If no `VkAllocationCallbacks` were provided when `imageView` was created, `pAllocator` must be NULL.

### Valid Usage (Implicit)

- VUID-vkDestroyImageView-device-parameter
  `device` must be a valid `VkDevice` handle.

- VUID-vkDestroyImageView-imageView-parameter
  If `imageView` is not `VK_NULL_HANDLE`, `imageView` must be a valid `VkImageView` handle.

- VUID-vkDestroyImageView-pAllocator-parameter
  If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure.

- VUID-vkDestroyImageView-imageView-parent
  If `imageView` is a valid handle, it must have been created, allocated, or retrieved from `device`.

### Host Synchronization

- Host access to `imageView` must be externally synchronized.

To get the handle for an image view, call:

```c
// Provided by VK_NVX_image_view_handle
```
```c
uint32_t vkGetImageViewHandleNVX(
    VkDevice device,
    const VkImageViewHandleInfoNVX* pInfo);
```

- **device** is the logical device that owns the image view.
- **pInfo** describes the image view to query and type of handle.

### Valid Usage (Implicit)

- **VUID-vkGetImageViewHandleNVX-device-parameter**
  
  *device* must be a valid *VkDevice* handle

- **VUID-vkGetImageViewHandleNVX-pInfo-parameter**
  
  *pInfo* must be a valid pointer to a valid *VkImageViewHandleInfoNVX* structure

The *VkImageViewHandleInfoNVX* structure is defined as:

```c
// Provided by VK_NVX_image_view_handle
typedef struct VkImageViewHandleInfoNVX {
    VkStructureType sType;
    const void* pNext;
    VkImageView imageView;
    VkDescriptorType descriptorType;
    VkSampler sampler;
} VkImageViewHandleInfoNVX;
```

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **imageView** is the image view to query.
- **descriptorType** is the type of descriptor for which to query a handle.
- **sampler** is the sampler to combine with the image view when generating the handle.

### Valid Usage

- **VUID-VkImageViewHandleInfoNVX-descriptorType-02654**
  
  *descriptorType* must be *VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE*, *VK_DESCRIPTOR_TYPE_STORAGE_IMAGE*, or *VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER*

- **VUID-VkImageViewHandleInfoNVX-sampler-02655**
  
  *sampler* must be a valid *VkSampler* if *descriptorType* is *VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER*

- **VUID-VkImageViewHandleInfoNVX-imageView-02656**
  
  If *descriptorType* is *VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE* or *VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER*, the image that *imageView* was created from must have been created with the *VK_IMAGE_USAGE_SAMPLED_BIT* usage bit set
If descriptorType is `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE`, the image that `imageView` was created from must have been created with the `VK_IMAGE_USAGE_STORAGE_BIT` usage bit set.

**Valid Usage (Implicit)**

- VUID-VkImageViewHandleInfoNVX-sType-sType
  sType must be `VK_STRUCTURE_TYPE_IMAGE_VIEW_HANDLE_INFO_NVX`

- VUID-VkImageViewHandleInfoNVX-pNext-pNext
  pNext must be NULL

- VUID-VkImageViewHandleInfoNVX-imageView-parameter
  `imageView` must be a valid `VkImageView` handle

- VUID-VkImageViewHandleInfoNVX-descriptorType-parameter
  descriptorType must be a valid `VkDescriptorType` value

- VUID-VkImageViewHandleInfoNVX-sampler-parameter
  If `sampler` is not `VK_NULL_HANDLE`, `sampler` must be a valid `VkSampler` handle

- VUID-VkImageViewHandleInfoNVX-commonparent
  Both of `imageView`, and `sampler` that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same `VkDevice`

To get the device address for an image view, call:

```c
// Provided by VK_NVX_image_view_handle
VkResult vkGetImageViewAddressNVX(
    VkDevice device,              
    VkImageView imageView,       
    VkImageViewAddressPropertiesNVX* pProperties);
```

- `device` is the logical device that owns the image view.
- `imageView` is a handle to the image view.
- `pProperties` contains the device address and size when the call returns.

**Valid Usage (Implicit)**

- VUID-vkGetImageViewAddressNVX-device-parameter
  `device` must be a valid `VkDevice` handle

- VUID-vkGetImageViewAddressNVX-imageView-parameter
  `imageView` must be a valid `VkImageView` handle

- VUID-vkGetImageViewAddressNVX-pProperties-parameter
  `pProperties` must be a valid pointer to a `VkImageViewAddressPropertiesNVX` structure

- VUID-vkGetImageViewAddressNVX-imageView-parent
Return Codes

Success
• VK_SUCCESS

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_UNKNOWN

The `VkImageViewAddressPropertiesNVX` structure is defined as:

```c
// Provided by VK_NVX_image_view_handle
typedef struct VkImageViewAddressPropertiesNVX {
  VkStructureType sType;
  void* pNext;
  VkDeviceAddress deviceAddress;
  VkDeviceSize size;
} VkImageViewAddressPropertiesNVX;
```

• `sType` is a `VkStructureType` value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.
• `deviceAddress` is the device address of the image view.
• `size` is the size in bytes of the image view device memory.

Valid Usage (Implicit)

• VUID-VkImageViewAddressPropertiesNVX-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_IMAGE_VIEW_ADDRESS_PROPERTIES_NVX`
• VUID-VkImageViewAddressPropertiesNVX-pNext-pNext
  `pNext` must be `NULL`

12.5.1. Image View Format Features

Valid uses of a `VkImageView` may depend on the image view's `format features`, defined below. Such constraints are documented in the affected valid usage statement.

• If Vulkan 1.3 is supported or the `VK_KHR_format_feature_flags2` extension is supported, and `VkImageViewCreateInfo::image` was created with `VK_IMAGE_TILING_LINEAR`, then the image view's set of `format features` is the value of `VkFormatProperties3::linearTilingFeatures` found by calling `vkGetPhysicalDeviceFormatProperties2` on the same `format` as `VkImageViewCreateInfo::format`.
• If Vulkan 1.3 is not supported and the VK_KHR_format_feature_flags2 extension is not supported, and VkImageViewCreateInfo::image was created with VK_IMAGE_TILING_LINEAR, then the image view's set of format features is the union of the value of VkFormatProperties::linearTilingFeatures found by calling vkGetPhysicalDeviceFormatProperties on the same format as VkImageViewCreateInfo::format, with:
  ◦ VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT if the format is a depth/stencil format and the image view features also contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_BIT.
  ◦ VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT if the format is one of the extended storage formats and shaderStorageImageReadWithoutFormat is enabled on the device.
  ◦ VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT if the format is one of the extended storage formats and shaderStorageImageWriteWithoutFormat is enabled on the device.

• If Vulkan 1.3 is supported or the VK_KHR_format_feature_flags2 extension is supported, and VkImageViewCreateInfo::image was created with VK_IMAGE_TILING_OPTIMAL, but without an Android hardware buffer external format, or a QNX Screen buffer external format, then the image view's set of format features is the value of VkFormatProperties::optimalTilingFeatures or VkFormatProperties3::optimalTilingFeatures found by calling vkGetPhysicalDeviceFormatProperties or vkGetPhysicalDeviceImageFormatProperties2 on the same format as VkImageViewCreateInfo::format.

• If Vulkan 1.3 is not supported and the VK_KHR_format_feature_flags2 extension is not supported, and VkImageViewCreateInfo::image was created with VK_IMAGE_TILING_OPTIMAL, but without an Android hardware buffer external format, or a QNX Screen buffer external format, then the image view's set of format features is the union of the value of VkFormatProperties::linearTilingFeatures found by calling vkGetPhysicalDeviceFormatProperties on the same format as VkImageViewCreateInfo::format, with:
  ◦ VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT if the format is a depth/stencil format and the image view features also contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_BIT.
  ◦ VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT if the format is one of the extended storage formats and shaderStorageImageReadWithoutFormat is enabled on the device.
  ◦ VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT if the format is one of the extended storage formats and shaderStorageImageWriteWithoutFormat is enabled on the device.

• If VkImageViewCreateInfo::image was created with an Android hardware buffer external format, then the image view's set of format features is the value of VkAndroidHardwareBufferFormatPropertiesANDROID::formatFeatures found by calling vkGetAndroidHardwareBufferPropertiesANDROID on the Android hardware buffer that was imported to the VkDeviceMemory to which the VkImageViewCreateInfo::image is bound.

• If VkImageViewCreateInfo::image was created with a QNX Screen buffer external format, then the image view's set of format features is the value of VkScreenBufferFormatPropertiesQNX::formatFeatures found by calling vkGetScreenBufferPropertiesQNX on the QNX Screen buffer that was imported to the VkDeviceMemory to which the VkImageViewCreateInfo::image is bound.

• If VkImageViewCreateInfo::image was created with a chained VkBufferCollectionImageCreateInfoFUCHSIA, then the image view's set of format features is the value of VkBufferCollectionPropertiesFUCHSIA::formatFeatures found by calling
vkGetBufferCollectionPropertiesFUCHSIA on the buffer collection passed as VkBufferCollectionImageCreateInfoFUCHSIA::collection when the image was created.

- If VkImageViewCreateInfo::image was created with VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT, then:
  - The image’s DRM format modifier is the value of VkImageDrmFormatModifierPropertiesEXT::drmFormatModifier found by calling vkGetImageDrmFormatModifierPropertiesEXT.
  - Let VkDrmFormatModifierPropertiesListEXT::pDrmFormatModifierProperties be the array found by calling vkGetPhysicalDeviceFormatProperties2 on the same format as VkImageViewCreateInfo::format.
  - Let VkDrmFormatModifierPropertiesEXT prop be the array element whose drmFormatModifier member is the value of the image’s DRM format modifier.
  - Then the image view’s set of format features is prop::drmFormatModifierTilingFeatures.

The VkImageViewMinLodCreateInfoEXT structure is defined as:

```c
// Provided by VK_EXT_image_view_min_lod
typedef struct VkImageViewMinLodCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    float minLod;
} VkImageViewMinLodCreateInfoEXT;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- minLod is the value to clamp the minimum LOD accessible by this VkImageView.

If the pNext chain includes a VkImageViewMinLodCreateInfoEXT structure, then that structure includes a parameter specifying a value to clamp the minimum LOD value during Image Level(s) Selection, Texel Gathering and Integer Texel Coordinate Operations.

If the image view contains VkImageViewMinLodCreateInfoEXT and it is used as part of a sampling operation:

\[ \text{minLodFloat}_{\text{imageView}} = \text{minLod} \]

otherwise:

\[ \text{minLodFloat}_{\text{imageView}} = 0.0 \]

An integer variant of this parameter is also defined for sampling operations which access integer mipmap levels:

\[ \text{minLodInteger}_{\text{imageView}} = \lfloor \text{minLodFloat}_{\text{imageView}} \rfloor \]
12.6. Acceleration Structures

Acceleration structures are opaque data structures that are built by the implementation to more efficiently perform spatial queries on the provided geometric data. For this extension, an acceleration structure is either a top-level acceleration structure containing a set of bottom-level acceleration structures or a bottom-level acceleration structure containing either a set of axis-aligned bounding boxes for custom geometry or a set of triangles.

Each instance in the top-level acceleration structure contains a reference to a bottom-level acceleration structure as well as an instance transform plus information required to index into the shader bindings. The top-level acceleration structure is what is bound to the acceleration descriptor, for example to trace inside the shader in the ray tracing pipeline.

Acceleration structures are represented by `VkAccelerationStructureKHR` handles:

```c
// Provided by VK_KHR_acceleration_structure
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkAccelerationStructureKHR)
```

Acceleration structures for the `VK_NV_ray_tracing` extension are represented by the similar `VkAccelerationStructureNV` handles:

```c
// Provided by VK_NV_ray_tracing
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkAccelerationStructureNV)
```

To create acceleration structures, call:

```c
// Provided by VK_NV_ray_tracing
VkResult vkCreateAccelerationStructureNV(
    VkDevice device,
    const VkAccelerationStructureCreateInfoNV* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
)
```
VkAccelerationStructureNV* pAccelerationStructure);

- **device** is the logical device that creates the buffer object.
- **pCreateInfo** is a pointer to a VkAccelerationStructureCreateInfoNV structure containing parameters affecting creation of the acceleration structure.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
- **pAccelerationStructure** is a pointer to a VkAccelerationStructureNV handle in which the resulting acceleration structure object is returned.

Similarly to other objects in Vulkan, the acceleration structure creation merely creates an object with a specific “shape” as specified by the information in VkAccelerationStructureInfoNV and compactedSize in pCreateInfo.

Once memory has been bound to the acceleration structure using vkBindAccelerationStructureMemoryNV, that memory is populated by calls to vkCmdBuildAccelerationStructureNV and vkCmdCopyAccelerationStructureNV.

Acceleration structure creation uses the count and type information from the geometries, but does not use the data references in the structures.

**Valid Usage (Implicit)**

- VUID-vkCreateAccelerationStructureNV-device-parameter
  - **device** must be a valid VkDevice handle
- VUID-vkCreateAccelerationStructureNV-pCreateInfo-parameter
  - **pCreateInfo** must be a valid pointer to a valid VkAccelerationStructureCreateInfoNV structure
- VUID-vkCreateAccelerationStructureNV-pAllocator-parameter
  - If **pAllocator** is not NULL, **pAllocator** must be a valid pointer to a valid VkAllocationCallbacks structure
- VUID-vkCreateAccelerationStructureNV-pAccelerationStructure-parameter
  - **pAccelerationStructure** must be a valid pointer to a VkAccelerationStructureNV handle

**Return Codes**

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY

The VkAccelerationStructureCreateInfoNV structure is defined as:

```cpp
// Provided by VK_NV_ray_tracing
```
typedef struct VkAccelerationStructureCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkDeviceSize compactedSize;
    VkAccelerationStructureInfoNV info;
} VkAccelerationStructureCreateInfoNV;

• **sType** is a *VkStructureType* value identifying this structure.
• **pNext** is `NULL` or a pointer to a structure extending this structure.
• **compactedSize** is the size from the result of `vkCmdWriteAccelerationStructuresPropertiesNV` if this acceleration structure is going to be the target of a compacting copy.
• **info** is the *VkAccelerationStructureInfoNV* structure specifying further parameters of the created acceleration structure.

### Valid Usage

- **VUID-VkAccelerationStructureCreateInfoNV-compactedSize-02421**
  - If `compactedSize` is not 0 then both `info.geometryCount` and `info.instanceCount` must be 0

### Valid Usage (Implicit)

- **VUID-VkAccelerationStructureCreateInfoNV-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_CREATE_INFO_NV`
- **VUID-VkAccelerationStructureCreateInfoNV-pNext-pNext**
  - `pNext` must be `NULL` or a pointer to a valid instance of `VkOpaqueCaptureDescriptorDataCreateInfoEXT`
- **VUID-VkAccelerationStructureCreateInfoNV-sType-unique**
  - The `sType` value of each struct in the `pNext` chain must be unique
- **VUID-VkAccelerationStructureCreateInfoNV-info-parameter**
  - `info` must be a valid *VkAccelerationStructureInfoNV* structure

The *VkAccelerationStructureInfoNV* structure is defined as:

```c
// Provided by VK_NV_ray_tracing
typedef struct VkAccelerationStructureCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkAccelerationStructureTypeNV type;
    VkBuildAccelerationStructureFlagsNV flags;
    uint32_t instanceCount;
    uint32_t geometryCount;
    const VkGeometryNV* pGeometries;
} VkAccelerationStructureCreateInfoNV;
```
- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **type** is a `VkAccelerationStructureTypeNV` value specifying the type of acceleration structure that will be created.
- **flags** is a bitmask of `VkBuildAccelerationStructureFlagBitsNV` specifying additional parameters of the acceleration structure.
- **instanceCount** specifies the number of instances that will be in the new acceleration structure.
- **geometryCount** specifies the number of geometries that will be in the new acceleration structure.
- **pGeometries** is a pointer to an array of `geometryCount` `VkGeometryNV` structures containing the scene data being passed into the acceleration structure.

`VkAccelerationStructureInfoNV` contains information that is used both for acceleration structure creation with `vkCreateAccelerationStructureNV` and in combination with the actual geometric data to build the acceleration structure with `vkCmdBuildAccelerationStructureNV`.

### Valid Usage

- **VUID-VkAccelerationStructureInfoNV-geometryCount-02422**
  - `geometryCount` **must** be less than or equal to `VkPhysicalDeviceRayTracingPropertiesNV::maxGeometryCount`

- **VUID-VkAccelerationStructureInfoNV-instanceCount-02423**
  - `instanceCount` **must** be less than or equal to `VkPhysicalDeviceRayTracingPropertiesNV::maxInstanceCount`

- **VUID-VkAccelerationStructureInfoNV-maxTriangleCount-02424**
  - The total number of triangles in all geometries **must** be less than or equal to `VkPhysicalDeviceRayTracingPropertiesNV::maxTriangleCount`

- **VUID-VkAccelerationStructureInfoNV-type-02425**
  - If `type` is `VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_NV` then `geometryCount` **must** be 0

- **VUID-VkAccelerationStructureInfoNV-type-02426**
  - If `type` is `VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_NV` then `instanceCount` **must** be 0

- **VUID-VkAccelerationStructureInfoNV-type-02786**
  - If `type` is `VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_NV` then the `geometryType` member of each geometry in `pGeometries` **must** be the same

- **VUID-VkAccelerationStructureInfoNV-type-04623**
  - `type` **must** not be `VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR`

- **VUID-VkAccelerationStructureInfoNV-flags-02592**
  - If `flags` has the `VK_BUILD_ACCELERATION_STRUCTURE_PREFER_FAST_TRACE_BIT_NV` bit set, then it **must** not have the `VK_BUILD_ACCELERATION_STRUCTURE_PREFER_FAST_BUILD_BIT_NV` bit set

- **VUID-VkAccelerationStructureInfoNV-scratch-02781**
  - `scratch` **must** have been created with `VK_BUFFER_USAGE_RAY_TRACING_BIT_NV` usage flag

- **VUID-VkAccelerationStructureInfoNV-instanceData-02782**
  - If `instanceData` is not `VK_NULL_HANDLE`, `instanceData` **must** have been created with
**VK_BUFFER_USAGE_RAY_TRACING_BIT_NV usage flag**

---

### Valid Usage (Implicit)

- **VUID-VkAccelerationStructureInfoNV-sType-sType**
  
  *sType* **must** be `VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_INFO_NV`

- **VUID-VkAccelerationStructureInfoNV-pNext-pNext**
  
  *pNext* **must** be `NULL`

- **VUID-VkAccelerationStructureInfoNV-type-parameter**
  
  *type* **must** be a valid `VkAccelerationStructureTypeNV` value

- **VUID-VkAccelerationStructureInfoNV-flags-parameter**
  
  *flags* **must** be a valid combination of `VkBuildAccelerationStructureFlagBitsNV` values

- **VUID-VkAccelerationStructureInfoNV-pGeometries-parameter**

  If `geometryCount` is not `0`, *pGeometries** must** be a valid pointer to an array of `geometryCount` valid `VkGeometryNV` structures

---

To create an acceleration structure, call:

```c
// Provided by VK_KHR_acceleration_structure
VkResult vkCreateAccelerationStructureKHR(  
    VkDevice device,  
    const VkAccelerationStructureCreateInfoKHR* pCreateInfo,  
    const VkAllocationCallbacks* pAllocator,  
    VkAccelerationStructureKHR* pAccelerationStructure);
```

- **device** is the logical device that creates the acceleration structure object.

- **pCreateInfo** is a pointer to a `VkAccelerationStructureCreateInfoKHR` structure containing parameters affecting creation of the acceleration structure.

- **pAllocator** controls host memory allocation as described in the **Memory Allocation** chapter.

- **pAccelerationStructure** is a pointer to a `VkAccelerationStructureKHR` handle in which the resulting acceleration structure object is returned.

---

Similar to other objects in Vulkan, the acceleration structure creation merely creates an object with a specific “shape”. The type and quantity of geometry that can be built into an acceleration structure is determined by the parameters of `VkAccelerationStructureCreateInfoKHR`.

The acceleration structure data is stored in the object referred to by `VkAccelerationStructureCreateInfoKHR::buffer`. Once memory has been bound to that buffer, it **must** be populated by acceleration structure build or acceleration structure copy commands such as `vkCmdBuildAccelerationStructuresKHR`, `vkBuildAccelerationStructuresKHR`, `vkCmdCopyAccelerationStructureKHR`, and `vkCopyAccelerationStructureKHR`.

---

**Note**
The expected usage for a trace capture/replay tool is that it will serialize and later deserialize the acceleration structure data using acceleration structure copy commands. During capture the tool will use 
\texttt{vkCopyAccelerationStructureToMemoryKHR} or \texttt{vkCmdCopyAccelerationStructureToMemoryKHR} with a mode of \texttt{VK_COPY_ACCELERATION_STRUCTURE_MODE_SERIALIZE_KHR}, and \texttt{vkCopyMemoryToAccelerationStructureKHR} or \texttt{vkCmdCopyMemoryToAccelerationStructureKHR} with a mode of \texttt{VK_COPY_ACCELERATION_STRUCTURE_MODE_DESERIALIZE_KHR} during replay.

The input buffers passed to acceleration structure build commands will be referenced by the implementation for the duration of the command. After the command completes, the acceleration structure may hold a reference to any acceleration structure specified by an active instance contained therein. Apart from this referencing, acceleration structures must be fully self-contained. The application can reuse or free any memory which was used by the command as an input or as scratch without affecting the results of ray traversal.

### Valid Usage

- **VUID-vkCreateAccelerationStructureKHR-accelerationStructure-03611**
  The \texttt{VkPhysicalDeviceAccelerationStructureFeaturesKHR::accelerationStructure} feature must be enabled

- **VUID-vkCreateAccelerationStructureKHR-deviceAddress-03488**
  If \texttt{VkAccelerationStructureCreateInfoKHR::deviceAddress} is not zero, the \texttt{accelerationStructureCaptureReplay} feature must be enabled

- **VUID-vkCreateAccelerationStructureKHR-device-03489**
  If device was created with multiple physical devices, then the \texttt{bufferDeviceAddressMultiDevice} feature must be enabled

### Valid Usage (Implicit)

- **VUID-vkCreateAccelerationStructureKHR-device-parameter**
  device must be a valid \texttt{VkDevice} handle

- **VUID-vkCreateAccelerationStructureKHR-pCreateInfo-parameter**
  pCreateInfo must be a valid pointer to a valid \texttt{VkAccelerationStructureCreateInfoKHR} structure

- **VUID-vkCreateAccelerationStructureKHR-pAllocator-parameter**
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid \texttt{VkAllocationCallbacks} structure

- **VUID-vkCreateAccelerationStructureKHR-pAccelerationStructure-parameter**
  pAccelerationStructure must be a valid pointer to a \texttt{VkAccelerationStructureKHR} handle
Return Codes

Success
• VK_SUCCESS

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS_KHR

The `VkAccelerationStructureCreateInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_acceleration_structure
typedef struct VkAccelerationStructureCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkAccelerationStructureCreateFlagsKHR createFlags;
    VkBuffer buffer;
    VkDeviceSize offset;
    VkDeviceSize size;
    VkAccelerationStructureTypeKHR type;
    VkDeviceAddress deviceAddress;
} VkAccelerationStructureCreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `createFlags` is a bitmask of `VkAccelerationStructureCreateFlagBitsKHR` specifying additional creation parameters of the acceleration structure.
- `buffer` is the buffer on which the acceleration structure will be stored.
- `offset` is an offset in bytes from the base address of the buffer at which the acceleration structure will be stored, and **must** be a multiple of 256.
- `size` is the size required for the acceleration structure.
- `type` is a `VkAccelerationStructureTypeKHR` value specifying the type of acceleration structure that will be created.
- `deviceAddress` is the device address requested for the acceleration structure if the `accelerationStructureCaptureReplay` feature is being used.

If `deviceAddress` is zero, no specific address is requested.

If `deviceAddress` is not zero, `deviceAddress` **must** be an address retrieved from an identically created acceleration structure on the same implementation. The acceleration structure **must** also be placed on an identically created `buffer` and at the same `offset`.

Applications **should** avoid creating acceleration structures with application-provided addresses and implementation-provided addresses in the same process, to reduce the likelihood of
VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS_KHR errors.

Note
The expected usage for this is that a trace capture/replay tool will add the VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT flag to all buffers that use VK_BUFFER_USAGE_SHADER_DEVICE_ADDRESS_BIT, and will add VK_BUFFER_USAGE_SHADER_DEVICE_ADDRESS_BIT to all buffers used as storage for an acceleration structure where deviceAddress is not zero. This also means that the tool will need to add VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT to memory allocations to allow the flag to be set where the application may not have otherwise required it. During capture the tool will save the queried opaque device addresses in the trace. During replay, the buffers will be created specifying the original address so any address values stored in the trace data will remain valid.

Implementations are expected to separate such buffers in the GPU address space so normal allocations will avoid using these addresses. Apps/tools should avoid mixing app-provided and implementation-provided addresses for buffers created with VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT, to avoid address space allocation conflicts.

Applications should create an acceleration structure with a specific VkAccelerationStructureTypeKHR other than VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR.

Note
VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR is intended to be used by API translation layers. This can be used at acceleration structure creation time in cases where the actual acceleration structure type (top or bottom) is not yet known. The actual acceleration structure type must be specified as VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_KHR or VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_KHR when the build is performed.

If the acceleration structure will be the target of a build operation, the required size for an acceleration structure can be queried with vkGetAccelerationStructureBuildSizesKHR. If the acceleration structure is going to be the target of a compacting copy, vkCmdWriteAccelerationStructuresPropertiesKHR or vkWriteAccelerationStructuresPropertiesKHR can be used to obtain the compacted size required.

If the acceleration structure will be the target of a build operation with VK_BUILD_ACCELERATION_STRUCTURE_MOTION_BIT_NV it must include VK_ACCELERATION_STRUCTURE_CREATE_MOTION_BIT_NV in createFlags and include VkAccelerationStructureMotionInfoNV as an extension structure in pNext with the number of instances as metadata for the object.

Valid Usage
- VUID-VkAccelerationStructureCreateInfoKHR-deviceAddress-03612
  If deviceAddress is not zero, createFlags must include
If `createFlags` includes `VK_ACCELERATION_STRUCTURE_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT_KHR`, `VkPhysicalDeviceAccelerationStructureFeaturesKHR::accelerationStructureCaptureReplay` must be `VK_TRUE`.

If `buffer` has been created with a usage value containing `VK_BUFFER_USAGE_ACCELERATION_STRUCTURE_STORAGE_BIT_KHR`, `buffer` must not have been created with `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT`.

The sum of `offset` and `size` must be less than the size of `buffer`.

`offset` must be a multiple of 256 bytes.

If `VK_ACCELERATION_STRUCTURE_CREATE_MOTION_BIT_NV` is set in `createFlags` and `type` is `VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_KHR`, one member of the `pNext` chain must be a pointer to a valid instance of `VkAccelerationStructureMotionInfoNV`.

If any geometry includes `VkAccelerationStructureGeometryMotionTrianglesDataNV` then `createFlags` must contain `VK_ACCELERATION_STRUCTURE_CREATE_MOTION_BIT_NV`.

If `createFlags` includes `VK_ACCELERATION_STRUCTURE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT`, the `descriptorBufferCaptureReplay` feature must be enabled.

If the `pNext` chain includes a `VkOpaqueCaptureDescriptorDataCreateInfoEXT` structure, `createFlags` must contain `VK_ACCELERATION_STRUCTURE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT`.

Valid Usage (Implicit)

- `sType` must be `VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_CREATE_INFO_KHR`.
- Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkAccelerationStructureMotionInfoNV` or `VkOpaqueCaptureDescriptorDataCreateInfoEXT`.
- The `sType` value of each struct in the `pNext` chain must be unique.

- `createFlags` parameter
**createFlags** must be a valid combination of `VkAccelerationStructureCreateFlagBitsKHR` values

- VUID-VkAccelerationStructureCreateInfoKHR-buffer-parameter
  buffer must be a valid `VkBuffer` handle

- VUID-VkAccelerationStructureCreateInfoKHR-type-parameter
  type must be a valid `VkAccelerationStructureTypeKHR` value

The `VkAccelerationStructureMotionInfoNV` structure is defined as:

```c
// Provided by VK_NV_ray_tracing_motion_blur
typedef struct VkAccelerationStructureMotionInfoNV {
    VkStructureType sType;
    const void* pNext;
    uint32_t maxInstances;
    VkAccelerationStructureMotionInfoFlagsNV flags;
} VkAccelerationStructureMotionInfoNV;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **maxInstances** is the maximum number of instances that may be used in the motion top-level acceleration structure.
- **flags** is 0 and reserved for future use.

### Valid Usage (Implicit)

- VUID-VkAccelerationStructureMotionInfoNV-sType-sType
  *sType* must be `VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_MOTION_INFO_NV`

- VUID-VkAccelerationStructureMotionInfoNV-flags-zerobitmask
  *flags* must be 0

```c
// Provided by VK_NV_ray_tracing_motion_blur
typedef VkFlags VkAccelerationStructureMotionInfoFlagsNV;
```

`VkAccelerationStructureMotionInfoFlagsNV` is a bitmask type for setting a mask, but is currently reserved for future use.

To get the build sizes for an acceleration structure, call:

```c
// Provided by VK_KHR_acceleration_structure
void vkGetAccelerationStructureBuildSizesKHR(
    VkDevice device,
    VkAccelerationStructureBuildTypeKHR buildType,
    const VkAccelerationStructureBuildGeometryInfoKHR* pBuildInfo,
    
```

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const uint32_t* pMaxPrimitiveCounts, VkAccelerationStructureBuildSizesInfoKHR* pSizeInfo);

- **device** is the logical device that will be used for creating the acceleration structure.
- **buildType** defines whether host or device operations (or both) are being queried for.
- **pBuildInfo** is a pointer to a `VkAccelerationStructureBuildGeometryInfoKHR` structure describing parameters of a build operation.
- **pMaxPrimitiveCounts** is a pointer to an array of `pBuildInfo->geometryCount` `uint32_t` values defining the number of primitives built into each geometry.
- **pSizeInfo** is a pointer to a `VkAccelerationStructureBuildSizesInfoKHR` structure which returns the size required for an acceleration structure and the sizes required for the scratch buffers, given the build parameters.

The `srcAccelerationStructure`, `dstAccelerationStructure`, and `mode` members of `pBuildInfo` are ignored. Any `VkDeviceOrHostAddressKHR` or `VkDeviceOrHostAddressConstKHR` members of `pBuildInfo` are ignored by this command, except that the `hostAddress` member of `VkAccelerationStructureGeometryTrianglesDataKHR::transformData` will be examined to check if it is NULL.

An acceleration structure created with the `accelerationStructureSize` returned by this command supports any build or update with a `VkAccelerationStructureBuildGeometryInfoKHR` structure and array of `VkAccelerationStructureBuildRangeInfoKHR` structures subject to the following properties:

- The build command is a host build command, and `buildType` is `VK_ACCELERATION_STRUCTURE_BUILD_TYPE_HOST_KHR` or `VK_ACCELERATION_STRUCTURE_BUILD_TYPE_HOST_OR_DEVICE_KHR`.
- The build command is a device build command, and `buildType` is `VK_ACCELERATION_STRUCTURE_BUILD_TYPE_DEVICE_KHR` or `VK_ACCELERATION_STRUCTURE_BUILD_TYPE_HOST_OR_DEVICE_KHR`.
- For `VkAccelerationStructureBuildGeometryInfoKHR`:
  - Its `type`, and `flags` members are equal to `pBuildInfo->type` and `pBuildInfo->flags`, respectively.
  - `geometryCount` is less than or equal to `pBuildInfo->geometryCount`.
  - For each element of either `pGeometries` or `ppGeometries` at a given index, its `geometryType` member is equal to `pBuildInfo->geometryType`.
  - For each element of either `pGeometries` or `ppGeometries` at a given index, its `flags` member is equal to the corresponding member of the same element in `pBuildInfo`.
  - For each element of either `pGeometries` or `ppGeometries` at a given index, with a `geometryType` member equal to `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, the `vertexFormat` and `indexType` members of `geometry.triangles` are equal to the corresponding members of the same element in `pBuildInfo`.
  - For each element of either `pGeometries` or `ppGeometries` at a given index, with a `geometryType` member equal to `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, the `maxVertex` member of
geometry.triangles is less than or equal to the corresponding member of the same element in pBuildInfo.

- For each element of either pGeometries or ppGeometries at a given index, with a geometryType member equal to VK_GEOMETRY_TYPE_TRIANGLES_KHR, if the applicable address in the transformData member of geometry.triangles is not NULL, the corresponding transformData.hostAddress parameter in pBuildInfo is not NULL.

- For each VkAccelerationStructureBuildRangeInfoKHR corresponding to the VkAccelerationStructureBuildGeometryInfoKHR:
  - Its primitiveCount member is less than or equal to the corresponding element of pMaxPrimitiveCounts.
  - For each element of either pGeometries or ppGeometries at a given index, with a geometryType member equal to VK_GEOMETRY_TYPE_TRIANGLES_KHR, if the pNext chain contains VkAccelerationStructureTrianglesOpacityMicromapEXT the corresponding member of pBuildInfo also contains VkAccelerationStructureTrianglesOpacityMicromapEXT and with an equivalent micromap.
  - For each element of either pGeometries or ppGeometries at a given index, with a geometryType member equal to VK_GEOMETRY_TYPE_TRIANGLES_KHR, if the pNext chain contains VkAccelerationStructureTrianglesDisplacementMicromapNV the corresponding member of pBuildInfo also contains VkAccelerationStructureTrianglesDisplacementMicromapNV and with an equivalent micromap.

Similarly, the updateScratchSize value will support any build command specifying the VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR mode under the above conditions, and the buildScratchSize value will support any build command specifying the VK_BUILD_ACCELERATION_STRUCTURE_MODE_BUILD_KHR mode under the above conditions.

---

**Valid Usage**

- VUID-vkGetAccelerationStructureBuildSizesKHR-accelerationStructure-08933
  The VkPhysicalDeviceAccelerationStructureFeaturesKHR::accelerationStructure feature must be enabled

- VUID-vkGetAccelerationStructureBuildSizesKHR-device-03618
  If device was created with multiple physical devices, then the bufferDeviceAddressMultiDevice feature must be enabled

- VUID-vkGetAccelerationStructureBuildSizesKHR-pBuildInfo-03619
  If pBuildInfo->geometryCount is not 0, pMaxPrimitiveCounts must be a valid pointer to an array of pBuildInfo->geometryCount uint32_t values

- VUID-vkGetAccelerationStructureBuildSizesKHR-pBuildInfo-03785
  If pBuildInfo->pGeometries or pBuildInfo->ppGeometries has a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR, each pMaxPrimitiveCounts[i] must be less than or equal to VkPhysicalDeviceAccelerationStructurePropertiesKHR::maxInstanceCount
Valid Usage (Implicit)

- VUID-vkGetAccelerationStructureBuildSizesKHR-device-parameter
device must be a valid VkDevice handle

- VUID-vkGetAccelerationStructureBuildSizesKHR-buildType-parameter
buildType must be a valid VkAccelerationStructureBuildTypeKHR value

- VUID-vkGetAccelerationStructureBuildSizesKHR-pBuildInfo-parameter
pBuildInfo must be a valid pointer to a valid VkAccelerationStructureBuildGeometryInfoKHR structure

- VUID-vkGetAccelerationStructureBuildSizesKHR-pMaxPrimitiveCounts-parameter
If pMaxPrimitiveCounts is not NULL, pMaxPrimitiveCounts must be a valid pointer to an array of pBuildInfo->geometryCount uint32_t values

- VUID-vkGetAccelerationStructureBuildSizesKHR-pSizeInfo-parameter
pSizeInfo must be a valid pointer to a VkAccelerationStructureBuildSizesInfoKHR structure

The VkAccelerationStructureBuildSizesInfoKHR structure describes the required build sizes for an acceleration structure and scratch buffers and is defined as:

```c
// Provided by VK_KHR_acceleration_structure
typedef struct VkAccelerationStructureBuildSizesInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkDeviceSize accelerationStructureSize;
    VkDeviceSize updateScratchSize;
    VkDeviceSize buildScratchSize;
} VkAccelerationStructureBuildSizesInfoKHR;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `accelerationStructureSize` is the size in bytes required in a VkAccelerationStructureKHR for a build or update operation.
- `updateScratchSize` is the size in bytes required in a scratch buffer for an update operation.
- `buildScratchSize` is the size in bytes required in a scratch buffer for a build operation.

Valid Usage (Implicit)

- VUID-VkAccelerationStructureBuildSizesInfoKHR-sType-sType
sType must be VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_BUILD_SIZES_INFO_KHR

- VUID-VkAccelerationStructureBuildSizesInfoKHR-pNext-pNext
pNext must be NULL
Values which can be set in VkAccelerationStructureCreateInfoKHR::type or VkAccelerationStructureInfoNV::type specifying the type of acceleration structure, are:

```c
// Provided by VK_KHR_acceleration_structure
typedef enum VkAccelerationStructureTypeKHR {
    VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_KHR = 0,
    VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_KHR = 1,
    VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR = 2,
} VkAccelerationStructureTypeKHR;
```

or the equivalent

```c
// Provided by VK_NV_ray_tracing
typedef VkAccelerationStructureTypeKHR VkAccelerationStructureTypeNV;
```

- **VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_KHR** is a top-level acceleration structure containing instance data referring to bottom-level acceleration structures.

- **VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_KHR** is a bottom-level acceleration structure containing the AABBs or geometry to be intersected.

- **VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR** is an acceleration structure whose type is determined at build time used for special circumstances. In these cases, the acceleration structure type is not known at creation time, but **must** be specified at build time as either top or bottom.

Bits which can be set in VkAccelerationStructureCreateInfoKHR::createFlags, specifying additional creation parameters for acceleration structures, are:

```c
// Provided by VK_KHR_acceleration_structure
typedef enum VkAccelerationStructureCreateFlagBitsKHR {
    VK_ACCELERATION_STRUCTURE_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT_KHR = 0x00000001,
    // Provided by VK_EXT_descriptor_buffer
    VK_ACCELERATION_STRUCTURE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT = 0x00000008,
    // Provided by VK_NV_ray_tracing_motion_blur
    VK_ACCELERATION_STRUCTURE_CREATE_MOTION_BIT_NV = 0x00000004,
} VkAccelerationStructureCreateFlagBitsKHR;
```

- **VK_ACCELERATION_STRUCTURE_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT_KHR** specifies that the acceleration structure’s address can be saved and reused on a subsequent run.
• `VK_ACCELERATION_STRUCTURE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT` specifies that the acceleration structure can be used with descriptor buffers when capturing and replaying (e.g. for trace capture and replay), see `VkOpaqueCaptureDescriptorDataCreateInfoEXT` for more detail.

```c
// Provided by VK_KHR_acceleration_structure
typedef VkFlags VkAccelerationStructureCreateFlagsKHR;
```

`VkAccelerationStructureCreateFlagsKHR` is a bitmask type for setting a mask of zero or more `VkAccelerationStructureCreateFlagBitsKHR`.

Bits which can be set in `VkAccelerationStructureBuildGeometryInfoKHR::flags` or `VkAccelerationStructureInfoNV::flags` specifying additional parameters for acceleration structure builds, are:

```c
// Provided by VK_KHR_acceleration_structure
typedef enum VkBuildAccelerationStructureFlagBitsKHR {
    VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_UPDATE_BIT_KHR = 0x00000001,
    VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_COMPACTION_BIT_KHR = 0x00000002,
    VK_BUILD_ACCELERATION_STRUCTURE_PREFER_FAST_TRACE_BIT_KHR = 0x00000004,
    VK_BUILD_ACCELERATION_STRUCTURE_PREFER_FAST_BUILD_BIT_KHR = 0x00000008,
    VK_BUILD_ACCELERATION_STRUCTURE_LOW_MEMORY_BIT_KHR = 0x00000010,
    VK_BUILD_ACCELERATION_STRUCTURE_MOTION_BIT_NV = 0x00000020,
    // Provided by VK_NV_ray_tracing_motion_blur
    // Provided by VK_EXT_opacity_micromap
    VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_OPACITY_MICROMAP_UPDATE_EXT = 0x00000040,
    // Provided by VK_EXT_opacity_micromap
    VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_DISABLE_OPACITY_MICROMAPS_EXT = 0x00000080,
    // Provided by VK_EXT_opacity_micromap
    VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_OPACITY_MICROMAP_DATA_UPDATE_EXT = 0x00000100,
    #ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_NV_displacement_micromap
    VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_DISPLACEMENT_MICROMAP_UPDATE_NV = 0x00000200,
    #endif
    // Provided by VK_KHR_ray_tracing_position_fetch
    VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_DATA_ACCESS_KHR = 0x00000800,
    // Provided by VK_NV_displacement_micromap
    VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_UPDATE_BIT_NV = VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_UPDATE_BIT_KHR,
    // Provided by VK_KHR_ray_tracing_position_fetch
    VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_COMPACTION_BIT_NV = VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_COMPACTION_BIT_KHR,
    // Provided by VK_NV_displacement_micromap
    VK_BUILD_ACCELERATION_STRUCTURE_PREFER_FAST_TRACE_BIT_NV = VK_BUILD_ACCELERATION_STRUCTURE_PREFER_FAST_TRACE_BIT_KHR,
    // Provided by VK_NV_displacement_micromap
    VK_BUILD_ACCELERATION_STRUCTURE_PREFER_FAST_BUILD_BIT_NV =
```

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**VK_BUILD_ACCELERATION_STRUCTURE_PREFER_FAST_BUILD_BIT_KHR,**

// Provided by VK_NV_ray_tracing

```cpp
VK_BUILD_ACCELERATION_STRUCTURE_LOW_MEMORY_BIT_NV = 
VK_BUILD_ACCELERATION_STRUCTURE_LOW_MEMORY_BIT_KHR,
```

} VkBuildAccelerationStructureFlagBitsKHR;

or the equivalent

```cpp
// Provided by VK_NV_ray_tracing
typedef VkBuildAccelerationStructureFlagBitsKHR VkBuildAccelerationStructureFlagBitsNV;
```

- **VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_UPDATE_BIT_KHR** indicates that the specified acceleration structure **can** be updated with a mode of **VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR** in VkAccelerationStructureBuildGeometryInfoKHR or an update of **VK_TRUE** in vkCmdBuildAccelerationStructureNV.

- **VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_COMPACTION_BIT_KHR** indicates that the specified acceleration structure **can** act as the source for a copy acceleration structure command with mode of **VK_COPY_ACCELERATION_STRUCTURE_MODE_COMPACT_KHR** to produce a compacted acceleration structure.

- **VK_BUILD_ACCELERATION_STRUCTURE_PREFER_FAST_TRACE_BIT_KHR** indicates that the given acceleration structure build **should** prioritize trace performance over build time.

- **VK_BUILD_ACCELERATION_STRUCTURE_PREFER_FAST_BUILD_BIT_KHR** indicates that the given acceleration structure build **should** prioritize build time over trace performance.

- **VK_BUILD_ACCELERATION_STRUCTURE_LOW_MEMORY_BIT_KHR** indicates that this acceleration structure **should** minimize the size of the scratch memory and the final result acceleration structure, potentially at the expense of build time or trace performance.

- **VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_OPACITY_MICROMAP_UPDATE_EXT** indicates that the opacity micromaps associated with the specified acceleration structure **may** change with an acceleration structure update.

- **VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_OPACITY_MICROMAP_DATA_UPDATE_EXT** indicates that the data of the opacity micromaps associated with the specified acceleration structure **may** change with an acceleration structure update.

- **VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_DISABLE_OPACITY_MICROMAPS_EXT** indicates that the specified acceleration structure **may** be referenced in an instance with **VK_GEOMETRY_INSTANCE_DISABLE_OPACITY_MICROMAPS_EXT** set.

- **VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_DATA_ACCESS_KHR** indicates that the specified acceleration structure **can** be used when fetching the vertex positions of a hit triangle.

- **VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_DISPLACEMENT_MICROMAP_UPDATE_NV** indicates that the displacement micromaps associated with the specified acceleration structure **may** change with an acceleration structure update.

---

**Note**
VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_UPDATE_BIT_KHR and VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_COMPACTION_BIT_KHR may take more time and memory than a normal build, and so should only be used when those features are needed.

```c
// Provided by VK_KHR_acceleration_structure
typedef VkFlags VkBuildAccelerationStructureFlagsKHR;
```

Or the equivalent

```c
// Provided by VK_NV_ray_tracing
typedef VkBuildAccelerationStructureFlagsKHR VkBuildAccelerationStructureFlagsNV;
```

VkBuildAccelerationStructureFlagsKHR is a bitmask type for setting a mask of zero or more VkBuildAccelerationStructureFlagBitsKHR.

The VkGeometryNV structure describes geometry in a bottom-level acceleration structure and is defined as:

```c
// Provided by VK_NV_ray_tracing
typedef struct VkGeometryNV {
    VkStructureType sType;
    const void* pNext;
    VkGeometryTypeKHR geometryType;
    VkGeometryDataNV geometry;
    VkGeometryFlagsKHR flags;
} VkGeometryNV;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `geometryType` specifies the VkGeometryTypeKHR which this geometry refers to.
- `geometry` contains the geometry data as described in VkGeometryDataNV.
- `flags` has VkGeometryFlagBitsKHR describing options for this geometry.

Valid Usage

- VUID-VkGeometryNV-geometryType-03503

  geometryType must be VK_GEOMETRY_TYPE_TRIANGLES_NV or VK_GEOMETRY_TYPE_AABBS_NV

Valid Usage (Implicit)

- VUID-VkGeometryNV-sType-sType

  sType must be VK_STRUCTURE_TYPE_GEOMETRY_NV
Geometry types are specified by \texttt{VkGeometryTypeKHR}, which takes values:

```c
// Provided by VK_KHR_acceleration_structure
typedef enum VkGeometryTypeKHR {
    VK_GEOMETRY_TYPE_TRIANGLES_KHR = 0,
    VK_GEOMETRY_TYPE_AABBS_KHR = 1,
    VK_GEOMETRY_TYPE_INSTANCES_KHR = 2,
    // Provided by VK_NV_ray_tracing
    VK_GEOMETRY_TYPE_TRIANGLES_NV = VK_GEOMETRY_TYPE_TRIANGLES_KHR,
    // Provided by VK_NV_ray_tracing
    VK_GEOMETRY_TYPE_AABBS_NV = VK_GEOMETRY_TYPE_AABBS_KHR,
} VkGeometryTypeKHR;
```

or the equivalent

```c
// Provided by VK_NV_ray_tracing
typedef VkGeometryTypeKHR VkGeometryTypeNV;
```

- \texttt{VK_GEOMETRY_TYPE_TRIANGLES_KHR} specifies a geometry type consisting of triangles.
- \texttt{VK_GEOMETRY_TYPE_AABBS_KHR} specifies a geometry type consisting of axis-aligned bounding boxes.
- \texttt{VK_GEOMETRY_TYPE_INSTANCES_KHR} specifies a geometry type consisting of acceleration structure instances.

Bits specifying additional parameters for geometries in acceleration structure builds, are:

```c
// Provided by VK_KHR_acceleration_structure
typedef enum VkGeometryFlagBitsKHR {
    VK_GEOMETRY_OPAQUE_BIT_KHR = 0x00000001,
    VK_GEOMETRY_NO_DUPLICATE_ANY_HIT_INVOCATION_BIT_KHR = 0x00000002,
    // Provided by VK_NV_ray_tracing
    VK_GEOMETRY_OPAQUE_BIT_NV = VK_GEOMETRY_OPAQUE_BIT_KHR,
    // Provided by VK_NV_ray_tracing
    VK_GEOMETRY_NO_DUPLICATE_ANY_HIT_INVOCATION_BIT_NV = VK_GEOMETRY_NO_DUPLICATE_ANY_HIT_INVOCATION_BIT_KHR,
} VkGeometryFlagBitsKHR;
```
or the equivalent

```c
// Provided by VK_NV_ray_tracing
typedef VkGeometryFlagBitsKHR VkGeometryFlagBitsNV;
```

- **VK_GEOMETRY_OPAQUE_BIT_KHR** indicates that this geometry does not invoke the any-hit shaders even if present in a hit group.

- **VK_GEOMETRY_NO_DUPLICATE_ANY_HIT_INVOCATION_BIT_KHR** indicates that the implementation must only call the any-hit shader a single time for each primitive in this geometry. If this bit is absent an implementation may invoke the any-hit shader more than once for this geometry.

or the equivalent

```c
// Provided by VK_KHR_acceleration_structure
typedef VkFlags VkGeometryFlagsKHR;
```

**VkGeometryFlagsKHR** is a bitmask type for setting a mask of zero or more **VkGeometryFlagBitsKHR**.

The **VkGeometryDataNV** structure specifies geometry in a bottom-level acceleration structure and is defined as:

```c
// Provided by VK_NV_ray_tracing
typedef struct VkGeometryDataNV {
    VkGeometryTrianglesNV triangles;
    VkGeometryAABBNV aabbs;
} VkGeometryDataNV;
```

- **triangles** contains triangle data if **VkGeometryNV::geometryType** is **VK_GEOMETRY_TYPE_TRIANGLES_NV**.

- **aabbs** contains axis-aligned bounding box data if **VkGeometryNV::geometryType** is **VK_GEOMETRY_TYPE_AABBS_NV**.

### Valid Usage (Implicit)

- **VUID-VkGeometryDataNV-triangles-parameter**
  **triangles** must be a valid **VkGeometryTrianglesNV** structure

- **VUID-VkGeometryDataNV-aabbs-parameter**
  **aabbs** must be a valid **VkGeometryAABBNV** structure

The **VkGeometryTrianglesNV** structure specifies triangle geometry in a bottom-level acceleration
structure and is defined as:

```c
// Provided by VK_NV_ray_tracing
typedef struct VkGeometryTrianglesNV {
  VkStructureType     sType;
  const void*          pNext;
  VkBuffer             vertexData;
  VkDeviceSize         vertexOffset;
  uint32_t             vertexCount;
  VkDeviceSize         vertexStride;
  VkFormat             vertexFormat;
  VkBuffer             indexData;
  VkDeviceSize         indexOffset;
  uint32_t             indexCount;
  VkIndexType          indexType;
  VkBuffer             transformData;
  VkDeviceSize         transformOffset;
} VkGeometryTrianglesNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `vertexData` is the buffer containing vertex data for this geometry.
- `vertexOffset` is the offset in bytes within `vertexData` containing vertex data for this geometry.
- `vertexCount` is the number of valid vertices.
- `vertexStride` is the stride in bytes between each vertex.
- `vertexFormat` is a `VkFormat` describing the format of each vertex element.
- `indexData` is the buffer containing index data for this geometry.
- `indexOffset` is the offset in bytes within `indexData` containing index data for this geometry.
- `indexCount` is the number of indices to include in this geometry.
- `indexType` is a `VkIndexType` describing the format of each index.
- `transformData` is an optional buffer containing an `VkTransformMatrixNV` structure defining a transformation to be applied to this geometry.
- `transformOffset` is the offset in bytes in `transformData` of the transform information described above.

If `indexType` is `VK_INDEX_TYPE_NONE_NV`, then this structure describes a set of triangles determined by `vertexCount`. Otherwise, this structure describes a set of indexed triangles determined by `indexCount`.

**Valid Usage**

- VUID-VkGeometryTrianglesNV-vertexOffset-02428 `vertexOffset` must be less than the size of `vertexData`
- VUID-VkGeometryTrianglesNV-vertexOffset-02429
vertexOffset must be a multiple of the component size of vertexFormat

- VUID-VkGeometryTrianglesNV-vertexFormat-02430
  vertexFormat must be one of VK_FORMAT_R32G32B32_SFLOAT, VK_FORMAT_R32G32_SFLOAT, VK_FORMAT_R16G16B16_SFLOAT, VK_FORMAT_R16G16_SFLOAT, VK_FORMAT_R16G16_SNORM, or VK_FORMAT_R16G16B16_SNORM

- VUID-VkGeometryTrianglesNV-vertexStride-03818
  vertexStride must be less than or equal to \(2^{32}-1\)

- VUID-VkGeometryTrianglesNV-indexOffset-02431
  indexOffset must be less than the size of indexData

- VUID-VkGeometryTrianglesNV-indexOffset-02432
  indexOffset must be a multiple of the element size of indexType

- VUID-VkGeometryTrianglesNV-indexType-02433
  indexType must be VK_INDEX_TYPE_UINT16, VK_INDEX_TYPE_UINT32, or VK_INDEX_TYPE_NONE_NV

- VUID-VkGeometryTrianglesNV-indexData-02434
  indexData must be VK_NULL_HANDLE if indexType is VK_INDEX_TYPE_NONE_NV

- VUID-VkGeometryTrianglesNV-indexData-02435
  indexData must be a valid VkBuffer handle if indexType is not VK_INDEX_TYPE_NONE_NV

- VUID-VkGeometryTrianglesNV-indexCount-02436
  indexCount must be 0 if indexType is VK_INDEX_TYPE_NONE_NV

- VUID-VkGeometryTrianglesNV-transformOffset-02437
  transformOffset must be less than the size of transformData

- VUID-VkGeometryTrianglesNV-transformOffset-02438
  transformOffset must be a multiple of 16

Valid Usage (Implicit)

- VUID-VkGeometryTrianglesNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_GEOMETRY_TRIANGLES_NV

- VUID-VkGeometryTrianglesNV-pNext-pNext
  pNext must be NULL

- VUID-VkGeometryTrianglesNV-vertexData-parameter
  If vertexData is not VK_NULL_HANDLE, vertexData must be a valid VkBuffer handle

- VUID-VkGeometryTrianglesNV-vertexFormat-parameter
  vertexFormat must be a valid VkFormat value

- VUID-VkGeometryTrianglesNV-indexData-parameter
  If indexData is not VK_NULL_HANDLE, indexData must be a valid VkBuffer handle

- VUID-VkGeometryTrianglesNV-indexType-parameter
  indexType must be a valid VkIndexType value

- VUID-VkGeometryTrianglesNV-transformData-parameter
  If transformData is not VK_NULL_HANDLE, transformData must be a valid VkBuffer handle
Each of `indexData`, `transformData`, and `vertexData` that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same `VkDevice`.

The `VkGeometryAABBNV` structure specifies axis-aligned bounding box geometry in a bottom-level acceleration structure, and is defined as:

```c
// Provided by VK_NV_ray_tracing
typedef struct VkGeometryAABBNV {
    VkStructureType sType;
    const void* pNext;
    VkBuffer aabbData;
    uint32_t numAABBs;
    uint32_t stride;
    VkDeviceSize offset;
} VkGeometryAABBNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `aabbData` is the buffer containing axis-aligned bounding box data.
- `numAABBs` is the number of AABBs in this geometry.
- `stride` is the stride in bytes between AABBs in `aabbData`.
- `offset` is the offset in bytes of the first AABB in `aabbData`.

The AABB data in memory is six 32-bit floats consisting of the minimum x, y, and z values followed by the maximum x, y, and z values.

### Valid Usage

- VUID-VkGeometryAABBNV-offset-02439
  `offset` must be less than the size of `aabbData`

- VUID-VkGeometryAABBNV-offset-02440
  `offset` must be a multiple of 8

- VUID-VkGeometryAABBNV-stride-02441
  `stride` must be a multiple of 8

### Valid Usage (Implicit)

- VUID-VkGeometryAABBNV-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_GEOMETRY_AABB_NV`

- VUID-VkGeometryAABBNV-pNext-pNext
  `pNext` must be `NULL`
To destroy an acceleration structure, call:

```c
void vkDestroyAccelerationStructureKHR(
    VkDevice device,
    VkAccelerationStructureKHR accelerationStructure,
    const VkAllocationCallbacks* pAllocator);
```

- `device` is the logical device that destroys the acceleration structure.
- `accelerationStructure` is the acceleration structure to destroy.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

### Valid Usage

- VUID-vkDestroyAccelerationStructureKHR-accelerationStructure-08934
  The `VkPhysicalDeviceAccelerationStructureFeaturesKHR::accelerationStructure` feature must be enabled
- VUID-vkDestroyAccelerationStructureKHR-accelerationStructure-02442
  All submitted commands that refer to `accelerationStructure` must have completed execution
- VUID-vkDestroyAccelerationStructureKHR-accelerationStructure-02443
  If `VkAllocationCallbacks` were provided when `accelerationStructure` was created, a compatible set of callbacks must be provided here
- VUID-vkDestroyAccelerationStructureKHR-accelerationStructure-02444
  If no `VkAllocationCallbacks` were provided when `accelerationStructure` was created, `pAllocator` must be NULL

### Valid Usage (Implicit)

- VUID-vkDestroyAccelerationStructureKHR-device-parameter
  `device` must be a valid `VkDevice` handle
- VUID-vkDestroyAccelerationStructureKHR-accelerationStructure-parameter
  If `accelerationStructure` is not `VK_NULL_HANDLE`, `accelerationStructure` must be a valid `VkAccelerationStructureKHR` handle
- VUID-vkDestroyAccelerationStructureKHR-pAllocator-parameter
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure
- VUID-vkDestroyAccelerationStructureKHR-accelerationStructure-parent
  If `accelerationStructure` is a valid handle, it must have been created, allocated, or
Host Synchronization

• Host access to accelerationStructure must be externally synchronized

To destroy an acceleration structure, call:

```c
// Provided by VK_NV_ray_tracing
define void vkDestroyAccelerationStructureNV(VkDevice device, VkAccelerationStructureNV accelerationStructure, const VkAllocationCallbacks* pAllocator);
```

• `device` is the logical device that destroys the buffer.
• `accelerationStructure` is the acceleration structure to destroy.
• `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

Valid Usage

• VUID-vkDestroyAccelerationStructureNV-accelerationStructure-03752
  All submitted commands that refer to accelerationStructure must have completed execution

• VUID-vkDestroyAccelerationStructureNV-accelerationStructure-03753
  If VkAllocationCallbacks were provided when accelerationStructure was created, a compatible set of callbacks must be provided here

• VUID-vkDestroyAccelerationStructureNV-accelerationStructure-03754
  If no VkAllocationCallbacks were provided when accelerationStructure was created, pAllocator must be NULL

Valid Usage (Implicit)

• VUID-vkDestroyAccelerationStructureNV-device-parameter
device must be a valid VkDevice handle

• VUID-vkDestroyAccelerationStructureNV-accelerationStructure-parameter
  If accelerationStructure is not VK_NULL_HANDLE, accelerationStructure must be a valid VkAccelerationStructureNV handle

• VUID-vkDestroyAccelerationStructureNV-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

• VUID-vkDestroyAccelerationStructureNV-accelerationStructure-parent

If `accelerationStructure` is a valid handle, it **must** have been created, allocated, or retrieved from `device`.

### Host Synchronization

- Host access to `accelerationStructure` **must** be externally synchronized.

An acceleration structure has memory requirements for the structure object itself, scratch space for the build, and scratch space for the update.

Scratch space is allocated as a `VkBuffer`, so for `VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_BUILD_SCRATCH_NV` and `VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_UPDATE_SCRATCH_NV` the `pMemoryRequirements->alignment` and `pMemoryRequirements->memoryTypeBits` values returned by this call **must** be filled with zero, and **should** be ignored by the application.

To query the memory requirements, call:

```c
// Provided by VK_NV_ray_tracing
void vkGetAccelerationStructureMemoryRequirementsNV(
    VkDevice device, 
    const VkAccelerationStructureMemoryRequirementsInfoNV* pInfo, 
    VkMemoryRequirements2KHR* pMemoryRequirements);
```

- `device` is the logical device on which the acceleration structure was created.
- `pInfo` is a pointer to a `VkAccelerationStructureMemoryRequirementsInfoNV` structure specifying the acceleration structure to get memory requirements for.
- `pMemoryRequirements` is a pointer to a `VkMemoryRequirements2KHR` structure in which the requested acceleration structure memory requirements are returned.

### Valid Usage (Implicit)

- **VUID-vkGetAccelerationStructureMemoryRequirementsNV-device-parameter** `device` must be a valid `VkDevice` handle.
- **VUID-vkGetAccelerationStructureMemoryRequirementsNV-pInfo-parameter** `pInfo` must be a valid pointer to a valid `VkAccelerationStructureMemoryRequirementsInfoNV` structure.
- **VUID-vkGetAccelerationStructureMemoryRequirementsNV-pMemoryRequirements-parameter** `pMemoryRequirements` must be a valid pointer to a `VkMemoryRequirements2KHR` structure.

The `VkAccelerationStructureMemoryRequirementsInfoNV` structure is defined as:
// Provided by VK_NV_ray_tracing

typedef struct VkAccelerationStructureMemoryRequirementsInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkAccelerationStructureMemoryRequirementsTypeNV type;
    VkAccelerationStructureNV accelerationStructure;
} VkAccelerationStructureMemoryRequirementsInfoNV;

• sType is a VkStructureType value identifying this structure.

• pNext is NULL or a pointer to a structure extending this structure.

• type selects the type of memory requirement being queried.

  VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_OBJECT_NV returns the memory
  requirements for the object itself.

  VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_BUILD_SCRATCH_NV returns the memory
  requirements for the scratch memory when doing a build.

  VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_UPDATE_SCRATCH_NV returns the memory
  requirements for the scratch memory when doing an update.

• accelerationStructure is the acceleration structure to be queried for memory requirements.

Valid Usage (Implicit)

• VUID-VkAccelerationStructureMemoryRequirementsInfoNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_INFO_NV

• VUID-VkAccelerationStructureMemoryRequirementsInfoNV-pNext-pNext
  pNext must be NULL

• VUID-VkAccelerationStructureMemoryRequirementsInfoNV-type-parameter
  type must be a valid VkAccelerationStructureMemoryRequirementsTypeNV value

• VUID-VkAccelerationStructureMemoryRequirementsInfoNV-accelerationStructure-parameter
  accelerationStructure must be a valid VkAccelerationStructureNV handle

Possible values of type in VkAccelerationStructureMemoryRequirementsInfoNV are:

// Provided by VK_NV_ray_tracing

typedef enum VkAccelerationStructureMemoryRequirementsTypeNV {
    VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_OBJECT_NV = 0,
    VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_BUILD_SCRATCH_NV = 1,
    VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_UPDATE_SCRATCH_NV = 2,
} VkAccelerationStructureMemoryRequirementsTypeNV;

• VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_OBJECT_NV requests the memory
  requirement for the VkAccelerationStructureNV backing store.

• VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_BUILD_SCRATCH_NV requests the memory
requirement for scratch space during the initial build.

- **VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_UPDATE_SCRATCH_NV** requests the memory requirement for scratch space during an update.

Possible values of `buildType` in `vkGetAccelerationStructureBuildSizesKHR` are:

```cpp
// Provided by VK_KHR_acceleration_structure
typedef enum VkAccelerationStructureBuildTypeKHR {
    VK_ACCELERATION_STRUCTURE_BUILD_TYPE_HOST_KHR = 0,
    VK_ACCELERATION_STRUCTURE_BUILD_TYPE_DEVICE_KHR = 1,
    VK_ACCELERATION_STRUCTURE_BUILD_TYPE_HOST_OR_DEVICE_KHR = 2,
} VkAccelerationStructureBuildTypeKHR;
```

- **VK_ACCELERATION_STRUCTURE_BUILD_TYPE_HOST_KHR** requests the memory requirement for operations performed by the host.

- **VK_ACCELERATION_STRUCTURE_BUILD_TYPE_DEVICE_KHR** requests the memory requirement for operations performed by the device.

- **VK_ACCELERATION_STRUCTURE_BUILD_TYPE_HOST_OR_DEVICE_KHR** requests the memory requirement for operations performed by either the host, or the device.

To attach memory to one or more acceleration structures at a time, call:

```cpp
// Provided by VK_NV_ray_tracing
VkResult vkBindAccelerationStructureMemoryNV(
    VkDevice device,          // Logical device
    uint32_t bindInfoCount,   // Number of elements in pBindInfos
    const VkBindAccelerationStructureMemoryInfoNV* pBindInfos);
```

- **device** is the logical device that owns the acceleration structures and memory.

- **bindInfoCount** is the number of elements in `pBindInfos`.

- **pBindInfos** is a pointer to an array of `VkBindAccelerationStructureMemoryInfoNV` structures describing acceleration structures and memory to bind.

### Valid Usage (Implicit)

- VUID-vkBindAccelerationStructureMemoryNV-device-parameter
device must be a valid `VkDevice` handle

- VUID-vkBindAccelerationStructureMemoryNV-pBindInfos-parameter
  pBindInfos must be a valid pointer to an array of `bindInfoCount` valid `VkBindAccelerationStructureMemoryInfoNV` structures

- VUID-vkBindAccelerationStructureMemoryNV-bindInfoCount-arraylength
  `bindInfoCount` must be greater than 0
Return Codes

Success
• VK_SUCCESS

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY

The `VkBindAccelerationStructureMemoryInfoNV` structure is defined as:

```c
// Provided by VK_NV_ray_tracing
typedef struct VkBindAccelerationStructureMemoryInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkAccelerationStructureNV accelerationStructure;
    VkDeviceMemory memory;
    VkDeviceSize memoryOffset;
    uint32_t deviceIndexCount;
    const uint32_t* pDeviceIndices;
} VkBindAccelerationStructureMemoryInfoNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `accelerationStructure` is the acceleration structure to be attached to memory.
- `memory` is a `VkDeviceMemory` object describing the device memory to attach.
- `memoryOffset` is the start offset of the region of memory that is to be bound to the acceleration structure. The number of bytes returned in the `VkMemoryRequirements::size` member in `memory`, starting from `memoryOffset` bytes, will be bound to the specified acceleration structure.
- `deviceIndexCount` is the number of elements in `pDeviceIndices`.
- `pDeviceIndices` is a pointer to an array of device indices.

Valid Usage

- VUID-VkBindAccelerationStructureMemoryInfoNV-accelerationStructure-03620: `accelerationStructure` must not already be backed by a memory object
- VUID-VkBindAccelerationStructureMemoryInfoNV-memoryOffset-03621: `memoryOffset` must be less than the size of `memory`
- VUID-VkBindAccelerationStructureMemoryInfoNV-memory-03622: `memory` must have been allocated using one of the memory types allowed in the `memoryTypeBits` member of the `VkMemoryRequirements` structure returned from a call to `vkGetAccelerationStructureMemoryRequirementsNV` with `accelerationStructure` and type of `VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_OBJECT_NV`
memoryOffset must be an integer multiple of the alignment member of the VkMemoryRequirements structure returned from a call to vkGetAccelerationStructureMemoryRequirementsNV with accelerationStructure and type of VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_OBJECT_NV.

The size member of the VkMemoryRequirements structure returned from a call to vkGetAccelerationStructureMemoryRequirementsNV with accelerationStructure and type of VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_OBJECT_NV must be less than or equal to the size of memory minus memoryOffset.

Valid Usage (Implicit)

- sType must be VK_STRUCTURE_TYPE_BIND_ACCELERATION_STRUCTURE_MEMORY_INFO_NV
- pNext must be NULL
- accelerationStructure must be a valid VkAccelerationStructureNV handle
- memory must be a valid VkDeviceMemory handle
- If deviceIndexCount is not 0, pDeviceIndices must be a valid pointer to an array of deviceIndexCount uint32_t values
- Both of accelerationStructure, and memory must have been created, allocated, or retrieved from the same VkDevice

To allow constructing geometry instances with device code if desired, we need to be able to query a opaque handle for an acceleration structure. This handle is a value of 8 bytes. To get this handle, call:

```c
// Provided by VK_NV_ray_tracing
VkResult vkGetAccelerationStructureHandleNV(
    VkDevice device, 
    VkAccelerationStructureNV accelerationStructure, 
    size_t dataSize, 
    void* pData);
```

- device is the logical device that owns the acceleration structures.
- accelerationStructure is the acceleration structure.
- dataSize is the size in bytes of the buffer pointed to by pData.
• pData is a pointer to a user-allocated buffer where the results will be written.

Valid Usage

- VUID-vkGetAccelerationStructureHandleNV-dataSize-02240
  
  dataSize must be large enough to contain the result of the query, as described above

- VUID-vkGetAccelerationStructureHandleNV-accelerationStructure-02787
  
  accelerationStructure must be bound completely and contiguously to a single VkDeviceMemory object via vkBindAccelerationStructureMemoryNV

Valid Usage (Implicit)

- VUID-vkGetAccelerationStructureHandleNV-device-parameter
  
  device must be a valid VkDevice handle

- VUID-vkGetAccelerationStructureHandleNV-accelerationStructure-parameter
  
  accelerationStructure must be a valid VkAccelerationStructureNV handle

- VUID-vkGetAccelerationStructureHandleNV-pData-parameter
  
  pData must be a valid pointer to an array of dataSize bytes

- VUID-vkGetAccelerationStructureHandleNV-dataSize-arraylength
  
  dataSize must be greater than 0

- VUID-vkGetAccelerationStructureHandleNV-accelerationStructure-parent
  
  accelerationStructure must have been created, allocated, or retrieved from device

Return Codes

Success

• VK_SUCCESS

Failure

• VK_ERROR_OUT_OF_HOST_MEMORY

• VK_ERROR_OUT_OF_DEVICE_MEMORY

To query the 64-bit device address for an acceleration structure, call:

```cpp
// Provided by VK_KHR_acceleration_structure
VkDeviceAddress vkGetAccelerationStructureDeviceAddressKHR(
    VkDevice device,
    const VkAccelerationStructureDeviceAddressInfoKHR* pInfo);
```

• device is the logical device that the acceleration structure was created on.

• pInfo is a pointer to a VkAccelerationStructureDeviceAddressInfoKHR structure specifying the
acceleration structure to retrieve an address for.

The 64-bit return value is an address of the acceleration structure, which can be used for device and shader operations that involve acceleration structures, such as ray traversal and acceleration structure building.

If the acceleration structure was created with a non-zero value of \texttt{VkAccelerationStructureCreateInfoKHR::deviceAddress}, the return value will be the same address.

If the acceleration structure was created with a type of \texttt{VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR}, the returned address \textbf{must} be consistent with the relative offset to other acceleration structures with type \texttt{VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR} allocated with the same \texttt{VkBuffer}. That is, the difference in returned addresses between the two \textbf{must} be the same as the difference in offsets provided at acceleration structure creation.

The returned address \textbf{must} be aligned to 256 bytes.

\textbf{Note}

The acceleration structure device address \textbf{may} be different from the buffer device address corresponding to the acceleration structure's start offset in its storage buffer for acceleration structure types other than \texttt{VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR}.

\textbf{Valid Usage}

- \textbf{VUID-vkGetAccelerationStructureDeviceAddressKHR-accelerationStructure-08935}
  The \texttt{VkPhysicalDeviceAccelerationStructureFeaturesKHR::accelerationStructure} feature \textbf{must} be enabled

- \textbf{VUID-vkGetAccelerationStructureDeviceAddressKHR-device-03504}
  If \texttt{device} was created with multiple physical devices, then the \texttt{bufferDeviceAddressMultiDevice} feature \textbf{must} be enabled

\textbf{Valid Usage (Implicit)}

- \textbf{VUID-vkGetAccelerationStructureDeviceAddressKHR-device-parameter}
  \texttt{device} \textbf{must} be a valid \texttt{VkDevice} handle

- \textbf{VUID-vkGetAccelerationStructureDeviceAddressKHR-pInfo-parameter}
  \texttt{pInfo} \textbf{must} be a valid pointer to a valid \texttt{VkAccelerationStructureDeviceAddressInfoKHR} structure

The \texttt{VkAccelerationStructureDeviceAddressInfoKHR} structure is defined as:

```c
// Provided by VK_KHR_acceleration_structure
typedef struct VkAccelerationStructureDeviceAddressInfoKHR {
    VkStructureType sType;
...}
```
const void* pNext;
VkAccelerationStructureKHR accelerationStructure;
} VkAccelerationStructureDeviceAddressInfoKHR;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `accelerationStructure` specifies the acceleration structure whose address is being queried.

### Valid Usage (Implicit)

- VUID-VkAccelerationStructureDeviceAddressInfoKHR-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_DEVICE_ADDRESS_INFO_KHR`
- VUID-VkAccelerationStructureDeviceAddressInfoKHR-pNext-pNext
  - `pNext` must be `NULL`
- VUID-VkAccelerationStructureDeviceAddressInfoKHR-accelerationStructure-parameter
  - `accelerationStructure` must be a valid `VkAccelerationStructureKHR` handle

### 12.7. Micromaps

Micromaps are opaque data structures that are built by the implementation to encode sub-triangle data to be included in an acceleration structure.

Micromaps are represented by `VkMicromapEXT` handles:

```c
// Provided by VK_EXT_opacity_micromap
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkMicromapEXT)
```

To create a micromap, call:

```c
VkResult vkCreateMicromapEXT(
    VkDevice device,
    const VkMicromapCreateInfoEXT* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkMicromapEXT* pMicromap);
```

- `device` is the logical device that creates the acceleration structure object.
- `pCreateInfo` is a pointer to a `VkMicromapCreateInfoEXT` structure containing parameters affecting creation of the micromap.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pMicromap` is a pointer to a `VkMicromapEXT` handle in which the resulting micromap object is returned.
Similar to other objects in Vulkan, the micromap creation merely creates an object with a specific “shape”. The type and quantity of geometry that can be built into a micromap is determined by the parameters of `VkMicromapCreateInfoEXT`.

The micromap data is stored in the object referred to by `VkMicromapCreateInfoEXT::buffer`. Once memory has been bound to that buffer, it must be populated by micromap build or micromap copy commands such as `vkCmdBuildMicromapsEXT`, `vkBuildMicromapsEXT`, `vkCmdCopyMicromapEXT`, and `vkCopyMicromapEXT`.

**Note**
The expected usage for a trace capture/replay tool is that it will serialize and later deserialize the micromap data using micromap copy commands. During capture the tool will use `vkCopyMicromapToMemoryEXT` or `vkCmdCopyMicromapToMemoryEXT` with a mode of `VK_COPY_MICROMAP_MODE_SERIALIZE_EXT`, and `vkCopyMemoryToMicromapEXT` or `vkCmdCopyMemoryToMicromapEXT` with a mode of `VK_COPY_MICROMAP_MODE_DESERIALIZE_EXT` during replay.

The input buffers passed to micromap build commands will be referenced by the implementation for the duration of the command. Micromaps must be fully self-contained. The application can reuse or free any memory which was used by the command as an input or as scratch without affecting the results of a subsequent acceleration structure build using the micromap or traversal of that acceleration structure.

### Valid Usage

- **VUID-vkCreateMicromapEXT-micromap-07430**
The micromap feature must be enabled

- **VUID-vkCreateMicromapEXT-deviceAddress-07431**
  If `VkMicromapCreateInfoEXT::deviceAddress` is not zero, the micromapCaptureReplay feature must be enabled

- **VUID-vkCreateMicromapEXT-device-07432**
  If device was created with multiple physical devices, then the bufferDeviceAddressMultiDevice feature must be enabled

### Valid Usage (Implicit)

- **VUID-vkCreateMicromapEXT-device-parameter**
  `device` must be a valid `VkDevice` handle

- **VUID-vkCreateMicromapEXT-pCreateInfo-parameter**
  `pCreateInfo` must be a valid pointer to a valid `VkMicromapCreateInfoEXT` structure

- **VUID-vkCreateMicromapEXT-pAllocator-parameter**
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure
pMicromap must be a valid pointer to a VkMicromapEXT handle

**Return Codes**

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS_KHR

The VkMicromapCreateInfoEXT structure is defined as:

```c
// Provided by VK_EXT_opacity_micromap
typedef struct VkMicromapCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkMicromapCreateFlagsEXT createFlags;
    VkBuffer buffer;
    VkDeviceSize offset;
    VkDeviceSize size;
    VkMicromapTypeEXT type;
    VkDeviceAddress deviceAddress;
} VkMicromapCreateInfoEXT;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **createFlags** is a bitmask of VkMicromapCreateFlagBitsEXT specifying additional creation parameters of the micromap.
- **buffer** is the buffer on which the micromap will be stored.
- **offset** is an offset in bytes from the base address of the buffer at which the micromap will be stored, and **must** be a multiple of 256.
- **size** is the size required for the micromap.
- **type** is a VkMicromapTypeEXT value specifying the type of micromap that will be created.
- **deviceAddress** is the device address requested for the micromap if the micromapCaptureReplay feature is being used.

If **deviceAddress** is zero, no specific address is requested.

If **deviceAddress** is not zero, **deviceAddress must** be an address retrieved from an identically created micromap on the same implementation. The micromap **must** also be placed on an identically created buffer and at the same offset.
Applications should avoid creating micromaps with application-provided addresses and implementation-provided addresses in the same process, to reduce the likelihood of VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS_KHR errors.

**Note**

The expected usage for this is that a trace capture/replay tool will add the VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT flag to all buffers that use VK_BUFFER_USAGE_SHADER_DEVICE_ADDRESS_BIT, and will add VK_BUFFER_USAGE_SHADER_DEVICE_ADDRESS_BIT to all buffers used as storage for a micromap where deviceAddress is not zero. This also means that the tool will need to add VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT to memory allocations to allow the flag to be set where the application may not have otherwise required it. During capture the tool will save the queried opaque device addresses in the trace. During replay, the buffers will be created specifying the original address so any address values stored in the trace data will remain valid.

Implementations are expected to separate such buffers in the GPU address space so normal allocations will avoid using these addresses. Apps/tools should avoid mixing app-provided and implementation-provided addresses for buffers created with VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT, to avoid address space allocation conflicts.

If the micromap will be the target of a build operation, the required size for a micromap can be queried with vkGetMicromapBuildSizesEXT.

### Valid Usage

- **VUID-VkMicromapCreateInfoEXT-deviceAddress-07433**
  If deviceAddress is not zero, createFlags must include VK_MICROMAP_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT_EXT

- **VUID-VkMicromapCreateInfoEXT-createFlags-07434**
  If createFlags includes VK_MICROMAP_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT_EXT, VkPhysicalDeviceOpacityMicromapFeaturesEXT::micromapCaptureReplay must be VK_TRUE

- **VUID-VkMicromapCreateInfoEXT-buffer-07435**
  buffer must have been created with a usage value containing VK_BUFFER_USAGE_MICROMAP_STORAGE_BIT_EXT

- **VUID-VkMicromapCreateInfoEXT-buffer-07436**
  buffer must not have been created with VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT

- **VUID-VkMicromapCreateInfoEXT-offset-07437**
  The sum of offset and size must be less than the size of buffer

- **VUID-VkMicromapCreateInfoEXT-offset-07438**
  offset must be a multiple of 256 bytes
Valid Usage (Implicit)

- VUID-VkMicromapCreateInfoEXT-sType-sType
  sType **must** be **VK_STRUCTURE_TYPE_MICROMAP_CREATE_INFO_EXT**

- VUID-VkMicromapCreateInfoEXT-pNext-pNext
  pNext **must** be **NULL**

- VUID-VkMicromapCreateInfoEXT-createFlags-parameter
  createFlags **must** be a valid combination of **VkMicromapCreateFlagBitsEXT** values

- VUID-VkMicromapCreateInfoEXT-buffer-parameter
  buffer **must** be a valid **VkBuffer** handle

- VUID-VkMicromapCreateInfoEXT-type-parameter
  type **must** be a valid **VkMicromapTypeEXT** value

To get the build sizes for a micromap, call:

```c
// Provided by VK_EXT_opacity_micromap
void vkGetMicromapBuildSizesEXT(
    VkDevice device,
    VkAccelerationStructureBuildTypeKHR buildType,
    const VkMicromapBuildInfoEXT* pBuildInfo,
    VkMicromapBuildSizesInfoEXT* pSizeInfo);
```

- **device** is the logical device that will be used for creating the micromap.
- **buildType** defines whether host or device operations (or both) are being queried for.
- **pBuildInfo** is a pointer to a **VkMicromapBuildInfoEXT** structure describing parameters of a build operation.
- **pSizeInfo** is a pointer to a **VkMicromapBuildSizesInfoEXT** structure which returns the size required for a micromap and the sizes required for the scratch buffers, given the build parameters.

The **dstMicromap** and **mode** members of **pBuildInfo** are ignored. Any **VkDeviceOrHostAddressKHR** members of **pBuildInfo** are ignored by this command.

A micromap created with the **micromapSize** returned by this command supports any build with a **VkMicromapBuildInfoEXT** structure subject to the following properties:

- The build command is a host build command, and **buildType** is
  **VK_ACCELERATION_STRUCTURE_BUILD_TYPE_HOST_KHR** or
  **VK_ACCELERATION_STRUCTURE_BUILD_TYPE_HOST_OR_DEVICE_KHR**

- The build command is a device build command, and **buildType** is
  **VK_ACCELERATION_STRUCTURE_BUILD_TYPE_DEVICE_KHR** or
  **VK_ACCELERATION_STRUCTURE_BUILD_TYPE_HOST_OR_DEVICE_KHR**

- For **VkMicromapBuildInfoEXT**:
- Its type, and flags members are equal to pBuildInfo->type and pBuildInfo->flags, respectively.
- The sum of usage information in either pUsageCounts or ppUsageCounts is equal to the sum of usage information in either pBuildInfo->pUsageCounts or pBuildInfo->ppUsageCounts.

Similarly, the buildScratchSize value will support any build command specifying the VK_BUILD_MICROMAP_MODE_BUILD_EXT mode under the above conditions.

### Valid Usage

- VUID-vkGetMicromapBuildSizesEXT-dstMicromap-09180
  VkMicromapBuildInfoEXT::dstMicromap must have been created from device
- VUID-vkGetMicromapBuildSizesEXT-micromap-07439
  The micromap feature must be enabled
- VUID-vkGetMicromapBuildSizesEXT-device-07440
  If device was created with multiple physical devices, then the bufferDeviceAddressMultiDevice feature must be enabled

### Valid Usage (Implicit)

- VUID-vkGetMicromapBuildSizesEXT-device-parameter
device must be a valid VkDevice handle
- VUID-vkGetMicromapBuildSizesEXT-buildType-parameter
  buildType must be a valid VkAccelerationStructureBuildTypeKHR value
- VUID-vkGetMicromapBuildSizesEXT-pBuildInfo-parameter
  pBuildInfo must be a valid pointer to a valid VkMicromapBuildInfoEXT structure
- VUID-vkGetMicromapBuildSizesEXT-pSizeInfo-parameter
  pSizeInfo must be a valid pointer to a VkMicromapBuildSizesInfoEXT structure

The VkMicromapBuildSizesInfoEXT structure describes the required build sizes for a micromap and scratch buffers and is defined as:

```c
// Provided by VK_EXT_opacity_micromap
typedef struct VkMicromapBuildSizesInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkDeviceSize micromapSize;
    VkDeviceSize buildScratchSize;
    VkBool32 discardable;
} VkMicromapBuildSizesInfoEXT;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
• **micromapSize** is the size in bytes required in a *VkMicromapEXT* for a build or update operation.

• **buildScratchSize** is the size in bytes required in a scratch buffer for a build operation.

• **discardable** indicates whether or not the micromap object may be destroyed after an acceleration structure build or update. A false value means that acceleration structures built with this micromap may contain references to the data contained therein, and the application must not destroy the micromap until ray traversal has concluded. A true value means that the information in the micromap will be copied by value into the acceleration structure, and the micromap may be destroyed after the acceleration structure build concludes.

### Valid Usage (Implicit)

- VUID-VkMicromapBuildSizesInfoEXT-sType-sType
  
  *sType* must be *VK_STRUCTURE_TYPE_MICROMAP_BUILD_SIZES_INFO_EXT*

- VUID-VkMicromapBuildSizesInfoEXT-pNext-pNext
  
  *pNext* must be NULL

Values which can be set in *VkMicromapCreateInfoEXT::type* specifying the type of micromap, are:

```c
// Provided by VK_EXT_opacity_micromap
typedef enum VkMicromapTypeEXT {
    VK_MICROMAP_TYPE_OPACITY_MICROMAP_EXT = 0,
    #ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_NV_displacement_micromap
        VK_MICROMAP_TYPE_DISPLACEMENT_MICROMAP_NV = 1000397000,
    #endif
} VkMicromapTypeEXT;
```

- **VK_MICROMAP_TYPE_OPACITY_MICROMAP_EXT** is a micromap containing data to control the opacity of a triangle.

- **VK_MICROMAP_TYPE_DISPLACEMENT_MICROMAP_NV** is a micromap containing data to control the displacement of subtriangles within a triangle.

Bits which can be set in *VkMicromapCreateInfoEXT::createFlags*, specifying additional creation parameters for micromaps, are:

```c
// Provided by VK_EXT_opacity_micromap
typedef enum VkMicromapCreateFlagBitsEXT {
    VK_MICROMAP_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT_EXT = 0x00000001,
} VkMicromapCreateFlagBitsEXT;
```

- **VK_MICROMAP_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT_EXT** specifies that the micromap's address can be saved and reused on a subsequent run.
typedef VkFlags VkMicromapCreateFlagsEXT;

VkMicromapCreateFlagsEXT is a bitmask type for setting a mask of zero or more VkMicromapCreateFlagBitsEXT.

Bits which can be set in VkMicromapCreateInfoEXT:flags specifying additional parameters for micromap builds, are:

```c
// Provided by VK_EXT_opacity_micromap
typedef enum VkBuildMicromapFlagBitsEXT {
    VK_BUILD_MICROMAP_PREFER_FAST_TRACE_BIT_EXT = 0x00000001,
    VK_BUILD_MICROMAP_PREFER_FAST_BUILD_BIT_EXT = 0x00000002,
    VK_BUILD_MICROMAP_ALLOW_COMPACTION_BIT_EXT = 0x00000004,
} VkBuildMicromapFlagBitsEXT;
```

- VK_BUILD_MICROMAP_PREFER_FAST_TRACE_BIT_EXT indicates that the given micromap build should prioritize trace performance over build time.
- VK_BUILD_MICROMAP_PREFER_FAST_BUILD_BIT_EXT indicates that the given micromap build should prioritize build time over trace performance.

VkBuildMicromapFlagsEXT is a bitmask type for setting a mask of zero or more VkBuildMicromapFlagBitsEXT.

To destroy a micromap, call:

```c
// Provided by VK_EXT_opacity_micromap
void vkDestroyMicromapEXT(
    VkDevice device,
    VkMicromapEXT micromap,
    const VkAllocationCallbacks* pAllocator);
```

- device is the logical device that destroys the micromap.
- micromap is the micromap to destroy.
- pAllocator controls host memory allocation as described in the Memory Allocation chapter.

**Valid Usage**

- VUID-vkDestroyMicromapEXT-micromap-07441
  All submitted commands that refer to micromap must have completed execution
- VUID-vkDestroyMicromapEXT-micromap-07442
  If VkAllocationCallbacks were provided when micromap was created, a compatible set of
callbacks must be provided here

- VUID-vkDestroyMicromapEXT-micromap-07443
  If no VkAllocationCallbacks were provided when micromap was created, pAllocator must be NULL.

Valid Usage (Implicit)

- VUID-vkDestroyMicromapEXT-device-parameter
device must be a valid VkDevice handle

- VUID-vkDestroyMicromapEXT-micromap-parameter
  If micromap is not VK_NULL_HANDLE, micromap must be a valid VkMicromapEXT handle

- VUID-vkDestroyMicromapEXT-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkDestroyMicromapEXT-micromap-parent
  If micromap is a valid handle, it must have been created, allocated, or retrieved from device

Host Synchronization

- Host access to micromap must be externally synchronized

12.8. Resource Memory Association

Resources are initially created as virtual allocations with no backing memory. Device memory is allocated separately (see Device Memory) and then associated with the resource. This association is done differently for sparse and non-sparse resources.

Resources created with any of the sparse creation flags are considered sparse resources. Resources created without these flags are non-sparse. The details on resource memory association for sparse resources is described in Sparse Resources.

Non-sparse resources must be bound completely and contiguously to a single VkDeviceMemory object before the resource is passed as a parameter to any of the following operations:

- creating image or buffer views
- updating descriptor sets
- recording commands in a command buffer

Once bound, the memory binding is immutable for the lifetime of the resource.

In a logical device representing more than one physical device, buffer and image resources exist on all physical devices but can be bound to memory differently on each. Each such replicated resource is an instance of the resource. For sparse resources, each instance can be bound to memory
arbitrarily differently. For non-sparse resources, each instance can either be bound to the local or a peer instance of the memory, or for images can be bound to rectangular regions from the local and/or peer instances. When a resource is used in a descriptor set, each physical device interprets the descriptor according to its own instance's binding to memory.

Note
There are no new copy commands to transfer data between physical devices. Instead, an application can create a resource with a peer mapping and use it as the source or destination of a transfer command executed by a single physical device to copy the data from one physical device to another.

To determine the memory requirements for a buffer resource, call:

```c
// Provided by VK_VERSION_1_0
void vkGetBufferMemoryRequirements(
    VkDevice device,
    VkBuffer buffer,
    VkMemoryRequirements* pMemoryRequirements);
```

- `device` is the logical device that owns the buffer.
- `buffer` is the buffer to query.
- `pMemoryRequirements` is a pointer to a `VkMemoryRequirements` structure in which the memory requirements of the buffer object are returned.

Valid Usage (Implicit)
- VUID-vkGetBufferMemoryRequirements-device-parameter
  `device` must be a valid `VkDevice` handle
- VUID-vkGetBufferMemoryRequirements-buffer-parameter
  `buffer` must be a valid `VkBuffer` handle
- VUID-vkGetBufferMemoryRequirements-pMemoryRequirements-parameter
  `pMemoryRequirements` must be a valid pointer to a `VkMemoryRequirements` structure
- VUID-vkGetBufferMemoryRequirements-buffer-parent
  `buffer` must have been created, allocated, or retrieved from `device`

To determine the memory requirements for an image resource which is not created with the `VK_IMAGE_CREATE_DISJOINT_BIT` flag set, call:

```c
// Provided by VK_VERSION_1_0
void vkGetImageMemoryRequirements(
    VkDevice device,
    VkImage image,
    VkMemoryRequirements* pMemoryRequirements);
```
• device is the logical device that owns the image.
• image is the image to query.
• pMemoryRequirements is a pointer to a VkMemoryRequirements structure in which the memory requirements of the image object are returned.

Valid Usage

• VUID-vkGetImageMemoryRequirements-image-01588
  image must not have been created with the VK_IMAGE_CREATE_DISJOINT_BIT flag set

• VUID-vkGetImageMemoryRequirements-image-04004
  If image was created with the VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID external memory handle type, then image must be bound to memory

• VUID-vkGetImageMemoryRequirements-image-08960
  If image was created with the VK_EXTERNAL_MEMORY_HANDLE_TYPE_SCREEN_BUFFER_BIT_QNX external memory handle type, then image must be bound to memory

Valid Usage (Implicit)

• VUID-vkGetImageMemoryRequirements-device-parameter
device must be a valid VkDevice handle

• VUID-vkGetImageMemoryRequirements-image-parameter
  image must be a valid VkImage handle

• VUID-vkGetImageMemoryRequirements-pMemoryRequirements-parameter
  pMemoryRequirements must be a valid pointer to a VkMemoryRequirements structure

• VUID-vkGetImageMemoryRequirements-image-parent
  image must have been created, allocated, or retrieved from device

The VkMemoryRequirements structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkMemoryRequirements {
    VkDeviceSize size;
    VkDeviceSize alignment;
    uint32_t memoryTypeBits;
} VkMemoryRequirements;
```

• size is the size, in bytes, of the memory allocation required for the resource.
• alignment is the alignment, in bytes, of the offset within the allocation required for the resource.
• memoryTypeBits is a bitmask and contains one bit set for every supported memory type for the resource. Bit i is set if and only if the memory type i in the VkPhysicalDeviceMemoryProperties
structure for the physical device is supported for the resource.

The precise size of images that will be bound to external Android hardware buffer memory is unknown until the memory has been imported or allocated, so applications must not call `vkGetImageMemoryRequirements` or `vkGetImageMemoryRequirements2` with such an `VkImage` before it has been bound to memory. For this reason, applications also must not call `vkGetDeviceImageMemoryRequirements` with a `VkImageCreateInfo` describing an external Android hardware buffer. When importing Android hardware buffer memory, the allocationSize can be determined by calling `vkGetAndroidHardwareBufferPropertiesANDROID`. When allocating new memory for a `VkImage` that can be exported to an Android hardware buffer, the memory’s allocationSize must be zero; the actual size will be determined by the dedicated image’s parameters. After the memory has been allocated, the amount of space allocated from the memory’s heap can be obtained by getting the image’s memory requirements or by calling `vkGetAndroidHardwareBufferPropertiesANDROID` with the Android hardware buffer exported from the memory.

When allocating new memory for a `VkBuffer` that can be exported to an Android hardware buffer an application may still call `vkGetBufferMemoryRequirements` or `vkGetBufferMemoryRequirements2` with `VkBuffer` before it has been bound to memory.

If the resource being queried was created with the `VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_BIT`, `VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_KMT_BIT`, or `VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_RESOURCE_BIT` external memory handle type, the value of size has no meaning and should be ignored.

The implementation guarantees certain properties about the memory requirements returned by `vkGetBufferMemoryRequirements2`, `vkGetImageMemoryRequirements2`, `vkGetDeviceBufferMemoryRequirements`, `vkGetDeviceImageMemoryRequirements`, `vkGetBufferMemoryRequirements` and `vkGetImageMemoryRequirements`:

- The `memoryTypeBits` member always contains at least one bit set.
- If `buffer` is a `VkBuffer` not created with the `VK_BUFFER_CREATE_SPARSE_BINDING_BIT` bit set, or if `image` is linear image, then the `memoryTypeBits` member always contains at least one bit set corresponding to a `VkMemoryType` with a `propertyFlags` that has both the `VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT` bit and the `VK_MEMORY_PROPERTY_HOST_COHERENT_BIT` bit set. In other words, mappable coherent memory can always be attached to these objects.
- If `buffer` was created with `VkExternalMemoryBufferCreateInfo::handleTypes` set to 0 or `image` was created with `VkExternalMemoryImageCreateInfo::handleTypes` set to 0, the `memoryTypeBits` member always contains at least one bit set corresponding to a `VkMemoryType` with a `propertyFlags` that has the `VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT` bit set.
- The `memoryTypeBits` member is identical for all `VkBuffer` objects created with the same value for the `flags` and `usage` members in the `VkBufferCreateInfo` structure and the `handleTypes` member of the `VkExternalMemoryBufferCreateInfo` structure passed to `vkCreateBuffer`. Further, if `usage1` and `usage2` of type `VkBufferUsageFlags` are such that the bits set in `usage2` are a subset of the bits set in `usage1`, and they have the same `flags` and `VkExternalMemoryBufferCreateInfo::handleTypes`, then the bits set in `memoryTypeBits` returned for `usage1` must be a subset of the bits set in `memoryTypeBits` returned for `usage2`, for all values of `flags`. 1102
• The alignment member is a power of two.

• The alignment member is identical for all VkBuffer objects created with the same combination of values for the usage and flags members in the VkBufferCreateInfo structure passed to vkCreateBuffer.

• If the maintenance4 feature is enabled, then the alignment member is identical for all VkImage objects created with the same combination of values for the flags, imageType, format, extent, mipLevels, arrayLayers, samples, tiling and usage members in the VkImageCreateInfo structure passed to vkCreateImage.

• The alignment member satisfies the buffer descriptor offset alignment requirements associated with the VkBuffer's usage:
  ◦ If usage included VK_BUFFER_USAGE_UNIFORM_TEXEL_BUFFER_BIT or VK_BUFFER_USAGE_STORAGE_TEXEL_BUFFER_BIT, alignment must be an integer multiple of VkPhysicalDeviceLimits::minTexelBufferOffsetAlignment.
  ◦ If usage included VK_BUFFER_USAGE_UNIFORM_BUFFER_BIT, alignment must be an integer multiple of VkPhysicalDeviceLimits::minUniformBufferOffsetAlignment.
  ◦ If usage included VK_BUFFER_USAGE_STORAGE_BUFFER_BIT, alignment must be an integer multiple of VkPhysicalDeviceLimits::minStorageBufferOffsetAlignment.

• For images created with a color format, the memoryTypeBits member is identical for all VkImage objects created with the same combination of values for the tiling member, the VK_IMAGE_CREATE_SPARSE_BINDING_BIT bit of the flags member, the VK_IMAGE_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT bit of the flags member, the VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT bit of the usage member if the VkPhysicalDeviceHostImageCopyPropertiesEXT::identicalMemoryTypeRequirements property is VK_FALSE, handleTypes member of VkExternalMemoryImageCreateInfo, and the VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT of the usage member in the VkImageCreateInfo structure passed to vkCreateImage.

• For images created with a depth/stencil format, the memoryTypeBits member is identical for all VkImage objects created with the same combination of values for the format member, the tiling member, the VK_IMAGE_CREATE_SPARSE_BINDING_BIT bit of the flags member, the VK_IMAGE_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT bit of the flags member, the VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT bit of the usage member if the VkPhysicalDeviceHostImageCopyPropertiesEXT::identicalMemoryTypeRequirements property is VK_FALSE, handleTypes member of VkExternalMemoryImageCreateInfo, and the VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT of the usage member in the VkImageCreateInfo structure passed to vkCreateImage.

• If the memory requirements are for a VkImage, the memoryTypeBits member must not refer to a VkMemoryType with a propertyFlags that has the VK_MEMORY_PROPERTY_LAZILY_ALLOCATED_BIT bit set if the image did not have VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT bit set in the usage member of the VkImageCreateInfo structure passed to vkCreateImage.

• If the memory requirements are for a VkBuffer, the memoryTypeBits member must not refer to a VkMemoryType with a propertyFlags that has the VK_MEMORY_PROPERTY_LAZILY_ALLOCATED_BIT bit set.

Note
The implication of this requirement is that lazily allocated memory is
disallowed for buffers in all cases.

- The size member is identical for all VkBuffer objects created with the same combination of creation parameters specified in VkBufferCreateInfo and its pNext chain.
- The size member is identical for all VkImage objects created with the same combination of creation parameters specified in VkImageCreateInfo and its pNext chain.

Note
This, however, does not imply that they interpret the contents of the bound memory identically with each other. That additional guarantee, however, can be explicitly requested using VK_IMAGE_CREATE_ALIAS_BIT.

- If the maintenance4 feature is enabled, these additional guarantees apply:
  - For a VkBuffer, the size memory requirement is never greater than that of another VkBuffer created with a greater or equal size specified in VkBufferCreateInfo, all other creation parameters being identical.
  - For a VkBuffer, the size memory requirement is never greater than the result of aligning VkBufferCreateInfo::size with the alignment memory requirement.
  - For a VkImage, the size memory requirement is never greater than that of another VkImage created with a greater or equal value in each of extent.width, extent.height, and extent.depth; all other creation parameters being identical.
  - The memory requirements returned by vkGetDeviceBufferMemoryRequirements are identical to those that would be returned by vkGetBufferMemoryRequirements2 if it were called with a VkBuffer created with the same VkBufferCreateInfo values.
  - The memory requirements returned by vkGetDeviceImageMemoryRequirements are identical to those that would be returned by vkGetImageMemoryRequirements2 if it were called with a VkImage created with the same VkImageCreateInfo values.

To determine the memory requirements for a buffer resource, call:

```c
// Provided by VK_VERSION_1_1
void vkGetBufferMemoryRequirements2(
    VkDevice device,
    const VkBufferMemoryRequirementsInfo2* pInfo,
    VkMemoryRequirements2* pMemoryRequirements);
```

or the equivalent command

```c
// Provided by VK_KHR_get_memory_requirements2
void vkGetBufferMemoryRequirements2KHR(
    VkDevice device,
    const VkBufferMemoryRequirementsInfo2* pInfo,
    VkMemoryRequirements2* pMemoryRequirements);
```
- **device** is the logical device that owns the buffer.
- **pInfo** is a pointer to a `VkBufferMemoryRequirementsInfo2` structure containing parameters required for the memory requirements query.
- **pMemoryRequirements** is a pointer to a `VkMemoryRequirements2` structure in which the memory requirements of the buffer object are returned.

**Valid Usage (Implicit)**

- VUID-vkGetBufferMemoryRequirements2-device-parameter
  - `device` must be a valid `VkDevice` handle
- VUID-vkGetBufferMemoryRequirements2-pInfo-parameter
  - `pInfo` must be a valid pointer to a valid `VkBufferMemoryRequirementsInfo2` structure
- VUID-vkGetBufferMemoryRequirements2-pMemoryRequirements-parameter
  - `pMemoryRequirements` must be a valid pointer to a `VkMemoryRequirements2` structure

To determine the memory requirements for a buffer resource without creating an object, call:

```c
// Provided by VK_VERSION_1_3
void vkGetDeviceBufferMemoryRequirements(
  VkDevice device,
  const VkDeviceBufferMemoryRequirements* pInfo,
  VkMemoryRequirements2* pMemoryRequirements);
```

or the equivalent command

```c
// Provided by VK_KHR_maintenance4
void vkGetDeviceBufferMemoryRequirementsKHR(
  VkDevice device,
  const VkDeviceBufferMemoryRequirements* pInfo,
  VkMemoryRequirements2* pMemoryRequirements);
```

- **device** is the logical device intended to own the buffer.
- **pInfo** is a pointer to a `VkDeviceBufferMemoryRequirements` structure containing parameters required for the memory requirements query.
- **pMemoryRequirements** is a pointer to a `VkMemoryRequirements2` structure in which the memory requirements of the buffer object are returned.

**Valid Usage (Implicit)**

- VUID-vkGetDeviceBufferMemoryRequirements2-device-parameter
  - `device` must be a valid `VkDevice` handle
- VUID-vkGetDeviceBufferMemoryRequirements2-pInfo-parameter
  - `pInfo` must be a valid pointer to a valid `VkDeviceBufferMemoryRequirements` structure
The `VkBufferMemoryRequirementsInfo2` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkBufferMemoryRequirementsInfo2 {
    VkStructureType sType;
    const void* pNext;
    VkBuffer buffer;
} VkBufferMemoryRequirementsInfo2;
```

or the equivalent

```c
// Provided by VK_KHR_get_memory_requirements2
typedef VkBufferMemoryRequirementsInfo2 VkBufferMemoryRequirementsInfo2KHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `buffer` is the buffer to query.

### Valid Usage (Implicit)

- `VUID-VkBufferMemoryRequirementsInfo2-sType-sType`  
  `sType must be VK_STRUCTURE_TYPE_BUFFER_MEMORY_REQUIREMENTS_INFO_2`

- `VUID-VkBufferMemoryRequirementsInfo2-pNext-pNext`  
  `pNext must be NULL`

- `VUID-VkBufferMemoryRequirementsInfo2-buffer-parameter`  
  `buffer must be a valid VkBuffer handle`

The `VkDeviceBufferMemoryRequirements` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkDeviceBufferMemoryRequirements {
    VkStructureType sType;
    const void* pNext;
    const VkBufferCreateInfo* pCreateInfo;
} VkDeviceBufferMemoryRequirements;
```

or the equivalent

```c
// Provided by VK_KHR_maintenance4
```
typedef VkDeviceBufferMemoryRequirements VkDeviceBufferMemoryRequirementsKHR;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **pCreateInfo** is a pointer to a `VkBufferCreateInfo` structure containing parameters affecting creation of the buffer to query.

### Valid Usage (Implicit)

- `VUID-VkDeviceBufferMemoryRequirements-sType-sType`  
  `sType` **must** be `VK_STRUCTURE_TYPE_DEVICE_BUFFER_MEMORY_REQUIREMENTS`
- `VUID-VkDeviceBufferMemoryRequirements-pNext-pNext`  
  `pNext` **must** be `NULL`
- `VUID-VkDeviceBufferMemoryRequirements-pCreateInfo-parameter`  
  `pCreateInfo` **must** be a valid pointer to a valid `VkBufferCreateInfo` structure

To determine the memory requirements for an image resource, call:

```c
// Provided by VK_VERSION_1_1
void vkGetImageMemoryRequirements2(
    VkDevice device, 
    const VkImageMemoryRequirementsInfo2* pInfo, 
    VkMemoryRequirements2* pMemoryRequirements);
```

or the equivalent command

```c
// Provided by VK_KHR_get_memory_requirements2
void vkGetImageMemoryRequirements2KHR(
    VkDevice device, 
    const VkImageMemoryRequirementsInfo2* pInfo, 
    VkMemoryRequirements2* pMemoryRequirements);
```

- **device** is the logical device that owns the image.
- **pInfo** is a pointer to a `VkImageMemoryRequirementsInfo2` structure containing parameters required for the memory requirements query.
- **pMemoryRequirements** is a pointer to a `VkMemoryRequirements2` structure in which the memory requirements of the image object are returned.

### Valid Usage (Implicit)

- `VUID-vkGetImageMemoryRequirements2-device-parameter`  
  `device` **must** be a valid `VkDevice` handle
To determine the memory requirements for an image resource without creating an object, call:

```c
// Provided by VK_VERSION_1_3
void vkGetDeviceImageMemoryRequirements(
    VkDevice device,
    const VkDeviceImageMemoryRequirements* pInfo,
    VkMemoryRequirements2* pMemoryRequirements);
```

or the equivalent command

```c
// Provided by VK_KHR_maintenance4
void vkGetDeviceImageMemoryRequirementsKHR(
    VkDevice device,
    const VkDeviceImageMemoryRequirements* pInfo,
    VkMemoryRequirements2* pMemoryRequirements);
```

- `device` is the logical device intended to own the image.
- `pInfo` is a pointer to a `VkDeviceImageMemoryRequirements` structure containing parameters required for the memory requirements query.
- `pMemoryRequirements` is a pointer to a `VkMemoryRequirements2` structure in which the memory requirements of the image object are returned.

**Valid Usage (Implicit)**

- VUID-vkGetDeviceImageMemoryRequirements-device-parameter
  `device` must be a valid `VkDevice` handle
- VUID-vkGetDeviceImageMemoryRequirements-pInfo-parameter
  `pInfo` must be a valid pointer to a valid `VkDeviceImageMemoryRequirements` structure
- VUID-vkGetDeviceImageMemoryRequirements-pMemoryRequirements-parameter
  `pMemoryRequirements` must be a valid pointer to a `VkMemoryRequirements2` structure

The `VkImageMemoryRequirementsInfo2` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkImageMemoryRequirementsInfo2 {
    VkStructureType sType;
    const void* pNext;
    VkImage image;
} VkImageMemoryRequirementsInfo2;
```
} VkImageMemoryRequirementsInfo2;

or the equivalent

```c
// Provided by VK_KHR_get_memory_requirements2
typedef VkImageMemoryRequirementsInfo2 VkImageMemoryRequirementsInfo2KHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `image` is the image to query.

### Valid Usage

- **VUID-VkImageMemoryRequirementsInfo2-image-01589**
  If `image` was created with a *multi-planar* format and the `VK_IMAGE_CREATE_DISJOINT_BIT` flag, there **must** be a `VkImagePlaneMemoryRequirementsInfo` included in the `pNext` chain of the `VkImageMemoryRequirementsInfo2` structure

- **VUID-VkImageMemoryRequirementsInfo2-image-02279**
  If `image` was created with `VK_IMAGE_CREATE_DISJOINT_BIT` and with `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`, then there **must** be a `VkImagePlaneMemoryRequirementsInfo` included in the `pNext` chain of the `VkImageMemoryRequirementsInfo2` structure

- **VUID-VkImageMemoryRequirementsInfo2-image-01590**
  If `image` was not created with the `VK_IMAGE_CREATE_DISJOINT_BIT` flag, there **must not** be a `VkImagePlaneMemoryRequirementsInfo` included in the `pNext` chain of the `VkImageMemoryRequirementsInfo2` structure

- **VUID-VkImageMemoryRequirementsInfo2-image-02280**
  If `image` was created with a single-plane format and with any tiling other than `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`, then there **must not** be a `VkImagePlaneMemoryRequirementsInfo` included in the `pNext` chain of the `VkImageMemoryRequirementsInfo2` structure

- **VUID-VkImageMemoryRequirementsInfo2-image-01897**
  If `image` was created with the `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID` external memory handle type, then `image` **must** be bound to memory

- **VUID-VkImageMemoryRequirementsInfo2-image-08961**
  If `image` was created with the `VK_EXTERNAL_MEMORY_HANDLE_TYPE_SCREEN_BUFFER_BIT_QNX` external memory handle type, then `image` **must** be bound to memory

### Valid Usage (Implicit)

- **VUID-VkImageMemoryRequirementsInfo2-sType-sType**
**sType** must be **VK_STRUCTURE_TYPE_IMAGE_MEMORY_REQUIREMENTS_INFO_2**

- VUID-VkImageMemoryRequirementsInfo2-pNext-pNext
  
  **pNext** must be **NULL** or a pointer to a valid instance of **VkImagePlaneMemoryRequirementsInfo**

- VUID-VkImageMemoryRequirementsInfo2-sType-unique
  
  The **sType** value of each struct in the **pNext** chain must be unique

- VUID-VkImageMemoryRequirementsInfo2-image-parameter
  
  **image** must be a valid **VkImage** handle

The **VkDeviceImageMemoryRequirements** structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkDeviceImageMemoryRequirements {
    VkStructureType sType;
    const void* pNext;
    const VkImageCreateInfo* pCreateInfo;
    VkImageAspectFlagBits planeAspect;
} VkDeviceImageMemoryRequirements;
```

or the equivalent

```c
// Provided by VK_KHR_maintenance4
typedef VkDeviceImageMemoryRequirements VkDeviceImageMemoryRequirementsKHR;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **pCreateInfo** is a pointer to a **VkImageCreateInfo** structure containing parameters affecting creation of the image to query.
- **planeAspect** is a **VkImageAspectFlagBits** value specifying the aspect corresponding to the image plane to query. This parameter is ignored unless **pCreateInfo::tiling** is **VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT**, or **pCreateInfo::flags** has **VK_IMAGE_CREATE_DISJOINT_BIT** set.

### Valid Usage

- VUID-VkDeviceImageMemoryRequirements-pCreateInfo-06416
  
  The **pCreateInfo::pNext** chain must not contain a **VkImageSwapchainCreateInfoKHR** structure

- VUID-VkDeviceImageMemoryRequirements-pCreateInfo-06776
  
  The **pCreateInfo::pNext** chain must not contain a **VkImageDrmFormatModifierExplicitCreateInfoEXT** structure

- VUID-VkDeviceImageMemoryRequirements-pNext-06996
Applications also **must** not call `vkGetDeviceImageMemoryRequirements` with a `VkImageCreateInfo` whose `pNext` chain includes a `VkExternalFormatANDROID` structure with non-zero `externalFormat`.

- VUID-VkDeviceImageMemoryRequirements-pNext-08962
  Applications also **must** not call `vkGetDeviceImageMemoryRequirements` with a `VkImageCreateInfo` whose `pNext` chain includes a `VkExternalFormatQNX` structure with non-zero `externalFormat`.

- VUID-VkDeviceImageMemoryRequirements-pCreateInfo-06417
  If `pCreateInfo::format` specifies a *multi-planar* format and `pCreateInfo::flags` has `VK_IMAGE_CREATE_DISJOINT_BIT` set then `planeAspect` **must** not be `VK_IMAGE_ASPECT_NONE_KHR`.

- VUID-VkDeviceImageMemoryRequirements-pCreateInfo-06419
  If `pCreateInfo::flags` has `VK_IMAGE_CREATE_DISJOINT_BIT` set and if the `pCreateInfo::tiling` is `VK_IMAGE_TILING_LINEAR` or `VK_IMAGE_TILING_OPTIMAL`, then `planeAspect` **must** be a single valid *multi-planar aspect mask* bit.

- VUID-VkDeviceImageMemoryRequirements-pCreateInfo-06420
  If `pCreateInfo::tiling` is `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`, then `planeAspect` **must** be a single valid *memory plane* for the image (that is, `aspectMask` **must** specify a plane index that is less than the `VkDrmFormatModifierPropertiesEXT::drmFormatModifierPlaneCount` associated with the image’s `format` and `VkImageDrmFormatModifierPropertiesEXT::drmFormatModifier`).

### Valid Usage (Implicit)

- VUID-VkDeviceImageMemoryRequirements-sType-sType
  `sType` **must** be `VK_STRUCTURE_TYPE_DEVICE_IMAGE_MEMORY_REQUIREMENTS`.

- VUID-VkDeviceImageMemoryRequirements-pNext-pNext
  `pNext` **must** be `NULL`.

- VUID-VkDeviceImageMemoryRequirements-pCreateInfo-parameter
  `pCreateInfo` **must** be a valid pointer to a valid `VkImageCreateInfo` structure.

- VUID-VkDeviceImageMemoryRequirements-planeAspect-parameter
  If `planeAspect` is not `0`, `planeAspect` **must** be a valid `VkImageAspectFlagBits` value.

To determine the memory requirements for a plane of a disjoint image, add a `VkImagePlaneMemoryRequirementsInfo` structure to the `pNext` chain of the `VkImageMemoryRequirementsInfo2` structure.

The `VkImagePlaneMemoryRequirementsInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkImagePlaneMemoryRequirementsInfo {
    VkStructureType sType;
    const void* pNext;
    VkImageAspectFlagBits planeAspect;
};
```
```c
// Provided by VK_KHR_sampler_ycbcr_conversion
typedef VkImagePlaneMemoryRequirementsInfo VkImagePlaneMemoryRequirementsInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `planeAspect` is a `VkImageAspectFlagBits` value specifying the aspect corresponding to the image plane to query.

### Valid Usage

- **VUID-VkImagePlaneMemoryRequirementsInfo-planeAspect-02281**
  If the image's tiling is `VK_IMAGE_TILING_LINEAR` or `VK_IMAGE_TILING_OPTIMAL`, then `planeAspect` must be a single valid multi-planar aspect mask bit

- **VUID-VkImagePlaneMemoryRequirementsInfo-planeAspect-02282**
  If the image's tiling is `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`, then `planeAspect` must be a single valid memory plane for the image (that is, `aspectMask` must specify a plane index that is less than the `VkDrmFormatModifierPropertiesEXT::drmFormatModifierPlaneCount` associated with the image's format and `VkImageDrmFormatModifierPropertiesEXT::drmFormatModifier`)

### Valid Usage (Implicit)

- **VUID-VkImagePlaneMemoryRequirementsInfo-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_IMAGE_PLANE_MEMORY_REQUIREMENTS_INFO`

- **VUID-VkImagePlaneMemoryRequirementsInfo-planeAspect-parameter**
  `planeAspect` must be a valid `VkImageAspectFlagBits` value

The `VkMemoryRequirements2` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkMemoryRequirements2 {
    VkStructureType sType;
    void* pNext;
    VkMemoryRequirements memoryRequirements;
} VkMemoryRequirements2;
```

or the equivalent
typedef VkMemoryRequirements2 VkMemoryRequirements2KHR;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• memoryRequirements is a VkMemoryRequirements structure describing the memory requirements of the resource.

Valid Usage (Implicit)

• VUID-VkMemoryRequirements2-sType-sType
  sType must be VK_STRUCTURE_TYPE_MEMORY_REQUIREMENTS_2
• VUID-VkMemoryRequirements2-pNext-pNext
  pNext must be NULL or a pointer to a valid instance of VkMemoryDedicatedRequirements
• VUID-VkMemoryRequirements2-sType-unique
  The sType value of each struct in the pNext chain must be unique.

The VkMemoryDedicatedRequirements structure is defined as:

typedef struct VkMemoryDedicatedRequirements {
  VkStructureType sType;
  void* pNext;
  VkBool32 prefersDedicatedAllocation;
  VkBool32 requiresDedicatedAllocation;
} VkMemoryDedicatedRequirements;

or the equivalent

typedef VkMemoryDedicatedRequirements VkMemoryDedicatedRequirementsKHR;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• prefersDedicatedAllocation specifies that the implementation would prefer a dedicated allocation for this resource. The application is still free to suballocate the resource but it may get better performance if a dedicated allocation is used.
• requiresDedicatedAllocation specifies that a dedicated allocation is required for this resource.

To determine the dedicated allocation requirements of a buffer or image resource, add a VkMemoryDedicatedRequirements structure to the pNext chain of the VkMemoryRequirements2
structure passed as the `pMemoryRequirements` parameter of `vkGetBufferMemoryRequirements2` or `vkGetImageMemoryRequirements2`, respectively.

Constraints on the values returned for buffer resources are:

- `requiresDedicatedAllocation` may be `VK_TRUE` if the `pNext` chain of `VkBufferCreateInfo` for the call to `vkCreateBuffer` used to create the buffer being queried included a `VkExternalMemoryBufferCreateInfo` structure, and any of the handle types specified in `VkExternalMemoryBufferCreateInfo::handleTypes` requires dedicated allocation, as reported by `vkGetPhysicalDeviceExternalBufferProperties` in `VkExternalBufferProperties::externalMemoryProperties.externalMemoryFeatures`. Otherwise, `requiresDedicatedAllocation` will be `VK_FALSE`.

- When the implementation sets `requiresDedicatedAllocation` to `VK_TRUE`, it must also set `prefersDedicatedAllocation` to `VK_TRUE`.

- If `VK_BUFFER_CREATE_SPARSE_BINDING_BIT` was set in `VkBufferCreateInfo::flags` when `buffer` was created, then both `prefersDedicatedAllocation` and `requiresDedicatedAllocation` will be `VK_FALSE`.

Constraints on the values returned for image resources are:

- `requiresDedicatedAllocation` may be `VK_TRUE` if the `pNext` chain of `VkImageCreateInfo` for the call to `vkCreateImage` used to create the image being queried included a `VkExternalMemoryImageCreateInfo` structure, and any of the handle types specified in `VkExternalMemoryImageCreateInfo::handleTypes` requires dedicated allocation, as reported by `vkGetPhysicalDeviceImageFormatProperties2` in `VkExternalImageFormatProperties::externalMemoryProperties.externalMemoryFeatures`.

- `requiresDedicatedAllocation` may be `VK_TRUE` if the image’s tiling is `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`.

- `requiresDedicatedAllocation` will otherwise be `VK_FALSE`.

- If `VK_IMAGE_CREATE_SPARSE_BINDING_BIT` was set in `VkImageCreateInfo::flags` when `image` was created, then both `prefersDedicatedAllocation` and `requiresDedicatedAllocation` will be `VK_FALSE`.

**Valid Usage (Implicit)**

- VUID-VkMemoryDedicatedRequirements-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_MEMORYDEDICATED_REQUIREMENTS`

To attach memory to a buffer object, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkBindBufferMemory(
    VkDevice device,
    VkBuffer buffer,
    VkDeviceMemory memory,
    VkDeviceSize memoryOffset);
```
• **device** is the logical device that owns the buffer and memory.
• **buffer** is the buffer to be attached to memory.
• **memory** is a **VkDeviceMemory** object describing the device memory to attach.
• **memoryOffset** is the start offset of the region of memory which is to be bound to the buffer. The number of bytes returned in the **VkMemoryRequirements::size** member in memory, starting from memoryOffset bytes, will be bound to the specified buffer.

`vkBindBufferMemory` is equivalent to passing the same parameters through `VkBindBufferMemoryInfo` to `vkBindBufferMemory2`.

### Valid Usage

- **VUID-vkBindBufferMemory-buffer-07459**
  buffer **must** not have been bound to a memory object

- **VUID-vkBindBufferMemory-buffer-01030**
  buffer **must** not have been created with any sparse memory binding flags

- **VUID-vkBindBufferMemory-memoryOffset-01031**
  memoryOffset **must** be less than the size of memory

- **VUID-vkBindBufferMemory-memory-01035**
  memory **must** have been allocated using one of the memory types allowed in the `memoryTypeBits` member of the **VkMemoryRequirements** structure returned from a call to `vkGetBufferMemoryRequirements` with buffer

- **VUID-vkBindBufferMemory-memoryOffset-01036**
  memoryOffset **must** be an integer multiple of the `alignment` member of the **VkMemoryRequirements** structure returned from a call to `vkGetBufferMemoryRequirements` with buffer

- **VUID-vkBindBufferMemory-size-01037**
  The `size` member of the **VkMemoryRequirements** structure returned from a call to `vkGetBufferMemoryRequirements` with buffer **must** be less than or equal to the size of memory minus memoryOffset

- **VUID-vkBindBufferMemory-buffer-01444**
  If buffer requires a dedicated allocation (as reported by `vkGetBufferMemoryRequirements2` in **VkMemoryDedicatedRequirements**::`requiresDedicatedAllocation` for buffer), memory **must** have been allocated with **VkMemoryDedicatedAllocateInfo::buffer** equal to buffer

- **VUID-vkBindBufferMemory-memory-01508**
  If the **VkMemoryAllocateInfo** provided when memory was allocated included a **VkMemoryDedicatedAllocateInfo** structure in its `pNext` chain, and **VkMemoryDedicatedAllocateInfo::buffer** was not **VK_NULL_HANDLE**, then buffer **must** equal **VkMemoryDedicatedAllocateInfo::buffer**, and memoryOffset **must** be zero

- **VUID-vkBindBufferMemory-None-01898**
  If buffer was created with the **VK_BUFFER_CREATE_PROTECTED_BIT** bit set, the buffer **must** be bound to a memory object allocated with a memory type that reports
If buffer was created with the VK_BUFFER_CREATE_PROTECTED_BIT bit not set, the buffer must not be bound to a memory object allocated with a memory type that reports VK_MEMORY_PROPERTY_PROTECTED_BIT.

If buffer was created with VkDedicatedAllocationBufferCreateInfoNV::dedicatedAllocation equal to VK_TRUE, memory must have been allocated with VkDedicatedAllocationMemoryAllocateInfoNV::buffer equal to a buffer handle created with identical creation parameters to buffer and memoryOffset must be zero.

If the VK_KHR_dedicated_allocation extension is not enabled, VkPhysicalDeviceProperties::apiVersion is less than Vulkan 1.1, and buffer was not created with VkDedicatedAllocationBufferCreateInfoNV::dedicatedAllocation equal to VK_TRUE, memory must not have been allocated dedicated for a specific buffer or image.

If the value of VkExportMemoryAllocateInfo::handleTypes used to allocate memory is not 0, it must include at least one of the handles set in VkExternalMemoryBufferCreateInfo::handleTypes when buffer was created.

If memory was allocated by a memory import operation, that is not VkImportAndroidHardwareBufferInfoANDROID with a non-NULL buffer value, the external handle type of the imported memory must also have been set in VkExternalMemoryBufferCreateInfo::handleTypes when buffer was created.

If memory was allocated with the VkImportAndroidHardwareBufferInfoANDROID memory import operation with a non-NULL buffer value, VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID must also have been set in VkExternalMemoryBufferCreateInfo::handleTypes when buffer was created.

If the VkPhysicalDeviceBufferDeviceAddressFeatures::bufferDeviceAddress feature is enabled and buffer was created with the VK_BUFFER_USAGE_SHADER_DEVICE_ADDRESS_BIT bit set, memory must have been allocated with the VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT bit set.

If the VkPhysicalDeviceBufferDeviceAddressFeatures::bufferDeviceAddressCaptureReplay feature is enabled and buffer was created with the VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT bit set, memory must have been allocated with the VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT bit set.

If buffer was created with VkBufferCollectionBufferCreateInfoFUCHSIA chained to VkBufferCreateInfo::pNext, memory must be allocated with a VkImportMemoryBufferCollectionFUCHSIA chained to VkMemoryAllocateInfo::pNext.

If buffer was created with VkBufferCollectionBufferCreateInfoFUCHSIA chained to VkBufferCreateInfo::pNext, memory must be allocated with a VkImportMemoryBufferCollectionFUCHSIA chained to VkMemoryAllocateInfo::pNext.
If the buffer was created with the VK_BUFFER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT bit set, memory must have been allocated with the VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT bit set.

- **VUID-vkBindBufferMemory-buffer-09201**
  If the buffer was created with the VK_BUFFER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT bit set, memory must have been allocated with the VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT bit set.

### Valid Usage (Implicit)

- **VUID-vkBindBufferMemory-device-parameter**
  device must be a valid VkDevice handle

- **VUID-vkBindBufferMemory-buffer-parameter**
  buffer must be a valid VkBuffer handle

- **VUID-vkBindBufferMemory-memory-parameter**
  memory must be a valid VkDeviceMemory handle

- **VUID-vkBindBufferMemory-buffer-parent**
  buffer must have been created, allocated, or retrieved from device

- **VUID-vkBindBufferMemory-memory-parent**
  memory must have been created, allocated, or retrieved from device

### Host Synchronization

- Host access to buffer must be externally synchronized

### Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS_KHR

To attach memory to buffer objects for one or more buffers at a time, call:

```c
// Provided by VK_VERSION_1_1
VkResult vkBindBufferMemory2(
    VkDevice device,
    uint32_t bindInfoCount,
    ...)
```
const VkBindBufferMemoryInfo* pBindInfos);

or the equivalent command

```c
// Provided by VK_KHR_bind_memory2
VkResult vkBindBufferMemory2KHR(
    VkDevice device,
    uint32_t bindInfoCount,
    const VkBindBufferMemoryInfo* pBindInfos);
```

- `device` is the logical device that owns the buffers and memory.
- `bindInfoCount` is the number of elements in `pBindInfos`.
- `pBindInfos` is a pointer to an array of `bindInfoCount` `VkBindBufferMemoryInfo` structures describing buffers and memory to bind.

On some implementations, it may be more efficient to batch memory bindings into a single command.

---

**Note**

If `vkBindBufferMemory2` fails, and `bindInfoCount` was greater than one, then the buffers referenced by `pBindInfos` will be in an indeterminable state, and must not be used. Applications should destroy these buffers.

---

### Valid Usage (Implicit)

- **VUID-vkBindBufferMemory2-device-parameter**
  - `device` must be a valid `VkDevice` handle

- **VUID-vkBindBufferMemory2-pBindInfos-parameter**
  - `pBindInfos` must be a valid pointer to an array of `bindInfoCount` valid `VkBindBufferMemoryInfo` structures

- **VUID-vkBindBufferMemory2-bindInfoCount-arraylength**
  - `bindInfoCount` must be greater than 0

---

### Return Codes

**Success**

- VK_SUCCESS

**Failure**

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS_KHR
VkBindBufferMemoryInfo contains members corresponding to the parameters of vkBindBufferMemory.

The VkBindBufferMemoryInfo structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkBindBufferMemoryInfo {
    VkStructureType sType;
    const void* pNext;
    VkBuffer buffer;
    VkDeviceMemory memory;
    VkDeviceSize memoryOffset;
} VkBindBufferMemoryInfo;
```

or the equivalent

```c
// Provided by VK_KHR_bind_memory2
typedef VkBindBufferMemoryInfo VkBindBufferMemoryInfoKHR;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **buffer** is the buffer to be attached to memory.
- **memory** is a VkDeviceMemory object describing the device memory to attach.
- **memoryOffset** is the start offset of the region of memory which is to be bound to the buffer. The number of bytes returned in the VkMemoryRequirements::size member in memory, starting from memoryOffset bytes, will be bound to the specified buffer.

**Valid Usage**

- VUID-VkBindBufferMemoryInfo-buffer-07459
  buffer must not have been bound to a memory object
- VUID-VkBindBufferMemoryInfo-buffer-01030
  buffer must not have been created with any sparse memory binding flags
- VUID-VkBindBufferMemoryInfo-memoryOffset-01031
  memoryOffset must be less than the size of memory
- VUID-VkBindBufferMemoryInfo-memory-01035
  memory must have been allocated using one of the memory types allowed in the memoryTypeBits member of the VkMemoryRequirements structure returned from a call to vkGetBufferMemoryRequirements with buffer
- VUID-VkBindBufferMemoryInfo-memoryOffset-01036
  memoryOffset must be an integer multiple of the alignment member of the VkMemoryRequirements structure returned from a call to vkGetBufferMemoryRequirements with buffer
• **VUID-VkBindBufferMemoryInfo-size-01037**
  The *size* member of the *VkMemoryRequirements* structure returned from a call to *vkGetBufferMemoryRequirements* with *buffer* must be less than or equal to the size of *memory minus memoryOffset*.

• **VUID-VkBindBufferMemoryInfo-buffer-01444**
  If *buffer* requires a dedicated allocation (as reported by *vkGetBufferMemoryRequirements2* in *VkMemoryDedicatedRequirements::requiresDedicatedAllocation* for *buffer*), *memory* must have been allocated with *VkMemoryDedicatedAllocateInfo::buffer* equal to *buffer*.

• **VUID-VkBindBufferMemoryInfo-memory-01508**
  If the *VkMemoryAllocateInfo* provided when *memory* was allocated included a *VkMemoryDedicatedAllocateInfo* structure in its *pNext* chain, and *VkMemoryDedicatedAllocateInfo::buffer* was not *VK_NULL_HANDLE*, then *buffer* must equal *VkMemoryDedicatedAllocateInfo::buffer*, and *memoryOffset* must be zero.

• **VUID-VkBindBufferMemoryInfo-None-01898**
  If *buffer* was created with the *VK_BUFFER_CREATE_PROTECTED_BIT* bit set, the *buffer* must be bound to a memory object allocated with a memory type that reports *VK_MEMORY_PROPERTY_PROTECTED_BIT*.

• **VUID-VkBindBufferMemoryInfo-None-01899**
  If *buffer* was created with the *VK_BUFFER_CREATE_PROTECTED_BIT* bit not set, the *buffer* must not be bound to a memory object allocated with a memory type that reports *VK_MEMORY_PROPERTY_PROTECTED_BIT*.

• **VUID-VkBindBufferMemoryInfo-buffer-01038**
  If *buffer* was created with *VkDedicatedAllocationBufferCreateInfoNV::dedicatedAllocation* equal to *VK_TRUE*, *memory* must have been allocated with *VkDedicatedAllocationMemoryAllocateInfoNV::buffer* equal to a buffer handle created with identical creation parameters to *buffer* and *memoryOffset* must be zero.

• **VUID-VkBindBufferMemoryInfo-apiVersion-07920**
  If the *VK_KHR_dedicated_allocation* extension is not enabled, *VkPhysicalDeviceProperties::apiVersion* is less than Vulkan 1.1, and *buffer* was not created with *VkDedicatedAllocationBufferCreateInfoNV::dedicatedAllocation* equal to *VK_TRUE*, *memory* must not have been allocated dedicated for a specific buffer or image.

• **VUID-VkBindBufferMemoryInfo-memory-02726**
  If the value of *VkExportMemoryAllocateInfo::handleTypes* used to allocate *memory* is not 0, it must include at least one of the handles set in *VkExternalMemoryBufferCreateInfo::handleTypes* when *buffer* was created.

• **VUID-VkBindBufferMemoryInfo-memory-02985**
  If *memory* was allocated by a memory import operation, that is not *VkImportAndroidHardwareBufferInfoANDROID* with a non-NULL *buffer* value, the external handle type of the imported memory must also have been set in *VkExternalMemoryBufferCreateInfo::handleTypes* when *buffer* was created.

• **VUID-VkBindBufferMemoryInfo-memory-02986**
  If *memory* was allocated with the *VkImportAndroidHardwareBufferInfoANDROID* memory import operation with a non-NULL *buffer* value,
VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID must also have been set in VkExternalMemoryBufferCreateInfo::handleTypes when buffer was created.

• VUID-VkBindBufferMemoryInfo-bufferDeviceAddress-03339
If the VkPhysicalDeviceBufferDeviceAddressFeatures::bufferDeviceAddress feature is enabled and buffer was created with the VK_BUFFER_USAGE_SHADER_DEVICE_ADDRESS_BIT bit set, memory must have been allocated with the VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT bit set.

• VUID-VkBindBufferMemoryInfo-bufferDeviceAddressCaptureReplay-09200
If the VkPhysicalDeviceBufferDeviceAddressFeatures::bufferDeviceAddressCaptureReplay feature is enabled and buffer was created with the VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT bit set, memory must have been allocated with the VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT bit set.

• VUID-VkBindBufferMemoryInfo-buffer-06408
If buffer was created with VkBufferCollectionBufferCreateInfoFUCHSIA chained to VkBufferCreateInfo::*pNext, memory must be allocated with a VkImportMemoryBufferCollectionFUCHSIA chained to VkMemoryAllocateInfo::*pNext.

• VUID-VkBindBufferMemoryInfo-descriptorBufferCaptureReplay-08112
If the buffer was created with the VK_BUFFER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT bit set, memory must have been allocated with the VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT bit set.

• VUID-VkBindBufferMemoryInfo-buffer-09201
If the buffer was created with the VK_BUFFER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT bit set, memory must have been allocated with the VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT bit set.

• VUID-VkBindBufferMemoryInfo-pNext-01605
If the pNext chain includes a VkBindBufferMemoryDeviceGroupInfo structure, all instances of memory specified by VkBindBufferMemoryDeviceGroupInfo::*pDeviceIndices must have been allocated.

Valid Usage (Implicit)

• VUID-VkBindBufferMemoryInfo-sType-sType
sType must be VK_STRUCTURE_TYPE_BIND_BUFFER_MEMORY_INFO

• VUID-VkBindBufferMemoryInfo-pNext-pNext
pNext must be NULL or a pointer to a valid instance of VkBindBufferMemoryDeviceGroupInfo

• VUID-VkBindBufferMemoryInfo-sType-unique
The sType value of each struct in the pNext chain must be unique.

• VUID-VkBindBufferMemoryInfo-buffer-parameter
buffer must be a valid VkBuffer handle.

• VUID-VkBindBufferMemoryInfo-memory-parameter
memory must be a valid VkDeviceMemory handle.
Both of buffer, and memory must have been created, allocated, or retrieved from the same VkDevice.

The VkBindBufferMemoryDeviceGroupInfo structure is defined as:

```c
typedef struct VkBindBufferMemoryDeviceGroupInfo {
    VkStructureType sType;
    const void* pNext;
    uint32_t deviceIndexCount;
    const uint32_t* pDeviceIndices;
} VkBindBufferMemoryDeviceGroupInfo;
```

or the equivalent

```c
typedef VkBindBufferMemoryDeviceGroupInfoKHR;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **deviceIndexCount** is the number of elements in pDeviceIndices.
- **pDeviceIndices** is a pointer to an array of device indices.

If the pNext chain of VkBindBufferMemoryInfo includes a VkBindBufferMemoryDeviceGroupInfo structure, then that structure determines how memory is bound to buffers across multiple devices in a device group.

If deviceIndexCount is greater than zero, then on device index i the buffer is attached to the instance of memory on the physical device with device index pDeviceIndices[i].

If deviceIndexCount is zero and memory comes from a memory heap with the VK_MEMORY_HEAP_MULTI_INSTANCE_BIT bit set, then it is as if pDeviceIndices contains consecutive indices from zero to the number of physical devices in the logical device, minus one. In other words, by default each physical device attaches to its own instance of memory.

If deviceIndexCount is zero and memory comes from a memory heap without the VK_MEMORY_HEAP_MULTI_INSTANCE_BIT bit set, then it is as if pDeviceIndices contains an array of zeros. In other words, by default each physical device attaches to instance zero.

**Valid Usage**

- VUID-VkBindBufferMemoryDeviceGroupInfo-deviceIndexCount-01606
  deviceIndexCount must either be zero or equal to the number of physical devices in the logical device.
All elements of \texttt{pDeviceIndices} must be valid device indices

\textbf{Valid Usage (Implicit)}

- \textbf{VUID-VkBindBufferMemoryDeviceGroupInfo-sType-sType} \texttt{sType} must be \texttt{VK_STRUCTURE_TYPE_BIND_BUFFER_MEMORY_DEVICE_GROUP_INFO}
- \textbf{VUID-VkBindBufferMemoryDeviceGroupInfo-pDeviceIndices-parameter} If \texttt{deviceIndexCount} is not 0, \texttt{pDeviceIndices} must be a valid pointer to an array of \texttt{deviceIndexCount} \texttt{uint32_t} values

To attach memory to a \texttt{VkImage} object created without the \texttt{VK_IMAGE_CREATE_DISJOINT_BIT} set, call:

```cpp
// Provided by VK_VERSION_1_0
VkResult vkBindImageMemory(
    VkDevice device,
    VkImage image,
    VkDeviceMemory memory,
    VkDeviceSize memoryOffset);
```

- \texttt{device} is the logical device that owns the image and memory.
- \texttt{image} is the image.
- \texttt{memory} is the \texttt{VkDeviceMemory} object describing the device memory to attach.
- \texttt{memoryOffset} is the start offset of the region of \texttt{memory} which is to be bound to the image. The number of bytes returned in the \texttt{VkMemoryRequirements::size} member in \texttt{memory}, starting from \texttt{memoryOffset} bytes, will be bound to the specified image.

\texttt{vkBindImageMemory} is equivalent to passing the same parameters through \texttt{VkBindImageMemoryInfo} to \texttt{vkBindImageMemory2}.

\textbf{Valid Usage}

- \textbf{VUID-vkBindImageMemory-image-07460} \texttt{image} must not have been bound to a memory object
- \textbf{VUID-vkBindImageMemory-image-01045} \texttt{image} must not have been created with any sparse memory binding flags
- \textbf{VUID-vkBindImageMemory-memoryOffset-01046} \texttt{memoryOffset} must be less than the size of \texttt{memory}
- \textbf{VUID-vkBindImageMemory-image-01445} If \texttt{image} requires a dedicated allocation (as reported by \texttt{vkGetImageMemoryRequirements2} in \texttt{VkMemoryDedicatedRequirements::{requiresDedicatedAllocation} for image}), \texttt{memory} must have been created with \texttt{VkMemoryDedicatedAllocateInfo::{image} equal to image}
If the `dedicatedAllocationImageAliasing` feature is not enabled, and the `VkMemoryAllocateInfo` provided when `memory` was allocated included a `VkMemoryDedicatedAllocateInfo` structure in its `pNext` chain, and `VkMemoryDedicatedAllocateInfo::image` was not `VK_NULL_HANDLE`, then `image` must equal `VkMemoryDedicatedAllocateInfo::image` and `memoryOffset` must be zero.

If the `dedicatedAllocationImageAliasing` feature is enabled, and the `VkMemoryAllocateInfo` provided when `memory` was allocated included a `VkMemoryDedicatedAllocateInfo` structure in its `pNext` chain, and `VkMemoryDedicatedAllocateInfo::image` was not `VK_NULL_HANDLE`, then `memoryOffset` must be zero, and `image` must be either equal to `VkMemoryDedicatedAllocateInfo::image` or an image that was created using the same parameters in `VkImageCreateInfo`, with the exception that `extent` and `arrayLayers` may differ subject to the following restrictions: every dimension in the `extent` parameter of the image being bound must be equal to or smaller than the original image for which the allocation was created; and the `arrayLayers` parameter of the image being bound must be equal to or smaller than the original image for which the allocation was created.

If image was created with the `VK_IMAGE_CREATE_PROTECTED_BIT` bit set, the image must be bound to a memory object allocated with a memory type that reports `VK_MEMORY_PROPERTY_PROTECTED_BIT`.

If image was created with the `VK_IMAGE_CREATE_PROTECTED_BIT` bit not set, the image must not be bound to a memory object created with a memory type that reports `VK_MEMORY_PROPERTY_PROTECTED_BIT`.

If image was created with `VkDedicatedAllocationImageCreateInfoNV::dedicatedAllocation` equal to `VK_TRUE`, `memory` must have been created with `VkDedicatedAllocationMemoryAllocateInfoNV::image` equal to an image handle created with identical creation parameters to `image` and `memoryOffset` must be zero.

If the `VK_KHR_dedicated_allocation` extension is not enabled, `VkPhysicalDeviceProperties::apiVersion` is less than Vulkan 1.1, and `image` was not created with `VkDedicatedAllocationImageCreateInfoNV::dedicatedAllocation` equal to `VK_TRUE`, `memory` must not have been allocated dedicated for a specific buffer or image.

If the value of `VkExportMemoryAllocateInfo::handleTypes` used to allocate `memory` is not 0, it must include at least one of the handles set in `VkExternalMemoryImageCreateInfo::handleTypes` when `image` was created.

If `memory` was created by a memory import operation, that is not `VkImportAndroidHardwareBufferInfoANDROID` with a non-NULL `buffer` value, the external handle type of the imported memory must also have been set in `VkExternalMemoryImageCreateInfo::handleTypes` when `image` was created.
If memory was created with the `VkImportAndroidHardwareBufferInfoANDROID` memory import operation with a non-NULL buffer value, `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID` must also have been set in `VkExternalMemoryImageCreateInfo::handleTypes` when image was created.

- VUID-vkBindImageMemory-descriptorBufferCaptureReplay-08113
  If the image was created with the `VK_IMAGE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT` bit set, memory must have been allocated with the `VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT` bit set.

- VUID-vkBindImageMemory-image-09202
  If the image was created with the `VK_IMAGE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT` bit set, memory must have been allocated with the `VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT` bit set.

- VUID-vkBindImageMemory-image-01608
  Image must not have been created with the `VK_IMAGE_CREATE_DISJOINT_BIT` set.

- VUID-vkBindImageMemory-memory-01047
  Memory must have been allocated using one of the memory types allowed in the `memoryTypeBits` member of the `VkMemoryRequirements` structure returned from a call to `vkGetImageMemoryRequirements` with image.

- VUID-vkBindImageMemory-memoryOffset-01048
  MemoryOffset must be an integer multiple of the `alignment` member of the `VkMemoryRequirements` structure returned from a call to `vkGetImageMemoryRequirements` with image.

- VUID-vkBindImageMemory-size-01049
  The difference of the size of memory and memoryOffset must be greater than or equal to the `size` member of the `VkMemoryRequirements` structure returned from a call to `vkGetImageMemoryRequirements` with the same image.

- VUID-vkBindImageMemory-image-06392
  If image was created with `VkBufferCollectionImageCreateInfoFUCHSIA` chained to `VkImageCreateInfo::pNext`, memory must be allocated with a `VkImportMemoryBufferCollectionFUCHSIA` chained to `VkMemoryAllocateInfo::pNext`.

### Valid Usage (Implicit)

- VUID-vkBindImageMemory-device-parameter
  Device must be a valid `VkDevice` handle.

- VUID-vkBindImageMemory-image-parameter
  Image must be a valid `VkImage` handle.

- VUID-vkBindImageMemory-memory-parameter
  Memory must be a valid `VkDeviceMemory` handle.

- VUID-vkBindImageMemory-image-parent
  Image must have been created, allocated, or retrieved from device.

- VUID-vkBindImageMemory-memory-parent
memory must have been created, allocated, or retrieved from device

Host Synchronization

• Host access to image must be externally synchronized

Return Codes

Success

• VK_SUCCESS

Failure

• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY

To attach memory to image objects for one or more images at a time, call:

```plaintext
// Provided by VK_VERSION_1_1
VkResult vkBindImageMemory2(
    VkDevice device,
    uint32_t bindInfoCount,
    const VkBindImageMemoryInfo* pBindInfos);
```

or the equivalent command

```plaintext
// Provided by VK_KHR_bind_memory2
VkResult vkBindImageMemory2KHR(
    VkDevice device,
    uint32_t bindInfoCount,
    const VkBindImageMemoryInfo* pBindInfos);
```

• device is the logical device that owns the images and memory.
• bindInfoCount is the number of elements in pBindInfos.
• pBindInfos is a pointer to an array of VkBindImageMemoryInfo structures, describing images and memory to bind.

On some implementations, it may be more efficient to batch memory bindings into a single command.

Note

If vkBindImageMemory2 fails, and bindInfoCount was greater than one, then the images referenced by pBindInfos will be in an indeterminate state, and must not be used. Applications should destroy these images.
Valid Usage

- VUID-vkBindImageMemory2-pBindInfos-02858
  If any VkBindImageMemoryInfo::image was created with VK_IMAGE_CREATE_DISJOINT_BIT then all planes of VkBindImageMemoryInfo::image must be bound individually in separate pBindInfos

- VUID-vkBindImageMemory2-pBindInfos-04006
  pBindInfos must not refer to the same image subresource more than once

Valid Usage (Implicit)

- VUID-vkBindImageMemory2-device-parameter
device must be a valid VkDevice handle

- VUID-vkBindImageMemory2-pBindInfos-parameter
  pBindInfos must be a valid pointer to an array of bindInfoCount valid VkBindImageMemoryInfo structures

- VUID-vkBindImageMemory2-bindInfoCount-arraylength
  bindInfoCount must be greater than 0

Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

VkBindImageMemoryInfo contains members corresponding to the parameters of vkBindImageMemory.

The VkBindImageMemoryInfo structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkBindImageMemoryInfo {
    VkStructureType sType;
    const void* pNext;
    VkImage image;
    VkDeviceMemory memory;
    VkDeviceSize memoryOffset;
} VkBindImageMemoryInfo;
```

or the equivalent
// Provided by VK_KHR_bind_memory2

typedef VkBindImageMemoryInfo VkBindImageMemoryInfoKHR;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **image** is the image to be attached to memory.
- **memory** is a `VkDeviceMemory` object describing the device memory to attach.
- **memoryOffset** is the start offset of the region of `memory` which is to be bound to the image. The number of bytes returned in the `VkMemoryRequirements::size` member in `memory`, starting from `memoryOffset` bytes, will be bound to the specified image.

**Valid Usage**

- **VUID-VkBindImageMemoryInfo-image-07460**
  - `image` must not have been bound to a memory object

- **VUID-VkBindImageMemoryInfo-image-01045**
  - `image` must not have been created with any sparse memory binding flags

- **VUID-VkBindImageMemoryInfo-memoryOffset-01046**
  - `memoryOffset` must be less than the size of `memory`

- **VUID-VkBindImageMemoryInfo-image-01445**
  - If `image` requires a dedicated allocation (as reported by `vkGetImageMemoryRequirements2` in `VkMemoryDedicatedRequirements::requiresDedicatedAllocation` for `image`), `memory` must have been created with `VkMemoryDedicatedAllocateInfo::image` equal to `image`

- **VUID-VkBindImageMemoryInfo-memory-02628**
  - If the `dedicatedAllocationImageAliasing` feature is not enabled, and the `VkMemoryAllocateInfo` provided when `memory` was allocated included a `VkMemoryDedicatedAllocateInfo` structure in its `pNext` chain, and `VkMemoryDedicatedAllocateInfo::image` was not `VK_NULL_HANDLE`, then `image` must equal `VkMemoryDedicatedAllocateInfo::image` and `memoryOffset` must be zero

- **VUID-VkBindImageMemoryInfo-memory-02629**
  - If the `dedicatedAllocationImageAliasing` feature is enabled, and the `VkMemoryAllocateInfo` provided when `memory` was allocated included a `VkMemoryDedicatedAllocateInfo` structure in its `pNext` chain, and `VkMemoryDedicatedAllocateInfo::image` was not `VK_NULL_HANDLE`, then `memoryOffset` must be zero, and `image` must be either equal to `VkMemoryDedicatedAllocateInfo::image` or an image that was created using the same parameters in `VkImageCreateInfo`, with the exception that `extent` and `arrayLayers` may differ subject to the following restrictions: every dimension in the `extent` parameter of the image being bound must be equal to or smaller than the original image for which the allocation was created; and the `arrayLayers` parameter of the image being bound must be equal to or smaller than the original image for which the allocation was created

- **VUID-VkBindImageMemoryInfo-None-01901**
If image was created with the `VK_IMAGE_CREATE_PROTECTED_BIT` bit set, the image **must** be bound to a memory object allocated with a memory type that reports `VK_MEMORY_PROPERTY_PROTECTED_BIT`

- **VUID-VkBindImageMemoryInfo-None-01902**
  If image was created with the `VK_IMAGE_CREATE_PROTECTED_BIT` bit not set, the image **must** not be bound to a memory object created with a memory type that reports `VK_MEMORY_PROPERTY_PROTECTED_BIT`

- **VUID-VkBindImageMemoryInfo-image-01050**
  If `image` was created with `VkDedicatedAllocationImageCreateInfoNV::dedicatedAllocation` equal to `VK_TRUE`, `memory` **must** have been created with `VkDedicatedAllocationMemoryAllocateInfoNV::image` equal to an image handle created with identical creation parameters to `image` and `memoryOffset` **must** be zero

- **VUID-VkBindImageMemoryInfo-apiVersion-07921**
  If the `VK_KHR_dedicated_allocation` extension is not enabled, `VkPhysicalDeviceProperties::apiVersion` is less than Vulkan 1.1, and `image` was not created with `VkDedicatedAllocationImageCreateInfoNV::dedicatedAllocation` equal to `VK_TRUE`, `memory` **must** not have been allocated dedicated for a specific buffer or image

- **VUID-VkBindImageMemoryInfo-memory-02728**
  If the value of `VkExportMemoryAllocateInfo::handleTypes` used to allocate `memory` is not 0, it **must** include at least one of the handles set in `VkExternalMemoryImageCreateInfo::handleTypes` when `image` was created

- **VUID-VkBindImageMemoryInfo-memory-02989**
  If `memory` was created by a memory import operation, that is not `VkImportAndroidHardwareBufferInfoANDROID` with a non-NULL buffer value, the external handle type of the imported memory **must** also have been set in `VkExternalMemoryImageCreateInfo::handleTypes` when `image` was created

- **VUID-VkBindImageMemoryInfo-memory-02990**
  If `memory` was created with the `VkImportAndroidHardwareBufferInfoANDROID` memory import operation with a non-NULL buffer value, `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID` **must** also have been set in `VkExternalMemoryImageCreateInfo::handleTypes` when `image` was created

- **VUID-VkBindImageMemoryInfo-descriptorBufferCaptureReplay-08113**
  If the `image` was created with the `VK_IMAGE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT` bit set, `memory` **must** have been allocated with the `VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT` bit set

- **VUID-VkBindImageMemoryInfo-image-09202**
  If the `image` was created with the `VK_IMAGE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT` bit set, `memory` **must** have been allocated with the `VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT` bit set

- **VUID-VkBindImageMemoryInfo-pNext-01615**
  If the `pNext` chain does not include a `VkBindImagePlaneMemoryInfo` structure, `memory` **must** have been allocated using one of the memory types allowed in the `memoryTypeBits` member of the `VkMemoryRequirements` structure returned from a call to `vkGetImageMemoryRequirements2` with `image`
If the `pNext` chain does not include a `VkBindImagePlaneMemoryInfo` structure, `memoryOffset` must be an integer multiple of the `alignment` member of the `VkMemoryRequirements` structure returned from a call to `vkGetImageMemoryRequirements2` with `image`.

If the `pNext` chain does not include a `VkBindImagePlaneMemoryInfo` structure, the difference of the size of `memory` and `memoryOffset` must be greater than or equal to the `size` member of the `VkMemoryRequirements` structure returned from a call to `vkGetImageMemoryRequirements2` with the same `image`.

If the `pNext` chain includes a `VkBindImagePlaneMemoryInfo` structure, `image` must have been created with the `VK_IMAGE_CREATE_DISJOINT_BIT` bit set.

If `image` was created with the `VK_IMAGE_CREATE_DISJOINT_BIT` bit set, then the `pNext` chain must include a `VkBindImagePlaneMemoryInfo` structure.

If the `pNext` chain includes a `VkBindImagePlaneMemoryInfo` structure, `memory` must have been allocated using one of the memory types allowed in the `memoryTypeBits` member of the `VkMemoryRequirements` structure returned from a call to `vkGetImageMemoryRequirements2` with `image` and where `VkBindImagePlaneMemoryInfo::planeAspect` corresponds to the `VkImagePlaneMemoryRequirementsInfo::planeAspect` in the `VkImageMemoryRequirementsInfo2` structure's `pNext` chain.

If the `pNext` chain includes a `VkBindImagePlaneMemoryInfo` structure, the difference of the size of `memory` and `memoryOffset` must be greater than or equal to the `size` member of the `VkMemoryRequirements` structure returned from a call to `vkGetImageMemoryRequirements2` with the same `image` and where `VkBindImagePlaneMemoryInfo::planeAspect` corresponds to the `VkImagePlaneMemoryRequirementsInfo::planeAspect` in the `VkImageMemoryRequirementsInfo2` structure's `pNext` chain.

If the `pNext` chain includes a `VkBindImageMemoryDeviceGroupInfo` structure, all instances of `memory` specified by `VkBindImageMemoryDeviceGroupInfo::pDeviceIndices` must have been allocated.

If the `pNext` chain includes a `VkBindImageMemoryInfo` structure, and
 VkBindImageMemoryDeviceGroupInfo::splitInstanceBindRegionCount is not zero, then image must have been created with the VK_IMAGE_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT bit set

• VUID-VkBindImageMemoryInfo-pNext-01628
  If the pNext chain includes a VkBindImageMemoryDeviceGroupInfo structure, all elements of VkBindImageMemoryDeviceGroupInfo::pSplitInstanceBindRegions must be valid rectangles contained within the dimensions of image

• VUID-VkBindImageMemoryInfo-pNext-01629
  If the pNext chain includes a VkBindImageMemoryDeviceGroupInfo structure, the union of the areas of all elements of VkBindImageMemoryDeviceGroupInfo::pSplitInstanceBindRegions that correspond to the same instance of image must cover the entire image

• VUID-VkBindImageMemoryInfo-image-01630
  If image was created with a valid swapchain handle in VkImageSwapchainCreateInfoKHR::swapchain, then the pNext chain must include a VkBindImageMemorySwapchainInfoKHR structure containing the same swapchain handle

• VUID-VkBindImageMemoryInfo-pNext-01631
  If the pNext chain includes a VkBindImageMemorySwapchainInfoKHR structure, memory must be VK_NULL_HANDLE

• VUID-VkBindImageMemoryInfo-pNext-01632
  If the pNext chain does not include a VkBindImageMemorySwapchainInfoKHR structure, memory must be a valid VkDeviceMemory handle

Valid Usage (Implicit)

• VUID-VkBindImageMemoryInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_INFO

• VUID-VkBindImageMemoryInfo-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkBindImageMemoryDeviceGroupInfo, VkBindImageMemorySwapchainInfoKHR, or VkBindImagePlaneMemoryInfo

• VUID-VkBindImageMemoryInfo-sType-unique
  The sType value of each struct in the pNext chain must be unique

• VUID-VkBindImageMemoryInfo-image-parameter
  image must be a valid VkImage handle

• VUID-VkBindImageMemoryInfo-commonparent
  Both of image, and memory that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice

The VkBindImageMemoryDeviceGroupInfo structure is defined as:
typedef struct VkBindImageMemoryDeviceGroupInfo {
    VkStructureType sType;
    const void* pNext;
    uint32_t deviceIndexCount;
    const uint32_t* pDeviceIndices;
    uint32_t splitInstanceBindRegionCount;
    const VkRect2D* pSplitInstanceBindRegions;
} VkBindImageMemoryDeviceGroupInfo;

or the equivalent

// Provided by VK_KHR_bind_memory2 with VK_KHR_device_group
typedef VkBindImageMemoryDeviceGroupInfo VkBindImageMemoryDeviceGroupInfoKHR;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• deviceIndexCount is the number of elements in pDeviceIndices.
• pDeviceIndices is a pointer to an array of device indices.
• splitInstanceBindRegionCount is the number of elements in pSplitInstanceBindRegions.
• pSplitInstanceBindRegions is a pointer to an array of VkRect2D structures describing which regions of the image are attached to each instance of memory.

If the pNext chain of VkBindImageMemoryInfo includes a VkBindImageMemoryDeviceGroupInfo structure, then that structure determines how memory is bound to images across multiple devices in a device group.

If deviceIndexCount is greater than zero, then on device index i image is attached to the instance of the memory on the physical device with device index pDeviceIndices[i].

Let N be the number of physical devices in the logical device. If splitInstanceBindRegionCount is greater than zero, then pSplitInstanceBindRegions is a pointer to an array of N^2 rectangles, where the image region specified by the rectangle at element i*N+j in resource instance i is bound to the memory instance j. The blocks of the memory that are bound to each sparse image block region use an offset in memory, relative to memoryOffset, computed as if the whole image was being bound to a contiguous range of memory. In other words, horizontally adjacent image blocks use consecutive blocks of memory, vertically adjacent image blocks are separated by the number of bytes per block multiplied by the width in blocks of image, and the block at (0,0) corresponds to memory starting at memoryOffset.

If splitInstanceBindRegionCount and deviceIndexCount are zero and the memory comes from a memory heap with the VK_MEMORY_HEAP_MULTI_INSTANCE_BIT bit set, then it is as if pDeviceIndices contains consecutive indices from zero to the number of physical devices in the logical device, minus one. In other words, by default each physical device attaches to its own instance of the memory.
If \texttt{splitInstanceBindRegionCount} and \texttt{deviceIndexCount} are zero and the memory comes from a memory heap without the \texttt{VK_MEMORY_HEAP_MULTI_INSTANCE_BIT} bit set, then it is as if \texttt{pDeviceIndices} contains an array of zeros. In other words, by default each physical device attaches to instance zero.

### Valid Usage

- **VUID-VkBindImageMemoryDeviceGroupInfo-deviceIndexCount-01633**
  At least one of \texttt{deviceIndexCount} and \texttt{splitInstanceBindRegionCount} must be zero

- **VUID-VkBindImageMemoryDeviceGroupInfo-deviceIndexCount-01634**
  \texttt{deviceIndexCount} must either be zero or equal to the number of physical devices in the logical device

- **VUID-VkBindImageMemoryDeviceGroupInfo-pDeviceIndices-01635**
  All elements of \texttt{pDeviceIndices} must be valid device indices

- **VUID-VkBindImageMemoryDeviceGroupInfo-splitInstanceBindRegionCount-01636**
  \texttt{splitInstanceBindRegionCount} must either be zero or equal to the number of physical devices in the logical device squared

- **VUID-VkBindImageMemoryDeviceGroupInfo-pSplitInstanceBindRegions-01637**
  Elements of \texttt{pSplitInstanceBindRegions} that correspond to the same instance of an image must not overlap

- **VUID-VkBindImageMemoryDeviceGroupInfo-offset-01638**
  The \texttt{offset.x} member of any element of \texttt{pSplitInstanceBindRegions} must be a multiple of the sparse image block width (\texttt{VkSparseImageFormatProperties::imageGranularity.width}) of all non-metadata aspects of the image

- **VUID-VkBindImageMemoryDeviceGroupInfo-offset-01639**
  The \texttt{offset.y} member of any element of \texttt{pSplitInstanceBindRegions} must be a multiple of the sparse image block height (\texttt{VkSparseImageFormatProperties::imageGranularity.height}) of all non-metadata aspects of the image

- **VUID-VkBindImageMemoryDeviceGroupInfo_extent-01640**
  The \texttt{extent.width} member of any element of \texttt{pSplitInstanceBindRegions} must either be a multiple of the sparse image block width of all non-metadata aspects of the image, or else \texttt{extent.width + offset.x} must equal the width of the image subresource

- **VUID-VkBindImageMemoryDeviceGroupInfo_extent-01641**
  The \texttt{extent.height} member of any element of \texttt{pSplitInstanceBindRegions} must either be a multiple of the sparse image block height of all non-metadata aspects of the image, or else \texttt{extent.height + offset.y} must equal the height of the image subresource

### Valid Usage (Implicit)

- **VUID-VkBindImageMemoryDeviceGroupInfo-sType-sType**
  \texttt{sType} must be \texttt{VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_DEVICE_GROUP_INFO}

- **VUID-VkBindImageMemoryDeviceGroupInfo-pDeviceIndices-parameter**
  If \texttt{deviceIndexCount} is not 0, \texttt{pDeviceIndices} must be a valid pointer to an array of \texttt{deviceIndexCount uint32_t} values
If splitInstanceBindRegionCount is not 0, pSplitInstanceBindRegions must be a valid pointer to an array of splitInstanceBindRegionCount VkRect2D structures.

If the pNext chain of VkBindImageMemoryInfo includes a VkBindImageMemorySwapchainInfoKHR structure, then that structure includes a swapchain handle and image index indicating that the image will be bound to memory from that swapchain.

The VkBindImageMemorySwapchainInfoKHR structure is defined as:

```c
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with VK_KHR_swapchain
typedef struct VkBindImageMemorySwapchainInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkSwapchainKHR swapchain;
    uint32_t imageIndex;
} VkBindImageMemorySwapchainInfoKHR;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **swapchain** is VK_NULL_HANDLE or a swapchain handle.
- **imageIndex** is an image index within swapchain.

If swapchain is not NULL, the swapchain and imageIndex are used to determine the memory that the image is bound to, instead of memory and memoryOffset.

Memory can be bound to a swapchain and use the pDeviceIndices or pSplitInstanceBindRegions members of VkBindImageMemoryDeviceGroupInfo.

**Valid Usage**

- VUID-VkBindImageMemorySwapchainInfoKHR-imageIndex-01644
  imageIndex must be less than the number of images in swapchain

- VUID-VkBindImageMemorySwapchainInfoKHR-swapchain-07756
  If the swapchain has been created with VK_SWAPCHAIN_CREATE_DEFERRED_MEMORY_ALLOCATION_BIT_EXT, imageIndex must be one that has previously been returned by vkAcquireNextImageKHR or vkAcquireNextImage2KHR

**Valid Usage (Implicit)**

- VUID-VkBindImageMemorySwapchainInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_SWAPCHAIN_INFO_KHR

- VUID-VkBindImageMemorySwapchainInfoKHR-swapchain-parameter
**swapchain** must be a valid `VkSwapchainKHR` handle

### Host Synchronization

- Host access to **swapchain** must be externally synchronized

In order to bind *planes* of a *disjoint image*, add a `VkBindImagePlaneMemoryInfo` structure to the `pNext` chain of `VkBindImageMemoryInfo`.

The `VkBindImagePlaneMemoryInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkBindImagePlaneMemoryInfo {
    VkStructureType       sType;
    const void*            pNext;
    VkImageAspectFlagBits  planeAspect;
} VkBindImagePlaneMemoryInfo;
```

or the equivalent

```c
// Provided by VK_KHR_sampler_ycbcr_conversion
typedef VkBindImagePlaneMemoryInfo VkBindImagePlaneMemoryInfoKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **planeAspect** is a `VkImageAspectFlagBits` value specifying the aspect of the disjoint image plane to bind.

### Valid Usage

- **VUID-VkBindImagePlaneMemoryInfo-planeAspect-02283**
  If the image's tiling is `VK_IMAGE_TILING_LINEAR` or `VK_IMAGE_TILING_OPTIMAL`, then `planeAspect` must be a single valid multi-planar aspect mask bit

- **VUID-VkBindImagePlaneMemoryInfo-planeAspect-02284**
  If the image's tiling is `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`, then `planeAspect` must be a single valid memory plane for the image (that is, `aspectMask` must specify a plane index that is less than the `VkDrmFormatModifierPropertiesEXT::drmFormatModifierPlaneCount` associated with the image's format and `VkImageDrmFormatModifierPropertiesEXT::drmFormatModifier`)
Valid Usage (Implicit)

- VUID-VkBindImagePlaneMemoryInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_BIND_IMAGE_PLANE_MEMORY_INFO
- VUID-VkBindImagePlaneMemoryInfo-planeAspect-parameter
  planeAspect must be a valid VkImageAspectFlagBits value

Buffer-Image Granularity

The implementation-dependent limit bufferImageGranularity specifies a page-like granularity at which linear and non-linear resources must be placed in adjacent memory locations to avoid aliasing. Two resources which do not satisfy this granularity requirement are said to alias. bufferImageGranularity is specified in bytes, and must be a power of two. Implementations which do not impose a granularity restriction may report a bufferImageGranularity value of one.

Note

Despite its name, bufferImageGranularity is really a granularity between “linear” and “non-linear” resources.

Given resourceA at the lower memory offset and resourceB at the higher memory offset in the same VkDeviceMemory object, where one resource is linear and the other is non-linear (as defined in the Glossary), and the following:

```plaintext
resourceA.end = resourceA.memoryOffset + resourceA.size - 1
resourceA.endPage = resourceA.end & ~(bufferImageGranularity-1)
resourceB.start = resourceB.memoryOffset
resourceB.startPage = resourceB.start & ~(bufferImageGranularity-1)
```

The following property must hold:

```plaintext
resourceA.endPage < resourceB.startPage
```

That is, the end of the first resource (A) and the beginning of the second resource (B) must be on separate “pages” of size bufferImageGranularity. bufferImageGranularity may be different than the physical page size of the memory heap. This restriction is only needed when a linear resource and a non-linear resource are adjacent in memory and will be used simultaneously. The memory ranges of adjacent resources can be closer than bufferImageGranularity, provided they meet the alignment requirement for the objects in question.

Sparse block size in bytes and sparse image and buffer memory alignments must all be multiples of the bufferImageGranularity. Therefore, memory bound to sparse resources naturally satisfies the bufferImageGranularity.
12.9. Resource Sharing Mode

Buffer and image objects are created with a sharing mode controlling how they can be accessed from queues. The supported sharing modes are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkSharingMode {
    VK_SHARING_MODE_EXCLUSIVE = 0,
    VK_SHARING_MODE_CONCURRENT = 1,
} VkSharingMode;
```

- **VK_SHARING_MODE_EXCLUSIVE** specifies that access to any range or image subresource of the object will be exclusive to a single queue family at a time.
- **VK_SHARING_MODE_CONCURRENT** specifies that concurrent access to any range or image subresource of the object from multiple queue families is supported.

**Note**

**VK_SHARING_MODE_CONCURRENT** may result in lower performance access to the buffer or image than **VK_SHARING_MODE_EXCLUSIVE**.

Ranges of buffers and image subresources of image objects created using **VK_SHARING_MODE_EXCLUSIVE** must only be accessed by queues in the queue family that has ownership of the resource. Upon creation, such resources are not owned by any queue family; ownership is implicitly acquired upon first use within a queue. Once a resource using **VK_SHARING_MODE_EXCLUSIVE** is owned by some queue family, the application must perform a queue family ownership transfer to make the memory contents of a range or image subresource accessible to a different queue family.

**Note**

Images still require a layout transition from **VK_IMAGE_LAYOUT_UNDEFINED** or **VK_IMAGE_LAYOUT_PREINITIALIZED** before being used on the first queue.

A queue family can take ownership of an image subresource or buffer range of a resource created with **VK_SHARING_MODE_EXCLUSIVE**, without an ownership transfer, in the same way as for a resource that was just created; however, taking ownership in this way has the effect that the contents of the image subresource or buffer range are undefined.

Ranges of buffers and image subresources of image objects created using **VK_SHARING_MODE_CONCURRENT** must only be accessed by queues from the queue families specified through the `queueFamilyIndexCount` and `pQueueFamilyIndices` members of the corresponding create info structures.

12.9.1. External Resource Sharing

Resources should only be accessed in the Vulkan instance that has exclusive ownership of their underlying memory. Only one Vulkan instance has exclusive ownership of a resource’s underlying memory at a given time, regardless of whether the resource was created using
VK_SHARING_MODE_EXCLUSIVE or VK_SHARING_MODE_CONCURRENT. Applications can transfer ownership of a resource’s underlying memory only if the memory has been imported from or exported to another instance or external API using external memory handles. The semantics for transferring ownership outside of the instance are similar to those used for transferring ownership of VK_SHARING_MODE_EXCLUSIVE resources between queues, and is also accomplished using VkBufferMemoryBarrier or VkImageMemoryBarrier operations. To make the contents of the underlying memory accessible in the destination instance or API, applications must

1. Release exclusive ownership from the source instance or API.
2. Ensure the release operation has completed using semaphores or fences.
3. Acquire exclusive ownership in the destination instance or API.

Unlike queue ownership transfers, the destination instance or API is not specified explicitly when releasing ownership, nor is the source instance or API specified when acquiring ownership. Instead, the image or memory barrier’s dstQueueFamilyIndex or srcQueueFamilyIndex parameters are set to the reserved queue family index VK_QUEUE_FAMILY_EXTERNAL or VK_QUEUE_FAMILY_FOREIGN_EXT to represent the external destination or source respectively.

Binding a resource to a memory object shared between multiple Vulkan instances or other APIs does not change the ownership of the underlying memory. The first entity to access the resource implicitly acquires ownership. An entity can also implicitly take ownership from another entity in the same way without an explicit ownership transfer. However, taking ownership in this way has the effect that the contents of the underlying memory are undefined.

Accessing a resource backed by memory that is owned by a particular instance or API has the same semantics as accessing a VK_SHARING_MODE_EXCLUSIVE resource, with one exception: Implementations must ensure layout transitions performed on one member of a set of identical subresources of identical images that alias the same range of an underlying memory object affect the layout of all the subresources in the set.

As a corollary, writes to any image subresources in such a set must not make the contents of memory used by other subresources in the set undefined. An application can define the content of a subresource of one image by performing device writes to an identical subresource of another image provided both images are bound to the same region of external memory. Applications may also add resources to such a set after the content of the existing set members has been defined without making the content undefined by creating a new image with the initial layout VK_IMAGE_LAYOUT_UNDEFINED and binding it to the same region of external memory as the existing images.

**Note**
Because layout transitions apply to all identical images aliasing the same region of external memory, the actual layout of the memory backing a new image as well as an existing image with defined content will not be undefined. Such an image is not usable until it acquires ownership of its memory from the existing owner. Therefore, the layout specified as part of this transition will be the true initial layout of the image. The undefined layout specified when creating it is a placeholder to simplify valid usage requirements.
12.10. Memory Aliasing

A range of a 
VkDeviceMemory allocation is aliased if it is bound to multiple resources simultaneously, as described below, via \texttt{vkBindImageMemory}, \texttt{vkBindBufferMemory}, \texttt{vkBindAccelerationStructureMemoryNV}, via sparse memory bindings, or by binding the memory to resources in multiple Vulkan instances or external APIs using external memory handle export and import mechanisms.

Consider two resources, resource \(_A\) and resource \(_B\), bound respectively to memory range \(_A\) and range \(_B\). Let \texttt{paddedRange}_A and \texttt{paddedRange}_B be, respectively, range \(_A\) and range \(_B\) aligned to \texttt{bufferImageGranularity}. If the resources are both linear or both non-linear (as defined in the Glossary), then the resources alias the memory in the intersection of range \(_A\) and range \(_B\). If one resource is linear and the other is non-linear, then the resources alias the memory in the intersection of \texttt{paddedRange}_A and \texttt{paddedRange}_B.

Applications can alias memory, but use of multiple aliases is subject to several constraints.

\begin{itemize}
  \item Note
  Memory aliasing can be useful to reduce the total device memory footprint of an application, if some large resources are used for disjoint periods of time.
\end{itemize}

When a non-linear, non-\texttt{VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT} image is bound to an aliased range, all image subresources of the image overlap the range. When a linear image is bound to an aliased range, the image subresources that (according to the image’s advertised layout) include bytes from the aliased range overlap the range. When a \texttt{VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT} image has sparse image blocks bound to an aliased range, only image subresources including those sparse image blocks overlap the range, and when the memory bound to the image’s mip tail overlaps an aliased range all image subresources in the mip tail overlap the range.

Buffers, and linear image subresources in either the \texttt{VK_IMAGE_LAYOUT_PREINITIALIZED} or \texttt{VK_IMAGE_LAYOUT_GENERAL} layouts, are host-accessible subresources. That is, the host has a well-defined addressing scheme to interpret the contents, and thus the layout of the data in memory can be consistently interpreted across aliases if each of those aliases is a host-accessible subresource. Non-linear images, and linear image subresources in other layouts, are not host-accessible.

If two aliases are both host-accessible, then they interpret the contents of the memory in consistent ways, and data written to one alias can be read by the other alias.

If two aliases are both images that were created with identical creation parameters, both were created with the \texttt{VK_IMAGE_CREATE_ALIAS_BIT} flag set, and both are bound identically to memory except for \texttt{VkBindImageMemoryDeviceGroupInfo::pDeviceIndices} and \texttt{VkBindImageMemoryDeviceGroupInfo::pSplitInstanceBindRegions}, then they interpret the contents of the memory in consistent ways, and data written to one alias can be read by the other alias.

Additionally, if an individual plane of a multi-planar image and a single-plane image alias the same memory, then they also interpret the contents of the memory in consistent ways under the same conditions, but with the following modifications:

\begin{itemize}
  \item Both must have been created with the \texttt{VK_IMAGE_CREATE_DISJOINT_BIT} flag.
\end{itemize}
• The single-plane image **must** have a *VkFormat* that is **equivalent** to that of the multi-planar image's individual plane.

• The single-plane image and the individual plane of the multi-planar image **must** be bound identically to memory except for *VkBindImageMemoryDeviceGroupInfo::pDeviceIndices* and *VkBindImageMemoryDeviceGroupInfo::pSplitInstanceBindRegions*.

• The **width** and **height** of the single-plane image are derived from the multi-planar image's dimensions in the manner listed for **plane compatibility** for the aliased plane.

• If either image's **tiling** is *VK_IMAGE_TILING_OPAQUE_FORMAT_MODIFIER_EXT*, then both images **must** be **linear**.

• All other creation parameters **must** be identical

Aliases created by binding the same memory to resources in multiple Vulkan instances or external APIs using external memory handle export and import mechanisms interpret the contents of the memory in consistent ways, and data written to one alias **can** be read by the other alias.

Otherwise, the aliases interpret the contents of the memory differently, and writes via one alias make the contents of memory partially or completely undefined to the other alias. If the first alias is a host-accessible subresource, then the bytes affected are those written by the memory operations according to its addressing scheme. If the first alias is not host-accessible, then the bytes affected are those overlapped by the image subresources that were written. If the second alias is a host-accessible subresource, the affected bytes become undefined. If the second alias is not host-accessible, all sparse image blocks (for sparse partially-resident images) or all image subresources (for non-sparse image and fully resident sparse images) that overlap the affected bytes become undefined.

If any image subresources are made undefined due to writes to an alias, then each of those image subresources **must** have its layout transitioned from *VK_IMAGE_LAYOUT_UNDEFINED* to a valid layout before it is used, or from *VK_IMAGE_LAYOUT_PREINITIALIZED* if the memory has been written by the host. If any sparse blocks of a sparse image have been made undefined, then only the image subresources containing them **must** be transitioned.

Use of an overlapping range by two aliases **must** be separated by a memory dependency using the appropriate **access types** if at least one of those uses performs writes, whether the aliases interpret memory consistently or not. If buffer or image memory barriers are used, the scope of the barrier **must** contain the entire range and/or set of image subresources that overlap.

If two aliasing image views are used in the same framebuffer, then the render pass **must** declare the attachments using the *VK_ATTACHMENT_DESCRIPTION_MAY_ALIAS_BIT*, and follow the other rules listed in that section.

---

**Note**

Memory recycled via an application suballocator (i.e. without freeing and reallocating the memory objects) is not substantially different from memory aliasing. However, a suballocator usually waits on a fence before recycling a region of memory, and signaling a fence involves sufficient implicit dependencies to satisfy all the above requirements.
12.10.1. Resource Memory Overlap

Applications can safely access a resource concurrently as long as the memory locations do not overlap as defined in Memory Location. This includes aliased resources if such aliasing is well-defined. It also includes access from different queues and/or queue families if such concurrent access is supported by the resource. Transfer commands only access memory locations specified by the range of the transfer command.

Note
The intent is that buffers (or linear images) can be accessed concurrently, even when they share cache lines, but otherwise do not access the same memory range. The concept of a device cache line size is not exposed in the memory model.

12.11. Buffer Collections

Fuchsia's FIDL-based Sysmem service interoperates with Vulkan via the VK_FUCHSIA_buffer_collection extension.

A buffer collection is a set of one or more buffers which were allocated together as a group and which all have the same properties. These properties describe the buffers' internal representation, such as its dimensions and memory layout. This ensures that all of the buffers can be used interchangeably by tasks that require swapping among multiple buffers, such as double-buffered graphics rendering.

On Fuchsia, the Sysmem service uses buffer collections as a core construct in its design.

Buffer collections are represented by VkBufferCollectionFUCHSIA handles:

```
// Provided by VK_FUCHSIA_buffer_collection
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkBufferCollectionFUCHSIA)
```

12.11.1. Definitions

• FIDL - Fuchsia Interface Definition Language. The declarative language used to define FIDL interprocess communication interfaces on Fuchsia. FIDL files use the fidl extension. FIDL is also used to refer to the services defined by interfaces declared in the FIDL language
• Sysmem - The FIDL service that facilitates optimal buffer sharing and reuse on Fuchsia
• client - Any participant of the buffer collection e.g. the Vulkan application
• token - A zx_handle_t Zircon channel object that allows participation in the buffer collection

12.11.2. Platform initialization for buffer collections

To initialize a buffer collection on Fuchsia:

• Connect to the Sysmem service to initialize a Sysmem allocator
• Create an initial buffer collection token using the Sysmem allocator
• Duplicate the token for each participant beyond the initiator
• See the Sysmem Overview and fuchsia.sysmem FIDL documentation on fuchsia.dev for more detailed information

12.11.3. Create the buffer collection

To create an VkBufferCollectionFUCHSIA for Vulkan to participate in the buffer collection:

```c
// Provided by VK_FUCHSIA_buffer_collection
VkResult vkCreateBufferCollectionFUCHSIA(
    VkDevice device,
    const VkBufferCollectionCreateInfoFUCHSIA* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkBufferCollectionFUCHSIA* pCollection);
```

• `device` is the logical device that creates the VkBufferCollectionFUCHSIA
• `pCreateInfo` is a pointer to a VkBufferCollectionCreateInfoFUCHSIA structure containing parameters affecting creation of the buffer collection
• `pAllocator` is a pointer to a VkAllocationCallbacks structure controlling host memory allocation as described in the Memory Allocation chapter
• `pBufferCollection` is a pointer to a VkBufferCollectionFUCHSIA handle in which the resulting buffer collection object is returned

Valid Usage (Implicit)

• VUID-vkCreateBufferCollectionFUCHSIA-device-parameter
  `device` must be a valid VkDevice handle
• VUID-vkCreateBufferCollectionFUCHSIA-pCreateInfo-parameter
  `pCreateInfo` must be a valid pointer to a valid VkBufferCollectionCreateInfoFUCHSIA structure
• VUID-vkCreateBufferCollectionFUCHSIA-pAllocator-parameter
  If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid VkAllocationCallbacks structure
• VUID-vkCreateBufferCollectionFUCHSIA-pCollection-parameter
  `pCollection` must be a valid pointer to a VkBufferCollectionFUCHSIA handle

Return Codes

Success
• VK_SUCCESS

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
Host Access

All functions referencing a VkBufferCollectionFUCHSIA must be externally synchronized with the exception of vkCreateBufferCollectionFUCHSIA.

The VkBufferCollectionCreateInfoFUCHSIA structure is defined as:

```c
// Provided by VK_FUCHSIA_buffer_collection
typedef struct VkBufferCollectionCreateInfoFUCHSIA {
    VkStructureType sType;
    const void* pNext;
    zx_handle_t collectionToken;
} VkBufferCollectionCreateInfoFUCHSIA;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **collectionToken** is a zx_handle_t containing the Sysmem client’s buffer collection token.

Valid Usage

- VUID-VkBufferCollectionCreateInfoFUCHSIA-collectionToken-06393
collectionToken must be a valid zx_handle_t to a Zircon channel allocated from Sysmem (fuchsia.sysmem.Allocator/AllocateSharedCollection) with ZX_DEFAULT_CHANNEL_RIGHTS rights.

Valid Usage (Implicit)

- VUID-VkBufferCollectionCreateInfoFUCHSIA-sType-sType
  sType must be VK_STRUCTURE_TYPE_BUFFER_COLLECTION_CREATE_INFO_FUCHSIA.
- VUID-VkBufferCollectionCreateInfoFUCHSIA-pNext-pNext
  pNext must be NULL.

### 12.11.4. Set the constraints

Buffer collections can be established for VkImage allocations or VkBuffer allocations.

**Set image-based buffer collection constraints**

Setting the constraints on the buffer collection initiates the format negotiation and allocation of the
buffer collection. To set the constraints on a VkImage buffer collection, call:

```c
// Provided by VK_FUCHSIA_buffer_collection
VkResult vkSetBufferCollectionImageConstraintsFUCHSIA(
    VkDevice device,
    VkBufferCollectionFUCHSIA collection,
    const VkImageConstraintsInfoFUCHSIA* pImageConstraintsInfo);
```

- `device` is the logical device
- `collection` is the VkBufferCollectionFUCHSIA handle
- `pImageConstraintsInfo` is a pointer to a VkImageConstraintsInfoFUCHSIA structure

`vkSetBufferCollectionImageConstraintsFUCHSIA` may fail if `pImageConstraintsInfo::formatConstraintsCount` is larger than the implementation-defined limit. If that occurs, `vkSetBufferCollectionImageConstraintsFUCHSIA` will return VK_ERROR_INITIALIZATION_FAILED.

`vkSetBufferCollectionImageConstraintsFUCHSIA` may fail if the implementation does not support any of the formats described by the `pImageConstraintsInfo` structure. If that occurs, `vkSetBufferCollectionImageConstraintsFUCHSIA` will return VK_ERROR_FORMAT_NOT_SUPPORTED.

**Valid Usage**

- VUID-vkSetBufferCollectionImageConstraintsFUCHSIA-collection-06394
  `vkSetBufferCollectionImageConstraintsFUCHSIA` or `vkSetBufferCollectionBufferConstraintsFUCHSIA` must not have already been called on `collection`

**Valid Usage (Implicit)**

- VUID-vkSetBufferCollectionImageConstraintsFUCHSIA-device-parameter
  `device` must be a valid VkDevice handle

- VUID-vkSetBufferCollectionImageConstraintsFUCHSIA-collection-parameter
  `collection` must be a valid VkBufferCollectionFUCHSIA handle

- VUID-vkSetBufferCollectionImageConstraintsFUCHSIA-pImageConstraintsInfo-parameter
  `pImageConstraintsInfo` must be a valid pointer to a valid VkImageConstraintsInfoFUCHSIA structure

- VUID-vkSetBufferCollectionImageConstraintsFUCHSIA-collection-parent
  `collection` must have been created, allocated, or retrieved from `device`

**Return Codes**

**Success**

- VK_SUCCESS
Failure

- VK_ERROR_INITIALIZATION_FAILED
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_FORMAT_NOT_SUPPORTED

The VkImageConstraintsInfoFUCHSIA structure is defined as:

```c
// Provided by VK_FUCHSIA_buffer_collection
typedef struct VkImageConstraintsInfoFUCHSIA {
    VkStructureType         sType;
    const void*              pNext;
    uint32_t                 formatConstraintsCount;
    const VkImageFormatConstraintsInfoFUCHSIA* pFormatConstraints;
    VkBufferCollectionConstraintsInfoFUCHSIA bufferCollectionConstraints;
    VkImageConstraintsInfoFlagsFUCHSIA   flags;
} VkImageConstraintsInfoFUCHSIA;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `formatConstraintsCount` is the number of elements in `pFormatConstraints`.
- `pFormatConstraints` is a pointer to an array of `VkImageFormatConstraintsInfoFUCHSIA` structures of size `formatConstraintsCount` that is used to further constrain buffer collection format selection for image-based buffer collections.
- `bufferCollectionConstraints` is a `VkBufferCollectionConstraintsInfoFUCHSIA` structure used to supply parameters for the negotiation and allocation for buffer-based buffer collections.
- `flags` is a `VkImageConstraintsInfoFlagBitsFUCHSIA` value specifying hints about the type of memory Sysmem should allocate for the buffer collection.

Valid Usage

- VUID-VkImageConstraintsInfoFUCHSIA-pFormatConstraints-06395
  All elements of `pFormatConstraints` must have at least one bit set in its `VkImageFormatConstraintsInfoFUCHSIA::requiredFormatFeatures`

- VUID-VkImageConstraintsInfoFUCHSIA-pFormatConstraints-06396
  If `pFormatConstraints::imageCreateInfo::usage` contains `VK_IMAGE_USAGE_SAMPLED_BIT`, then `pFormatConstraints::requiredFormatFeatures` must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT`

- VUID-VkImageConstraintsInfoFUCHSIA-pFormatConstraints-06397
  If `pFormatConstraints::imageCreateInfo::usage` contains `VK_IMAGE_USAGE_STORAGE_BIT`, then `pFormatConstraints::requiredFormatFeatures` must contain `VK_FORMAT_FEATURE_STORAGE_IMAGE_BIT`

- VUID-VkImageConstraintsInfoFUCHSIA-pFormatConstraints-06398
If \( pFormatConstraints::imageCreateInfo::usage \) contains \( VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT \), then \( pFormatConstraints::requiredFormatFeatures \) must contain \( VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT \)

- **VUID-VkImageConstraintsInfoFUCHSIA-pFormatConstraints-06399**
  If \( pFormatConstraints::imageCreateInfo::usage \) contains \( VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT \), then \( pFormatConstraints::requiredFormatFeatures \) must contain \( VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT \)

- **VUID-VkImageConstraintsInfoFUCHSIA-pFormatConstraints-06400**
  If \( pFormatConstraints::imageCreateInfo::usage \) contains \( VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT \), then \( pFormatConstraints::requiredFormatFeatures \) must contain at least one of \( VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT \) or \( VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT \)

- **VUID-VkImageConstraintsInfoFUCHSIA-attachmentFragmentShadingRate-06401**
  If the \( attachmentFragmentShadingRate \) feature is enabled, and \( pFormatConstraints::imageCreateInfo::usage \) contains \( VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR \), then \( pFormatConstraints::requiredFormatFeatures \) must contain \( VK_FORMAT_FEATURE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR \)

### Valid Usage (Implicit)

- **VUID-VkImageConstraintsInfoFUCHSIA-sType-sType**
  \( sType \) must be \( VK_STRUCTURE_TYPE_IMAGE_CONSTRAINTS_INFO_FUCHSIA \)

- **VUID-VkImageConstraintsInfoFUCHSIA-pNext-pNext**
  \( pNext \) must be \( NULL \)

- **VUID-VkImageConstraintsInfoFUCHSIA-pFormatConstraints-parameter**
  \( pFormatConstraints \) must be a valid pointer to an array of \( formatConstraintsCount \) valid \( VkImageFormatConstraintsInfoFUCHSIA \) structures

- **VUID-VkImageConstraintsInfoFUCHSIA-bufferCollectionConstraints-parameter**
  \( bufferCollectionConstraints \) must be a valid \( VkBufferCollectionConstraintsInfoFUCHSIA \) structure

- **VUID-VkImageConstraintsInfoFUCHSIA-flags-parameter**
  \( flags \) must be a valid combination of \( VkImageConstraintsInfoFlagBitsFUCHSIA \) values

- **VUID-VkImageConstraintsInfoFUCHSIA-formatConstraintsCount-arraylength**
  \( formatConstraintsCount \) must be greater than \( 0 \)

// Provided by VK_FUCHSIA_buffer_collection

```c
typedef VkFlags VkImageConstraintsInfoFlagsFUCHSIA;
```

\( VkImageConstraintsInfoFlagsFUCHSIA \) is a bitmask type for setting a mask of zero or more \( VkImageConstraintsInfoFlagBitsFUCHSIA \) bits.
Bits which can be set in `VkImageConstraintsInfoFlagBitsFUCHSIA::flags` include:

```c
typedef enum VkImageConstraintsInfoFlagBitsFUCHSIA {
    VK_IMAGE_CONSTRAINTS_INFO_CPU_READ_RARELY_FUCHSIA = 0x00000001,
    VK_IMAGE_CONSTRAINTS_INFO_CPU_READ_OFTEN_FUCHSIA = 0x00000002,
    VK_IMAGE_CONSTRAINTS_INFO_CPU_WRITE_RARELY_FUCHSIA = 0x00000004,
    VK_IMAGE_CONSTRAINTS_INFO_CPU_WRITE_OFTEN_FUCHSIA = 0x00000008,
    VK_IMAGE_CONSTRAINTS_INFO_PROTECTED_OPTIONAL_FUCHSIA = 0x00000010,
} VkImageConstraintsInfoFlagBitsFUCHSIA;
```

General hints about the type of memory that should be allocated by Sysmem based on the expected usage of the images in the buffer collection include:

- `VK_IMAGE_CONSTRAINTS_INFO_CPU_READ_RARELY_FUCHSIA`
- `VK_IMAGE_CONSTRAINTS_INFO_CPU_READ_OFTEN_FUCHSIA`
- `VK_IMAGE_CONSTRAINTS_INFO_CPU_WRITE_RARELY_FUCHSIA`
- `VK_IMAGE_CONSTRAINTS_INFO_CPU_WRITE_OFTEN_FUCHSIA`

For protected memory:

- `VK_IMAGE_CONSTRAINTS_INFO_PROTECTED_OPTIONAL_FUCHSIA` specifies that protected memory is optional for the buffer collection.

Note that if all participants in the buffer collection (Vulkan or otherwise) specify that protected memory is optional, Sysmem will not allocate protected memory.

The `VkImageFormatConstraintsInfoFUCHSIA` structure is defined as:

```c
typedef struct VkImageFormatConstraintsInfoFUCHSIA {
    VkStructureType sType;                         
    const void* pNext;                           
    VkImageCreateInfo imageCreateInfo;           
    VkFormatFeatureFlags requiredFormatFeatures; 
    VkImageFormatConstraintsFlagsFUCHSIA flags;   
    uint64_t sysmemPixelFormat;                  
    uint32_t colorSpaceCount;                    
    const VkSysmemColorSpaceFUCHSIA* pColorSpaces; 
} VkImageFormatConstraintsInfoFUCHSIA;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `imageCreateInfo` is the `VkImageCreateInfo` used to create a `VkImage` that is to use memory from the `VkBufferCollectionFUCHSIA`.
- `requiredFormatFeatures` is a bitmask of `VkFormatFeatureFlagBits` specifying required features of
the buffers in the buffer collection

• **flags** is reserved for future use

• **sysmemPixelFormat** is a **PixelFormatType** value from the **fuchsia.sysmem/image_formats.fidl** FIDL interface

• **colorSpaceCount** the element count of **pColorSpaces**

• **pColorSpaces** is a pointer to an array of **VkSysmemColorSpaceFUCHSIA** structs of size **colorSpaceCount**

---

**Valid Usage (Implicit)**

- **VUID-VkImageFormatConstraintsInfoFUCHSIA-sType-sType**
  
  **sType** must be **VK_STRUCTURE_TYPE_IMAGE_FORMAT_CONSTRAINTS_INFO_FUCHSIA**

- **VUID-VkImageFormatConstraintsInfoFUCHSIA-pNext-pNext**
  
  **pNext** must be **NULL**

- **VUID-VkImageFormatConstraintsInfoFUCHSIA-imageCreateInfo-parameter**
  
  **imageCreateInfo** must be a valid **VkImageCreateInfo** structure

- **VUID-VkImageFormatConstraintsInfoFUCHSIA-requiredFormatFeatures-parameter**
  
  **requiredFormatFeatures** must be a valid combination of **VkFormatFeatureFlagBits** values

- **VUID-VkImageFormatConstraintsInfoFUCHSIA-requiredFormatFeatures-requiredbitmask**
  
  **requiredFormatFeatures** must not be 0

- **VUID-VkImageFormatConstraintsInfoFUCHSIA-flags-zeroBitmask**
  
  **flags** must be 0

- **VUID-VkImageFormatConstraintsInfoFUCHSIA-pColorSpaces-parameter**
  
  **pColorSpaces** must be a valid pointer to an array of **colorSpaceCount** valid **VkSysmemColorSpaceFUCHSIA** structures

- **VUID-VkImageFormatConstraintsInfoFUCHSIA-colorSpaceCount-arraylength**
  
  **colorSpaceCount** must be greater than 0

---

```c
// Provided by VK_FUCHSIA_buffer_collection
typedef VkFlags VkImageFormatConstraintsFlagsFUCHSIA;
```

**VkImageFormatConstraintsFlagsFUCHSIA** is a bitmask type for setting a mask, but is currently reserved for future use.

The **VkBufferCollectionConstraintsInfoFUCHSIA** structure is defined as:

```c
// Provided by VK_FUCHSIA_buffer_collection
typedef struct VkBufferCollectionConstraintsInfoFUCHSIA {
    VkStructureType sType;
    const void* pNext;
    uint32_t minBufferCount;
    uint32_t maxBufferCount;
} VkBufferCollectionConstraintsInfoFUCHSIA;
```
uint32_t minBufferCountForCamping;
uint32_t minBufferCountForDedicatedSlack;
uint32_t minBufferCountForSharedSlack;
} VkBufferCollectionConstraintsInfoFUCHSIA;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure
- **minBufferCount** is the minimum number of buffers available in the collection
- **maxBufferCount** is the maximum number of buffers allowed in the collection
- **minBufferCountForCamping** is the per-participant minimum buffers for camping
- **minBufferCountForDedicatedSlack** is the per-participant minimum buffers for dedicated slack
- **minBufferCountForSharedSlack** is the per-participant minimum buffers for shared slack

Sysmem uses all buffer count parameters in combination to determine the number of buffers it will allocate. Sysmem defines buffer count constraints in `fuchsia.sysmem/constraints.fidl`.

**Camping** as referred to by `minBufferCountForCamping`, is the number of buffers that should be available for the participant that are not for transient use. This number of buffers is required for the participant to logically operate.

**Slack** as referred to by `minBufferCountForDedicatedSlack` and `minBufferCountForSharedSlack`, refers to the number of buffers desired by participants for optimal performance. `minBufferCountForDedicatedSlack` refers to the current participant. `minBufferCountForSharedSlack` refers to buffer slack for all participants in the collection.

**Valid Usage (Implicit)**

- VUID-VkBufferCollectionConstraintsInfoFUCHSIA-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_BUFFER_COLLECTION_CONSTRAINTS_INFO_FUCHSIA`
- VUID-VkBufferCollectionConstraintsInfoFUCHSIA-pNext-pNext
  - `pNext` must be NULL

The `VkSysmemColorSpaceFUCHSIA` structure is defined as:

```c
// Provided by VK_FUCHSIA_buffer_collection
typedef struct VkSysmemColorSpaceFUCHSIA {
    VkStructureType sType;
    const void* pNext;
    uint32_t colorSpace;
} VkSysmemColorSpaceFUCHSIA;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure
• `colorSpace` value of the Sysmem `ColorSpaceType`

**Valid Usage**

• VUID-VkSysmemColorSpaceFUCHSIA-colorSpace-06402
  `colorSpace` must be a `ColorSpaceType` as defined in `fuchsia.sysmem/image_formats.fidl`

**Valid Usage (Implicit)**

• VUID-VkSysmemColorSpaceFUCHSIA-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_SYSEM_COLOR_SPACE_FUCHSIA`

• VUID-VkSysmemColorSpaceFUCHSIA-pNext-pNext
  `pNext` must be `NULL`

**Set buffer-based buffer collection constraints**

To set the constraints on a `VkBuffer` buffer collection, call:

```c
// Provided by VK_FUCHSIA_buffer_collection
VkResult vkSetBufferCollectionBufferConstraintsFUCHSIA(
    VkDevice device,  
    VkBufferCollectionFUCHSIA collection,  
    const VkBufferConstraintsInfoFUCHSIA* pBufferConstraintsInfo);
```

• `device` is the logical device

• `collection` is the `VkBufferCollectionFUCHSIA` handle

• `pBufferConstraintsInfo` is a pointer to a `VkBufferConstraintsInfoFUCHSIA` structure

`vkSetBufferCollectionBufferConstraintsFUCHSIA` may fail if the implementation does not support the constraints specified in the `bufferCollectionConstraints` structure. If that occurs, `vkSetBufferCollectionBufferConstraintsFUCHSIA` will return `VK_ERROR_FORMAT_NOT_SUPPORTED`.

**Valid Usage**

• VUID-vkSetBufferCollectionBufferConstraintsFUCHSIA-collection-06403
  `vkSetBufferCollectionImageConstraintsFUCHSIA` or `vkSetBufferCollectionBufferConstraintsFUCHSIA` must not have already been called on `collection`

**Valid Usage (Implicit)**

• VUID-vkSetBufferCollectionBufferConstraintsFUCHSIA-device-parameter
  `device` must be a valid `VkDevice` handle
• VUID-vkSetBufferCollectionBufferConstraintsFUCHSIA-collection-parameter collection must be a valid VkBufferCollectionFUCHSIA handle

• VUID-vkSetBufferCollectionBufferConstraintsFUCHSIA-pBufferConstraintsInfo-parameter pBufferConstraintsInfo must be a valid pointer to a valid VkBufferConstraintsInfoFUCHSIA structure

• VUID-vkSetBufferCollectionBufferConstraintsFUCHSIA-collection-parent collection must have been created, allocated, or retrieved from device

Return Codes

Success
• VK_SUCCESS

Failure
• VK_ERROR_INITIALIZATION_FAILED
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_FORMAT_NOT_SUPPORTED

The VkBufferConstraintsInfoFUCHSIA structure is defined as:

```
// Provided by VK_FUCHSIA_buffer_collection
typedef struct VkBufferConstraintsInfoFUCHSIA {
    VkStructureType sType;
    const void* pNext;
    VkBufferCreateInfo createInfo;
    VkFormatFeatureFlags requiredFormatFeatures;
    VkBufferCollectionConstraintsInfoFUCHSIA bufferCollectionConstraints;
} VkBufferConstraintsInfoFUCHSIA;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure
• pBufferCreateInfo a pointer to a VkBufferCreateInfo struct describing the buffer attributes for the buffer collection
• requiredFormatFeatures bitmask of VkFormatFeatureFlagBits required features of the buffers in the buffer collection
• bufferCollectionConstraints is used to supply parameters for the negotiation and allocation of the buffer collection

Valid Usage

• VUID-VkBufferConstraintsInfoFUCHSIA-requiredFormatFeatures-06404
  The requiredFormatFeatures bitmask of VkFormatFeatureFlagBits must be chosen from
Valid Usage (Implicit)

- VUID-VkBufferConstraintsInfoFUCHSIA-sType-sType
  sType must be VK_STRUCTURE_TYPE_BUFFER_CONSTRAINTS_INFO_FUCHSIA

- VUID-VkBufferConstraintsInfoFUCHSIA-pNext-pNext
  pNext must be NULL

- VUID-VkBufferConstraintsInfoFUCHSIA-createInfo-parameter
  createInfo must be a valid VkBufferCreateInfo structure

- VUID-VkBufferConstraintsInfoFUCHSIA-requiredFormatFeatures-parameter
  requiredFormatFeatures must be a valid combination of VkFormatFeatureFlagBits values

- VUID-VkBufferConstraintsInfoFUCHSIA-bufferCollectionConstraints-parameter
  bufferCollectionConstraints must be a valid VkBufferCollectionConstraintsInfoFUCHSIA structure

12.11.5. Retrieve buffer collection properties

After constraints have been set on the buffer collection by calling vkSetBufferCollectionImageConstraintsFUCHSIA or vkSetBufferCollectionBufferConstraintsFUCHSIA, call vkGetBufferCollectionPropertiesFUCHSIA to retrieve the negotiated and finalized properties of the buffer collection.

The call to vkGetBufferCollectionPropertiesFUCHSIA is synchronous. It waits for the Sysmem format negotiation and buffer collection allocation to complete before returning.

```c
// Provided by VK_FUCHSIA_buffer_collection
VkResult vkGetBufferCollectionPropertiesFUCHSIA(
    VkDevice device,
    VkBufferCollectionFUCHSIA collection,
    VkBufferCollectionPropertiesFUCHSIA* pProperties);
```

- device is the logical device handle
- collection is the VkBufferCollectionFUCHSIA handle
- pProperties is a pointer to the retrieved VkBufferCollectionPropertiesFUCHSIA struct

For image-based buffer collections, upon calling vkGetBufferCollectionPropertiesFUCHSIA, Sysmem will choose an element of the VkImageConstraintsInfoFUCHSIA::pImageCreateInfos established by the preceding call to vkSetBufferCollectionImageConstraintsFUCHSIA. The index of the element chosen is stored in and can be retrieved from VkBufferCollectionPropertiesFUCHSIA::createInfoIndex.

For buffer-based buffer collections, a single VkBufferCreateInfo is specified as VkBufferConstraintsInfoFUCHSIA::createInfo.
::createInfoIndex will therefore always be zero.

vkGetBufferCollectionPropertiesFUCHSIA may fail if Sysmem is unable to resolve the constraints of all of the participants in the buffer collection. If that occurs, vkGetBufferCollectionPropertiesFUCHSIA will return VK_ERROR_INITIALIZATION_FAILED.

Valid Usage

- VUID-vkGetBufferCollectionPropertiesFUCHSIA-None-06405
  Prior to calling vkGetBufferCollectionPropertiesFUCHSIA, the constraints on the buffer collection must have been set by either vkSetBufferCollectionImageConstraintsFUCHSIA or vkSetBufferCollectionBufferConstraintsFUCHSIA

Valid Usage (Implicit)

- VUID-vkGetBufferCollectionPropertiesFUCHSIA-device-parameter
device must be a valid VkDevice handle

- VUID-vkGetBufferCollectionPropertiesFUCHSIA-collection-parameter
collection must be a valid VkBufferCollectionFUCHSIA handle

- VUID-vkGetBufferCollectionPropertiesFUCHSIA-pProperties-parameter
  pProperties must be a valid pointer to a VkBufferCollectionPropertiesFUCHSIA structure

- VUID-vkGetBufferCollectionPropertiesFUCHSIA-collection-parent
collection must have been created, allocated, or retrieved from device

Return Codes

Success
  • VK_SUCCESS

Failure
  • VK_ERROR_OUT_OF_HOST_MEMORY
  • VK_ERROR_INITIALIZATION_FAILED

The VkBufferCollectionPropertiesFUCHSIA structure is defined as:

```c
// Provided by VK_FUCHSIA_buffer_collection
typedef struct VkBufferCollectionPropertiesFUCHSIA {
  VkStructureType sType;
  void* pNext;
  uint32_t memoryTypeBits;
  uint32_t bufferCount;
  uint32_t createInfoIndex;
  uint64_t sysmemPixelFormat;
  VkFormatFeatureFlags formatFeatures;
} VkBufferCollectionPropertiesFUCHSIA;
```
VkBufferCollectionPropertiesFUCHSIA {
    VkSysmemColorSpaceFUCHSIA sysmemColorSpaceIndex;
    VkComponentMapping samplerYcbcrConversionComponents;
    VkSamplerYcbcrModelConversion suggestedYcbcrModel;
    VkSamplerYcbcrRange suggestedYcbcrRange;
    VkChromaLocation suggestedXChromaOffset;
    VkChromaLocation suggestedYChromaOffset;
} VkBufferCollectionPropertiesFUCHSIA;

• **sType** is a VkStructureType value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure
• **memoryTypeBits** is a bitmask containing one bit set for every memory type which the buffer collection can be imported as buffer collection
• **bufferCount** is the number of buffers in the collection
• **createInfoIndex** as described in Sysmem chosen create infos
• **sysmemPixelFormat** is the Sysmem PixelFormatType as defined in fuchsia.sysmem/image_formats.fidl
• **formatFeatures** is a bitmask of VkFormatFeatureFlagBits shared by the buffer collection
• **sysmemColorSpaceIndex** is a VkSysmemColorSpaceFUCHSIA struct specifying the color space
• **samplerYcbcrConversionComponents** is a VkComponentMapping struct specifying the component mapping
• **suggestedYcbcrModel** is a VkSamplerYcbcrModelConversion value specifying the suggested Y’C_B C_R model
• **suggestedYcbcrRange** is a VkSamplerYcbcrRange value specifying the suggested Y’C_B C_R range
• **suggestedXChromaOffset** is a VkChromaLocation value specifying the suggested X chroma offset
• **suggestedYChromaOffset** is a VkChromaLocation value specifying the suggested Y chroma offset

**sysmemColorSpace** is only set for image-based buffer collections where the constraints were specified using VkImageConstraintsInfoFUCHSIA in a call to vkSetBufferCollectionImageConstraintsFUCHSIA.

For image-based buffer collections, **createInfoIndex** will identify both the VkImageConstraintsInfoFUCHSIA::pImageCreateInfos element and the VkImageConstraintsInfoFUCHSIA::pFormatConstraints element chosen by Sysmem when vkSetBufferCollectionImageConstraintsFUCHSIA was called. The value of **sysmemColorSpaceIndex** will be an index to one of the color spaces provided in the VkImageFormatConstraintsInfoFUCHSIA::pColorSpaces array.

The implementation must have **formatFeatures** with all bits set that were set in VkImageFormatConstraintsInfoFUCHSIA::requiredFormatFeatures, by the call to vkSetBufferCollectionImageConstraintsFUCHSIA, at **createInfoIndex** (other bits could be set as well).

### Valid Usage (Implicit)

• VUID-VkBufferCollectionPropertiesFUCHSIA-sType-sType
**sType** must be **VK_STRUCTURE_TYPE_BUFFER_COLLECTION_PROPERTIES_FUCHSIA**

- **pNext** must be **NULL**

- **formatFeatures** must be a valid combination of **VkFormatFeatureFlagBits** values

- **sysmemColorSpaceIndex** must be a valid **VkSysmemColorSpaceFUCHSIA** structure

- **samplerYcbcrConversionComponents** must be a valid **VkComponentMapping** structure

- **suggestedYcbcrModel** must be a valid **VkSamplerYcbcrModelConversion** value

- **suggestedYcbcrRange** must be a valid **VkSamplerYcbcrRange** value

- **suggestedXChromaOffset** must be a valid **VkChromaLocation** value

- **suggestedYChromaOffset** must be a valid **VkChromaLocation** value

---

### 12.11.6. Memory allocation

To import memory from a buffer collection into a **VkImage** or a **VkBuffer**, chain a **VkImportMemoryBufferCollectionFUCHSIA** structure to the **pNext** member of the **VkMemoryAllocateInfo** in the call to **vkAllocateMemory**.

The **VkImportMemoryBufferCollectionFUCHSIA** structure is defined as:

```c
// Provided by VK_FUCHSIA_buffer_collection
typedef struct VkImportMemoryBufferCollectionFUCHSIA {
    VkStructureType sType;
    const void* pNext;
    VkBufferCollectionFUCHSIA collection;
    uint32_t index;
} VkImportMemoryBufferCollectionFUCHSIA;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure
- **collection** is the **VkBufferCollectionFUCHSIA** handle
- **index** the index of the buffer to import from **collection**
Valid Usage

- VUID-VkImportMemoryBufferCollectionFUCHSIA-index-06406
  index must be less than the value retrieved as VkBufferCollectionPropertiesFUCHSIA:bufferCount

Valid Usage (Implicit)

- VUID-VkImportMemoryBufferCollectionFUCHSIA-sType-sType
  sType must be VK_STRUCTURE_TYPE_IMPORT_MEMORY_BUFFER_COLLECTION_FUCHSIA

- VUID-VkImportMemoryBufferCollectionFUCHSIA-collection-parameter
  collection must be a valid VkBufferCollectionFUCHSIA handle

To release a VkBufferCollectionFUCHSIA:

```c
// Provided by VK_FUCHSIA_buffer_collection
void vkDestroyBufferCollectionFUCHSIA(
    VkDevice device, 
    VkBufferCollectionFUCHSIA collection, 
    const VkAllocationCallbacks* pAllocator);
```

- device is the logical device that creates the VkBufferCollectionFUCHSIA
- collection is the VkBufferCollectionFUCHSIA handle
- pAllocator is a pointer to a VkAllocationCallbacks structure controlling host memory allocation as described in the Memory Allocation chapter

Valid Usage

- VUID-vkDestroyBufferCollectionFUCHSIA-collection-parameter
  VkImage and VkBuffer objects that referenced collection upon creation by inclusion of a VkBufferCollectionImageCreateInfoFUCHSIA or VkBufferCollectionBufferCreateInfoFUCHSIA chained to their VkImageCreateInfo or VkBufferCreateInfo structures respectively, may outlive collection

Valid Usage (Implicit)

- VUID-vkDestroyBufferCollectionFUCHSIA-device-parameter
  device must be a valid VkDevice handle

- VUID-vkDestroyBufferCollectionFUCHSIA-collection-parameter
  collection must be a valid VkBufferCollectionFUCHSIA handle

- VUID-vkDestroyBufferCollectionFUCHSIA-pAllocator-parameter

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If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

- VUID-vkDestroyBufferCollectionFUCHSIA-collection-parent collection must have been created, allocated, or retrieved from `device`
Chapter 13. Samplers

\textbf{VkSampler} objects represent the state of an image sampler which is used by the implementation to read image data and apply filtering and other transformations for the shader.

Samplers are represented by \textbf{VkSampler} handles:

\begin{verbatim}
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkSampler)
\end{verbatim}

To create a sampler object, call:

\begin{verbatim}
// Provided by VK_VERSION_1_0
VkResult vkCreateSampler(
    VkDevice device,
    const VkSamplerCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkSampler* pSampler);
\end{verbatim}

- \textit{device} is the logical device that creates the sampler.
- \textit{pCreateInfo} is a pointer to a \textbf{VkSamplerCreateInfo} structure specifying the state of the sampler object.
- \textit{pAllocator} controls host memory allocation as described in the Memory Allocation chapter.
- \textit{pSampler} is a pointer to a \textbf{VkSampler} handle in which the resulting sampler object is returned.

\textbf{Valid Usage}

- VUID-vkCreateSampler-maxSamplerAllocationCount-04110 There \textbf{must} be less than \textbf{VkPhysicalDeviceLimits::maxSamplerAllocationCount} \textbf{VkSampler} objects currently created on the device

\textbf{Valid Usage (Implicit)}

- VUID-vkCreateSampler-device-parameter \textbf{device} \textbf{must} be a valid \textbf{VkDevice} handle
- VUID-vkCreateSampler-pCreateInfo-parameter \textbf{pCreateInfo} \textbf{must} be a valid pointer to a valid \textbf{VkSamplerCreateInfo} structure
- VUID-vkCreateSampler-pAllocator-parameter If \textit{pAllocator} is not \textbf{NULL}, \textbf{pAllocator} \textbf{must} be a valid pointer to a valid \textbf{VkAllocationCallbacks} structure
- VUID-vkCreateSampler-pSampler-parameter \textbf{pSampler} \textbf{must} be a valid pointer to a \textbf{VkSampler} handle
Return Codes

Success
• VK_SUCCESS

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY
• VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS_KHR

The `VkSamplerCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkSamplerCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkSamplerCreateFlags flags;
    VkFilter magFilter;
    VkFilter minFilter;
    VkSamplerMipmapMode mipmapMode;
    VkSamplerAddressMode addressModeU;
    VkSamplerAddressMode addressModeV;
    VkSamplerAddressMode addressModeW;
    float mipLodBias;
    VkBool32 anisotropyEnable;
    float maxAnisotropy;
    VkBool32 compareEnable;
    VkCompareOp compareOp;
    float minLod;
    float maxLod;
    VkBorderColor borderColor;
    VkBool32 unnormalizedCoordinates;
} VkSamplerCreateInfo;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkSamplerCreateFlagBits` describing additional parameters of the sampler.
- `magFilter` is a `VkFilter` value specifying the magnification filter to apply to lookups.
- `minFilter` is a `VkFilter` value specifying the minification filter to apply to lookups.
- `mipmapMode` is a `VkSamplerMipmapMode` value specifying the mipmap filter to apply to lookups.
- `addressModeU` is a `VkSamplerAddressMode` value specifying the addressing mode for U coordinates outside [0,1).
- `addressModeV` is a `VkSamplerAddressMode` value specifying the addressing mode for V coordinates outside [0,1).
• `addressModeW` is a `VkSamplerAddressMode` value specifying the addressing mode for W coordinates outside [0,1).

• `mipLodBias` is the bias to be added to mipmap LOD calculation and bias provided by image sampling functions in SPIR-V, as described in the LOD Operation section.

• `anisotropyEnable` is `VK_TRUE` to enable anisotropic filtering, as described in the Texel Anisotropic Filtering section, or `VK_FALSE` otherwise.

• `maxAnisotropy` is the anisotropy value clamp used by the sampler when `anisotropyEnable` is `VK_TRUE`. If `anisotropyEnable` is `VK_FALSE`, `maxAnisotropy` is ignored.

• `compareEnable` is `VK_TRUE` to enable comparison against a reference value during lookups, or `VK_FALSE` otherwise.
  ◦ Note: Some implementations will default to shader state if this member does not match.

• `compareOp` is a `VkCompareOp` value specifying the comparison operator to apply to fetched data before filtering as described in the Depth Compare Operation section.

• `minLod` is used to clamp the minimum of the computed LOD value.

• `maxLod` is used to clamp the maximum of the computed LOD value. To avoid clamping the maximum value, set `maxLod` to the constant `VK_LOD_CLAMP_NONE`.

• `borderColor` is a `VkBorderColor` value specifying the predefined border color to use.

• `unnormalizedCoordinates` controls whether to use unnormalized or normalized texel coordinates to address texels of the image. When set to `VK_TRUE`, the range of the image coordinates used to lookup the texel is in the range of zero to the image size in each dimension. When set to `VK_FALSE` the range of image coordinates is zero to one.

When `unnormalizedCoordinates` is `VK_TRUE`, images the sampler is used with in the shader have the following requirements:

◦ The `viewType` must be either `VK_IMAGE_VIEW_TYPE_1D` or `VK_IMAGE_VIEW_TYPE_2D`.

◦ The image view must have a single layer and a single mip level.

When `unnormalizedCoordinates` is `VK_TRUE`, image built-in functions in the shader that use the sampler have the following requirements:

◦ The functions must not use projection.

◦ The functions must not use offsets.

### Mapping of OpenGL to Vulkan filter modes

`magFilter` values of `VK_FILTER_NEAREST` and `VK_FILTER_LINEAR` directly correspond to `GL_NEAREST` and `GL_LINEAR` magnification filters. `minFilter` and `mipmapMode` combine to correspond to the similarly named OpenGL minification filter of `GL_minFilter_MIPMAP_mipmapMode` (e.g. `minFilter` of `VK_FILTER_LINEAR` and `mipmapMode` of `VK_SAMPLER_MIPMAP_MODE_NEAREST` correspond to `GL_LINEAR_MIPMAP_NEAREST`).

There are no Vulkan filter modes that directly correspond to OpenGL minification filters of `GL_LINEAR` or `GL_NEAREST`, but they can be emulated using `VK_SAMPLER_MIPMAP_MODE_NEAREST`, `minLod = 0`, and `maxLod = 0.25`, and using `minFilter = VK_FILTER_LINEAR` or `minFilter = VK_FILTER_NEAREST`, respectively.
Note that using a maxLod of zero would cause magnification to always be performed, and the magfilter to always be used. This is valid, just not an exact match for OpenGL behavior. Clamping the maximum LOD to 0.25 allows the λ value to be non-zero and minification to be performed, while still always rounding down to the base level. If the minFilter and magFilter are equal, then using a maxLod of zero also works.

The maximum number of sampler objects which can be simultaneously created on a device is implementation-dependent and specified by the maxSamplerAllocationCount member of the VkPhysicalDeviceLimits structure.

For historical reasons, if maxSamplerAllocationCount is exceeded, some implementations may return VK_ERROR_TOO_MANY_OBJECTS. Exceeding this limit will result in undefined behavior, and an application should not rely on the use of the returned error code in order to identify when the limit is reached.

Since VkSampler is a non-dispatchable handle type, implementations may return the same handle for sampler state vectors that are identical. In such cases, all such objects would only count once against the maxSamplerAllocationCount limit.

### Valid Usage

- **VUID-VkSamplerCreateInfo-mipLodBias-01069**
  The absolute value of mipLodBias must be less than or equal to VkPhysicalDeviceLimits::maxSamplerLodBias.

- **VUID-VkSamplerCreateInfo-samplerMipLodBias-04467**
  If the VK_KHR_portability_subset extension is enabled, and VkPhysicalDevicePortabilitySubsetFeaturesKHR::samplerMipLodBias is VK_FALSE, mipLodBias must be zero.

- **VUID-VkSamplerCreateInfo-maxLod-01973**
  maxLod must be greater than or equal to minLod

- **VUID-VkSamplerCreateInfo-anisotropyEnable-01070**
  If the samplerAnisotropy feature is not enabled, anisotropyEnable must be VK_FALSE.

- **VUID-VkSamplerCreateInfo-anisotropyEnable-01071**
  If anisotropyEnable is VK_TRUE, maxAnisotropy must be between 1.0 and VkPhysicalDeviceLimits::maxSamplerAnisotropy, inclusive.

- **VUID-VkSamplerCreateInfo-minFilter-01645**
  If sampler Y'CbCr conversion is enabled and the potential format features of the sampler Y'CbCr conversion do not support VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_SEPARATE_RECONSTRUCTION_FILTER_BIT, minFilter and magFilter must be equal to the sampler Y'CbCr conversion's chromaFilter.

- **VUID-VkSamplerCreateInfo-unnormalizedCoordinates-01072**
  If unnormalizedCoordinates is VK_TRUE, minFilter and magFilter must be equal.
If unnormalizedCoordinates is VK_TRUE, mipmapMode must be VK_SAMPLER_MIPMAP_MODE_NEAREST.

If unnormalizedCoordinates is VK_TRUE, minLod and maxLod must be zero.

If unnormalizedCoordinates is VK_TRUE, addressModeU and addressModeV must each be either VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE or VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_BORDER.

If unnormalizedCoordinates is VK_TRUE, anisotropyEnable must be VK_FALSE.

If unnormalizedCoordinates is VK_TRUE, compareEnable must be VK_FALSE.

If any of addressModeU, addressModeV or addressModeW are VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_BORDER, borderColor must be a valid VkBorderColor value.

If sampler Y′C_bC_R conversion is enabled, addressModeU, addressModeV, and addressModeW must be VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE, anisotropyEnable must be VK_FALSE, and unnormalizedCoordinates must be VK_FALSE.

If sampler Y′C_bC_R conversion is enabled and the pNext chain includes a VkSamplerReductionModeCreateInfo structure, then the sampler reduction mode must be set to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE.

If samplerFilterMinmax is not enabled and the pNext chain includes a VkSamplerReductionModeCreateInfo structure, then the sampler reduction mode must be set to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE.

If samplerMirrorClampToEdge is not enabled, and if the VK_KHR_sampler_mirror_clamp_to_edge extension is not enabled, addressModeU, addressModeV and addressModeW must not be VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE.

If compareEnable is VK_TRUE, compareOp must be a valid VkCompareOp value.

If either magFilter or minFilter is VK_FILTER_CUBIC_EXT, anisotropyEnable must be VK_FALSE.

If the VK_EXT_filter_cubic extension is not enabled and either magFilter or minFilter is VK_FILTER_CUBIC_EXT, the reductionMode member of VkSamplerReductionModeCreateInfo must be VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE.

If compareEnable is VK_TRUE, the reductionMode member of VkSamplerReductionModeCreateInfo must be VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE.
- VUID-VkSamplerCreateInfo-flags-02574
  If flags includes VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT, then minFilter and magFilter must be equal.

- VUID-VkSamplerCreateInfo-flags-02575
  If flags includes VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT, then mipmapMode must be VK_SAMPLER_MIPMAP_MODE_NEAREST.

- VUID-VkSamplerCreateInfo-flags-02576
  If flags includes VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT, then minLod and maxLod must be zero.

- VUID-VkSamplerCreateInfo-flags-02577
  If flags includes VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT, then addressModeU and addressModeV must each be either VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE or VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_BORDER.

- VUID-VkSamplerCreateInfo-flags-02578
  If flags includes VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT, then anisotropyEnable must be VK_FALSE.

- VUID-VkSamplerCreateInfo-flags-02579
  If flags includes VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT, then compareEnable must be VK_FALSE.

- VUID-VkSamplerCreateInfo-flags-02580
  If flags includes VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT, then unnormalizedCoordinates must be VK_FALSE.

- VUID-VkSamplerCreateInfo-nonSeamlessCubeMap-06788
  If the nonSeamlessCubeMap feature is not enabled, flags must not include VK_SAMPLER_CREATE_NON_SEAMLESS_CUBE_MAP_BIT_EXT.

- VUID-VkSamplerCreateInfo-borderColor-04011
  If borderColor is one of VK_BORDER_COLOR_FLOAT_CUSTOM_EXT or VK_BORDER_COLOR_INT_CUSTOM_EXT, then a VkSamplerCustomBorderColorCreateInfoEXT must be included in the pNext chain.

- VUID-VkSamplerCreateInfo-customBorderColors-04085
  If the customBorderColors feature is not enabled, borderColor must not be VK_BORDER_COLOR_FLOAT_CUSTOM_EXT or VK_BORDER_COLOR_INT_CUSTOM_EXT.

- VUID-VkSamplerCreateInfo-borderColor-04442
  If borderColor is one of VK_BORDER_COLOR_FLOAT_CUSTOM_EXT or VK_BORDER_COLOR_INT_CUSTOM_EXT, and VkSamplerCustomBorderColorCreateInfoEXT::format is not VK_FORMAT_UNDEFINED, VkSamplerCustomBorderColorCreateInfoEXT::customBorderColor must be within the range of values representable in format.

- VUID-VkSamplerCreateInfo-None-04012
  The maximum number of samplers with custom border colors which can be simultaneously created on a device is implementation-dependent and specified by the maxCustomBorderColorSamplers member of the VkPhysicalDeviceCustomBorderColorPropertiesEXT structure.

- VUID-VkSamplerCreateInfo-flags-08110
If flags includes `VK_SAMPLER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT`, the descriptorBufferCaptureReplay feature must be enabled

- VUID-VkSamplerCreateInfo-pNext-08111
  If the pNext chain includes a `VkOpaqueCaptureDescriptorDataCreateInfoEXT` structure, flags must contain `VK_SAMPLER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT`

- VUID-VkSamplerCreateInfo-flags-06964
  If flags includes `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`, then minFilter and magFilter must be `VK_FILTER_NEAREST`

- VUID-VkSamplerCreateInfo-flags-06965
  If flags includes `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`, then mipmapMode must be `VK_SAMPLER_MIPMAP_MODE_NEAREST`

- VUID-VkSamplerCreateInfo-flags-06966
  [If flags includes `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`, then minLod and maxLod must be zero]

- VUID-VkSamplerCreateInfo-flags-06967
  If flags includes `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`, then addressModeU and addressModeV must each be either `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE` or `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_BORDER`

- VUID-VkSamplerCreateInfo-flags-06968
  If flags includes `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`, and if addressModeU or addressModeV is `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_BORDER`, then borderColor must be `VK_BORDER_COLOR_FLOAT_TRANSPARENT_BLACK`

- VUID-VkSamplerCreateInfo-flags-06969
  If flags includes `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`, then anisotropyEnable must be `VK_FALSE`

- VUID-VkSamplerCreateInfo-flags-06970
  If flags includes `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`, then compareEnable must be `VK_FALSE`

---

### Valid Usage (Implicit)

- VUID-VkSamplerCreateInfo-sType-sType
  sType must be `VK_STRUCTURE_TYPE_SAMPLER_CREATE_INFO`

- VUID-VkSamplerCreateInfo-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of `VkOpaqueCaptureDescriptorDataCreateInfoEXT`, `VkSamplerBlockMatchWindowCreateInfoQCOM`, `VkSamplerBorderColorComponentMappingCreateInfoEXT`, `VkSamplerCubicWeightsCreateInfoQCOM`, `VkSamplerCustomBorderColorCreateInfoEXT`, `VkSamplerReductionModeCreateInfo`, or `VkSamplerYcbcrConversionInfo`

- VUID-VkSamplerCreateInfo-sType-unique
  The sType value of each struct in the pNext chain must be unique
• **VUID-VkSamplerCreateInfo-flags-parameter**
  - *flags* must be a valid combination of *VkSamplerCreateFlagBits* values

• **VUID-VkSamplerCreateInfo-magFilter-parameter**
  - *magFilter* must be a valid *VkFilter* value

• **VUID-VkSamplerCreateInfo-minFilter-parameter**
  - *minFilter* must be a valid *VkFilter* value

• **VUID-VkSamplerCreateInfo-mipmapMode-parameter**
  - *mipmapMode* must be a valid *VkSamplerMipmapMode* value

• **VUID-VkSamplerCreateInfo-addressModeU-parameter**
  - *addressModeU* must be a valid *VkSamplerAddressMode* value

• **VUID-VkSamplerCreateInfo-addressModeV-parameter**
  - *addressModeV* must be a valid *VkSamplerAddressMode* value

• **VUID-VkSamplerCreateInfo-addressModeW-parameter**
  - *addressModeW* must be a valid *VkSamplerAddressMode* value

*VK_LOD_CLAMP_NONE* is a special constant value used for *VkSamplerCreateInfo::maxLod* to indicate that maximum LOD clamping should not be performed.

```c
#define VK_LOD_CLAMP_NONE 1000.0F
```

Bits which can be set in *VkSamplerCreateInfo::flags*, specifying additional parameters of a sampler, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkSamplerCreateFlagBits {
    // Provided by VK_EXT_fragment_density_map
    VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT = 0x00000001,
    // Provided by VK_EXT_fragment_density_map
    VK_SAMPLER_CREATE_SUBSAMPLED_COARSE_RECONSTRUCTION_BIT_EXT = 0x00000002,
    // Provided by VK_EXT_descriptor_buffer
    VK_SAMPLER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT = 0x00000008,
    // Provided by VK_EXT_non_seamless_cube_map
    VK_SAMPLER_CREATE_NON_SEAMLESS_CUBE_MAP_BIT_EXT = 0x00000004,
    // Provided by VK_QCOM_image_processing
    VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM = 0x00000010,
} VkSamplerCreateFlagBits;
```

• **VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT** specifies that the sampler will read from an image created with *flags* containing *VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT*.

• **VK_SAMPLER_CREATE_SUBSAMPLED_COARSE_RECONSTRUCTION_BIT_EXT** specifies that the implementation may use approximations when reconstructing a full color value for texture access from a subsampled image.

• **VK_SAMPLER_CREATE_NON_SEAMLESS_CUBE_MAP_BIT_EXT** specifies that *cube map edge handling* is not
• **VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM** specifies that the sampler will read from images using only `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM`.

<table>
<thead>
<tr>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>The approximations used when <strong>VK_SAMPLER_CREATE_SUBSAMPLED_COARSE_RECONSTRUCTION_BIT_EXT</strong> is specified are implementation defined. Some implementations may interpolate between fragment density levels in a subsampled image. In that case, this bit may be used to decide whether the interpolation factors are calculated per fragment or at a coarser granularity.</td>
</tr>
</tbody>
</table>

• **VK_SAMPLER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT** specifies that the sampler can be used with descriptor buffers when capturing and replaying (e.g. for trace capture and replay), see **VkOpaqueCaptureDescriptorDataCreateInfoEXT** for more detail.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkSamplerCreateFlags;
```

**VkSamplerCreateFlags** is a bitmask type for setting a mask of zero or more **VkSamplerCreateFlagBits**.

The **VkSamplerReductionModeCreateInfo** structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkSamplerReductionModeCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkSamplerReductionMode reductionMode;
} VkSamplerReductionModeCreateInfo;
```

or the equivalent

```c
// Provided by VK_EXT_sampler_filter_minmax
typedef VkSamplerReductionModeCreateInfo VkSamplerReductionModeCreateInfoEXT;
```

• **sType** is a **VkStructureType** value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **reductionMode** is a **VkSamplerReductionMode** value controlling how texture filtering combines texel values.

If the **pNext** chain of **VkSamplerCreateInfo** includes a **VkSamplerReductionModeCreateInfo** structure, then that structure includes a mode controlling how texture filtering combines texel values.
If this structure is not present, `reductionMode` is considered to be `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE`.

### Valid Usage (Implicit)

- **VUID-VkSamplerReductionModeCreateInfo-sType-**
  - `sType` must be `VK_STRUCTURE_TYPE_SAMPLER_REDUCTION_MODE_CREATE_INFO`
- **VUID-VkSamplerReductionModeCreateInfo-reductionMode-parameter**
  - `reductionMode` must be a valid `VkSamplerReductionMode` value

Reduction modes are specified by `VkSamplerReductionMode`, which takes values:

```c
// Provided by VK_VERSION_1_2
typedef enum VkSamplerReductionMode {
    VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE = 0,
    VK_SAMPLER_REDUCTION_MODE_MIN = 1,
    VK_SAMPLER_REDUCTION_MODE_MAX = 2,
    // Provided by VK_QCOM_filter_cubic_clamp
    VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM = 1000521000,
    // Provided by VK_EXT_sampler_filter_minmax
    VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_EXT = VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE,
    // Provided by VK_EXT_sampler_filter_minmax
    VK_SAMPLER_REDUCTION_MODE_MIN_EXT = VK_SAMPLER_REDUCTION_MODE_MIN,
    // Provided by VK_EXT_sampler_filter_minmax
    VK_SAMPLER_REDUCTION_MODE_MAX_EXT = VK_SAMPLER_REDUCTION_MODE_MAX,
} VkSamplerReductionMode;
```

or the equivalent

```c
// Provided by VK_EXT_sampler_filter_minmax
typedef VkSamplerReductionMode VkSamplerReductionModeEXT;
```

- `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE` specifies that texel values are combined by computing a weighted average of values in the footprint, using weights as specified in the image operations chapter.
- `VK_SAMPLER_REDUCTION_MODE_MIN` specifies that texel values are combined by taking the component-wise minimum of values in the footprint with non-zero weights.
- `VK_SAMPLER_REDUCTION_MODE_MAX` specifies that texel values are combined by taking the component-wise maximum of values in the footprint with non-zero weights.
- `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` specifies values are combined as described by `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE`, followed by a texel range clamp.

The `VkSamplerCubicWeightsCreateInfoQCOM` structure is defined as:
typedef struct VkSamplerCubicWeightsCreateInfoQCOM {
    VkStructureType sType;
    const void* pNext;
    VkCubicFilterWeightsQCOM cubicWeights;
} VkSamplerCubicWeightsCreateInfoQCOM;

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **cubicWeights** is a VkCubicFilterWeightsQCOM value controlling which cubic weights are used.

If the **pNext** chain of VkSamplerCreateInfo includes a VkSamplerCubicWeightsCreateInfoQCOM structure, then that structure specifies which cubic weights are used.

If that structure is not present, **cubicWeights** is considered to be VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM.

### Valid Usage (Implicit)
- VUID-VkSamplerCubicWeightsCreateInfoQCOM-sType-sType  
  **sType** must be VK_STRUCTURE_TYPE_SAMPLER_CUBIC_WEIGHTS_CREATE_INFO_QCOM
- VUID-VkSamplerCubicWeightsCreateInfoQCOM-cubicWeights-parameter  
  **cubicWeights** must be a valid VkCubicFilterWeightsQCOM value

Possible values of the VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights, specifying cubic weights used in Texel Cubic Filtering are:

typedef enum VkCubicFilterWeightsQCOM {
    VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM = 0,
    VK_CUBIC_FILTER_WEIGHTS_ZERO_TANGENT_CARDINAL_QCOM = 1,
    VK_CUBIC_FILTER_WEIGHTS_B_SPLINE_QCOM = 2,
    VK_CUBIC_FILTER_WEIGHTS_MITCHELL_NETRAVALI_QCOM = 3,
} VkCubicFilterWeightsQCOM;

- **VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM** specifies Catmull-Rom weights.
- **VK_CUBIC_FILTER_WEIGHTS_ZERO_TANGENT_CARDINAL_QCOM** specifies Zero Tangent Cardinal weights.
- **VK_CUBIC_FILTER_WEIGHTS_B_SPLINE_QCOM** specifies B-Spline weights.
- **VK_CUBIC_FILTER_WEIGHTS_MITCHELL_NETRAVALI_QCOM** specifies Mitchell-Netravali weights.

Possible values of the VkSamplerCreateInfo::magFilter and minFilter parameters, specifying filters used for texture lookups, are:

// Provided by VK_VERSION_1_0
typedef enum VkFilter {
    VK_FILTER_NEAREST = 0,
    VK_FILTER_LINEAR = 1,
    // Provided by VK_EXT_filter_cubic
    VK_FILTER_CUBIC_EXT = 0x100015000,
    // Provided by VK_IMG_filter_cubic
    VK_FILTER_CUBIC_IMG = VK_FILTER_CUBIC_EXT,
} VkFilter;

- **VK_FILTER_NEAREST** specifies nearest filtering.
- **VK_FILTER_LINEAR** specifies linear filtering.
- **VK_FILTER_CUBIC_EXT** specifies cubic filtering.

These filters are described in detail in *Texel Filtering*.

Possible values of the `VkSamplerCreateInfo::mipmapMode`, specifying the mipmap mode used for texture lookups, are:

```cpp
// Provided by VK_VERSION_1_0
typedef enum VkSamplerMipmapMode {
    VK_SAMPLER_MIPMAP_MODE_NEAREST = 0,
    VK_SAMPLER_MIPMAP_MODE_LINEAR = 1,
} VkSamplerMipmapMode;
```

- **VK_SAMPLER_MIPMAP_MODE_NEAREST** specifies nearest filtering.
- **VK_SAMPLER_MIPMAP_MODE_LINEAR** specifies linear filtering.

These modes are described in detail in *Texel Filtering*.

Possible values of the `VkSamplerCreateInfo::addressMode` parameters, specifying the behavior of sampling with coordinates outside the range [0,1] for the respective u, v, or w coordinate as defined in the *Wrapping Operation* section, are:

```cpp
// Provided by VK_VERSION_1_0
typedef enum VkSamplerAddressMode {
    VK_SAMPLER_ADDRESS_MODE_REPEAT = 0,
    VK_SAMPLER_ADDRESS_MODE_MIRRORED_REPEAT = 1,
    VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE = 2,
    VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_BORDER = 3,
    // Provided by VK_VERSION_1_2, VK_KHR_sampler_mirror_clamp_to_edge
    VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE_KHR = VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE,
} VkSamplerAddressMode;
```

- **VK_SAMPLER_ADDRESS_MODE_REPEAT** specifies that the repeat wrap mode will be used.
• **VK_SAMPLER_ADDRESS_MODE_MIRRORED_REPEAT** specifies that the mirrored repeat wrap mode will be used.

• **VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE** specifies that the clamp to edge wrap mode will be used.

• **VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_BORDER** specifies that the clamp to border wrap mode will be used.

• **VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE** specifies that the mirror clamp to edge wrap mode will be used. This is only valid if `samplerMirrorClampToEdge` is enabled, or if the `VK_KHR_sampler_mirror_clamp_to_edge` extension is enabled.

*Comparison operators* compare a *reference* and a *test* value, and return a true (“passed”) or false (“failed”) value depending on the comparison operator chosen. The supported operators are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkCompareOp {
    VK_COMPARE_OP_NEVER = 0,
    VK_COMPARE_OP_LESS = 1,
    VK_COMPARE_OP_EQUAL = 2,
    VK_COMPARE_OP_LESS_OR_EQUAL = 3,
    VK_COMPARE_OP_GREATER = 4,
    VK_COMPARE_OP_NOT_EQUAL = 5,
    VK_COMPARE_OP_GREATER_OR_EQUAL = 6,
    VK_COMPARE_OP_ALWAYS = 7,
} VkCompareOp;
```

• **VK_COMPARE_OP_NEVER** specifies that the comparison always evaluates false.

• **VK_COMPARE_OP_LESS** specifies that the comparison evaluates *reference* < *test*.

• **VK_COMPARE_OP_EQUAL** specifies that the comparison evaluates *reference* = *test*.

• **VK_COMPARE_OP_LESS_OR_EQUAL** specifies that the comparison evaluates *reference* ≤ *test*.

• **VK_COMPARE_OP_GREATER** specifies that the comparison evaluates *reference* > *test*.

• **VK_COMPARE_OP_NOT_EQUAL** specifies that the comparison evaluates *reference* ≠ *test*.

• **VK_COMPARE_OP_GREATER_OR_EQUAL** specifies that the comparison evaluates *reference* ≥ *test*.

• **VK_COMPARE_OP_ALWAYS** specifies that the comparison always evaluates true.

Comparison operators are used for:

• The **Depth Compare Operation** operator for a sampler, specified by `VkSamplerCreateInfo::compareOp`.

• The stencil comparison operator for the **stencil test**, specified by `vkCmdSetStencilOp::compareOp` or `VkStencilOpState::compareOp`.

• The **Depth Comparison** operator for the **depth test**, specified by `vkCmdSetDepthCompareOp::depthCompareOp` or `VkPipelineDepthStencilStateCreateInfo::depthCompareOp`.

Each such use describes how the *reference* and *test* values for that comparison are determined.
Possible values of `VkSamplerCreateInfo::borderColor`, specifying the border color used for texture lookups, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkBorderColor {
    VK_BORDER_COLOR_FLOAT_TRANSPARENT_BLACK = 0,
    VK_BORDER_COLOR_INT_TRANSPARENT_BLACK = 1,
    VK_BORDER_COLOR_FLOAT_OPAQUE_BLACK = 2,
    VK_BORDER_COLOR_INT_OPAQUE_BLACK = 3,
    VK_BORDER_COLOR_FLOAT_OPAQUE_WHITE = 4,
    VK_BORDER_COLOR_INT_OPAQUE_WHITE = 5,
    // Provided by VK_EXT_custom_border_color
    VK_BORDER_COLOR_FLOAT_CUSTOM_EXT = 1000287003,
    // Provided by VK_EXT_custom_border_color
    VK_BORDER_COLOR_INT_CUSTOM_EXT = 1000287004,
} VkBorderColor;
```

- `VK_BORDER_COLOR_FLOAT_TRANSPARENT_BLACK` specifies a transparent, floating-point format, black color.
- `VK_BORDER_COLOR_INT_TRANSPARENT_BLACK` specifies a transparent, integer format, black color.
- `VK_BORDER_COLOR_FLOAT_OPAQUE_BLACK` specifies an opaque, floating-point format, black color.
- `VK_BORDER_COLOR_INT_OPAQUE_BLACK` specifies an opaque, integer format, black color.
- `VK_BORDER_COLOR_FLOAT_OPAQUE_WHITE` specifies an opaque, floating-point format, white color.
- `VK_BORDER_COLOR_INT_OPAQUE_WHITE` specifies an opaque, integer format, white color.
- `VK_BORDER_COLOR_FLOAT_CUSTOM_EXT` indicates that a `VkSamplerCustomBorderColorCreateInfoEXT` structure is included in the `VkSamplerCreateInfo::pNext` chain containing the color data in floating-point format.
- `VK_BORDER_COLOR_INT_CUSTOM_EXT` indicates that a `VkSamplerCustomBorderColorCreateInfoEXT` structure is included in the `VkSamplerCreateInfo::pNext` chain containing the color data in integer format.

These colors are described in detail in [Texel Replacement](#).

To destroy a sampler, call:

```c
// Provided by VK_VERSION_1_0
void vkDestroySampler(
    VkDevice device,
    VkSampler sampler,
    const VkAllocationCallbacks* pAllocator);
```

- `device` is the logical device that destroys the sampler.
- `sampler` is the sampler to destroy.
- `pAllocator` controls host memory allocation as described in the [Memory Allocation](#) chapter.
13.1. Sampler Y’C_B C_R conversion

To create a sampler with Y’C_B C_R conversion enabled, add a VkSamplerYcbcrConversionInfo structure to the pNext chain of the VkSamplerCreateInfo structure. To create a sampler Y’C_B C_R conversion, the samplerYcbcrConversion feature must be enabled. Conversion must be fixed at pipeline creation time, through use of a combined image sampler with an immutable sampler in VkDescriptorSetLayoutBinding.

A VkSamplerYcbcrConversionInfo must be provided for samplers to be used with image views that access VK_IMAGE_ASPECT_COLOR_BIT if the format is one of the formats that require a sampler Y’C_B C_R conversion, or if the image view has an external format.

The VkSamplerYcbcrConversionInfo structure is defined as:

```c
// Provided by VK_VERSION_1_1
```
**typedef struct VkSamplerYcbcrConversionInfo {**

  VkStructureType sType;
  const void* pNext;
  VkSamplerYcbcrConversion conversion;

} VkSamplerYcbcrConversionInfo;

or the equivalent

```c
// Provided by VK_KHR_sampler_ycbcr_conversion
typedef VkSamplerYcbcrConversionInfo VkSamplerYcbcrConversionInfoKHR;
```

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **conversion** is a *VkSamplerYcbcrConversion* handle created with `vkCreateSamplerYcbcrConversion`.

**Valid Usage (Implicit)**

- VUID-VkSamplerYcbcrConversionInfo-sType-sType
  - **sType** must be `VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_INFO`
- VUID-VkSamplerYcbcrConversionInfo-conversion-parameter
  - **conversion** must be a valid *VkSamplerYcbcrConversion* handle

A sampler Y’C₉₆C₉₆ conversion is an opaque representation of a device-specific sampler Y’C₉₆C₉₆ conversion description, represented as a *VkSamplerYcbcrConversion* handle:

```c
// Provided by VK_VERSION_1_1
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkSamplerYcbcrConversion)
```

or the equivalent

```c
// Provided by VK_KHR_sampler_ycbcr_conversion
typedef VkSamplerYcbcrConversion VkSamplerYcbcrConversionKHR;
```

To create a *VkSamplerYcbcrConversion*, call:

```c
// Provided by VK_VERSION_1_1
VkResult vkCreateSamplerYcbcrConversion(
    VkDevice device,
    const VkSamplerYcbcrConversionCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkSamplerYcbcrConversion* pYcbcrConversion);
```
or the equivalent command

```c
// Provided by VK_KHR_sampler_ycbcr_conversion
VkResult vkCreateSamplerYcbcrConversionKHR(
    VkDevice device,
    const VkSamplerYcbcrConversionCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkSamplerYcbcrConversion* pYcbcrConversion);
```

- `device` is the logical device that creates the sampler $Y'CbCr$ conversion.
- `pCreateInfo` is a pointer to a `VkSamplerYcbcrConversionCreateInfo` structure specifying the requested sampler $Y'CbCr$ conversion.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pYcbcrConversion` is a pointer to a `VkSamplerYcbcrConversion` handle in which the resulting sampler $Y'CbCr$ conversion is returned.

The interpretation of the configured sampler $Y'CbCr$ conversion is described in more detail in the description of sampler $Y'CbCr$ conversion in the Image Operations chapter.

**Valid Usage**

- VUID-vkCreateSamplerYcbcrConversion-None-01648
  The `samplerYcbcrConversion` feature **must** be enabled

**Valid Usage (Implicit)**

- VUID-vkCreateSamplerYcbcrConversion-device-parameter
  `device` **must** be a valid `VkDevice` handle
- VUID-vkCreateSamplerYcbcrConversion-pCreateInfo-parameter
  `pCreateInfo` **must** be a valid pointer to a valid `VkSamplerYcbcrConversionCreateInfo` structure
- VUID-vkCreateSamplerYcbcrConversion-pAllocator-parameter
  If `pAllocator` is not `NULL`, `pAllocator` **must** be a valid pointer to a valid `VkAllocationCallbacks` structure
- VUID-vkCreateSamplerYcbcrConversion-pYcbcrConversion-parameter
  `pYcbcrConversion` **must** be a valid pointer to a `VkSamplerYcbcrConversion` handle

**Return Codes**

**Success**
- `VK_SUCCESS`
Failure

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The `VkSamplerYcbcrConversionCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkSamplerYcbcrConversionCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkFormat format;
    VkSamplerYcbcrModelConversion ycbcrModel;
    VkSamplerYcbcrRange ycbcrRange;
    VkComponentMapping components;
    VkChromaLocation xChromaOffset;
    VkChromaLocation yChromaOffset;
    VkFilter chromaFilter;
    VkBool32 forceExplicitReconstruction;
} VkSamplerYcbcrConversionCreateInfo;
```

or the equivalent

```c
// Provided by VK_KHR_sampler_ycbcr_conversion
typedef VkSamplerYcbcrConversionCreateInfo VkSamplerYcbcrConversionCreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `format` is the format of the image from which color information will be retrieved.
- `ycbcrModel` describes the color matrix for conversion between color models.
- `ycbcrRange` describes whether the encoded values have headroom and foot room, or whether the encoding uses the full numerical range.
- `components` applies a swizzle based on `VkComponentSwizzle` enums prior to range expansion and color model conversion.
- `xChromaOffset` describes the sample location associated with downsampled chroma components in the x dimension. `xChromaOffset` has no effect for formats in which chroma components are not downsampled horizontally.
- `yChromaOffset` describes the sample location associated with downsampled chroma components in the y dimension. `yChromaOffset` has no effect for formats in which the chroma components are not downsampled vertically.
- `chromaFilter` is the filter for chroma reconstruction.
- `forceExplicitReconstruction` can be used to ensure that reconstruction is done explicitly, if supported.
Note

Setting forceExplicitReconstruction to VK_TRUE may have a performance penalty on implementations where explicit reconstruction is not the default mode of operation.

If format supports VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_BIT the forceExplicitReconstruction value behaves as if it was set to VK_TRUE.

If the pNext chain includes a VkExternalFormatANDROID structure with non-zero externalFormat member, the sampler Y'CbCr conversion object represents an external format conversion, and format must be VK_FORMAT_UNDEFINED. Such conversions must only be used to sample image views with a matching external format. When creating an external format conversion, the value of components is ignored.

Valid Usage

- VUID-VkSamplerYcbcrConversionCreateInfo-format-01904
  If an external format conversion is being created, format must be VK_FORMAT_UNDEFINED

- VUID-VkSamplerYcbcrConversionCreateInfo-format-04061
  If an external format conversion is not being created, format must represent unsigned normalized values (i.e. the format must be a UNORM format)

- VUID-VkSamplerYcbcrConversionCreateInfo-format-01650
  The potential format features of the sampler Y'CbCr conversion must support VK_FORMAT_FEATURE_MIDPOINT_CHROMA_SAMPLES_BIT or VK_FORMAT_FEATURE_COSITED_CHROMA_SAMPLES_BIT

- VUID-VkSamplerYcbcrConversionCreateInfo-xChromaOffset-01651
  If the potential format features of the sampler Y'CbCr conversion do not support VK_FORMAT_FEATURE_COSITED_CHROMA_SAMPLES_BIT, xChromaOffset and yChromaOffset must not be VK_CHROMA_LOCATION_COSITED_EVEN if the corresponding components are downsampled

- VUID-VkSamplerYcbcrConversionCreateInfo-xChromaOffset-01652
  If the potential format features of the sampler Y'CbCr conversion do not support VK_FORMAT_FEATURE_MIDPOINT_CHROMA_SAMPLES_BIT, xChromaOffset and yChromaOffset must not be VK_CHROMA_LOCATION_MIDPOINT if the corresponding components are downsampled

- VUID-VkSamplerYcbcrConversionCreateInfo-components-02581
  If the format has a _422 or _420 suffix, then components.g must be the identity swizzle

- VUID-VkSamplerYcbcrConversionCreateInfo-components-02582
  If the format has a _422 or _420 suffix, then components.a must be the identity swizzle, VK_COMPONENT_SWIZZLE_ONE, or VK_COMPONENT_SWIZZLE_ZERO

- VUID-VkSamplerYcbcrConversionCreateInfo-components-02583
  If the format has a _422 or _420 suffix, then components.r must be the identity swizzle or VK_COMPONENT_SWIZZLE_B

- VUID-VkSamplerYcbcrConversionCreateInfo-components-02584
  If the format has a _422 or _420 suffix, then components.b must be the identity swizzle or
If the format has a _422 or _420 suffix, and if either components.r or components.b is the identity swizzle, both values must be the identity swizzle.

If ycbcrModel is not VK_SAMPLER_YCBCR_MODEL_CONVERSION_RGB_IDENTITY, then components.r, components.g, and components.b must correspond to components of the format; that is, components.r, components.g, and components.b must not be VK_COMPONENT_SWIZZLE_ZERO or VK_COMPONENT_SWIZZLE_ONE, and must not correspond to a component containing zero or one as a consequence of conversion to RGBA.

If ycbcrRange is VK_SAMPLER_YCBCR_RANGE_ITU_NARROW then the R, G and B components obtained by applying the component swizzle to format must each have a bit-depth greater than or equal to 8.

If the potential format features of the sampler Y’C_bC_R conversion do not support VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_FORCEABLE_BIT forceExplicitReconstruction must be VK_FALSE.

If the potential format features of the sampler Y’C_bC_R conversion do not support VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_LINEAR_FILTER_BIT, chromaFilter must not be VK_FILTER_LINEAR.

If the pNext chain includes a VkSamplerYcbcrConversionYcbcrDegammaCreateInfoQCOM structure, and if the ycbcrDegamma feature is not enabled, then VkSamplerYcbcrConversionYcbcrDegammaCreateInfoQCOM::enableYDegamma must be VK_FALSE.

If the pNext chain includes a VkSamplerYcbcrConversionYcbcrDegammaCreateInfoQCOM structure, format must be a format with 8-bit R, G, and B components.

Valid Usage (Implicit)

sType must be VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_CREATE_INFO.

Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkExternalFormatANDROID,
VkExternalFormatQNX, or VkSamplerYcbcrConversionYcbcrDegammaCreateInfoQCOM

- VUID-VkSamplerYcbcrConversionCreateInfo-sType-unique
  The sType value of each struct in the pNext chain must be unique

- VUID-VkSamplerYcbcrConversionCreateInfo-format-parameter
  format must be a valid VkFormat value

- VUID-VkSamplerYcbcrConversionCreateInfo-ycbcrModel-parameter
  ycbcrModel must be a valid VkSamplerYcbcrModelConversion value

- VUID-VkSamplerYcbcrConversionCreateInfo-ycbcrRange-parameter
  ycbcrRange must be a valid VkSamplerYcbcrRange value

- VUID-VkSamplerYcbcrConversionCreateInfo-components-parameter
  components must be a valid VkComponentMapping structure

- VUID-VkSamplerYcbcrConversionCreateInfo-xChromaOffset-parameter
  xChromaOffset must be a valid VkChromaLocation value

- VUID-VkSamplerYcbcrConversionCreateInfo-yChromaOffset-parameter
  yChromaOffset must be a valid VkChromaLocation value

- VUID-VkSamplerYcbcrConversionCreateInfo-chromaFilter-parameter
  chromaFilter must be a valid VkFilter value

If chromaFilter is VK_FILTER_NEAREST, chroma samples are reconstructed to luma component resolution using nearest-neighbour sampling. Otherwise, chroma samples are reconstructed using interpolation. More details can be found in the description of sampler Y’C_bC_r conversion in the Image Operations chapter.

VkSamplerYcbcrModelConversion defines the conversion from the source color model to the shader color model. Possible values are:

```c
// Provided by VK_VERSION_1_1
typedef enum VkSamplerYcbcrModelConversion {
    VK_SAMPLER_YCBCR_MODEL_CONVERSION_RGB_IDENTITY = 0,
    VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_IDENTITY = 1,
    VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_709 = 2,
    VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_601 = 3,
    VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_2020 = 4,
};
```
or the equivalent

```c
// Provided by VK_KHR_sampler_ycbcr_conversion
typedef VkSamplerYcbcrModelConversion VkSamplerYcbcrModelConversionKHR;
```

- **VK_SAMPLER_YCBCR_MODEL_CONVERSION_RGB_IDENTITY** specifies that the input values to the conversion are unmodified.
- **VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_IDENTITY** specifies no model conversion but the inputs are range expanded as for Y′C_bC_r.
- **VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_709** specifies the color model conversion from Y′C_bC_r to R′G′B′ defined in BT.709 and described in the “BT.709 Y′C_bC_r conversion” section of the Khronos Data Format Specification.
- **VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_601** specifies the color model conversion from Y′C_bC_r to R′G′B′ defined in BT.601 and described in the “BT.601 Y′C_bC_r conversion” section of the Khronos Data Format Specification.
- **VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_2020** specifies the color model conversion from Y′C_bC_r to R′G′B′ defined in BT.2020 and described in the “BT.2020 Y′C_bC_r conversion” section of the Khronos Data Format Specification.

In the **VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_** color models, for the input to the sampler Y′C_bC_r range expansion and model conversion:

- the Y (Y′ luma) component corresponds to the G component of an RGB image.
- the CB (C_b or “U” blue color difference) component corresponds to the B component of an RGB image.
- the CR (C_r or “V” red color difference) component corresponds to the R component of an RGB image.
- the alpha component, if present, is not modified by color model conversion.

These rules reflect the mapping of components after the component swizzle operation (controlled by `VkSamplerYcbcrConversionCreateInfo::components`).

**Note**

For example, an “YUVA” 32-bit format comprising four 8-bit components can be implemented as `VK_FORMAT_R8G8B8A8_UNORM` with a component mapping:

- `components.a = VK_COMPONENT_SWIZZLE_IDENTITY`
- `components.r = VK_COMPONENT_SWIZZLE_B`
- `components.g = VK_COMPONENT_SWIZZLE_R`
• components.b = VK_COMPONENT_SWIZZLE_G

The `VkSamplerYcbcrRange` enum describes whether color components are encoded using the full range of numerical values or whether values are reserved for headroom and foot room. `VkSamplerYcbcrRange` is defined as:

```c
// Provided by VK_VERSION_1_1
typedef enum VkSamplerYcbcrRange {
    VK_SAMPLER_YCBCR_RANGE_ITU_FULL = 0,
    VK_SAMPLER_YCBCR_RANGE_ITU_NARROW = 1,
    // Provided by VK_KHR_sampler_ycbcr_conversion
    VK_SAMPLER_YCBCR_RANGE_ITU_FULL_KHR = VK_SAMPLER_YCBCR_RANGE_ITU_FULL,
    // Provided by VK_KHR_sampler_ycbcr_conversion
    VK_SAMPLER_YCBCR_RANGE_ITU_NARROW_KHR = VK_SAMPLER_YCBCR_RANGE_ITU_NARROW,
} VkSamplerYcbcrRange;
```

or the equivalent

```c
// Provided by VK_KHR_sampler_ycbcr_conversion
typedef VkSamplerYcbcrRange VKSamplerYcbcrRangeKHR;
```

• `VK_SAMPLER_YCBCR_RANGE_ITU_FULL` specifies that the full range of the encoded values are valid and interpreted according to the ITU “full range” quantization rules.

• `VK_SAMPLER_YCBCR_RANGE_ITU_NARROW` specifies that headroom and foot room are reserved in the numerical range of encoded values, and the remaining values are expanded according to the ITU “narrow range” quantization rules.

The formulae for these conversions is described in the Sampler Y’C₆C₆ Range Expansion section of the Image Operations chapter.

No range modification takes place if `ycbcrModel` is `VK_SAMPLER_YCBCR_MODEL_CONVERSION_RGB_IDENTITY`; the `ycbcrRange` field of `VkSamplerYcbcrConversionCreateInfo` is ignored in this case.

The `VkChromaLocation` enum defines the location of downsampled chroma component samples relative to the luma samples, and is defined as:

```c
// Provided by VK_VERSION_1_1
typedef enum VkChromaLocation {
    VK_CHROMA_LOCATION_COSITED_EVEN = 0,
    VK_CHROMA_LOCATION_MIDPOINT = 1,
    // Provided by VK_KHR_sampler_ycbcr_conversion
    VK_CHROMA_LOCATION_COSITED_EVEN_KHR = VK_CHROMA_LOCATION_COSITED_EVEN,
    // Provided by VK_KHR_sampler_ycbcr_conversion
    VK_CHROMA_LOCATION_MIDPOINT_KHR = VK_CHROMA_LOCATION_MIDPOINT,
} VkChromaLocation;
```
or the equivalent

```c
// Provided by VK_KHR_sampler_ycbcr_conversion
typedef VkChromaLocation VkChromaLocationKHR;
```

- **VK_CHROMA_LOCATION_COSITED_EVEN** specifies that downsampled chroma samples are aligned with luma samples with even coordinates.
- **VK_CHROMA_LOCATION_MIDPOINT** specifies that downsampled chroma samples are located halfway between each even luma sample and the nearest higher odd luma sample.

Applications can enable sRGB to linear conversion for the R, G, and B components of a \( Y'C_bC_r \) image during format conversion by including `VkSamplerYcbcrConversionYcbcrDegammaCreateInfoQCOM` structure in the `pNext` chain of `VkSamplerYcbcrConversionCreateInfo`.

The `VkSamplerYcbcrConversionYcbcrDegammaCreateInfoQCOM` structure is defined as:

```c
// Provided by VK_QCOM_ycbcr_degamma
typedef struct VkSamplerYcbcrConversionYcbcrDegammaCreateInfoQCOM {
    VkStructureType   sType;
    void*             pNext;
    VkBool32          enableYDegamma;
    VkBool32          enableCbCrDegamma;
} VkSamplerYcbcrConversionYcbcrDegammaCreateInfoQCOM;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `enableYDegamma` indicates sRGB to linear conversion is enabled for the G component.
- `enableCbCrDegamma` indicates sRGB to linear conversion is enabled for the R and B components.

**Valid Usage (Implicit)**

```c
VUID-VkSamplerYcbcrConversionYcbcrDegammaCreateInfoQCOM-sType-sType
VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_YCBCR_DEGAMMA_CREATE_INFO_QCOM
```

To destroy a sampler \( Y'C_bC_r \) conversion, call:

```c
// Provided by VK_VERSION_1_1
void vkDestroySamplerYcbcrConversion(
    VkDevice device,
    VkSamplerYcbcrConversion ycbcrConversion,
    const VkAllocationCallbacks* pAllocator);
```

or the equivalent VkAllocationCallbacks command.
```c
void vkDestroySamplerYcbcrConversionKHR(
  VkDevice device,
  VkSamplerYcbcrConversion ycbcrConversion,
  const VkAllocationCallbacks* pAllocator);
```

- **device** is the logical device that destroys the Y’C₆C₅R conversion.
- **ycbcrConversion** is the conversion to destroy.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.

### Valid Usage (Implicit)

- VUID-vkDestroySamplerYcbcrConversion-device-parameter
  device must be a valid VkDevice handle
- VUID-vkDestroySamplerYcbcrConversion-ycbcrConversion-parameter
  If ycbcrConversion is not VK_NULL_HANDLE, ycbcrConversion must be a valid VkSamplerYcbcrConversion handle
- VUID-vkDestroySamplerYcbcrConversion-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure
- VUID-vkDestroySamplerYcbcrConversion-ycbcrConversion-parent
  If ycbcrConversion is a valid handle, it must have been created, allocated, or retrieved from device

### Host Synchronization

- Host access to ycbcrConversion must be externally synchronized

In addition to the predefined border color values, applications can provide a custom border color value by including the `VkSamplerCustomBorderColorCreateInfoEXT` structure in the `VkSamplerCreateInfo::pNext` chain.

The `VkSamplerCustomBorderColorCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_custom_border_color
typedef struct VkSamplerCustomBorderColorCreateInfoEXT {
  VkStructureType sType;
  const void* pNext;
  VkClearColorValue customBorderColor;
  VkFormat format;
} VkSamplerCustomBorderColorCreateInfoEXT;
```

- **sType** is a VkStructureType value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.
• `customBorderColor` is a `VkClearColorValue` representing the desired custom sampler border color.
• `format` is a `VkFormat` representing the format of the sampled image view(s). This field may be `VK_FORMAT_UNDEFINED` if the `customBorderColorWithoutFormat` feature is enabled.

**Note**

If `format` is a depth/stencil format, the aspect is determined by the value of `VkSamplerCreateInfo::borderColor`. If `VkSamplerCreateInfo::borderColor` is `VK_BORDER_COLOR_FLOAT_CUSTOM_EXT`, the depth aspect is considered. If `VkSamplerCreateInfo::borderColor` is `VK_BORDER_COLOR_INT_CUSTOM_EXT`, the stencil aspect is considered.

If `format` is `VK_FORMAT_UNDEFINED`, the `VkSamplerCreateInfo::borderColor` is `VK_BORDER_COLOR_INT_CUSTOM_EXT`, and the sampler is used with an image with a stencil format, then the implementation must source the custom border color from either the first or second components of `VkSamplerCreateInfo::customBorderColor` and should source it from the first component.

---

### Valid Usage

- **VUID-VkSamplerCustomBorderColorCreateInfoEXT-format-07605**
  If `format` is not `VK_FORMAT_UNDEFINED` and `format` is not a depth/stencil format then the `VkSamplerCreateInfo::borderColor` type must match the sampled type of the provided `format`, as shown in the SPIR-V Type column of the Interpretation of Numeric Format table.

- **VUID-VkSamplerCustomBorderColorCreateInfoEXT-format-04014**
  If the `customBorderColorWithoutFormat` feature is not enabled then `format` must not be `VK_FORMAT_UNDEFINED`.

- **VUID-VkSamplerCustomBorderColorCreateInfoEXT-format-04015**
  If the sampler is used to sample an image view of `VK_FORMAT_B4G4R4A4_UNORM_PACK16`, `VK_FORMAT_B5G6R5_UNORM_PACK16`, `VK_FORMAT_A1B5G5R5_UNORM_PACK16_KHR`, or `VK_FORMAT_B5G5R5A1_UNORM_PACK16` format then `format` must not be `VK_FORMAT_UNDEFINED`.

---

### Valid Usage (Implicit)

- **VUID-VkSamplerCustomBorderColorCreateInfoEXT-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_SAMPLER_CUSTOM_BORDER_COLOR_CREATE_INFO_EXT`.

- **VUID-VkSamplerCustomBorderColorCreateInfoEXT-format-parameter**
  `format` must be a valid `VkFormat` value.

If the sampler is created with `VK_BORDER_COLOR_FLOAT_OPAQUE_BLACK`, `VK_BORDER_COLOR_INT_OPAQUE_BLACK`, `VK_BORDER_COLOR_FLOAT_CUSTOM_EXT`, or `VK_BORDER_COLOR_INT_CUSTOM_EXT` `borderColor`, and that sampler will be combined with an image view...
that does not have an identity swizzle, and `VkPhysicalDeviceBorderColorSwizzleFeaturesEXT::borderColorSwizzleFromImage` is not enabled, then it is necessary to specify the component mapping of the border color, by including the `VkSamplerBorderColorComponentMappingCreateInfoEXT` structure in the `VkSamplerCreateInfo::pNext` chain, to get defined results.

The `VkSamplerBorderColorComponentMappingCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_border_color_swizzle
typedef struct VkSamplerBorderColorComponentMappingCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkComponentMapping components;
    VkBool32 srgb;
} VkSamplerBorderColorComponentMappingCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `components` is a `VkComponentMapping` structure specifying a remapping of the border color components.
- `srgb` indicates that the sampler will be combined with an image view that has an image format which is sRGB encoded.

The `VkComponentMapping` `components` member describes a remapping from components of the border color to components of the vector returned by shader image instructions when the border color is used.

**Valid Usage**

- VUID-VkSamplerBorderColorComponentMappingCreateInfoEXT-borderColorSwizzle-06437

The `borderColorSwizzle` feature must be enabled.

**Valid Usage (Implicit)**

- VUID-VkSamplerBorderColorComponentMappingCreateInfoEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_SAMPLER_BORDER_COLOR_COMPONENT_MAPPING_CREATE_INFO_EXT`

- VUID-VkSamplerBorderColorComponentMappingCreateInfoEXT-components-parameter
  `components` must be a valid `VkComponentMapping` structure

The `VkSamplerBlockMatchWindowCreateInfoQCOM` structure is defined as:

```c
// Provided by VK_QCOM_image_processing2
typedef struct VkSamplerBlockMatchWindowCreateInfoQCOM {
```

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VkStructureType sType;
const void* pNext;
VkExtent2D windowExtent;
VkBlockMatchWindowCompareModeQCOM windowCompareMode;
} VkSamplerBlockMatchWindowCreateInfoQCOM;

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **windowExtent** is a VkExtent2D specifying a the width and height of the block match window.
- **windowCompareMode** is a VkBlockMatchWindowCompareModeQCOM specifying the compare mode.

### Valid Usage

- VUID-VkSamplerBlockMatchWindowCreateInfoQCOM-WindowExtent-09210
  WindowExtent must not be larger than VkPhysicalDeviceImageProcessing2PropertiesQCOM::maxBlockMatchWindow.

### Valid Usage (Implicit)

- VUID-VkSamplerBlockMatchWindowCreateInfoQCOM-sType-sType
  sType must be VK_STRUCTURE_TYPE_SAMPLER_BLOCK_MATCH_WINDOW_CREATE_INFO_QCOM

- VUID-VkSamplerBlockMatchWindowCreateInfoQCOM-windowCompareMode-parameter
  windowCompareMode must be a valid VkBlockMatchWindowCompareModeQCOM value

The **VkBlockMatchWindowCompareModeQCOM** enum describes how block match values within the window are compared. **VkBlockMatchWindowCompareModeQCOM** is defined as:

```c
// Provided by VK_QCOM_image_processing2
typedef enum VkBlockMatchWindowCompareModeQCOM {
    VK_BLOCK_MATCH_WINDOW_COMPARE_MODE_MIN_QCOM = 0,
    VK_BLOCK_MATCH_WINDOW_COMPARE_MODE_MAX_QCOM = 1,
} VkBlockMatchWindowCompareModeQCOM;
```

- **VK_BLOCK_MATCH_WINDOW_COMPARE_MODE_MIN_QCOM** specifies that windowed block match operations return the minimum error within the window.
- **VK_BLOCK_MATCH_WINDOW_COMPARE_MODE_MAX_QCOM** specifies that windowed block match operations return the maximum error within the window.
Chapter 14. Resource Descriptors

A descriptor is an opaque data structure representing a shader resource such as a buffer, buffer view, image view, sampler, or combined image sampler. Descriptors are organized into descriptor sets, which are bound during command recording for use in subsequent drawing commands. The arrangement of content in each descriptor set is determined by a descriptor set layout, which determines what descriptors can be stored within it. The sequence of descriptor set layouts that can be used by a pipeline is specified in a pipeline layout. Each pipeline object can use up to maxBoundDescriptorSets (see Limits) descriptor sets.

If the descriptorBuffer feature is enabled, the implementation supports placing descriptors into descriptor buffers which are bound during command recording in a similar way to descriptor sets.

Shaders access resources via variables decorated with a descriptor set and binding number that link them to a descriptor in a descriptor set. The shader interface mapping to bound descriptor sets is described in the Shader Resource Interface section.

Shaders can also access buffers without going through descriptors by using Physical Storage Buffer Access to access them through 64-bit addresses.

14.1. Descriptor Types

There are a number of different types of descriptor supported by Vulkan, corresponding to different resources or usage. The following sections describe the API definitions of each descriptor type. The mapping of each type to SPIR-V is listed in the Shader Resource and Descriptor Type Correspondence and Shader Resource and Storage Class Correspondence tables in the Shader Interfaces chapter.

14.1.1. Storage Image

A storage image (VK_DESCRIPTOR_TYPE_STORAGE_IMAGE) is a descriptor type associated with an image resource via an image view that load, store, and atomic operations can be performed on.

Storage image loads are supported in all shader stages for image views whose format features contain VK_FORMAT_FEATURE_STORAGE_IMAGE_BIT.

Stores to storage images are supported in task, mesh and compute shaders for image views whose format features contain VK_FORMAT_FEATURE_STORAGE_IMAGE_BIT.

Atomic operations on storage images are supported in task, mesh and compute shaders for image views whose format features contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT.

When the fragmentStoresAndAtomics feature is enabled, stores and atomic operations are also supported for storage images in fragment shaders with the same set of image formats as supported in compute shaders. When the vertexPipelineStoresAndAtomics feature is enabled, stores and atomic operations are also supported in vertex, tessellation, and geometry shaders with the same set of image formats as supported in compute shaders.

The image subresources for a storage image must be in the VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR or...
VK_IMAGE_LAYOUT_GENERAL layout in order to access its data in a shader.

### 14.1.2. Sampler

A sampler descriptor (VK_DESCRIPTOR_TYPE_SAMPLER) is a descriptor type associated with a sampler object, used to control the behavior of sampling operations performed on a sampled image.

### 14.1.3. Sampled Image

A sampled image (VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE) is a descriptor type associated with an image resource via an image view that sampling operations can be performed on.

Shaders combine a sampled image variable and a sampler variable to perform sampling operations.

Sampled images are supported in all shader stages for image views whose format features contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT.

An image subresources for a sampled image must be in one of the following layouts:

- VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL
- VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL
- VK_IMAGE_LAYOUT_GENERAL
- VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR
- VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL
- VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL
- VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL
- VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL
- VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR
- VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT

### 14.1.4. Combined Image Sampler

A combined image sampler (VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER) is a single descriptor type associated with both a sampler and an image resource, combining both a sampler and sampled image descriptor into a single descriptor.

If the descriptor refers to a sampler that performs Y’CₙCₚ conversion or samples a subsampled image, the sampler must only be used to sample the image in the same descriptor. Otherwise, the sampler and image in this type of descriptor can be used freely with any other samplers and images.

An image subresources for a combined image sampler must be in one of the following layouts:

- VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL
- VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL
- VK_IMAGE_LAYOUT_GENERAL
- VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR
- VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL
- VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL
- VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL
- VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL
- VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR
- VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT

**Note**
On some implementations, it **may** be more efficient to sample from an image using a combination of sampler and sampled image that are stored together in the descriptor set in a combined descriptor.

### 14.1.5. Uniform Texel Buffer

A **uniform texel buffer** (VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER) is a descriptor type associated with a **buffer resource** via a **buffer view** that **image sampling operations** **can** be performed on.

Uniform texel buffers define a tightly-packed 1-dimensional linear array of texels, with texels going through format conversion when read in a shader in the same way as they are for an image.

Load operations from uniform texel buffers are supported in all shader stages for buffer view formats which report **format features** support for **VK_FORMAT_FEATURE_UNIFORM_TEXEL_BUFFER_BIT**

### 14.1.6. Storage Texel Buffer

A **storage texel buffer** (VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER) is a descriptor type associated with a **buffer resource** via a **buffer view** that **image load, store, and atomic operations** **can** be performed on.

Storage texel buffers define a tightly-packed 1-dimensional linear array of texels, with texels going through format conversion when read in a shader in the same way as they are for an image. Unlike uniform texel buffers, these buffers can also be written to in the same way as for **storage images**.

Storage texel buffer loads are supported in all shader stages for texel buffer view formats which report **format features** support for **VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_BIT**

Stores to storage texel buffers are supported in task, mesh and compute shaders for texel buffer formats which report **format features** support for **VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_BIT**

Atomic operations on storage texel buffers are supported in task, mesh and compute shaders for texel buffer formats which report **format features** support for **VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT**

When the **fragmentStoresAndAtomics** feature is enabled, stores and atomic operations are also supported for storage texel buffers in fragment shaders with the same set of texel buffer formats as
supported in compute shaders. When the `vertexPipelineStoresAndAtomics` feature is enabled, stores and atomic operations are also supported in vertex, tessellation, and geometry shaders with the same set of texel buffer formats as supported in compute shaders.

### 14.1.7. Storage Buffer

A *storage buffer* (`VK_DESCRIPTOR_TYPE_STORAGE_BUFFER`) is a descriptor type associated with a *buffer resource* directly, described in a shader as a structure with various members that load, store, and atomic operations can be performed on.

**Note**
Atomic operations can only be performed on members of certain types as defined in the SPIR-V environment appendix.

### 14.1.8. Uniform Buffer

A *uniform buffer* (`VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER`) is a descriptor type associated with a *buffer resource* directly, described in a shader as a structure with various members that load operations can be performed on.

### 14.1.9. Dynamic Uniform Buffer

A *dynamic uniform buffer* (`VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC`) is almost identical to a *uniform buffer*, and differs only in how the offset into the buffer is specified. The base offset calculated by the `VkDescriptorBufferInfo` when initially updating the descriptor set is added to a *dynamic offset* when binding the descriptor set.

### 14.1.10. Dynamic Storage Buffer

A *dynamic storage buffer* (`VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC`) is almost identical to a *storage buffer*, and differs only in how the offset into the buffer is specified. The base offset calculated by the `VkDescriptorBufferInfo` when initially updating the descriptor set is added to a *dynamic offset* when binding the descriptor set.

### 14.1.11. Inline Uniform Block

An *inline uniform block* (`VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK`) is almost identical to a *uniform buffer*, and differs only in taking its storage directly from the encompassing descriptor set instead of being backed by buffer memory. It is typically used to access a small set of constant data that does not require the additional flexibility provided by the indirection enabled when using a uniform buffer where the descriptor and the referenced buffer memory are decoupled. Compared to push constants, they allow reusing the same set of constant data across multiple disjoint sets of drawing and dispatching commands.

Inline uniform block descriptors cannot be aggregated into arrays. Instead, the array size specified for an inline uniform block descriptor binding specifies the binding’s capacity in bytes.
14.1.12. Sample Weight Image

A sample weight image (VK_DESCRIPTOR_TYPE_SAMPLE_WEIGHT_IMAGE_QCOM) is a descriptor type associated with an image resource via an image view that can be used in weight image sampling. The image view must have been created with VkImageViewSampleWeightCreateInfoQCOM.

Shaders can combine a weight image variable, a sampled image variable, and a sampler variable to perform weight image sampling.

Weight image sampling is supported in all shader stages if the weight image view specifies a format that supports format feature VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM and the sampled image view specifies a format that supports format feature VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM.

The image subresources for the weight image must be in the VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL, or VK_IMAGE_LAYOUT_GENERAL layout in order to access its data in a shader.

14.1.13. Block Matching Image

A block matching image (VK_DESCRIPTOR_TYPE_BLOCK_MATCH_IMAGE_QCOM) is a descriptor type associated with an image resource via an image view that can be used in block matching.

Shaders can combine a target image variable, a reference image variable, and a sampler variable to perform block matching.

Block matching is supported in all shader stages for if both the target view and reference view specifies a format that supports format feature VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM.

The image subresources for block matching must be in the VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL, or VK_IMAGE_LAYOUT_GENERAL layout in order to access its data in a shader.


An input attachment (VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT) is a descriptor type associated with an image resource via an image view that can be used for framebuffer local load operations in fragment shaders.

All image formats that are supported for color attachments (VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT or VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV) or depth/stencil attachments (VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT) for a given image tiling mode are also supported for input attachments.

An image view used as an input attachment must be in one of the following layouts:

- VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL
- VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL
- VK_IMAGE_LAYOUT_GENERAL
14.1.15. Acceleration Structure

An *acceleration structure* (VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR or
VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_NV) is a descriptor type that is used to retrieve scene geometry from within shaders that are used for ray traversal. Shaders have read-only access to the memory.

14.1.16. Mutable

A descriptor of *mutable* (VK_DESCRIPTOR_TYPE_MUTABLE_EXT) type indicates that this descriptor can mutate to any of the descriptor types given in the VkMutableDescriptorTypeCreateInfoEXT::pDescriptorTypes list of descriptor types in the pNext chain of VkDescriptorSetLayoutCreateInfo for this binding. At any point, each individual descriptor of mutable type has an active descriptor type. The active descriptor type can be any one of the declared types in pDescriptorTypes. Additionally, a mutable descriptor's active descriptor type can be of the VK_DESCRIPTOR_TYPE_MUTABLE_EXT type, which is the initial active descriptor type. The active descriptor type can change when the descriptor is updated. When a descriptor is consumed by binding a descriptor set, the active descriptor type is considered, not VK_DESCRIPTOR_TYPE_MUTABLE_EXT.

An active descriptor type of VK_DESCRIPTOR_TYPE_MUTABLE_EXT is considered an undefined descriptor. If a descriptor is consumed where the active descriptor type does not match what the shader expects, the descriptor is considered an undefined descriptor.

**Note**

To find which descriptor types are supported as VK_DESCRIPTOR_TYPE_MUTABLE_EXT, the application can use vkGetDescriptorSetLayoutSupport with an VK_DESCRIPTOR_TYPE_MUTABLE_EXT binding, with the list of descriptor types to query in the VkMutableDescriptorTypeCreateInfoEXT::pDescriptorTypes array for that binding.

**Note**

The intention of a mutable descriptor type is that implementations allocate N bytes per descriptor, where N is determined by the maximum descriptor size for a given descriptor binding. Implementations are not expected to keep track of the active descriptor type, and it should be considered a C-like union type.

A mutable descriptor type is not considered as efficient in terms of runtime performance as using a non-mutable descriptor type, and applications are not encouraged to use them outside API layering efforts. Mutable descriptor types can be more efficient if the alternative is using many different descriptors to emulate
mutable descriptor types.

14.2. Descriptor Sets

Descriptors are grouped together into descriptor set objects. A descriptor set object is an opaque object containing storage for a set of descriptors, where the types and number of descriptors is defined by a descriptor set layout. The layout object may be used to define the association of each descriptor binding with memory or other implementation resources. The layout is used both for determining the resources that need to be associated with the descriptor set, and determining the interface between shader stages and shader resources.

14.2.1. Descriptor Set Layout

A descriptor set layout object is defined by an array of zero or more descriptor bindings. Each individual descriptor binding is specified by a descriptor type, a count (array size) of the number of descriptors in the binding, a set of shader stages that can access the binding, and (if using immutable samplers) an array of sampler descriptors.

Descriptor set layout objects are represented by VkDescriptorSetLayout handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkDescriptorSetLayout)
```

To create descriptor set layout objects, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkCreateDescriptorSetLayout(
    VkDevice device,
    const VkDescriptorSetLayoutCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkDescriptorSetLayout* pSetLayout);
```

- **device** is the logical device that creates the descriptor set layout.
- **pCreateInfo** is a pointer to a VkDescriptorSetLayoutCreateInfo structure specifying the state of the descriptor set layout object.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
- **pSetLayout** is a pointer to a VkDescriptorSetLayout handle in which the resulting descriptor set layout object is returned.

Valid Usage (Implicit)

- VUID-vkCreateDescriptorSetLayout-device-parameter
device must be a valid VkDevice handle
- VUID-vkCreateDescriptorSetLayout-pCreateInfo-parameter
pCreateInfo must be a valid pointer to a valid VkDescriptorSetLayoutCreateInfo structure

- VUID-vkCreateDescriptorSetLayout-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkCreateDescriptorSetLayout-pSetLayout-parameter
  pSetLayout must be a valid pointer to a VkDescriptorSetLayout handle

Return Codes

Success

- VK_SUCCESS

Failure

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

Information about the descriptor set layout is passed in a VkDescriptorSetLayoutCreateInfo structure:

```c
// Provided by VK_VERSION_1_0
typedef struct VkDescriptorSetLayoutCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkDescriptorSetLayoutCreateFlags flags;
    uint32_t bindingCount;
    const VkDescriptorSetLayoutBinding* pBindings;
} VkDescriptorSetLayoutCreateInfo;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- flags is a bitmask of VkDescriptorSetLayoutCreateFlagBits specifying options for descriptor set layout creation.
- bindingCount is the number of elements in pBindings.
- pBindings is a pointer to an array of VkDescriptorSetLayoutBinding structures.

Valid Usage

- VUID-VkDescriptorSetLayoutCreateInfo-binding-00279
  The VkDescriptorSetLayoutBinding::binding members of the elements of the pBindings array must each have different values

- VUID-VkDescriptorSetLayoutCreateInfo-flags-00280
  If flags contains VK_DESCRIPTOR_SET_LAYOUT_CREATE_PUSH_DESCRIPTOR_BIT_KHR, then all
elements of pBindings must not have a descriptorType of VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC or VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC

• VUID-VkDescriptorSetLayoutCreateInfo-flags-02208
  If flags contains VK_DESCRIPTOR_SET_LAYOUT_CREATE_PUSH_DESCRIPTOR_BIT_KHR, then all elements of pBindings must not have a descriptorType of VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK

• VUID-VkDescriptorSetLayoutCreateInfo-flags-00281
  If flags contains VK_DESCRIPTOR_SET_LAYOUT_CREATE_PUSH_DESCRIPTOR_BIT_KHR, then the total number of elements of all bindings must be less than or equal to VkPhysicalDevicePushDescriptorPropertiesKHR::maxPushDescriptors

• VUID-VkDescriptorSetLayoutCreateInfo-flags-04590
  If flags contains VK_DESCRIPTOR_SET_LAYOUT_CREATE_PUSH_DESCRIPTOR_BIT_KHR, flags must not contain VK_DESCRIPTOR_SET_LAYOUT_CREATE_HOST_ONLY_POOL_BIT_EXT

• VUID-VkDescriptorSetLayoutCreateInfo-flags-04591
  If flags contains VK_DESCRIPTOR_SET_LAYOUT_CREATE_PUSH_DESCRIPTOR_BIT_KHR, pBindings must not have a descriptorType of VK_DESCRIPTOR_TYPE_MUTABLE_EXT

• VUID-VkDescriptorSetLayoutCreateInfo-flags-03000
  If any binding has the VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT bit set, flags must include VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT

• VUID-VkDescriptorSetLayoutCreateInfo-descriptorType-03001
  If any binding has the VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT bit set, then all bindings must not have descriptorType of VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC or VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC

• VUID-VkDescriptorSetLayoutCreateInfo-flags-04592
  If flags contains VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT, flags must not contain VK_DESCRIPTOR_SET_LAYOUT_CREATE_HOST_ONLY_POOL_BIT_EXT

• VUID-VkDescriptorSetLayoutCreateInfo-pBindings-07303
  If any element pBindings[i] has a descriptorType of VK_DESCRIPTOR_TYPE_MUTABLE_EXT, then a VkMutableDescriptorTypeCreateInfoEXT must be present in the pNext chain, and mutableDescriptorTypeListCount must be greater than i

• VUID-VkDescriptorSetLayoutCreateInfo-flags-04594
  If a binding has a descriptorType value of VK_DESCRIPTOR_TYPE_MUTABLE_EXT, then pImmutableSamplers must be NULL

• VUID-VkDescriptorSetLayoutCreateInfo-flags-04595
  If VkPhysicalDeviceMutableDescriptorTypeFeaturesEXT::mutableDescriptorType is not enabled, pBindings must not contain a descriptorType of VK_DESCRIPTOR_TYPE_MUTABLE_EXT

• VUID-VkDescriptorSetLayoutCreateInfo-flags-04596
  If flags contains VK_DESCRIPTOR_SET_LAYOUT_CREATE_HOST_ONLY_POOL_BIT_EXT, VkPhysicalDeviceMutableDescriptorTypeFeaturesEXT::mutableDescriptorType must be enabled

• VUID-VkDescriptorSetLayoutCreateInfo-flags-08000
  If flags contains VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, then all elements of pBindings must not have a descriptorType of
VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC or VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC

- VUID-VkDescriptorSetLayoutCreateInfo-flags-08001
  If flags contains VK_DESCRIPTOR_SET_LAYOUT_CREATE_EMBEDDED_IMMUTABLE_SAMPLERS_BIT_EXT, flags must also contain VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-VkDescriptorSetLayoutCreateInfo-flags-08002
  If flags contains VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, then flags must not contain VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT

- VUID-VkDescriptorSetLayoutCreateInfo-flags-08003
  If flags contains VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, then flags must not contain VK_DESCRIPTOR_SET_LAYOUT_CREATE_HOST_ONLY_POOL_BIT_VALVE

Valid Usage (Implicit)

- VUID-VkDescriptorSetLayoutCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_CREATE_INFO

- VUID-VkDescriptorSetLayoutCreateInfo-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkDescriptorSetLayoutBindingFlagsCreateInfo or VkMutableDescriptorTypeCreateInfoEXT

- VUID-VkDescriptorSetLayoutCreateInfo-sType-unique
  The sType value of each struct in the pNext chain must be unique

- VUID-VkDescriptorSetLayoutCreateInfo-flags-parameter
  flags must be a valid combination of VkDescriptorSetLayoutCreateFlagBits values

- VUID-VkDescriptorSetLayoutCreateInfo-pBindings-parameter
  If bindingCount is not 0, pBindings must be a valid pointer to an array of bindingCount valid VkDescriptorSetLayoutBinding structures

If the pNext chain of a VkDescriptorSetLayoutCreateInfo or VkDescriptorPoolCreateInfo structure includes a VkMutableDescriptorTypeCreateInfoEXT structure, then that structure specifies Information about the possible descriptor types for mutable descriptor types.

The VkMutableDescriptorTypeCreateInfoEXT structure is defined as:

```c
// Provided by VK_EXT_mutable_descriptor_type
typedef struct VkMutableDescriptorTypeCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    uint32_t mutableDescriptorTypeListCount;
    const VkMutableDescriptorTypeListEXT* pMutableDescriptorTypeLists;
} VkMutableDescriptorTypeCreateInfoEXT;
```

or the equivalent
• **sType** is a *VkStructureType* value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **mutableDescriptorTypeListCount** is the number of elements in **pMutableDescriptorTypeLists**.

• **pMutableDescriptorTypeLists** is a pointer to an array of *VkMutableDescriptorTypeListEXT* structures.

If **mutableDescriptorTypeListCount** is zero or if this structure is not included in the **pNext** chain, the *VkMutableDescriptorTypeListEXT* for each element is considered to be zero or **NULL** for each member. Otherwise, the descriptor set layout binding at *VkDescriptorSetLayoutCreateInfo* ::**pBindings[i]** uses the descriptor type lists in *VkMutableDescriptorTypeCreateInfoEXT* ::**pMutableDescriptorTypeLists[i]**.

### Valid Usage (Implicit)

- VUID-VkMutableDescriptorTypeCreateInfoEXT-sType-sType
  
  **sType** must be **VK_STRUCTURE_TYPE_MUTABLE_DESCRIPTOR_TYPE_CREATE_INFO_EXT**

- VUID-VkMutableDescriptorTypeCreateInfoEXT-pMutableDescriptorTypeLists-parameter

  If **mutableDescriptorTypeListCount** is not 0, **pMutableDescriptorTypeLists** must be a valid pointer to an array of **mutableDescriptorTypeListCount** valid *VkMutableDescriptorTypeListEXT* structures

The list of potential descriptor types a given mutable descriptor can mutate to is passed in a *VkMutableDescriptorTypeListEXT* structure.

The *VkMutableDescriptorTypeListEXT* structure is defined as:

```c
// Provided by VK_EXT_mutable_descriptor_type
typedef struct VkMutableDescriptorTypeListEXT {
    uint32_t descriptorTypeCount;
    const VkDescriptorType* pDescriptorTypes;
} VkMutableDescriptorTypeListEXT;
```

or the equivalent

```c
// Provided by VK_VALVE_mutable_descriptor_type
typedef VkMutableDescriptorTypeListEXT VkMutableDescriptorTypeListVALVE;
```

• **descriptorTypeCount** is the number of elements in **pDescriptorTypes**.

• **pDescriptorTypes** is **NULL** or a pointer to an array of **descriptorTypeCount** *VkDescriptorType* values defining which descriptor types a given binding may mutate to.
Valid Usage

- VUID-VkMutableDescriptorTypeListEXT-descriptorTypeCount-04597
descriptorTypeCount must not be 0 if the corresponding binding is of VK_DESCRIPTOR_TYPE_MUTABLE_EXT

- VUID-VkMutableDescriptorTypeListEXT-pDescriptorTypes-04598
pDescriptorTypes must be a valid pointer to an array of descriptorTypeCount valid, unique VkDescriptorType values if the given binding is of VK_DESCRIPTOR_TYPE_MUTABLE_EXT type

- VUID-VkMutableDescriptorTypeListEXT-descriptorTypeCount-04599
descriptorTypeCount must be 0 if the corresponding binding is not of VK_DESCRIPTOR_TYPE_MUTABLE_EXT

- VUID-VkMutableDescriptorTypeListEXT-pDescriptorTypes-04600
pDescriptorTypes must not contain VK_DESCRIPTOR_TYPE_MUTABLE_EXT

- VUID-VkMutableDescriptorTypeListEXT-pDescriptorTypes-04601
pDescriptorTypes must not contain VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC

- VUID-VkMutableDescriptorTypeListEXT-pDescriptorTypes-04602
pDescriptorTypes must not contain VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC

- VUID-VkMutableDescriptorTypeListEXT-pDescriptorTypes-04603
pDescriptorTypes must not contain VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK

Valid Usage (Implicit)

- VUID-VkMutableDescriptorTypeListEXT-pDescriptorTypes-parameter
If descriptorTypeCount is not 0, pDescriptorTypes must be a valid pointer to an array of descriptorTypeCount valid VkDescriptorType values

Bits which can be set in VkDescriptorSetLayoutCreateInfo::flags, specifying options for descriptor set layout, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkDescriptorSetLayoutCreateFlagBits {
    // Provided by VK_VERSION_1_2
    VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT = 0x00000002,
    // Provided by VK_KHR_push_descriptor
    VK_DESCRIPTOR_SET_LAYOUT_CREATE_PUSH_DESCRIPTOR_BIT_KHR = 0x00000001,
    // Provided by VK_EXT_descriptor_buffer
    VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT = 0x00000010,
    // Provided by VK_EXT_descriptor_buffer
    VK_DESCRIPTOR_SET_LAYOUT_CREATE_EMBEDDED_IMMUTABLE_SAMPLERS_BIT_EXT = 0x00000020,
    // Provided by VK_NV_device_generated_commands_compute
    VK_DESCRIPTOR_SET_LAYOUT_CREATE_INDIRECT_BINDABLE_BIT_NV = 0x00000080,
    // Provided by VK_EXT.mutable_descriptor_type
    VK_DESCRIPTOR_SET_LAYOUT_CREATE_HOST_ONLY_POOL_BIT_EXT = 0x00000004,
} VkDescriptorSetLayoutCreateFlagBits;
```
VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT_EXT =
VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT,
// Provided by VK_VALVEmutable_descriptor_type
VK_DESCRIPTOR_SET_LAYOUT_CREATE_HOST_ONLY_POOL_BIT_VALVE =
VK_DESCRIPTOR_SET_LAYOUT_CREATE_HOST_ONLY_POOL_BIT_EXT,
} VkDescriptorSetLayoutCreateFlagBits;

• VK_DESCRIPTOR_SET_LAYOUT_CREATE_PUSH_DESCRIPTOR_BIT_KHR specifies that descriptor sets must not be allocated using this layout, and descriptors are instead pushed by vkCmdPushDescriptorSetKHR.

• VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT specifies that descriptor sets using this layout must be allocated from a descriptor pool created with the VK_DESCRIPTOR_POOL_CREATE_UPDATE_AFTER_BIND_BIT bit set. Descriptor set layouts created with this bit set have alternate limits for the maximum number of descriptors per-stage and per-pipeline layout. The non-UpdateAfterBind limits only count descriptors in sets created without this flag. The UpdateAfterBind limits count all descriptors, but the limits may be higher than the non-UpdateAfterBind limits.

• VK_DESCRIPTOR_SET_LAYOUT_CREATE_INDIRECT_BINDABLE_BIT_NV specifies that descriptor sets using this layout allows them to be bound with compute pipelines that are created with VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV flag set to be used in Device-Generated Commands.

• VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT specifies that this layout must only be used with descriptor buffers.

• VK_DESCRIPTOR_SET_LAYOUT_CREATE_EMBEDDED_IMMUTABLE_SAMPLERS_BIT_EXT specifies that this is a layout only containing immutable samplers that can be bound by vkCmdBindDescriptorBufferEmbeddedSamplersEXT. Unlike normal immutable samplers, embedded immutable samplers do not require the application to provide them in a descriptor buffer.

• VK_DESCRIPTOR_SET_LAYOUT_CREATE_HOST_ONLY_POOL_BIT_EXT specifies that descriptor sets using this layout must be allocated from a descriptor pool created with the VK_DESCRIPTOR_POOL_CREATE_HOST_ONLY_BIT_EXT bit set. Descriptor set layouts created with this bit have no expressible limit for maximum number of descriptors per-stage. Host descriptor sets are limited only by available host memory, but may be limited for implementation specific reasons. Implementations may limit the number of supported descriptors to UpdateAfterBind limits or non-UpdateAfterBind limits, whichever is larger.

// Provided by VK_VERSION_1_0
typedef VkFlags VkDescriptorSetLayoutCreateFlags;

VkDescriptorSetLayoutCreateFlags is a bitmask type for setting a mask of zero or more VkDescriptorSetLayoutCreateFlagBits.

The VkDescriptorSetLayoutBinding structure is defined as:

// Provided by VK_VERSION_1_0
typedef struct VkDescriptorSetLayoutBinding {
    uint32_t binding;
    VkDescriptorType descriptorType;
    uint32_t descriptorCount;
    VkShaderStageFlags stageFlags;
    const VkSampler* pImmutableSamplers;
} VkDescriptorSetLayoutBinding;

• **binding** is the binding number of this entry and corresponds to a resource of the same binding number in the shader stages.

• **descriptorType** is a **VkDescriptorType** specifying which type of resource descriptors are used for this binding.

• **descriptorCount** is the number of descriptors contained in the binding, accessed in a shader as an array, except if **descriptorType** is **VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK** in which case **descriptorCount** is the size in bytes of the inline uniform block. If **descriptorCount** is zero this binding entry is reserved and the resource **must** not be accessed from any stage via this binding within any pipeline using the set layout.

• **stageFlags** member is a bitmask of **VkShaderStageFlagBits** specifying which pipeline shader stages **can** access a resource for this binding. **VK_SHADER_STAGE_ALL** is a shorthand specifying that all defined shader stages, including any additional stages defined by extensions, **can** access the resource.

    If a shader stage is not included in **stageFlags**, then a resource **must** not be accessed from that stage via this binding within any pipeline using the set layout. Other than input attachments which are limited to the fragment shader, there are no limitations on what combinations of stages **can** use a descriptor binding, and in particular a binding **can** be used by both graphics stages and the compute stage.

• **pImmutableSamplers** affects initialization of samplers. If **descriptorType** specifies a **VK_DESCRIPTOR_TYPE_SAMPLER** or **VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER** type descriptor, then **pImmutableSamplers** **can** be used to initialize a set of **immutable samplers**. Immutable samplers are permanently bound into the set layout and **must** not be changed; updating a **VK_DESCRIPTOR_TYPE_SAMPLER** descriptor with immutable samplers is not allowed and updates to a **VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER** descriptor with immutable samplers does not modify the samplers (the image views are updated, but the sampler updates are ignored). If **pImmutableSamplers** is not **NULL**, then it is a pointer to an array of sampler handles that will be copied into the set layout and used for the corresponding binding. Only the sampler handles are copied; the sampler objects **must** not be destroyed before the final use of the set layout and any descriptor pools and sets created using it. If **pImmutableSamplers** is **NULL**, then the sampler slots are dynamic and sampler handles **must** be bound into descriptor sets using this layout. If **descriptorType** is not one of these descriptor types, then **pImmutableSamplers** is ignored.

The above layout definition allows the descriptor bindings to be specified sparsely such that not all binding numbers between 0 and the maximum binding number need to be specified in the **pBindings** array. Bindings that are not specified have a **descriptorCount** and **stageFlags** of zero, and the value of **descriptorType** is undefined. However, all binding numbers between 0 and the maximum binding number in the **VkDescriptorSetLayoutCreateInfo::pBindings** array **may** consume
memory in the descriptor set layout even if not all descriptor bindings are used, though it should not consume additional memory from the descriptor pool.

Note
The maximum binding number specified should be as compact as possible to avoid wasted memory.

Valid Usage

- VUID-VkDescriptorSetLayoutBinding-descriptorType-00282
  If descriptorType is VK_DESCRIPTOR_TYPE_SAMPLER or VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER, and descriptorCount is not 0 and pImmutableSamplers is not NULL, pImmutableSamplers must be a valid pointer to an array of descriptorCount valid VkSampler handles.

- VUID-VkDescriptorSetLayoutBinding-descriptorType-04604
  If the inlineUniformBlock feature is not enabled, descriptorType must not be VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK.

- VUID-VkDescriptorSetLayoutBinding-descriptorType-02209
  If descriptorType is VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK then descriptorCount must be a multiple of 4.

- VUID-VkDescriptorSetLayoutBinding-descriptorType-08004
  If descriptorType is VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK and VkDescriptorSetLayoutCreateInfo::flags does not contain VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT then descriptorCount must be less than or equal to VkPhysicalDeviceInlineUniformBlockPropertiesEXT::maxInlineUniformBlockSize.

- VUID-VkDescriptorSetLayoutBinding-flags-08005
  If VkDescriptorSetLayoutCreateInfo::flags contains VK_DESCRIPTOR_SET_LAYOUT_CREATE_EMBEDDED_IMMUTABLE_SAMPLERS_BIT_EXT, descriptorType must be VK_DESCRIPTOR_TYPE_SAMPLER.

- VUID-VkDescriptorSetLayoutBinding-flags-08006
  If VkDescriptorSetLayoutCreateInfo::flags contains VK_DESCRIPTOR_SET_LAYOUT_CREATE_EMBEDDED_IMMUTABLE_SAMPLERS_BIT_EXT, descriptorCount must be less than or equal to 1.

- VUID-VkDescriptorSetLayoutBinding-flags-08007
  If VkDescriptorSetLayoutCreateInfo::flags contains VK_DESCRIPTOR_SET_LAYOUT_CREATE_EMBEDDED_IMMUTABLE_SAMPLERS_BIT_EXT and descriptorCount is equal to 1, pImmutableSamplers must not be NULL.

- VUID-VkDescriptorSetLayoutBinding-descriptorCount-00283
  If descriptorCount is not 0, stageFlags must be a valid combination of VkShaderStageFlagBits values.

- VUID-VkDescriptorSetLayoutBinding-descriptorType-01510
  If descriptorType is VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT and descriptorCount is not 0, then stageFlags must be 0 or VK_SHADER_STAGE_FRAGMENT_BIT.
The sampler objects indicated by `pImmutableSamplers` must not have a `borderColor` with one of the values `VK_BORDER_COLOR_FLOAT_CUSTOM_EXT` or `VK_BORDER_COLOR_INT_CUSTOM_EXT`.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`, then `pImmutableSamplers` must be `NULL`.

### Valid Usage (Implicit)

- `VUID-VkDescriptorSetLayoutBinding-descriptorType-04605`
  
  If `descriptorType` is `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`, then `pImmutableSamplers` must be `NULL`.

If the `pNext` chain of a `VkDescriptorSetLayoutCreateInfo` structure includes a `VkDescriptorSetLayoutBindingFlagsCreateInfo` structure, then that structure includes an array of flags, one for each descriptor set layout binding.

The `VkDescriptorSetLayoutBindingFlagsCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkDescriptorSetLayoutBindingFlagsCreateInfo {
    VkStructureType sType;
    const void*     pNext;
    uint32_t        bindingCount;
    const VkDescriptorBindingFlags* pBindingFlags;
} VkDescriptorSetLayoutBindingFlagsCreateInfo;
```

or the equivalent

```c
// Provided by VK_EXT_descriptor_indexing
typedef VkDescriptorSetLayoutBindingFlagsCreateInfo
VkDescriptorSetLayoutBindingFlagsCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `bindingCount` is zero or the number of elements in `pBindingFlags`.
- `pBindingFlags` is a pointer to an array of `VkDescriptorBindingFlags` bitfields, one for each descriptor set layout binding.

If `bindingCount` is zero or if this structure is not included in the `pNext` chain, the `VkDescriptorBindingFlags` for each descriptor set layout binding is considered to be zero. Otherwise, the descriptor set layout binding at `VkDescriptorSetLayoutCreateInfo::pBindings[i]` uses the flags in `pBindingFlags[i]`. 
Valid Usage

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-bindingCount-03002**
  If `bindingCount` is not zero, `bindingCount` must equal `VkDescriptorSetLayoutCreateInfo::bindingCount`.

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-flags-03003**
  If `VkDescriptorSetLayoutCreateInfo::flags` includes `VK_DESCRIPTOR_SET_LAYOUT_CREATE_PUSH_DESCRIPTOR_BIT_KHR`, then all elements of `pBindingFlags` must not include `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT`, `VK_DESCRIPTOR_BINDING_UPDATE_UNUSED_WHILE_PENDING_BIT`, or `VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT`.

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-pBindingFlags-03004**
  If an element of `pBindingFlags` includes `VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT`, then all other elements of `VkDescriptorSetLayoutCreateInfo::pBindings` must have a smaller value of `binding`.

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-descriptorBindingUniformBufferUpdateAfterBind-03005**
  If `VkPhysicalDeviceDescriptorIndexingFeatures::descriptorBindingUniformBufferUpdateAfterBind` is not enabled, all bindings with descriptor type `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER` must not use `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT`.

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-descriptorBindingSampledImageUpdateAfterBind-03006**
  If `VkPhysicalDeviceDescriptorIndexingFeatures::descriptorBindingSampledImageUpdateAfterBind` is not enabled, all bindings with descriptor type `VK_DESCRIPTOR_TYPE_SAMPLER`, `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`, or `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE` must not use `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT`.

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-descriptorBindingStorageImageUpdateAfterBind-03007**
  If `VkPhysicalDeviceDescriptorIndexingFeatures::descriptorBindingStorageImageUpdateAfterBind` is not enabled, all bindings with descriptor type `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE` must not use `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT`.

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-descriptorBindingStorageBufferUpdateAfterBind-03008**
  If `VkPhysicalDeviceDescriptorIndexingFeatures::descriptorBindingStorageBufferUpdateAfterBind` is not enabled, all bindings with descriptor type `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER` must not use `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT`.

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-descriptorBindingUniformTexelBufferUpdateAfterBind-03009**
  If `VkPhysicalDeviceDescriptorIndexingFeatures::descriptorBindingUniformTexelBufferUpdateAfterBind` is not enabled, all bindings with descriptor type `VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER` must not use `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT`.
**descriptor type** VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER must not use VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-descriptorBindingStorageTexelBufferUpdateAfterBind-03010**
  If **VkPhysicalDeviceDescriptorIndexingFeatures**::descriptorBindingStorageTexelBufferUpdateAfterBind is not enabled, all bindings with **descriptor type** VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER must not use VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-descriptorBindingInlineUniformBlockUpdateAfterBind-02211**
  If **VkPhysicalDeviceInlineUniformBlockFeatures**::descriptorBindingInlineUniformBlockUpdateAfterBind is not enabled, all bindings with **descriptor type** VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK must not use VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-descriptorBindingAccelerationStructureUpdateAfterBind-03570**
  If **VkPhysicalDeviceAccelerationStructureFeaturesKHR**::descriptorBindingAccelerationStructureUpdateAfterBind is not enabled, all bindings with **descriptor type** VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR or VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_NV must not use VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-None-03011**
  All bindings with **descriptor type** VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT, VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC, or VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC must not use VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-descriptorBindingUpdateUnusedWhilePending-03012**
  If **VkPhysicalDeviceDescriptorIndexingFeatures**::descriptorBindingUpdateUnusedWhilePending is not enabled, all elements of **pBindingFlags** must not include VK_DESCRIPTOR_BINDING_UPDATE_UNUSED_WHILE_PENDING_BIT

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-descriptorBindingPartiallyBound-03013**
  If **VkPhysicalDeviceDescriptorIndexingFeatures**::descriptorBindingPartiallyBound is not enabled, all elements of **pBindingFlags** must not include VK_DESCRIPTOR_BINDING_PARTIALLY_BOUND_BIT

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-descriptorBindingVariableDescriptorCount-03014**
  If **VkPhysicalDeviceDescriptorIndexingFeatures**::descriptorBindingVariableDescriptorCount is not enabled, all elements of **pBindingFlags** must not include VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT

- **VUID-VkDescriptorSetLayoutBindingFlagsCreateInfo-pBindingFlags-03015**
  If an element of **pBindingFlags** includes VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT, that element's **descriptor type** must not be VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC or VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC
Valid Usage (Implicit)

- VUID-VkDescriptorsetLayoutBindingFlagsCreateInfo-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_BINDING_FLAGS_CREATE_INFO`

- VUID-VkDescriptorsetLayoutBindingFlagsCreateInfo-pBindingFlags-parameter
  
  If `bindingCount` is not 0, `pBindingFlags` must be a valid pointer to an array of `bindingCount`
  valid combinations of `VkDescriptorBindingFlagBits` values.

Bits which can be set in each element of `VkDescriptorsetLayoutBindingFlagsCreateInfo::pBindingFlags`, specifying options for the corresponding descriptor set layout binding, are:

```c
// Provided by VK_VERSION_1_2
typedef enum VkDescriptorBindingFlagBits {
    VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT = 0x00000001,
    VK_DESCRIPTOR_BINDING_UPDATE_UNUSED_WHILE_PENDING_BIT = 0x00000002,
    VK_DESCRIPTOR_BINDING_PARTIALLY_BOUND_BIT = 0x00000004,
    VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT = 0x00000008,
    // Provided by VK_EXT_descriptor_indexing
    VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT_EXT =
    VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT,
    // Provided by VK_EXT_descriptor_indexing
    VK_DESCRIPTOR_BINDING_UPDATE_UNUSED_WHILE_PENDING_BIT_EXT =
    VK_DESCRIPTOR_BINDING_UPDATE_UNUSED_WHILE_PENDING_BIT,
    // Provided by VK_EXT_descriptor_indexing
    VK_DESCRIPTOR_BINDING_PARTIALLY_BOUND_BIT_EXT =
    VK_DESCRIPTOR_BINDING_PARTIALLY_BOUND_BIT,
    // Provided by VK_EXT_descriptor_indexing
    VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT_EXT =
    VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT,
} VkDescriptorBindingFlagBits;
```

or the equivalent

```c
// Provided by VK_EXT_descriptor_indexing
typedef VkDescriptorBindingFlagBits VkDescriptorBindingFlagBitsEXT;
```

- `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT` indicates that if descriptors in this binding are
  updated between when the descriptor set is bound in a command buffer and when that
  command buffer is submitted to a queue, then the submission will use the most recently set
  descriptors for this binding and the updates do not invalidate the command buffer. Descriptor
  bindings created with this flag are also partially exempt from the external synchronization
  requirement in `vkUpdateDescriptorSetWithTemplateKHR` and `vkUpdateDescriptorSets`. Multiple
  descriptors with this flag set can be updated concurrently in different threads, though the same
  descriptor must not be updated concurrently by two threads. Descriptors with this flag set can
  be updated concurrently with the set being bound to a command buffer in another thread, but
  not concurrently with the set being reset or freed.
• **VK_DESCRIPTOR_BINDING_PARTIALLY_BOUND_BIT** indicates that descriptors in this binding that are not *dynamically used* need not contain valid descriptors at the time the descriptors are consumed. A descriptor is dynamically used if any shader invocation executes an instruction that performs any memory access using the descriptor. If a descriptor is not dynamically used, any resource referenced by the descriptor is not considered to be referenced during command execution.

• **VK_DESCRIPTOR_BINDING_UPDATE_UNUSED_WHILE_PENDING_BIT** indicates that descriptors in this binding *can* be updated after a command buffer has bound this descriptor set, or while a command buffer that uses this descriptor set is pending execution, as long as the descriptors that are updated are not used by those command buffers. Descriptor bindings created with this flag are also partially exempt from the external synchronization requirement in `vkUpdateDescriptorSetWithTemplateKHR` and `vkUpdateDescriptorSets` in the same way as for **VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT**. If **VK_DESCRIPTOR_BINDING_PARTIALLY_BOUND_BIT** is also set, then descriptors *can* be updated as long as they are not dynamically used by any shader invocations. If **VK_DESCRIPTOR_BINDING_PARTIALLY_BOUND_BIT** is not set, then descriptors *can* be updated as long as they are not statically used by any shader invocations.

• **VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT** indicates that this is a *variable-sized descriptor binding* whose size will be specified when a descriptor set is allocated using this layout. The value of `descriptorCount` is treated as an upper bound on the size of the binding. This *must* only be used for the last binding in the descriptor set layout (i.e. the binding with the largest value of `binding`). For the purposes of counting against limits such as `maxDescriptorSet` and `maxPerStageDescriptor*`, the full value of `descriptorCount` is counted, except for descriptor bindings with a descriptor type of **VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK**, when `VkDescriptorSetLayoutCreateInfo::flags` does not contain **VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT**. In this case, `descriptorCount` specifies the upper bound on the byte size of the binding; thus it counts against the `maxInlineUniformBlockSize` and `maxInlineUniformTotalSize` limits instead.

Note

Note that while **VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT** and **VK_DESCRIPTOR_BINDING_UPDATE_UNUSED_WHILE_PENDING_BIT** both involve updates to descriptor sets after they are bound, **VK_DESCRIPTOR_BINDING_UPDATE_UNUSED_WHILE_PENDING_BIT** is a weaker requirement since it is only about descriptors that are not used, whereas **VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT** requires the implementation to observe updates to descriptors that are used.

```c
// Provided by VK_VERSION_1_2
typedef VkFlags VkDescriptorBindingFlags;
```

or the equivalent

```c
// Provided by VK_EXT_descriptor_indexing
typedef VkDescriptorBindingFlags VkDescriptorBindingFlagsEXT;
```
VkDescriptorBindingFlags is a bitmask type for setting a mask of zero or more VkDescriptorBindingFlagBits.

To query information about whether a descriptor set layout can be created, call:

```c
// Provided by VK_VERSION_1_1
void vkGetDescriptorSetLayoutSupport(
    VkDevice device,
    const VkDescriptorSetLayoutCreateInfo* pCreateInfo,
    VkDescriptorSetLayoutSupport* pSupport);
```

or the equivalent command

```c
// Provided by VK_KHR_maintenance3
void vkGetDescriptorSetLayoutSupportKHR(
    VkDevice device,
    const VkDescriptorSetLayoutCreateInfo* pCreateInfo,
    VkDescriptorSetLayoutSupport* pSupport);
```

- device is the logical device that would create the descriptor set layout.
- pCreateInfo is a pointer to a VkDescriptorSetLayoutCreateInfo structure specifying the state of the descriptor set layout object.
- pSupport is a pointer to a VkDescriptorSetLayoutSupport structure, in which information about support for the descriptor set layout object is returned.

Some implementations have limitations on what fits in a descriptor set which are not easily expressible in terms of existing limits like maxDescriptorSet*, for example if all descriptor types share a limited space in memory but each descriptor is a different size or alignment. This command returns information about whether a descriptor set satisfies this limit. If the descriptor set layout satisfies the VkPhysicalDeviceMaintenance3Properties::maxPerSetDescriptors limit, this command is guaranteed to return VK_TRUE in VkDescriptorSetLayoutSupport::supported. If the descriptor set layout exceeds the VkPhysicalDeviceMaintenance3Properties::maxPerSetDescriptors limit, whether the descriptor set layout is supported is implementation-dependent and may depend on whether the descriptor sizes and alignments cause the layout to exceed an internal limit.

This command does not consider other limits such as maxPerStageDescriptor*, and so a descriptor set layout that is supported according to this command must still satisfy the pipeline layout limits such as maxPerStageDescriptor* in order to be used in a pipeline layout.

Note
This is a VkDevice query rather than VkPhysicalDevice because the answer may depend on enabled features.

Valid Usage (Implicit)
- VUID-vkGetDescriptorSetLayoutSupport-device-parameter
device must be a valid VkDevice handle

- VUID-vkGetDescriptorSetLayoutSupport-pCreateInfo-parameter pCreateInfo must be a valid pointer to a valid VkDescriptorSetLayoutCreateInfo structure
- VUID-vkGetDescriptorSetLayoutSupport-pSupport-parameter pSupport must be a valid pointer to a VkDescriptorSetLayoutSupport structure

Information about support for the descriptor set layout is returned in a VkDescriptorSetLayoutSupport structure:

```c
// Provided by VK_VERSION_1_1
typedef struct VkDescriptorSetLayoutSupport {
    VkStructureType sType;
    void* pNext;
    VkBool32 supported;
} VkDescriptorSetLayoutSupport;
```

or the equivalent

```c
// Provided by VK_KHR_maintenance3
typedef VkDescriptorSetLayoutSupport VkDescriptorSetLayoutSupportKHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- supported specifies whether the descriptor set layout can be created.

supported is set to VK_TRUE if the descriptor set can be created, or else is set to VK_FALSE.

### Valid Usage (Implicit)

- VUID-VkDescriptorSetLayoutSupport-sType-sType sType must be VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_SUPPORT
- VUID-VkDescriptorSetLayoutSupport-pNext-pNext pNext must be NULL or a pointer to a valid instance of VkDescriptorSetVariableDescriptorCountLayoutSupport
- VUID-VkDescriptorSetLayoutSupport-sType-unique The sType value of each struct in the pNext chain must be unique

If the pNext chain of a VkDescriptorSetLayoutSupport structure includes a VkDescriptorSetVariableDescriptorCountLayoutSupport structure, then that structure returns additional information about whether the descriptor set layout is supported.

```c
// Provided by VK_VERSION_1_2
typedef struct VkDescriptorSetVariableDescriptorCountLayoutSupport {
```

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struct VkDescriptorSetVariableDescriptorCountLayoutSupport {
    VkStructureType sType;
    void* pNext;
    uint32_t maxVariableDescriptorCount;
} VkDescriptorSetVariableDescriptorCountLayoutSupport;

or the equivalent

// Provided by VK_EXT_descriptor_indexing
typedef VkDescriptorSetVariableDescriptorCountLayoutSupport
    VkDescriptorSetVariableDescriptorCountLayoutSupportEXT;

• **sType** is a VkStructureType value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.
• **maxVariableDescriptorCount** indicates the maximum number of descriptors supported in the highest numbered binding of the layout, if that binding is variable-sized. If the highest numbered binding of the layout has a descriptor type of VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK then **maxVariableDescriptorCount** indicates the maximum byte size supported for the binding, if that binding is variable-sized.

If the VkDescriptorSetLayoutCreateInfo structure specified in vkGetDescriptorSetLayoutSupport::pCreateInfo includes a variable-sized descriptor, then supported is determined assuming the requested size of the variable-sized descriptor, and **maxVariableDescriptorCount** is set to the maximum size of that descriptor that can be successfully created (which is greater than or equal to the requested size passed in). If the VkDescriptorSetLayoutCreateInfo structure does not include a variable-sized descriptor, or if the VkPhysicalDeviceDescriptorIndexingFeatures::descriptorBindingVariableDescriptorCount feature is not enabled, then **maxVariableDescriptorCount** is set to zero. For the purposes of this command, a variable-sized descriptor binding with a descriptorCount of zero is treated as having a descriptorCount of four if descriptorType is VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK, or one otherwise, and thus the binding is not ignored and the maximum descriptor count will be returned. If the layout is not supported, then the value written to **maxVariableDescriptorCount** is undefined.

### Valid Usage (Implicit)

- **VUID-VkDescriptorSetVariableDescriptorCountLayoutSupport-sType-sType**

The following examples show a shader snippet using two descriptor sets, and application code that creates corresponding descriptor set layouts.

**GLSL example**

```glsl
// binding to a single sampled image descriptor in set 0
```
layout (set=0, binding=0) uniform texture2D mySampledImage;

// binding to an array of sampled image descriptors in set 0
// layout (set=0, binding=1) uniform texture2D myArrayOfSampledImages[12];

// binding to a single uniform buffer descriptor in set 1
// layout (set=1, binding=0) uniform myUniformBuffer
// {  vec4 myElement[32];
};

SPIR-V example

...%1 = OpExtInstImport "GLSL.std.450"
...
OpName %9 "mySampledImage"
OpName %14 "myArrayOfSampledImages"
OpName %18 "myUniformBuffer"
OpMemberName %18 0 "myElement"
OpName %20 ""
OpDecorate %9 DescriptorSet 0
OpDecorate %9 Binding 0
OpDecorate %14 DescriptorSet 0
OpDecorate %14 Binding 1
OpDecorate %17 ArrayStride 16
OpMemberDecorate %18 0 Offset 0
OpDecorate %18 Block
OpDecorate %20 DescriptorSet 1
OpDecorate %20 Binding 0
%2 = OpTypeVoid
%3 = OpTypeFunction %2
%6 = OpTypeFloat 32
%7 = OpTypeImage %6 2D 0 0 0 1 Unknown
%8 = OpTypePointer UniformConstant %7
%9 = OpVariable %8 UniformConstant
%10 = OpTypeInt 32 0
%11 = OpConstant %10 12
%12 = OpTypeArray %7 %11
%13 = OpTypePointer UniformConstant %12
%14 = OpVariable %13 UniformConstant
%15 = OpTypeVector %6 4
%16 = OpConstant %10 32
%17 = OpTypeArray %15 %16
%18 = OpTypeStruct %17
%19 = OpTypePointer Uniform %18
API example

```cpp
VkResult myResult;

const VkDescriptorSetLayoutBinding myDescriptorSetLayoutBinding[] = {
    // binding to a single image descriptor
    { .binding = 0,
      .descriptorType = VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE,
      .descriptorCount = 1,
      .stageFlags = VK_SHADER_STAGE_FRAGMENT_BIT,
      .pImmutableSamplers = NULL
    },

    // binding to an array of image descriptors
    { .binding = 1,
      .descriptorType = VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE,
      .descriptorCount = 12,
      .stageFlags = VK_SHADER_STAGE_FRAGMENT_BIT,
      .pImmutableSamplers = NULL
    },

    // binding to a single uniform buffer descriptor
    { .binding = 0,
      .descriptorType = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER,
      .descriptorCount = 1,
      .stageFlags = VK_SHADER_STAGE_FRAGMENT_BIT,
      .pImmutableSamplers = NULL
    }
};

const VkDescriptorSetLayoutCreateInfo myDescriptorSetLayoutCreateInfo[] = {
    // Information for first descriptor set with two descriptor bindings
    { .sType = VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_CREATE_INFO,
      .pNext = NULL,
      .flags = 0,
      .bindingCount = 2,
      .pBindings = &myDescriptorSetLayoutBinding[0]
    },

    // Information for second descriptor set with one descriptor binding
    {
```

```c
.sType = VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_CREATE_INFO,
.pNext = NULL,
.flags = 0,
.bindingCount = 1,
.pBindings = &myDescriptorSetLayoutBinding[2]
};

VkDescriptorSetLayout myDescriptorSetLayout[2];

// Create first descriptor set layout
//
myResult = vkCreateDescriptorSetLayout(
    myDevice,
    &myDescriptorSetLayoutCreateInfo[0],
    NULL,
    &myDescriptorSetLayout[0]);

// Create second descriptor set layout
//
myResult = vkCreateDescriptorSetLayout(
    myDevice,
    &myDescriptorSetLayoutCreateInfo[1],
    NULL,
    &myDescriptorSetLayout[1]);
```

To destroy a descriptor set layout, call:

```c
// Provided by VK_VERSION_1_0
void vkDestroyDescriptorSetLayout(
    VkDevice device,
    VkDescriptorSetLayout descriptorSetLayout,
    const VkAllocationCallbacks* pAllocator);
```

- `device` is the logical device that destroys the descriptor set layout.
- `descriptorSetLayout` is the descriptor set layout to destroy.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

**Valid Usage**

- VUID-vkDestroyDescriptorSetLayout-descriptorSetLayout-00284
  If `VkAllocationCallbacks` were provided when `descriptorSetLayout` was created, a compatible set of callbacks must be provided here
- VUID-vkDestroyDescriptorSetLayout-descriptorSetLayout-00285
  If no `VkAllocationCallbacks` were provided when `descriptorSetLayout` was created,
Valid Usage (Implicit)

- VUID-vkDestroyDescriptorSetLayout-device-parameter
device must be a valid VkDevice handle

- VUID-vkDestroyDescriptorSetLayout-descriptorSetLayout-parameter
  If descriptorSetLayout is not VK_NULL_HANDLE, descriptorSetLayout must be a valid VkDescriptorSetLayout handle

- VUID-vkDestroyDescriptorSetLayout-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkDestroyDescriptorSetLayout-descriptorSetLayout-parent
  If descriptorSetLayout is a valid handle, it must have been created, allocated, or retrieved from device

Host Synchronization

- Host access to descriptorSetLayout must be externally synchronized

14.2.2. Pipeline Layouts

Access to descriptor sets from a pipeline is accomplished through a pipeline layout. Zero or more descriptor set layouts and zero or more push constant ranges are combined to form a pipeline layout object describing the complete set of resources that can be accessed by a pipeline. The pipeline layout represents a sequence of descriptor sets with each having a specific layout. This sequence of layouts is used to determine the interface between shader stages and shader resources. Each pipeline is created using a pipeline layout.

Pipeline layout objects are represented by VkPipelineLayout handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkPipelineLayout)
```

To create a pipeline layout, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkCreatePipelineLayout(
    VkDevice device,
    const VkPipelineLayoutCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkPipelineLayout* pPipelineLayout);
```
• **device** is the logical device that creates the pipeline layout.
• **pCreateInfo** is a pointer to a **VkPipelineLayoutCreateInfo** structure specifying the state of the pipeline layout object.
• **pAllocator** controls host memory allocation as described in the **Memory Allocation** chapter.
• **pPipelineLayout** is a pointer to a **VkPipelineLayout** handle in which the resulting pipeline layout object is returned.

### Valid Usage (Implicit)

- VUID-vkCreatePipelineLayout-device-parameter  
  device must be a valid **VkDevice** handle
- VUID-vkCreatePipelineLayout-pCreateInfo-parameter  
  pCreateInfo must be a valid pointer to a valid **VkPipelineLayoutCreateInfo** structure
- VUID-vkCreatePipelineLayout-pAllocator-parameter  
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid **VkAllocationCallbacks** structure
- VUID-vkCreatePipelineLayout-pPipelineLayout-parameter  
  pPipelineLayout must be a valid pointer to a **VkPipelineLayout** handle

### Return Codes

**Success**
- **VK_SUCCESS**

**Failure**
- **VK_ERROR_OUT_OF_HOST_MEMORY**
- **VK_ERROR_OUT_OF_DEVICE_MEMORY**

The **VkPipelineLayoutCreateInfo** structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPipelineLayoutCreateInfo {
    VkStructureType          sType;
    const void*              pNext;
    VkPipelineLayoutCreateFlags   flags;
    uint32_t                  setLayoutCount;
    const VkDescriptorSetLayout*  pSetLayouts;
    uint32_t                  pushConstantRangeCount;
    const VkPushConstantRange*  pPushConstantRanges;
} VkPipelineLayoutCreateInfo;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
• **flags** is a bitmask of `VkPipelineLayoutCreateFlagBits` specifying options for pipeline layout creation.

• **setLayoutCount** is the number of descriptor sets included in the pipeline layout.

• **pSetLayouts** is a pointer to an array of `VkDescriptorSetLayout` objects.

• **pushConstantRangeCount** is the number of push constant ranges included in the pipeline layout.

• **pPushConstantRanges** is a pointer to an array of `VkPushConstantRange` structures defining a set of push constant ranges for use in a single pipeline layout. In addition to descriptor set layouts, a pipeline layout also describes how many push constants can be accessed by each stage of the pipeline.

  **Note**

  Push constants represent a high speed path to modify constant data in pipelines that is expected to outperform memory-backed resource updates.

**Valid Usage**

• **VUID-VkPipelineLayoutCreateInfo-setLayoutCount-00286**
  
  setLayoutCount must be less than or equal to `VkPhysicalDeviceLimits::maxBoundDescriptorSets`

• **VUID-VkPipelineLayoutCreateInfo-descriptorType-03016**
  
  The total number of descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set with a `descriptorType` of `VK_DESCRIPTOR_TYPE_SAMPLER` and `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER` accessible to any given shader stage across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceLimits::maxPerStageDescriptorSamplers`

• **VUID-VkPipelineLayoutCreateInfo-descriptorType-03017**
  
  The total number of descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set with a `descriptorType` of `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER` and `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC` accessible to any given shader stage across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceLimits::maxPerStageDescriptorUniformBuffers`

• **VUID-VkPipelineLayoutCreateInfo-descriptorType-03018**
  
  The total number of descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set with a `descriptorType` of `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER` and `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC` accessible to any given shader stage across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceLimits::maxPerStageDescriptorStorageBuffers`

• **VUID-VkPipelineLayoutCreateInfo-descriptorType-06939**
  
  The total number of descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set with a `descriptorType` of `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`, `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE`, `VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER`, `VK_DESCRIPTOR_TYPE_SAMPLE_WEIGHT_IMAGE_QCOM`, and `VK_DESCRIPTOR_TYPE_BLOCK_MATCH_IMAGE_QCOM` accessible to any given shader stage across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceLimits`
The total number of descriptors in descriptor set layouts created without the VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set with a descriptorType of VK_DESCRIPTOR_TYPE_STORAGE_IMAGE, and VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER accessible to any given shader stage across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceLimits::maxPerStageDescriptorStorageImages.

The total number of descriptors in descriptor set layouts created without the VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set with a descriptorType of VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT accessible to any given shader stage across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceLimits::maxPerStageDescriptorInputAttachments.

The total number of bindings in descriptor set layouts created without the VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set with a descriptorType of VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK accessible to any given shader stage across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceInlineUniformBlockProperties::maxPerStageDescriptorInlineUniformBlocks.

The total number of descriptors with a descriptorType of VK_DESCRIPTOR_TYPE_SAMPLER and VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER accessible to any given shader stage across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceDescriptorIndexingProperties::maxPerStageDescriptorUpdateAfterBindSamplers.

The total number of descriptors with a descriptorType of VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER and VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC accessible to any given shader stage across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceDescriptorIndexingProperties::maxPerStageDescriptorUpdateAfterBindUniformBuffers.

The total number of descriptors with a descriptorType of VK_DESCRIPTOR_TYPE_STORAGE_BUFFER and VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC accessible to any given shader stage across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceDescriptorIndexingProperties::maxPerStageDescriptorUpdateAfterBindStorageBuffers.

The total number of descriptors with a descriptorType of VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER, VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE, and VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER accessible to any given shader stage across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceDescriptorIndexingProperties::maxPerStageDescriptorUpdateAfterBindSampledImages.

The total number of bindings in descriptor set layouts created without the VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set with a descriptorType of VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT accessible to any given shader stage across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceInlineUniformBlockProperties::maxPerStageDescriptorInputAttachments.

The total number of bindings in descriptor set layouts created without the VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set with a descriptorType of VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK accessible to any given shader stage across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceInlineUniformBlockProperties::maxPerStageDescriptorInlineUniformBlocks.
The total number of descriptors with a `descriptorType` of `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE`, and `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER` accessible to any given shader stage across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceDescriptorIndexingProperties::maxPerStageDescriptorUpdateAfterBindStorageImages`.

- VUID-VkPipelineLayoutCreateInfo-descriptorType-03027
  The total number of descriptors with a `descriptorType` of `VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT` accessible to any given shader stage across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceDescriptorIndexingProperties::maxPerStageDescriptorUpdateAfterBindInputAttachments`.

- VUID-VkPipelineLayoutCreateInfo-descriptorType-02215
  The total number of bindings with a `descriptorType` of `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK` accessible to any given shader stage across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceInlineUniformBlockProperties::maxPerStageDescriptorUpdateAfterBindInlineUniformBlocks`.

- VUID-VkPipelineLayoutCreateInfo-descriptorType-03028
  The total number of descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set with a `descriptorType` of `VK_DESCRIPTOR_TYPE_SAMPLER` and `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER` accessible across all shader stages and across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceLimits::maxDescriptorSetSamplers`.

- VUID-VkPipelineLayoutCreateInfo-descriptorType-03029
  The total number of descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set with a `descriptorType` of `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER` accessible across all shader stages and across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceLimits::maxDescriptorSetUniformBuffers`.

- VUID-VkPipelineLayoutCreateInfo-descriptorType-03030
  The total number of descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set with a `descriptorType` of `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC` accessible across all shader stages and across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceLimits::maxDescriptorSetUniformBuffersDynamic`.

- VUID-VkPipelineLayoutCreateInfo-descriptorType-03031
  The total number of descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set with a `descriptorType` of `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER` accessible across all shader stages and across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceLimits::maxDescriptorSetStorageBuffers`.

- VUID-VkPipelineLayoutCreateInfo-descriptorType-03032
  The total number of descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set with a `descriptorType` of `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC` accessible across all shader stages and...
The total number of descriptors in descriptor set layouts created without the
VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set with a descriptorType
of VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER, VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE, and
VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER accessible across all shader stages and across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceLimits::maxDescriptorSetSampledImages

The total number of descriptors in descriptor set layouts created without the
VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set with a descriptorType
of VK_DESCRIPTOR_TYPE_STORAGE_IMAGE, and VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER accessible across all shader stages and across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceLimits::maxDescriptorSetStorageImages

The total number of descriptors in descriptor set layouts created without the
VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set with a descriptorType
of VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT accessible across all shader stages and across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceLimits::maxDescriptorSetInputAttachments

The total number of bindings in descriptor set layouts created without the
VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set with a descriptorType
of VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK accessible across all shader stages and across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceInlineUniformBlockProperties::maxDescriptorSetInlineUniformBlocks

The total number of descriptors of the type VK_DESCRIPTOR_TYPE_SAMPLER and
VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER accessible across all shader stages and across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceDescriptorIndexingProperties::maxDescriptorSetUpdateAfterBindSamplers

The total number of descriptors of the type VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER accessible across all shader stages and across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceDescriptorIndexingProperties::maxDescriptorSetUpdateAfterBindUniformBuffers

The total number of descriptors of the type VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC accessible across all shader stages and across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceDescriptorIndexingProperties::maxDescriptorSetUpdateAfterBindUniformBuffersDynamic

The total number of descriptors of the type VK_DESCRIPTOR_TYPE_STORAGE_BUFFER accessible across all shader stages and across all elements of pSetLayouts must be less than or equal to VkPhysicalDeviceLimits::maxDescriptorSetStorageBuffersDynamic
• VUID-VkPipelineLayoutCreateInfo-pSetLayouts-03040
  The total number of descriptors of the type \texttt{VK\_DESCRIPTOR\_TYPE\_STORAGE\_BUFFER\_DYNAMIC}
  accessible across all shader stages and across all elements of \texttt{pSetLayouts} must be less than or equal to \texttt{VkPhysicalDeviceDescriptorIndexingProperties::maxDescriptorSetUpdateAfterBindStorageBuffersDynamic}

• VUID-VkPipelineLayoutCreateInfo-pSetLayouts-03041
  The total number of descriptors of the type \texttt{VK\_DESCRIPTOR\_TYPE\_COMBINED\_IMAGE\_SAMPLER}, \texttt{VK\_DESCRIPTOR\_TYPE\_SAMPLED\_IMAGE}, and \texttt{VK\_DESCRIPTOR\_TYPE\_UNIFORM\_TEXEL\_BUFFER}
  accessible across all shader stages and across all elements of \texttt{pSetLayouts} must be less than or equal to \texttt{VkPhysicalDeviceDescriptorIndexingProperties::maxDescriptorSetUpdateAfterBindSampledImages}

• VUID-VkPipelineLayoutCreateInfo-pSetLayouts-03042
  The total number of descriptors of the type \texttt{VK\_DESCRIPTOR\_TYPE\_STORAGE\_IMAGE}, and \texttt{VK\_DESCRIPTOR\_TYPE\_STORAGE\_TEXEL\_BUFFER}
  accessible across all shader stages and across all elements of \texttt{pSetLayouts} must be less than or equal to \texttt{VkPhysicalDeviceDescriptorIndexingProperties::maxDescriptorSetUpdateAfterBindStorageImages}

• VUID-VkPipelineLayoutCreateInfo-pSetLayouts-03043
  The total number of descriptors of the type \texttt{VK\_DESCRIPTOR\_TYPE\_INPUT\_ATTACHMENT}
  accessible across all shader stages and across all elements of \texttt{pSetLayouts} must be less than or equal to \texttt{VkPhysicalDeviceDescriptorIndexingProperties::maxDescriptorSetUpdateAfterBindInputAttachments}

• VUID-VkPipelineLayoutCreateInfo-descriptorType-02217
  The total number of bindings with a \texttt{descriptorType} of \texttt{VK\_DESCRIPTOR\_TYPE\_INLINE\_UNIFORM\_BLOCK}
  accessible across all shader stages and across all elements of \texttt{pSetLayouts} must be less than or equal to \texttt{VkPhysicalDeviceInlineUniformBlockProperties::maxDescriptorSetUpdateAfterBindInlineUniformBlocks}

• VUID-VkPipelineLayoutCreateInfo-descriptorType-06531
  The total number of descriptors with a \texttt{descriptorType} of \texttt{VK\_DESCRIPTOR\_TYPE\_INLINE\_UNIFORM\_BLOCK}
  accessible across all shader stages and across all elements of \texttt{pSetLayouts} must be less than or equal to \texttt{VkPhysicalDeviceVulkan13Properties::maxInlineUniformTotalSize}

• VUID-VkPipelineLayoutCreateInfo-pPushConstantRanges-00292
  Any two elements of \texttt{pPushConstantRanges} must not include the same stage in \texttt{stageFlags}

• VUID-VkPipelineLayoutCreateInfo-pSetLayouts-00293
  \texttt{pSetLayouts} must not contain more than one descriptor set layout that was created with \texttt{VK\_DESCRIPTOR\_SET\_LAYOUT\_CREATE\_PUSH\_DESCRIPTOR\_BIT\_KHR} set

• VUID-VkPipelineLayoutCreateInfo-descriptorType-03571
  The total number of bindings in descriptor set layouts created without the \texttt{VK\_DESCRIPTOR\_SET\_LAYOUT\_CREATE\_UPDATE\_AFTER\_BIND\_POOL\_BIT} bit set with a \texttt{descriptorType}
  of \texttt{VK\_DESCRIPTOR\_TYPE\_ACCELERATION\_STRUCTURE\_KHR} accessible to any given shader stage
across all elements of `pSetLayouts` must be less than or equal to
`VkPhysicalDeviceAccelerationStructurePropertiesKHR::maxPerStageDescriptorAccelerationStructures`

- **VUID-VkPipelineLayoutCreateInfo-descriptorType-03572**
The total number of bindings with a `descriptorType` of `VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR` accessible to any given shader stage across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceAccelerationStructurePropertiesKHR::maxPerStageDescriptorUpdateAfterBindAccelerationStructures`

- **VUID-VkPipelineLayoutCreateInfo-descriptorType-03573**
The total number of bindings in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set with a `descriptorType` of `VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR` accessible across all shader stages and across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceAccelerationStructurePropertiesKHR::maxDescriptorSetAccelerationStructures`

- **VUID-VkPipelineLayoutCreateInfo-descriptorType-03574**
The total number of bindings with a `descriptorType` of `VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR` accessible across all shader stages and across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceRayTracingPropertiesNV::maxDescriptorSetAccelerationStructures`

- **VUID-VkPipelineLayoutCreateInfo-pImmutableSamplers-03566**
The total number of `pImmutableSamplers` created with flags containing `VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT` or `VK_SAMPLER_CREATE_SUBSAMPLED_COARSE_RECONSTRUCTION_BIT_EXT` across all shader stages and across all elements of `pSetLayouts` must be less than or equal to `VkPhysicalDeviceFragmentDensityMap2PropertiesEXT::maxDescriptorSetSubsampledSamplers`

- **VUID-VkPipelineLayoutCreateInfo-pSetLayouts-04606**
Any element of `pSetLayouts` must not have been created with the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_HOST_ONLY_POOL_BIT_EXT` bit set

- **VUID-VkPipelineLayoutCreateInfo-graphicsPipelineLibrary-06753**
If `graphicsPipelineLibrary` is not enabled, elements of `pSetLayouts` must be valid `VkDescriptorSetLayout` objects

- **VUID-VkPipelineLayoutCreateInfo-pSetLayouts-08008**
If any element of `pSetLayouts` was created with the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT` bit set, all elements of `pSetLayouts` must have been created with the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT` bit set
Valid Usage (Implicit)

- **VUID-VkPipelineLayoutCreateInfo-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_LAYOUT_CREATE_INFO`

- **VUID-VkPipelineLayoutCreateInfo-pNext-pNext**
  - `pNext` must be `NULL`

- **VUID-VkPipelineLayoutCreateInfo-flags-parameter**
  - `flags` must be a valid combination of `VkPipelineLayoutCreateFlagBits` values

- **VUID-VkPipelineLayoutCreateInfo-pSetLayouts-parameter**
  - If `setLayoutCount` is not 0, `pSetLayouts` must be a valid pointer to an array of `setLayoutCount` valid or `VK_NULL_HANDLE` `VkDescriptorSetLayout` handles

- **VUID-VkPipelineLayoutCreateInfo-pPushConstantRanges-parameter**
  - If `pushConstantRangeCount` is not 0, `pPushConstantRanges` must be a valid pointer to an array of `pushConstantRangeCount` valid `VkPushConstantRange` structures

// Provided by VK_EXT_graphics_pipeline_library
typedef enum VkPipelineLayoutCreateFlagBits {
    // Provided by VK_EXT_graphics_pipeline_library
    VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT = 0x00000002,
} VkPipelineLayoutCreateFlagBits;

**VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT** specifies that implementations must ensure that the properties and/or absence of a particular descriptor set do not influence any other properties of the pipeline layout. This allows pipelines libraries linked without `VK_PIPELINE_CREATE_LINK_TIME_OPTIMIZATION_BIT_EXT` to be created with a subset of the total descriptor sets.

// Provided by VK_VERSION_1_0
typedef VkFlags VkPipelineLayoutCreateFlags;

`VkPipelineLayoutCreateFlags` is a bitmask type for setting a mask of `VkPipelineLayoutCreateFlagBits`.

The `VkPushConstantRange` structure is defined as:

// Provided by VK_VERSION_1_0
typedef struct VkPushConstantRange {
    VkShaderStageFlags stageFlags;
    uint32_t offset;
    uint32_t size;
} VkPushConstantRange;

- **stageFlags** is a set of stage flags describing the shader stages that will access a range of push constants. If a particular stage is not included in the range, then accessing members of that
range of push constants from the corresponding shader stage will return undefined values.

- **offset** and **size** are the start offset and size, respectively, consumed by the range. Both **offset** and **size** are in units of bytes and must be a multiple of 4. The layout of the push constant variables is specified in the shader.

<table>
<thead>
<tr>
<th>Valid Usage</th>
</tr>
</thead>
</table>
| • VUID-VkPushConstantRange-offset-00294  
  *offset* must be less than *VkPhysicalDeviceLimits::maxPushConstantsSize* |
| • VUID-VkPushConstantRange-offset-00295  
  *offset* must be a multiple of 4 |
| • VUID-VkPushConstantRange-size-00296  
  *size* must be greater than 0 |
| • VUID-VkPushConstantRange-size-00297  
  *size* must be a multiple of 4 |
| • VUID-VkPushConstantRange-size-00298  
  *size* must be less than or equal to *VkPhysicalDeviceLimits::maxPushConstantsSize* minus *offset* |

<table>
<thead>
<tr>
<th>Valid Usage (Implicit)</th>
</tr>
</thead>
</table>
| • VUID-VkPushConstantRange-stageFlags-parameter  
  *stageFlags* must be a valid combination of *VkShaderStageFlagBits* values |
| • VUID-VkPushConstantRange-stageFlags-requiredbitmask  
  *stageFlags* must not be 0 |

Once created, pipeline layouts are used as part of pipeline creation (see Pipelines), as part of binding descriptor sets (see Descriptor Set Binding), and as part of setting push constants (see Push Constant Updates). Pipeline creation accepts a pipeline layout as input, and the layout may be used to map (set, binding, arrayElement) tuples to implementation resources or memory locations within a descriptor set. The assignment of implementation resources depends only on the bindings defined in the descriptor sets that comprise the pipeline layout, and not on any shader source.

All resource variables **statically used** in all shaders in a pipeline must be declared with a (set, binding, arrayElement) that exists in the corresponding descriptor set layout and is of an appropriate descriptor type and includes the set of shader stages it is used by in **stageFlags**. The pipeline layout can include entries that are not used by a particular pipeline. The pipeline layout allows the application to provide a consistent set of bindings across multiple pipeline compiles, which enables those pipelines to be compiled in a way that the implementation may cheaply switch pipelines without reprogramming the bindings.

Similarly, the push constant block declared in each shader (if present) must only place variables at offsets that are each included in a push constant range with **stageFlags** including the bit corresponding to the shader stage that uses it. The pipeline layout can include ranges or portions of
ranges that are not used by a particular pipeline.

There is a limit on the total number of resources of each type that can be included in bindings in all descriptor set layouts in a pipeline layout as shown in Pipeline Layout Resource Limits. The “Total Resources Available” column gives the limit on the number of each type of resource that can be included in bindings in all descriptor sets in the pipeline layout. Some resource types count against multiple limits. Additionally, there are limits on the total number of each type of resource that can be used in any pipeline stage as described in Shader Resource Limits.

Table 18. Pipeline Layout Resource Limits

<table>
<thead>
<tr>
<th>Total Resources Available</th>
<th>Resource Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>maxDescriptorSetSamplers or maxDescriptorSetUpdateAfterBindSamplers</td>
<td>sampler</td>
</tr>
<tr>
<td>maxDescriptorSetSampledImages or maxDescriptorSetUpdateAfterBindSampledImages</td>
<td>combined image sampler</td>
</tr>
<tr>
<td>maxDescriptorSetStorageImages or maxDescriptorSetUpdateAfterBindStorageImages</td>
<td>sampled image</td>
</tr>
<tr>
<td>maxDescriptorSetSampledImages or maxDescriptorSetUpdateAfterBindSampledImages</td>
<td>combined image sampler</td>
</tr>
<tr>
<td>maxDescriptorSetStorageImages or maxDescriptorSetUpdateAfterBindStorageImages</td>
<td>uniform texel buffer</td>
</tr>
<tr>
<td>maxDescriptorSetUniformBuffers or maxDescriptorSetUpdateAfterBindUniformBuffers</td>
<td>storage image</td>
</tr>
<tr>
<td>maxDescriptorSetUniformBuffersDynamic or maxDescriptorSetUpdateAfterBindUniformBuffersDynamic</td>
<td>uniform buffer dynamic</td>
</tr>
<tr>
<td>maxDescriptorSetUniformBuffersDynamic or maxDescriptorSetUpdateAfterBindUniformBuffersDynamic</td>
<td>uniform buffer dynamic</td>
</tr>
<tr>
<td>maxDescriptorSetStorageBuffers or maxDescriptorSetUpdateAfterBindStorageBuffers</td>
<td>storage buffer</td>
</tr>
<tr>
<td>maxDescriptorSetStorageBuffersDynamic or maxDescriptorSetUpdateAfterBindStorageBuffersDynamic</td>
<td>storage buffer dynamic</td>
</tr>
<tr>
<td>maxDescriptorSetStorageBuffersDynamic or maxDescriptorSetUpdateAfterBindStorageBuffersDynamic</td>
<td>storage buffer dynamic</td>
</tr>
<tr>
<td>maxDescriptorSetInputAttachments or maxDescriptorSetUpdateAfterBindInputAttachments</td>
<td>input attachment</td>
</tr>
<tr>
<td>maxDescriptorSetInlineUniformBlocks or maxDescriptorSetUpdateAfterBindInlineUniformBlocks</td>
<td>inline uniform block</td>
</tr>
<tr>
<td>maxDescriptorSetAccelerationStructures or maxDescriptorSetUpdateAfterBindAccelerationStructures</td>
<td>acceleration structure</td>
</tr>
</tbody>
</table>

To destroy a pipeline layout, call:

```c
// Provided by VK_VERSION_1_0
void vkDestroyPipelineLayout(VkDevice device, ...
```
VkPipelineLayout pipelineLayout,
const VkAllocationCallbacks* pAllocator);

- **device** is the logical device that destroys the pipeline layout.
- **pipelineLayout** is the pipeline layout to destroy.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.

### Valid Usage

- VUID-vkDestroyPipelineLayout-pipelineLayout-00299
  If VkAllocationCallbacks were provided when pipelineLayout was created, a compatible set of callbacks **must** be provided here.

- VUID-vkDestroyPipelineLayout-pipelineLayout-00300
  If no VkAllocationCallbacks were provided when pipelineLayout was created, pAllocator **must** be NULL.

- VUID-vkDestroyPipelineLayout-pipelineLayout-02004
  pipelineLayout **must** not have been passed to any vkCmd* command for any command buffers that are still in the recording state when vkDestroyPipelineLayout is called.

### Valid Usage (Implicit)

- VUID-vkDestroyPipelineLayout-device-parameter
  device **must** be a valid VkDevice handle.

- VUID-vkDestroyPipelineLayout-pipelineLayout-parameter
  If pipelineLayout is not VK_NULL_HANDLE, pipelineLayout **must** be a valid VkPipelineLayout handle.

- VUID-vkDestroyPipelineLayout-pAllocator-parameter
  If pAllocator is not NULL, pAllocator **must** be a valid pointer to a valid VkAllocationCallbacks structure.

- VUID-vkDestroyPipelineLayout-pipelineLayout-parent
  If pipelineLayout is a valid handle, it **must** have been created, allocated, or retrieved from device.

### Host Synchronization

- Host access to pipelineLayout **must** be externally synchronized.

### Pipeline Layout Compatibility

Two pipeline layouts are defined to be “compatible for push constants” if they were created with identical push constant ranges. Two pipeline layouts are defined to be “compatible for set N” if they were created with *identically defined* descriptor set layouts for sets zero through N, if both of them...
either were or were not created with `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`, and if they were created with identical push constant ranges.

When binding a descriptor set (see `Descriptor Set Binding`) to set number N, a previously bound descriptor set bound with lower index M than N is disturbed if the pipeline layouts for set M and N are not compatible for set M. Otherwise, the bound descriptor set in M is not disturbed.

If, additionally, the previously bound descriptor set for set N was bound using a pipeline layout not compatible for set N, then all bindings in sets numbered greater than N are disturbed.

When binding a pipeline, the pipeline can correctly access any previously bound descriptor set N if it was bound with compatible pipeline layout for set N, and it was not disturbed.

Layout compatibility means that descriptor sets can be bound to a command buffer for use by any pipeline created with a compatible pipeline layout, and without having bound a particular pipeline first. It also means that descriptor sets can remain valid across a pipeline change, and the same resources will be accessible to the newly bound pipeline.

When a descriptor set is disturbed by binding descriptor sets, the disturbed set is considered to contain undefined descriptors bound with the same pipeline layout as the disturbing descriptor set.

---

**Implementor’s Note**

A consequence of layout compatibility is that when the implementation compiles a pipeline layout and maps pipeline resources to implementation resources, the mechanism for set N should only be a function of sets [0..N].

---

**Note**

Place the least frequently changing descriptor sets near the start of the pipeline layout, and place the descriptor sets representing the most frequently changing resources near the end. When pipelines are switched, only the descriptor set bindings that have been invalidated will need to be updated and the remainder of the descriptor set bindings will remain in place.

The maximum number of descriptor sets that can be bound to a pipeline layout is queried from physical device properties (see `maxBoundDescriptorSets` in `Limits`).

**API example**

```cpp
const VkDescriptorSetLayout layouts[] = { layout1, layout2 };

const VkPushConstantRange ranges[] = {
  {
    .stageFlags = VK_SHADER_STAGE_VERTEX_BIT,
    .offset = 0,
    .size = 4,
  },
};
```

1224
{  .stageFlags = VK_SHADER_STAGE_FRAGMENT_BIT,
   .offset = 4,
   .size = 4
 },
};

const VkPipelineLayoutCreateInfo createInfo =
{  .sType = VK_STRUCTURE_TYPE_PIPELINE_LAYOUT_CREATE_INFO,
   .pNext = NULL,
   .flags = 0,
   .setLayoutCount = 2,
   .pSetLayouts = layouts,
   .pushConstantRangeCount = 2,
   .pPushConstantRanges = ranges
};

VkPipelineLayout myPipelineLayout;
myResult = vkCreatePipelineLayout(
   myDevice,
   &createInfo,
   NULL,
   &myPipelineLayout);

14.2.3. Allocation of Descriptor Sets

A descriptor pool maintains a pool of descriptors, from which descriptor sets are allocated. Descriptor pools are externally synchronized, meaning that the application must not allocate and/or free descriptor sets from the same pool in multiple threads simultaneously.

Descriptor pools are represented by VkDescriptorPool handles:

// Provided by VK_VERSION_1_0
VkResult vkCreateDescriptorPool(
   VkDevice device,
   const VkDescriptorPoolCreateInfo* pCreateInfo,
   const VkAllocationCallbacks* pAllocator,
   VkDescriptorPool* pDescriptorPool);

• device is the logical device that creates the descriptor pool.
• pCreateInfo is a pointer to a VkDescriptorPoolCreateInfo structure specifying the state of the
descriptor pool object.

- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
- **pDescriptorPool** is a pointer to a `VkDescriptorPool` handle in which the resulting descriptor pool object is returned.

The created descriptor pool is returned in `pDescriptorPool`.

### Valid Usage (Implicit)

- **VUID-vkCreateDescriptorPool-device-parameter**
  
  device **must** be a valid `VkDevice` handle

- **VUID-vkCreateDescriptorPool-pCreateInfo-parameter**
  
  `pCreateInfo` **must** be a valid pointer to a valid `VkDescriptorPoolCreateInfo` structure

- **VUID-vkCreateDescriptorPool-pAllocator-parameter**
  
  If `pAllocator` is not `NULL`, `pAllocator` **must** be a valid pointer to a valid `VkAllocationCallbacks` structure

- **VUID-vkCreateDescriptorPool-pDescriptorPool-parameter**
  
  `pDescriptorPool` **must** be a valid pointer to a `VkDescriptorPool` handle

### Return Codes

**Success**

- **VK_SUCCESS**

**Failure**

- **VK_ERROR_OUT_OF_HOST_MEMORY**
- **VK_ERROR_OUT_OF_DEVICE_MEMORY**
- **VK_ERROR_FRAGMENTATION_EXT**

Additional information about the pool is passed in a `VkDescriptorPoolCreateInfo` structure:

```c
// Provided by VK_VERSION_1_0
typedef struct VkDescriptorPoolCreateInfo {
    VkStructureType   sType;
    const void*       pNext;
    VkDescriptorPoolCreateFlags flags;
    uint32_t          maxSets;
    const VkDescriptorPoolSize* pPoolSizes;
} VkDescriptorPoolCreateInfo;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
• **flags** is a bitmask of `VkDescriptorPoolCreateFlagBits` specifying certain supported operations on the pool.

• **maxSets** is the maximum number of descriptor sets that **can** be allocated from the pool.

• **poolSizeCount** is the number of elements in `pPoolSizes`.

• **pPoolSizes** is a pointer to an array of `VkDescriptorPoolSize` structures, each containing a descriptor type and number of descriptors of that type to be allocated in the pool.

If multiple `VkDescriptorPoolSize` structures containing the same descriptor type appear in the `pPoolSizes` array then the pool will be created with enough storage for the total number of descriptors of each type.

Fragmentation of a descriptor pool is possible and **may** lead to descriptor set allocation failures. A failure due to fragmentation is defined as failing a descriptor set allocation despite the sum of all outstanding descriptor set allocations from the pool plus the requested allocation requiring no more than the total number of descriptors requested at pool creation. Implementations provide certain guarantees of when fragmentation **must** not cause allocation failure, as described below.

If a descriptor pool has not had any descriptor sets freed since it was created or most recently reset then fragmentation **must** not cause an allocation failure (note that this is always the case for a pool created without the `VK_DESCRIPTOR_POOL_CREATE_FREE_DESCRIPTOR_SET_BIT` bit set). Additionally, if all sets allocated from the pool since it was created or most recently reset use the same number of descriptors (of each type) and the requested allocation also uses that same number of descriptors (of each type), then fragmentation **must** not cause an allocation failure.

If an allocation failure occurs due to fragmentation, an application **can** create an additional descriptor pool to perform further descriptor set allocations.

If **flags** has the `VK_DESCRIPTOR_POOL_CREATE_UPDATE_AFTER_BIND_BIT` bit set, descriptor pool creation **may** fail with the error `VK_ERROR_FRAGMENTATION` if the total number of descriptors across all pools (including this one) created with this bit set exceeds `maxUpdateAfterBindDescriptorsInAllPools`, or if fragmentation of the underlying hardware resources occurs.

If a `pPoolSizes[i]::type` is `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`, a `VkMutableDescriptorTypeCreateInfoEXT` struct in the `pNext` chain **can** be used to specify which mutable descriptor types **can** be allocated from the pool. If included in the `pNext` chain, `VkMutableDescriptorTypeCreateInfoEXT::pMutableDescriptorTypeLists[i]` specifies which kind of `VK_DESCRIPTOR_TYPE_MUTABLE_EXT` descriptors **can** be allocated from this pool entry. If `VkMutableDescriptorTypeCreateInfoEXT` does not exist in the `pNext` chain, or `VkMutableDescriptorTypeCreateInfoEXT::pMutableDescriptorTypeLists[i]` is out of range, the descriptor pool allocates enough memory to be able to allocate a `VK_DESCRIPTOR_TYPE_MUTABLE_EXT` descriptor with any supported `VkDescriptorType` as a mutable descriptor. A mutable descriptor **can** be allocated from a pool entry if the type list in `VkDescriptorSetLayoutCreateInfo` is a subset of the type list declared in the descriptor pool, or if the pool entry is created without a descriptor type list. Multiple `pPoolSizes` entries with `VK_DESCRIPTOR_TYPE_MUTABLE_EXT` **can** be declared. When multiple such pool entries are present in `pPoolSizes`, they specify sets of supported descriptor types which either fully overlap, partially overlap, or are disjoint. Two sets fully overlap if the sets of supported descriptor types are equal. If the sets are not disjoint they partially overlap. A pool entry without a `VkMutableDescriptorTypeListEXT` assigned to it is considered to partially overlap any other pool entry.
which has a `VkMutableDescriptorTypeListEXT` assigned to it. The application must ensure that partial overlap does not exist in `pPoolSizes`.

**Note**
The requirement of no partial overlap is intended to resolve ambiguity for validation as there is no confusion which `pPoolSizes` entries will be allocated from. An implementation is not expected to depend on this requirement.

---

### Valid Usage

- **VUID-VkDescriptorPoolCreateInfo-descriptorPoolOverallocation-09227**
  If the `descriptorPoolOverallocation` feature is not enabled, or `flags` does not have `VK_DESCRIPTOR_POOL_CREATE_ALLOW_OVERALLOCATION_SETS_BIT_NV` set, `maxSets` must be greater than 0.

- **VUID-VkDescriptorPoolCreateInfo-flags-09228**
  If `flags` has the `VK_DESCRIPTOR_POOL_CREATE_ALLOW_OVERALLOCATION_SETS_BIT_NV` or `VK_DESCRIPTOR_POOL_CREATE_ALLOW_OVERALLOCATION_POOLS_BIT_NV` bits set, then `descriptorPoolOverallocation` must be enabled.

- **VUID-VkDescriptorPoolCreateInfo-flags-04607**
  If `flags` has the `VK_DESCRIPTOR_POOL_CREATE_HOST_ONLY_BIT_EXT` bit set, then the `VK_DESCRIPTOR_POOL_CREATE_UPDATE_AFTER_BIND_BIT` bit must not be set.

- **VUID-VkDescriptorPoolCreateInfo-mutableDescriptorType-04608**
  If `VkPhysicalDeviceMutableDescriptorTypeFeaturesEXT::mutableDescriptorType` is not enabled, `pPoolSizes` must not contain a `descriptorType` of `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`.

- **VUID-VkDescriptorPoolCreateInfo-flags-04609**
  If `flags` has the `VK_DESCRIPTOR_POOL_CREATE_HOST_ONLY_BIT_EXT` bit set, `VkPhysicalDeviceMutableDescriptorTypeFeaturesEXT::mutableDescriptorType` must be enabled.

- **VUID-VkDescriptorPoolCreateInfo-pPoolSizes-04787**
  If `pPoolSizes` contains a `descriptorType` of `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`, any other `VK_DESCRIPTOR_TYPE_MUTABLE_EXT` element in `pPoolSizes` must not have sets of supported descriptor types which partially overlap.

---

### Valid Usage (Implicit)

- **VUID-VkDescriptorPoolCreateInfo-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_DESCRIPTOR_POOL_CREATE_INFO`.

- **VUID-VkDescriptorPoolCreateInfo-pNext-pNext**
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkDescriptorPoolInlineUniformBlockCreateInfo` or `VkMutableDescriptorTypeCreateInfoEXT`.

- **VUID-VkDescriptorPoolCreateInfo-sType-unique**
  The `sType` value of each struct in the `pNext` chain must be unique.
• VUID-VkDescriptorPoolCreateInfo-flags-parameter
  flags must be a valid combination of VkDescriptorPoolCreateFlagBits values

• VUID-VkDescriptorPoolCreateInfo-pPoolSizes-parameter
  If poolSizeCount is not 0, pPoolSizes must be a valid pointer to an array of poolSizeCount valid VkDescriptorPoolSize structures

In order to be able to allocate descriptor sets having inline uniform block bindings the descriptor pool must be created with specifying the inline uniform block binding capacity of the descriptor pool, in addition to the total inline uniform data capacity in bytes which is specified through a VkDescriptorPoolSize structure with a descriptorType value of VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK. This can be done by adding a VkDescriptorPoolInlineUniformBlockCreateInfo structure to the pNext chain of VkDescriptorPoolCreateInfo.

The VkDescriptorPoolInlineUniformBlockCreateInfo structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkDescriptorPoolInlineUniformBlockCreateInfo {
  VkStructureType sType;
  const void* pNext;
  uint32_t maxInlineUniformBlockBindings;
} VkDescriptorPoolInlineUniformBlockCreateInfo;
```

or the equivalent

```c
// Provided by VK_EXT_inline_uniform_block
typedef VkDescriptorPoolInlineUniformBlockCreateInfo VkDescriptorPoolInlineUniformBlockCreateInfoEXT;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- maxInlineUniformBlockBindings is the number of inline uniform block bindings to allocate.

### Valid Usage (Implicit)

- VUID-VkDescriptorPoolInlineUniformBlockCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_DESCRIPTOR_POOL_INLINE_UNIFORM_BLOCK_CREATE_INFO

Bits which can be set in VkDescriptorPoolCreateInfo::flags, enabling operations on a descriptor pool, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkDescriptorPoolCreateFlagBits {
  VK_DESCRIPTOR_POOL_CREATE_FREE_DESCRIPTOR_SET_BIT = 0x00000001,
} VkDescriptorPoolCreateFlagBits;
```
• **VK_DESCRIPTOR_POOL_CREATE_FREE_DESCRIPTOR_SET_BIT** specifies that descriptor sets can return their individual allocations to the pool, i.e. all of `vkAllocateDescriptorSets`, `vkFreeDescriptorSets`, and `vkResetDescriptorPool` are allowed. Otherwise, descriptor sets allocated from the pool must not be individually freed back to the pool, i.e. only `vkAllocateDescriptorSets` and `vkResetDescriptorPool` are allowed.

• **VK_DESCRIPTOR_POOL_CREATE_UPDATE_AFTER_BIND_BIT** specifies that descriptor sets allocated from this pool can include bindings with the `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT` bit set. It is valid to allocate descriptor sets that have bindings that do not set the `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT` bit from a pool that has `VK_DESCRIPTOR_POOL_CREATE_UPDATE_AFTER_BIND_BIT` set.

• **VK_DESCRIPTOR_POOL_CREATE_HOST_ONLY_BIT_EXT** specifies that this descriptor pool and the descriptor sets allocated from it reside entirely in host memory and cannot be bound. Similar to descriptor sets allocated without this flag, applications can copy-from and copy-to descriptors sets allocated from this descriptor pool. Descriptor sets allocated from this pool are partially exempt from the external synchronization requirement in `vkUpdateDescriptorSetWithTemplateKHR` and `vkUpdateDescriptorSets`. Descriptor sets and their descriptors can be updated concurrently in different threads, though the same descriptor must not be updated concurrently by two threads.

• **VK_DESCRIPTOR_POOL_CREATE_ALLOW_OVERALLOCATION_SETS_BIT_NV** specifies that the implementation should allow the application to allocate more than `VkDescriptorPoolCreateInfo::maxSets` descriptor set objects from the descriptor pool as available resources allow. The implementation may use the `maxSets` value to allocate the initial available sets, but using zero is permitted.

• **VK_DESCRIPTOR_POOL_CREATE_ALLOW_OVERALLOCATION_POOLS_BIT_NV** specifies that the implementation should allow the application to allocate more descriptors from the pool than was specified by the `VkDescriptorPoolSize::descriptorCount` for any descriptor type as specified by `VkDescriptorPoolCreateInfo::poolSizeCount` and `VkDescriptorPoolCreateInfo::pPoolSizes`, as available resources allow. The implementation may use the `descriptorCount` for each descriptor type to allocate the initial pool, but the application is allowed to set the `poolSizeCount` to zero, or any of the `descriptorCount` values in the `pPoolSizes` array to zero.
VkDescriptorPoolCreateFlags is a bitmask type for setting a mask of zero or more VkDescriptorPoolCreateFlagBits.

The VkDescriptorPoolSize structure is defined as:

```c
typedef struct VkDescriptorPoolSize {
    VkDescriptorType type;
    uint32_t descriptorCount;
} VkDescriptorPoolSize;
```

- `type` is the type of descriptor.
- `descriptorCount` is the number of descriptors of that type to allocate. If `type` is VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK then `descriptorCount` is the number of bytes to allocate for descriptors of this type.

**Note**
When creating a descriptor pool that will contain descriptors for combined image samplers of multi-planar formats, an application needs to account for non-trivial descriptor consumption when choosing the `descriptorCount` value, as indicated by VkSamplerYcbcrConversionImageFormatProperties::combinedImageSamplerDescriptorCount.

**Valid Usage**

- VUID-VkDescriptorPoolSize(descriptorCount)-00302
  `descriptorCount` must be greater than 0

- VUID-VkDescriptorPoolSize(type)-02218
  If `type` is VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK then `descriptorCount` must be a multiple of 4

**Valid Usage (Implicit)**

- VUID-VkDescriptorPoolSize(type)-parameter
  `type` must be a valid VkDescriptorType value

To destroy a descriptor pool, call:

```c
// Provided by VK_VERSION_1_0
void vkDestroyDescriptorPool()
```
VkDevice device,
VkDescriptorPool descriptorPool,
const VkAllocationCallbacks* pAllocator);

- **device** is the logical device that destroys the descriptor pool.
- **descriptorPool** is the descriptor pool to destroy.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.

When a pool is destroyed, all descriptor sets allocated from the pool are implicitly freed and become invalid. Descriptor sets allocated from a given pool do not need to be freed before destroying that descriptor pool.

### Valid Usage

- **VUID-vkDestroyDescriptorPool-descriptorPool-00303**
  All submitted commands that refer to **descriptorPool** (via any allocated descriptor sets) **must** have completed execution

- **VUID-vkDestroyDescriptorPool-descriptorPool-00304**
  If **VkAllocationCallbacks** were provided when **descriptorPool** was created, a compatible set of callbacks **must** be provided here

- **VUID-vkDestroyDescriptorPool-descriptorPool-00305**
  If no **VkAllocationCallbacks** were provided when **descriptorPool** was created, **pAllocator** **must** be **NULL**

### Valid Usage (Implicit)

- **VUID-vkDestroyDescriptorPool-device-parameter**
  **device** **must** be a valid **VkDevice** handle

- **VUID-vkDestroyDescriptorPool-descriptorPool-parameter**
  If **descriptorPool** is not **VK_NULL_HANDLE**, **descriptorPool** **must** be a valid **VkDescriptorPool** handle

- **VUID-vkDestroyDescriptorPool-pAllocator-parameter**
  If **pAllocator** is not **NULL**, **pAllocator** **must** be a valid pointer to a valid **VkAllocationCallbacks** structure

- **VUID-vkDestroyDescriptorPool-descriptorPool-parent**
  If **descriptorPool** is a valid handle, it **must** have been created, allocated, or retrieved from **device**

### Host Synchronization

- Host access to **descriptorPool** **must** be externally synchronized
Descriptor sets are allocated from descriptor pool objects, and are represented by `VkDescriptorSet` handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkDescriptorSet)
```

To allocate descriptor sets from a descriptor pool, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkAllocateDescriptorSets(
    VkDevice device,
    const VkDescriptorSetAllocateInfo* pAllocateInfo,
    VkDescriptorSet* pDescriptorSets);
```

- `device` is the logical device that owns the descriptor pool.
- `pAllocateInfo` is a pointer to a `VkDescriptorSetAllocateInfo` structure describing parameters of the allocation.
- `pDescriptorSets` is a pointer to an array of `VkDescriptorSet` handles in which the resulting descriptor set objects are returned.

The allocated descriptor sets are returned in `pDescriptorSets`.

When a descriptor set is allocated, the initial state is largely uninitialized and all descriptors are undefined, with the exception that samplers with a non-null `pImmutableSamplers` are initialized on allocation. Descriptors also become undefined if the underlying resource or view object is destroyed. Descriptor sets containing undefined descriptors can still be bound and used, subject to the following conditions:

- For descriptor set bindings created with the `VK_DESCRIPTOR_BINDING_PARTIALLY_BOUND_BIT` bit set, all descriptors in that binding that are dynamically used must have been populated before the descriptor set is consumed.
- For descriptor set bindings created without the `VK_DESCRIPTOR_BINDING_PARTIALLY_BOUND_BIT` bit set, all descriptors in that binding that are statically used must have been populated before the descriptor set is consumed.
- Descriptor bindings with descriptor type of `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK` can be undefined when the descriptor set is consumed; though values in that block will be undefined.
- Entries that are not used by a pipeline can have undefined descriptors.

If a call to `vkAllocateDescriptorSets` would cause the total number of descriptor sets allocated from the pool to exceed the value of `VkDescriptorPoolCreateInfo::maxSets` used to create `pAllocateInfo->descriptorPool`, then the allocation may fail due to lack of space in the descriptor pool. Similarly, the allocation may fail due to lack of space if the call to `vkAllocateDescriptorSets` would cause the number of any given descriptor type to exceed the sum of all the `descriptorCount` members of each element of `VkDescriptorPoolCreateInfo::pPoolSizes` with a `type` equal to that type.
Additionally, the allocation may also fail if a call to `vkAllocateDescriptorSets` would cause the total number of inline uniform block bindings allocated from the pool to exceed the value of `VkDescriptorPoolInlineUniformBlockCreateInfo::maxInlineUniformBlockBindings` used to create the descriptor pool.

If the allocation fails due to no more space in the descriptor pool, and not because of system or device memory exhaustion, then `VK_ERROR_OUT_OF_POOL_MEMORY` must be returned.

`vkAllocateDescriptorSets` can be used to create multiple descriptor sets. If the creation of any of those descriptor sets fails, then the implementation must destroy all successfully created descriptor set objects from this command, set all entries of the `pDescriptorSets` array to `VK_NULL_HANDLE` and return the error.

### Valid Usage (Implicit)

- VUID-vkAllocateDescriptorSets-device-parameter
  
  `device` must be a valid `VkDevice` handle

- VUID-vkAllocateDescriptorSets-pAllocateInfo-parameter
  
  `pAllocateInfo` must be a valid pointer to a valid `VkDescriptorSetAllocateInfo` structure

- VUID-vkAllocateDescriptorSets-pDescriptorSets-parameter
  
  `pDescriptorSets` must be a valid pointer to an array of `pAllocateInfo->descriptorSetCount` `VkDescriptorSet` handles

- VUID-vkAllocateDescriptorSets-pAllocateInfo::descriptorSetCount-arraylength
  
  `pAllocateInfo->descriptorSetCount` must be greater than 0

### Host Synchronization

- Host access to `pAllocateInfo->descriptorPool` must be externally synchronized

### Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_FRAGMENTED_POOL`
- `VK_ERROR_OUT_OF_POOL_MEMORY`

The `VkDescriptorSetAllocateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
```
typedef struct VkDescriptorSetAllocateInfo {
    VkStructureType sType;
    const void*pNext;
    VkDescriptorPool descriptorPool;
    uint32_t descriptorSetCount;
    const VkDescriptorSetLayout*pSetLayouts;
} VkDescriptorSetAllocateInfo;

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **descriptorPool** is the pool which the sets will be allocated from.
- **descriptorSetCount** determines the number of descriptor sets to be allocated from the pool.
- **pSetLayouts** is a pointer to an array of descriptor set layouts, with each member specifying how the corresponding descriptor set is allocated.

### Valid Usage

- **VUID-VkDescriptorSetAllocateInfo-apiVersion-07895**
  If the VK_KHR_maintenance1 extension is not enabled, VkPhysicalDeviceProperties::apiVersion is less than Vulkan 1.1, **descriptorSetCount** must not be greater than the number of sets that are currently available for allocation in **descriptorPool**

- **VUID-VkDescriptorSetAllocateInfo-apiVersion-07896**
  If the VK_KHR_maintenance1 extension is not enabled, VkPhysicalDeviceProperties::apiVersion is less than Vulkan 1.1, **descriptorPool** must have enough free descriptor capacity remaining to allocate the descriptor sets of the specified layouts

- **VUID-VkDescriptorSetAllocateInfo-pSetLayouts-00308**
  Each element of **pSetLayouts** must not have been created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_PUSH_DESCRIPTOR_BIT_KHR set

- **VUID-VkDescriptorSetAllocateInfo-pSetLayouts-03044**
  If any element of **pSetLayouts** was created with the VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set, **descriptorPool** must have been created with the VK_DESCRIPTOR_POOL_CREATE_UPDATE_AFTER_BIND_BIT flag set

- **VUID-VkDescriptorSetAllocateInfo-pSetLayouts-04610**
  If any element of **pSetLayouts** was created with the VK_DESCRIPTOR_SET_LAYOUT_CREATE_HOST_ONLY_POOL_BIT_EXT bit set, **descriptorPool** must have been created with the VK_DESCRIPTOR_POOL_CREATE_HOST_ONLY_BIT_EXT flag set

- **VUID-VkDescriptorSetAllocateInfo-pSetLayouts-08009**
  Each element of **pSetLayouts** must not have been created with the VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT bit set

### Valid Usage (Implicit)

- **VUID-VkDescriptorSetAllocateInfo-sType-sType**
**sType** must be `VK_STRUCTURE_TYPE_DESCRIPTOR_SET_ALLOCATE_INFO`.

- **VUID-VkDescriptorSetAllocateInfo-pNext-pNext**
  - `pNext` must be `NULL` or a pointer to a valid instance of `VkDescriptorSetVariableDescriptorCountAllocateInfo`.

- **VUID-VkDescriptorSetAllocateInfo-sType-unique**
  - The `sType` value of each struct in the `pNext` chain must be unique.

- **VUID-VkDescriptorSetAllocateInfo-descriptorPool-parameter**
  - `descriptorPool` must be a valid `VkDescriptorPool` handle.

- **VUID-VkDescriptorSetAllocateInfo-pSetLayouts-parameter**
  - `pSetLayouts` must be a valid pointer to an array of `descriptorSetCount` valid `VkDescriptorSetLayout` handles.

- **VUID-VkDescriptorSetAllocateInfo-descriptorSetCount-arraylength**
  - `descriptorSetCount` must be greater than 0.

- **VUID-VkDescriptorSetAllocateInfo-commonparent**
  - Both of `descriptorPool`, and the elements of `pSetLayouts` must have been created, allocated, or retrieved from the same `VkDevice`.

If the `pNext` chain of a `VkDescriptorSetAllocateInfo` structure includes a `VkDescriptorSetVariableDescriptorCountAllocateInfo` structure, then that structure includes an array of descriptor counts for variable-sized descriptor bindings, one for each descriptor set being allocated.

The `VkDescriptorSetVariableDescriptorCountAllocateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkDescriptorSetVariableDescriptorCountAllocateInfo {
    VkStructureType sType;
    const void* pNext;
    uint32_t descriptorSetCount;
    const uint32_t* pDescriptorCounts;
} VkDescriptorSetVariableDescriptorCountAllocateInfo;
```

or the equivalent

```c
// Provided by VK_EXT_descriptor_indexing
typedef VkDescriptorSetVariableDescriptorCountAllocateInfo
VkDescriptorSetVariableDescriptorCountAllocateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `descriptorSetCount` is zero or the number of elements in `pDescriptorCounts`.
- `pDescriptorCounts` is a pointer to an array of descriptor counts, with each member specifying the number of descriptors in a variable-sized descriptor binding in the corresponding descriptor set.
being allocated.

If `descriptorSetCount` is zero or this structure is not included in the `pNext` chain, then the variable lengths are considered to be zero. Otherwise, `pDescriptorCounts[i]` is the number of descriptors in the variable-sized descriptor binding in the corresponding descriptor set layout. If the variable-sized descriptor binding in the corresponding descriptor set layout has a descriptor type of `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK` then `pDescriptorCounts[i]` specifies the binding’s capacity in bytes. If `VkDescriptorSetAllocateInfo::pSetLayouts[i]` does not include a variable-sized descriptor binding, then `pDescriptorCounts[i]` is ignored.

**Valid Usage**

- VUID-VkDescriptorSetVariableDescriptorCountAllocateInfo-descriptorSetCount-03045
  If `descriptorSetCount` is not zero, `descriptorSetCount` must equal `VkDescriptorSetAllocateInfo::descriptorSetCount`

- VUID-VkDescriptorSetVariableDescriptorCountAllocateInfo-pSetLayouts-03046
  If `VkDescriptorSetAllocateInfo::pSetLayouts[i]` has a variable-sized descriptor binding, then `pDescriptorCounts[i]` must be less than or equal to the descriptor count specified for that binding when the descriptor set layout was created.

**Valid Usage (Implicit)**

- VUID-VkDescriptorSetVariableDescriptorCountAllocateInfo-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_DESCRIPTOR_SET_VARIABLE_DESCRIPTOR_COUNT_ALLOCATE_INFO`

- VUID-VkDescriptorSetVariableDescriptorCountAllocateInfo-pDescriptorCounts-parameter
  If `descriptorSetCount` is not 0, `pDescriptorCounts` must be a valid pointer to an array of `descriptorSetCount uint32_t` values

To free allocated descriptor sets, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkFreeDescriptorSets(
 VkDevice device,
  VkDescriptorPool descriptorPool,
  uint32_t descriptorSetCount,
  const VkDescriptorSet* pDescriptorSets);
```

- `device` is the logical device that owns the descriptor pool.
- `descriptorPool` is the descriptor pool from which the descriptor sets were allocated.
- `descriptorSetCount` is the number of elements in the `pDescriptorSets` array.
- `pDescriptorSets` is a pointer to an array of handles to `VkDescriptorSet` objects.

After calling `vkFreeDescriptorSets`, all descriptor sets in `pDescriptorSets` are invalid.
Valid Usage

- VUID-vkFreeDescriptorSets-pDescriptorSets-00309
  All submitted commands that refer to any element of `pDescriptorSets` must have completed execution

- VUID-vkFreeDescriptorSets-pDescriptorSets-00310
  `pDescriptorSets` must be a valid pointer to an array of `descriptorSetCount` `VkDescriptorSet` handles, each element of which must either be a valid handle or `VK_NULL_HANDLE`

- VUID-vkFreeDescriptorSets-descriptorPool-00312
  `descriptorPool` must have been created with the `VK_DESCRIPTOR_POOL_CREATE_FREE_DESCRIPTOR_SET_BIT` flag

Valid Usage (Implicit)

- VUID-vkFreeDescriptorSets-device-parameter
  `device` must be a valid `VkDevice` handle

- VUID-vkFreeDescriptorSets-descriptorPool-parameter
  `descriptorPool` must be a valid `VkDescriptorPool` handle

- VUID-vkFreeDescriptorSets-descriptorSetCount-arraylength
  `descriptorSetCount` must be greater than 0

- VUID-vkFreeDescriptorSets-descriptorPool-parent
  `descriptorPool` must have been created, allocated, or retrieved from `device`

- VUID-vkFreeDescriptorSets-pDescriptorSets-parent
  Each element of `pDescriptorSets` that is a valid handle must have been created, allocated, or retrieved from `descriptorPool`

Host Synchronization

- Host access to `descriptorPool` must be externally synchronized
- Host access to each member of `pDescriptorSets` must be externally synchronized

Return Codes

**Success**

- `VK_SUCCESS`

To return all descriptor sets allocated from a given pool to the pool, rather than freeing individual descriptor sets, call:

```cpp
// Provided by VK_VERSION_1_0
```
VkResult vkResetDescriptorPool(
    VkDevice device,
    VkDescriptorPool descriptorPool,
    VkDescriptorPoolResetFlags flags);

- device is the logical device that owns the descriptor pool.
- descriptorPool is the descriptor pool to be reset.
- flags is reserved for future use.

Resetting a descriptor pool recycles all of the resources from all of the descriptor sets allocated from the descriptor pool back to the descriptor pool, and the descriptor sets are implicitly freed.

Valid Usage

- VUID-vkResetDescriptorPool-descriptorPool-00313
  All uses of descriptorPool (via any allocated descriptor sets) must have completed execution

Valid Usage (Implicit)

- VUID-vkResetDescriptorPool-device-parameter
device must be a valid VkDevice handle

- VUID-vkResetDescriptorPool-descriptorPool-parameter
descriptorPool must be a valid VkDescriptorPool handle

- VUID-vkResetDescriptorPool-flags-zerobitmask
  flags must be 0

- VUID-vkResetDescriptorPool-descriptorPool-parent
descriptorPool must have been created, allocated, or retrieved from device

Host Synchronization

- Host access to descriptorPool must be externally synchronized

- Host access to any VkDescriptorSet objects allocated from descriptorPool must be externally synchronized

Return Codes

Success
- VK_SUCCESS
typedef VkFlags VkDescriptorPoolResetFlags;

VkDescriptorPoolResetFlags is a bitmask type for setting a mask, but is currently reserved for future use.

### 14.2.4. Descriptor Set Updates

Once allocated, descriptor sets can be updated with a combination of write and copy operations. To update descriptor sets, call:

```c
void vkUpdateDescriptorSets(
    VkDevice device,
    uint32_t descriptorWriteCount, // Provided by VK_VERSION_1_0
    const VkWriteDescriptorSet* pDescriptorWrites,
    uint32_t descriptorCopyCount,
    const VkCopyDescriptorSet* pDescriptorCopies);
```

- **device** is the logical device that updates the descriptor sets.
- **descriptorWriteCount** is the number of elements in the `pDescriptorWrites` array.
- **pDescriptorWrites** is a pointer to an array of VkWriteDescriptorSet structures describing the descriptor sets to write to.
- **descriptorCopyCount** is the number of elements in the `pDescriptorCopies` array.
- **pDescriptorCopies** is a pointer to an array of VkCopyDescriptorSet structures describing the descriptor sets to copy between.

The operations described by `pDescriptorWrites` are performed first, followed by the operations described by `pDescriptorCopies`. Within each array, the operations are performed in the order they appear in the array.

Each element in the `pDescriptorWrites` array describes an operation updating the descriptor set using descriptors for resources specified in the structure.

Each element in the `pDescriptorCopies` array is a VkCopyDescriptorSet structure describing an operation copying descriptors between sets.

If the `dstSet` member of any element of `pDescriptorWrites` or `pDescriptorCopies` is bound, accessed, or modified by any command that was recorded to a command buffer which is currently in the recording or executable state, and any of the descriptor bindings that are updated were not created with the VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT or VK_DESCRIPTOR_BINDING_UPDATE_UNUSED_WHILE_PENDING_BIT bits set, that command buffer becomes invalid.
Valid Usage

• VUID-vkUpdateDescriptorSets-pDescriptorWrites-06236
For each element i where pDescriptorWrites[i].descriptorType is
VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER or VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER,
elements of the pTexelBufferView member of pDescriptorWrites[i] must have been created
on device

• VUID-vkUpdateDescriptorSets-pDescriptorWrites-06237
For each element i where pDescriptorWrites[i].descriptorType is
VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER, VK_DESCRIPTOR_TYPE_STORAGE_BUFFER,
VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC, or
VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC, the buffer member of any element of the
pBufferInfo member of pDescriptorWrites[i] must have been created on device

• VUID-vkUpdateDescriptorSets-pDescriptorWrites-06238
For each element i where pDescriptorWrites[i].descriptorType is
VK_DESCRIPTOR_TYPE_SAMPLER or VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER, and
dstSet was not allocated with a layout that included immutable samplers for dstBinding with
descriptorType, the sampler member of any element of the pImageInfo member of
pDescriptorWrites[i] must have been created on device

• VUID-vkUpdateDescriptorSets-pDescriptorWrites-06239
For each element i where pDescriptorWrites[i].descriptorType is
VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE, VK_DESCRIPTOR_TYPE_STORAGE_IMAGE,
VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT, or VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER the
imageView member of any element of pDescriptorWrites[i] must have been created on device

• VUID-vkUpdateDescriptorSets-pDescriptorWrites-06240
For each element i where pDescriptorWrites[i].descriptorType is
VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR, elements of the pAccelerationStructures
member of a VkWriteDescriptorSetAccelerationStructureKHR structure in the pNext chain
of pDescriptorWrites[i] must have been created on device

• VUID-vkUpdateDescriptorSets-pDescriptorWrites-06241
For each element i where pDescriptorWrites[i].descriptorType is
VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_NV, elements of the pAccelerationStructures
member of a VkWriteDescriptorSetAccelerationStructureNV structure in the pNext chain
of pDescriptorWrites[i] must have been created on device

• VUID-vkUpdateDescriptorSets-pDescriptorWrites-06940
For each element i where pDescriptorWrites[i].descriptorType is
VK_DESCRIPTOR_TYPE_SAMPLE_WEIGHT_IMAGE_QCOM or
VK_DESCRIPTOR_TYPE_BLOCK_MATCH_IMAGE_QCOM, the imageView member of any element of
pDescriptorWrites[i] must have been created on device

• VUID-vkUpdateDescriptorSets-pDescriptorWrites-06493
For each element i where pDescriptorWrites[i].descriptorType is
VK_DESCRIPTOR_TYPE_SAMPLER, VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER,
VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE, VK_DESCRIPTOR_TYPE_STORAGE_IMAGE,
VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT, pDescriptorWrites[i].pImageInfo must be a valid pointer to an array of pDescriptorWrites[i].descriptorCount valid VkDescriptorImageInfo structures.

- **VUID-vkUpdateDescriptorSets-pDescriptorWrites-06941**
  For each element i where pDescriptorWrites[i].descriptorType is VK_DESCRIPTOR_TYPE_SAMPLE_WEIGHT_IMAGE_QCOM or VK_DESCRIPTOR_TYPE_BLOCK_MATCH_IMAGE_QCOM, pDescriptorWrites[i].pImageInfo must be a valid pointer to an array of pDescriptorWrites[i].descriptorCount valid VkDescriptorImageInfo structures.

- **VUID-vkUpdateDescriptorSets-None-03047**
  Descriptor bindings updated by this command which were created without the VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT or VK_DESCRIPTOR_BINDING_UPDATE_UNUSED_WHILE_PENDING_BIT bits set must not be used by any command that was recorded to a command buffer which is in the pending state.

- **VUID-vkUpdateDescriptorSets-pDescriptorWrites-06993**
  Host access to pDescriptorWrites[i].dstSet and pDescriptorCopies[i].dstSet must be externally synchronized unless explicitly denoted otherwise for specific flags.

**Valid Usage (Implicit)**

- **VUID-vkUpdateDescriptorSets-device-parameter**
  device must be a valid VkDevice handle.

- **VUID-vkUpdateDescriptorSets-pDescriptorWrites-parameter**
  If descriptorWriteCount is not 0, pDescriptorWrites must be a valid pointer to an array of descriptorWriteCount valid VkWriteDescriptorSet structures.

- **VUID-vkUpdateDescriptorSets-pDescriptorCopies-parameter**
  If descriptorCopyCount is not 0, pDescriptorCopies must be a valid pointer to an array of descriptorCopyCount valid VkCopyDescriptorSet structures.

The VkWriteDescriptorSet structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkWriteDescriptorSet {
    VkStructureType sType;
    const void* pNext;
    VkDescriptorSet dstSet;
    uint32_t dstBinding;
    uint32_t dstArrayElement;
    uint32_t descriptorCount;
    VkDescriptorType descriptorType;
    const VkDescriptorImageInfo* pImageInfo;
    const VkDescriptorBufferInfo* pBufferInfo;
    const VkBufferView* pTexelBufferView;
} VkWriteDescriptorSet;
```
• *sType* is a *VkStructureType* value identifying this structure.

• *pNext* is NULL or a pointer to a structure extending this structure.

• *dstSet* is the destination descriptor set to update.

• *dstBinding* is the descriptor binding within that set.

• *dstArrayElement* is the starting element in that array. If the descriptor binding identified by *dstSet* and *dstBinding* has a descriptor type of *VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK* then *dstArrayElement* specifies the starting byte offset within the binding.

• *descriptorCount* is the number of descriptors to update. If the descriptor binding identified by *dstSet* and *dstBinding* has a descriptor type of *VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK*, then *descriptorCount* specifies the number of bytes to update. Otherwise, *descriptorCount* is one of:
  ◦ the number of elements in *pImageInfo*
  ◦ the number of elements in *pBufferInfo*
  ◦ the number of elements in *pTexelBufferView*
  ◦ a value matching the *dataSize* member of a *VkWriteDescriptorSetInlineUniformBlock* structure in the *pNext* chain
  ◦ a value matching the *accelerationStructureCount* of a *VkWriteDescriptorSetAccelerationStructureKHR* structure in the *pNext* chain

• *descriptorType* is a *VkDescriptorType* specifying the type of each descriptor in *pImageInfo*, *pBufferInfo*, or *pTexelBufferView*, as described below. If *VkDescriptorsetLayoutBinding* for *dstSet* at *dstBinding* is not equal to *VK_DESCRIPTOR_TYPE_MUTABLE_EXT*, *descriptorType* must be the same type as the *descriptorType* specified in *VkDescriptorsetLayoutBinding* for *dstSet* at *dstBinding*. The type of the descriptor also controls which array the descriptors are taken from.

• *pImageInfo* is a pointer to an array of *VkDescriptorImageInfo* structures or is ignored, as described below.

• *pBufferInfo* is a pointer to an array of *VkDescriptorBufferInfo* structures or is ignored, as described below.

• *pTexelBufferView* is a pointer to an array of *VkBufferView* handles as described in the *Buffer Views* section or is ignored, as described below.

Only one of *pImageInfo*, *pBufferInfo*, or *pTexelBufferView* members is used according to the descriptor type specified in the *descriptorType* member of the containing *VkWriteDescriptorSet* structure, or none of them in case *descriptorType* is *VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK*, in which case the source data for the descriptor writes is taken from the *VkWriteDescriptorSetInlineUniformBlock* structure included in the *pNext* chain of *VkWriteDescriptorSet*, or if *descriptorType* is *VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR*, in which case the source data for the descriptor writes is taken from the *VkWriteDescriptorSetAccelerationStructureKHR* structure in the *pNext* chain of *VkWriteDescriptorSet*, or if *descriptorType* is *VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_NV*, in which case the source data for the descriptor writes is taken from the *VkWriteDescriptorSetAccelerationStructureNV* structure in the *pNext* chain of *VkWriteDescriptorSet*, as specified below.

If the *nullDescriptor* feature is enabled, the buffer, acceleration structure, imageView, or
bufferView can be VK_NULL_HANDLE. Loads from a null descriptor return zero values and stores and atomics to a null descriptor are discarded. A null acceleration structure descriptor results in the miss shader being invoked.

If the destination descriptor is a mutable descriptor, the active descriptor type for the destination descriptor becomes descriptorType.

If the dstBinding has fewer than descriptorCount array elements remaining starting from dstArrayElement, then the remainder will be used to update the subsequent binding - dstBinding+1 starting at array element zero. If a binding has a descriptorCount of zero, it is skipped. This behavior applies recursively, with the update affecting consecutive bindings as needed to update all descriptorCount descriptors. Consecutive bindings must have identical VkDescriptorType, VkShaderStageFlags, VkDescriptorBindingFlagBits, and immutable samplers references. In addition, if the VkDescriptorType is VK_DESCRIPTOR_TYPE_MUTABLE_EXT, the supported descriptor types in VkMutableDescriptorTypeCreateInfoEXT must be equally defined.

Note
The same behavior applies to bindings with a descriptor type of VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK where descriptorCount specifies the number of bytes to update while dstArrayElement specifies the starting byte offset, thus in this case if the dstBinding has a smaller byte size than the sum of dstArrayElement and descriptorCount, then the remainder will be used to update the subsequent binding - dstBinding+1 starting at offset zero. This falls out as a special case of the above rule.

Valid Usage

- VUID-VkWriteDescriptorSet-dstBinding-00315
dstBinding must be less than or equal to the maximum value of binding of all VkDescriptorSetLayoutBinding structures specified when dstSet's descriptor set layout was created

- VUID-VkWriteDescriptorSet-dstBinding-00316
dstBinding must be a binding with a non-zero descriptorCount

- VUID-VkWriteDescriptorSet-descriptorCount-00317
All consecutive bindings updated via a single VkWriteDescriptorSet structure, except those with a descriptorCount of zero, must have identical descriptorType and stageFlags

- VUID-VkWriteDescriptorSet-descriptorCount-00318
All consecutive bindings updated via a single VkWriteDescriptorSet structure, except those with a descriptorCount of zero, must all either use immutable samplers or must all not use immutable samplers

- VUID-VkWriteDescriptorSet-descriptorType-00319
descriptorType must match the type of dstBinding within dstSet

- VUID-VkWriteDescriptorSet-dstSet-00320
dstSet must be a valid VkDescriptorSet handle

- VUID-VkWriteDescriptorSet-dstArrayElement-00321
The sum of dstArrayElement and descriptorCount must be less than or equal to the number of array elements in the descriptor set binding specified by dstBinding, and all applicable consecutive bindings, as described by consecutive binding updates.

- VUID-VkWriteDescriptorSet-descriptorType-02219
  If descriptorType is VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK, dstArrayElement must be an integer multiple of 4.

- VUID-VkWriteDescriptorSet-descriptorType-02220
  If descriptorType is VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK, descriptorCount must be an integer multiple of 4.

- VUID-VkWriteDescriptorSet-descriptorType-02994
  If descriptorType is VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER or VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER, each element of pTexelBufferView must be either a valid VkBufferView handle or VK_NULL_HANDLE.

- VUID-VkWriteDescriptorSet-descriptorType-02995
  If descriptorType is VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER or VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER and the nullDescriptor feature is not enabled, each element of pTexelBufferView must not be VK_NULL_HANDLE.

- VUID-VkWriteDescriptorSet-descriptorType-00324
  If descriptorType is VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER, VK_DESCRIPTOR_TYPE_STORAGE_BUFFER, VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC, or VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC, pBufferInfo must be a valid pointer to an array of descriptorCount valid VkDescriptorBufferInfo structures.

- VUID-VkWriteDescriptorSet-descriptorType-00325
  If descriptorType is VK_DESCRIPTOR_TYPE_SAMPLER or VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER, and dstSet was not allocated with a layout that included immutable samplers for dstBinding with descriptorType, the sampler member of each element of pImageInfo must be a valid VkSampler object.

- VUID-VkWriteDescriptorSet-descriptorType-02996
  If descriptorType is VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER, VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE, or VK_DESCRIPTOR_TYPE_STORAGE_IMAGE, the imageView member of each element of pImageInfo must be either a valid VkImageView handle or VK_NULL_HANDLE.

- VUID-VkWriteDescriptorSet-descriptorType-02997
  If descriptorType is VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER, VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE, or VK_DESCRIPTOR_TYPE_STORAGE_IMAGE, and the nullDescriptor feature is not enabled, the imageView member of each element of pImageInfo must not be VK_NULL_HANDLE.

- VUID-VkWriteDescriptorSet-descriptorType-07683
  If descriptorType is VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT, the imageView member of each element of pImageInfo must not be VK_NULL_HANDLE.

- VUID-VkWriteDescriptorSet-descriptorType-02221
  If descriptorType is VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK, the pNext chain must include a VkWriteDescriptorSetInlineUniformBlock structure whose dataSize member equals descriptorCount.
If `descriptorType` is `VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR`, the `pNext` chain must include a `VkWriteDescriptorSetAccelerationStructureKHR` structure whose `accelerationStructureCount` member equals `descriptorCount`.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_NV`, the `pNext` chain must include a `VkWriteDescriptorSetAccelerationStructureNV` structure whose `accelerationStructureCount` member equals `descriptorCount`.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE`, then the `imageView` member of each `pImageInfo` element must have been created without a `VkSamplerYcbcrConversionInfo` structure in its `pNext` chain.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`, and if any element of `pImageInfo` has an `imageView` member that was created with a `VkSamplerYcbcrConversionInfo` structure in its `pNext` chain, then `dstSet` must have been allocated with a layout that included immutable samplers for `dstBinding`, and the corresponding immutable sampler must have been created with an identically defined `VkSamplerYcbcrConversionInfo` object.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`, and `dstSet` was allocated with a layout that included immutable samplers for `dstBinding`, then the `imageView` member of each element of `pImageInfo` which corresponds to an immutable sampler that enables `sampler Y'CbCr` conversion must have been created with a `VkSamplerYcbcrConversionInfo` structure in its `pNext` chain with an identically defined `VkSamplerYcbcrConversionInfo` to the corresponding immutable sampler.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER` or `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC`, the `offset` member of each element of `pBufferInfo` must be a multiple of `VkPhysicalDeviceLimits::minUniformBufferOffsetAlignment`.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER` or `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC`, the `offset` member of each element of `pBufferInfo` must be a multiple of `VkPhysicalDeviceLimits::minStorageBufferOffsetAlignment`.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER`, `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC`, `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER`, or `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC`, and the `buffer` member of any element of `pBufferInfo` is the handle of a non-sparse buffer, then that buffer must be bound completely and contiguously to a single `VkDeviceMemory` object.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER` or `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC`, the `buffer` member of each element of `pBufferInfo` must have been created with `VK_BUFFER_USAGE_UNIFORM_BUFFER_BIT` set.
If `descriptorType` is `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER` or `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC`, the `buffer` member of each element of `pBufferInfo` must have been created with `VK_BUFFER_USAGE_STORAGE_BUFFER_BIT` set.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER` or `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC`, the range member of each element of `pBufferInfo`, or the effective range if `range` is `VK_WHOLE_SIZE`, must be less than or equal to `VkPhysicalDeviceLimits::maxUniformBufferRange`.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER` or `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC`, the range member of each element of `pBufferInfo`, or the effective range if `range` is `VK_WHOLE_SIZE`, must be less than or equal to `VkPhysicalDeviceLimits::maxStorageBufferRange`.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER`, the `pTexelBufferView` buffer view usage must include `VK_BUFFER_USAGE_UNIFORM_TEXEL_BUFFER_BIT`.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER`, the `pTexelBufferView` buffer view usage must include `VK_BUFFER_USAGE_STORAGE_TEXEL_BUFFER_BIT`.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE` or `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`, the `imageView` member of each element of `pImageInfo` must have been created with the identity swizzle.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT` the `imageView` member of each element of `pImageInfo` must be a member of the list given in Sampled Image.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE` the `imageLayout` member of each element of `pImageInfo` must be a member of the list given in Combined Image Sampler.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT` the `imageLayout` member of each element of `pImageInfo` must be a member of the list given in Input Attachment.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE` the `imageLayout` member of each element of `pImageInfo` must be a member of the list given in Storage Image.

If `descriptorType` is `VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT`, the `imageView` member of each
element of `pImageInfo` must have been created with `VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT` set

- **VUID-VkWriteDescriptorSet-descriptorType-00339**
  If `descriptorType` is `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE`, the `imageView` member of each element of `pImageInfo` must have been created with `VK_IMAGE_USAGE_STORAGE_BIT` set

- **VUID-VkWriteDescriptorSet-descriptorType-02752**
  If `descriptorType` is `VK_DESCRIPTOR_TYPE_SAMPLER`, then `dstSet` must not have been allocated with a layout that included immutable samplers for `dstBinding`

- **VUID-VkWriteDescriptorSet-dstSet-04611**
  If the `VkDescriptorSetLayoutBinding` for `dstSet` at `dstBinding` is `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`, the new active descriptor type `descriptorType` must exist in the corresponding `pMutableDescriptorTypeLists` list for `dstBinding`

- **VUID-VkWriteDescriptorSet-descriptorType-06450**
  If `descriptorType` is `VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT`, the `imageView` member of each element of `pImageInfo` must have either been created without a `VkImageViewMinLodCreateInfoEXT` included in the `pNext` chain or with a `VkImageViewMinLodCreateInfoEXT::minLod` of 0.0

- **VUID-VkWriteDescriptorSet-descriptorType-06942**
  If `descriptorType` is `VK_DESCRIPTOR_TYPE_SAMPLE_WEIGHT_IMAGE_QCOM`, the `imageView` member of each element of `pImageInfo` must have been created with a view created with an image created with `VK_IMAGE_USAGE_SAMPLE_WEIGHT_BIT_QCOM`

- **VUID-VkWriteDescriptorSet-descriptorType-06943**
  If `descriptorType` is `VK_DESCRIPTOR_TYPE_BLOCK_MATCH_IMAGE_QCOM`, the `imageView` member of each element of `pImageInfo` must have been created with a view created with an image created with `VK_IMAGE_USAGE_SAMPLE_BLOCK_MATCH_BIT_QCOM`

**Valid Usage (Implicit)**

- **VUID-VkWriteDescriptorSet-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET`

- **VUID-VkWriteDescriptorSet-pNext-pNext**
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkWriteDescriptorSetAccelerationStructureKHR`, `VkWriteDescriptorSetAccelerationStructureNV`, or `VkWriteDescriptorSetInlineUniformBlock`

- **VUID-VkWriteDescriptorSet-sType-unique**
  The `sType` value of each struct in the `pNext` chain must be unique

- **VUID-VkWriteDescriptorSet-descriptorType-parameter**
  `descriptorType` must be a valid `VkDescriptorType` value

- **VUID-VkWriteDescriptorSet-descriptorCount-arraylength**
  `descriptorCount` must be greater than 0

- **VUID-VkWriteDescriptorSet-commonparent**
Both of \texttt{dstSet}, and the elements of \texttt{pTexelBufferView} that are valid handles of non-ignored parameters \textbf{must} have been created, allocated, or retrieved from the same \texttt{VkDevice}.

The type of descriptors in a descriptor set is specified by \texttt{VkWriteDescriptorSet::descriptorType}, which \textbf{must} be one of the values:

```cpp
// Provided by VK_VERSION_1_0
typedef enum VkDescriptorType {
    VK_DESCRIPTOR_TYPE_SAMPLER = 0,
    VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER = 1,
    VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE = 2,
    VK_DESCRIPTOR_TYPE_STORAGE_IMAGE = 3,
    VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER = 4,
    VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER = 5,
    VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER = 6,
    VK_DESCRIPTOR_TYPE_STORAGE_BUFFER = 7,
    VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC = 8,
    VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC = 9,
    VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT = 10,
    // Provided by VK_VERSION_1_3
    VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK = 1000138000,
    // Provided by VK_KHR_acceleration_structure
    VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR = 1000150000,
    // Provided by VK_NV_ray_tracing
    VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_NV = 1000165000,
    // Provided by VK_QCOM_image_processing
    VK_DESCRIPTOR_TYPE_SAMPLE_WEIGHT_IMAGE_QCOM = 1000440000,
    // Provided by VK_QCOM_image_processing
    VK_DESCRIPTOR_TYPE_BLOCK_MATCH_IMAGE_QCOM = 1000440001,
    // Provided by VK_EXT_mutable_descriptor_type
    VK_DESCRIPTOR_TYPE_MUTABLE_EXT = 1000351000,
    // Provided by VK_EXT_inline_uniform_block
    VK_DESCRIPTOR_TYPE_MUTABLE_VALVE = VK_DESCRIPTOR_TYPE_MUTABLE_EXT,

    VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK = VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK
} VkDescriptorType;
```

- \texttt{VK_DESCRIPTOR_TYPE_SAMPLER} specifies a \texttt{sampled} descriptor.
- \texttt{VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER} specifies a \texttt{combined image sampler} descriptor.
- \texttt{VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE} specifies a \texttt{sampled} image descriptor.
- \texttt{VK_DESCRIPTOR_TYPE_STORAGE_IMAGE} specifies a \texttt{storage} image descriptor.
- \texttt{VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER} specifies a \texttt{uniform texel buffer} descriptor.
- \texttt{VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER} specifies a \texttt{storage texel buffer} descriptor.
- \texttt{VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER} specifies a \texttt{uniform buffer} descriptor.
- \texttt{VK_DESCRIPTOR_TYPE_STORAGE_BUFFER} specifies a \texttt{storage buffer} descriptor.
• **VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC** specifies a dynamic uniform buffer descriptor.
• **VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC** specifies a dynamic storage buffer descriptor.
• **VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT** specifies an input attachment descriptor.
• **VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK** specifies an inline uniform block.
• **VK_DESCRIPTOR_TYPE_MUTABLE_EXT** specifies a descriptor of mutable type.
• **VK_DESCRIPTOR_TYPE_SAMPLE_WEIGHT_IMAGE_QCOM** specifies a sampled weight image descriptor.
• **VK_DESCRIPTOR_TYPE_BLOCK_MATCH_IMAGE_QCOM** specifies a block matching image descriptor.

When a descriptor set is updated via elements of `VkWriteDescriptorSet`, members of `pImageInfo`, `pBufferInfo` and `pTexelBufferView` are only accessed by the implementation when they correspond to descriptor type being defined - otherwise they are ignored. The members accessed are as follows for each descriptor type:

• **For **`VK_DESCRIPTOR_TYPE_SAMPLER`**, only the **sampler** member of each element of `VkWriteDescriptorSet::pImageInfo` is accessed.

• **For **`VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE`, `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE`, or `VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT`**, only the **imageView** and **imageLayout** members of each element of `VkWriteDescriptorSet::pImageInfo` are accessed.

• **For **`VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`**, all members of each element of `VkWriteDescriptorSet::pImageInfo` are accessed.

• **For **`VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER`, `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER`, `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC`, or `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC`**, all members of each element of `VkWriteDescriptorSet::pBufferInfo` are accessed.

• **For **`VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER`** or **`VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER`**, each element of `VkWriteDescriptorSet::pTexelBufferView` is accessed.

When updating descriptors with a `descriptorType` of `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK`, none of the `pImageInfo`, `pBufferInfo`, or `pTexelBufferView` members are accessed, instead the source data of the descriptor update operation is taken from the `VkWriteDescriptorSetInlineUniformBlock` structure in the `pNext` chain of `VkWriteDescriptorSet`. When updating descriptors with a `descriptorType` of `VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR`, none of the `pImageInfo`, `pBufferInfo`, or `pTexelBufferView` members are accessed, instead the source data of the descriptor update operation is taken from the `VkWriteDescriptorSetAccelerationStructureKHR` structure in the `pNext` chain of `VkWriteDescriptorSet`. When updating descriptors with a `descriptorType` of `VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_NV`, none of the `pImageInfo`, `pBufferInfo`, or `pTexelBufferView` members are accessed, instead the source data of the descriptor update operation is taken from the `VkWriteDescriptorSetAccelerationStructureNV` structure in the `pNext` chain of `VkWriteDescriptorSet`.

The `VkDescriptorBufferInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkDescriptorBufferInfo {
    VkBuffer buffer;
    VkDeviceSize offset;
```

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VkDeviceSize range;
} VkDescriptorBufferInfo;

- **buffer** is `VK_NULL_HANDLE` or the buffer resource.
- **offset** is the offset in bytes from the start of **buffer**. Access to buffer memory via this descriptor uses addressing that is relative to this starting offset.
- **range** is the size in bytes that is used for this descriptor update, or `VK_WHOLE_SIZE` to use the range from **offset** to the end of the buffer.

**Note**
When setting **range** to `VK_WHOLE_SIZE`, the effective range must not be larger than the maximum range for the descriptor type (`maxUniformBufferRange` or `maxStorageBufferRange`). This means that `VK_WHOLE_SIZE` is not typically useful in the common case where uniform buffer descriptors are suballocated from a buffer that is much larger than `maxUniformBufferRange`.

For **VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC** and **VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC** descriptor types, **offset** is the base offset from which the dynamic offset is applied and **range** is the static size used for all dynamic offsets.

When **range** is `VK_WHOLE_SIZE` the effective range is calculated at `vkUpdateDescriptorSets` is by taking the size of **buffer** minus the **offset**.

**Valid Usage**

- VUID-VkDescriptorBufferInfo-offset-00340
  **offset** must be less than the size of **buffer**

- VUID-VkDescriptorBufferInfo-range-00341
  If **range** is not equal to `VK_WHOLE_SIZE`, **range** must be greater than 0

- VUID-VkDescriptorBufferInfo-range-00342
  If **range** is not equal to `VK_WHOLE_SIZE`, **range** must be less than or equal to the size of **buffer** minus **offset**

- VUID-VkDescriptorBufferInfo-buffer-02998
  If the nullDescriptor feature is not enabled, **buffer** must not be `VK_NULL_HANDLE`

- VUID-VkDescriptorBufferInfo-buffer-02999
  If **buffer** is `VK_NULL_HANDLE`, **offset** must be zero and **range** must be `VK_WHOLE_SIZE`

**Valid Usage (Implicit)**

- VUID-VkDescriptorBufferInfo-buffer-parameter
  If **buffer** is not `VK_NULL_HANDLE`, **buffer** must be a valid `VkBuffer` handle

The **VkDescriptorImageInfo** structure is defined as:
typedef struct VkDescriptorImageInfo {
    VkSampler sampler;
    VkImageView imageView;
    VkImageLayout imageLayout;
} VkDescriptorImageInfo;

- **sampler** is a sampler handle, and is used in descriptor updates for types `VK_DESCRIPTOR_TYPE_SAMPLER` and `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER` if the binding being updated does not use immutable samplers.

- **imageView** is `VK_NULL_HANDLE` or an image view handle, and is used in descriptor updates for types `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE`, `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE`, `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`, and `VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT`.

- **imageLayout** is the layout that the image subresources accessible from `imageView` will be in at the time this descriptor is accessed. `imageLayout` is used in descriptor updates for types `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE`, `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE`, `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`, and `VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT`.

Members of `VkDescriptorImageInfo` that are not used in an update (as described above) are ignored.

### Valid Usage

- **VUID-VkDescriptorImageInfo-imageView-06712**
  `imageView` must not be a 2D array image view created from a 3D image

- **VUID-VkDescriptorImageInfo-imageView-07795**
  If `imageView` is a 2D view created from a 3D image, then `descriptorType` must be `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE`, `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE`, or `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`

- **VUID-VkDescriptorImageInfo-imageView-07796**
  If `imageView` is a 2D view created from a 3D image, then the image must have been created with `VK_IMAGE_CREATE_2D_VIEW_COMPATIBLE_BIT_EXT` set

- **VUID-VkDescriptorImageInfo-descriptorType-06713**
  If the `image2DViewOf3D` feature is not enabled or `descriptorType` is not `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE` then `imageView` must not be a 2D view created from a 3D image

- **VUID-VkDescriptorImageInfo-descriptorType-06714**
  If the `sampler2DViewOf3D` feature is not enabled or `descriptorType` is not `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE` or `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER` then `imageView` must not be a 2D view created from a 3D image

- **VUID-VkDescriptorImageInfo-imageView-01976**
  If `imageView` is created from a depth/stencil image, the `aspectMask` used to create the `imageView` must include either `VK_IMAGE_ASPECT_DEPTH_BIT` or `VK_IMAGE_ASPECT_STENCIL_BIT` but not both

- **VUID-VkDescriptorImageInfo-imageView-00344**

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**ImageLayout** must match the actual **VkImageLayout** of each subresource accessible from **imageView** at the time this descriptor is accessed as defined by the image layout matching rules.

- **VUID-VkDescriptorImageInfo-sampler-01564**
  If **sampler** is used and the **VkFormat** of the image is a multi-planar format, the image must have been created with **VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT**, and the **aspectMask** of the **imageView** must be a valid multi-planar aspect mask bit.

- **VUID-VkDescriptorImageInfo-mutableComparisonSamplers-04450**
  If the **VK_KHR_portability_subset** extension is enabled, and **VkPhysicalDevicePortabilitySubsetFeaturesKHR::mutableComparisonSamplers** is **VK_FALSE**, then **sampler** must have been created with **VkSamplerCreateInfo::compareEnable** set to **VK_FALSE**.

**Valid Usage (Implicit)**

- **VUID-VkDescriptorImageInfo-commonparent**
  Both of **imageView**, and **sampler** that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same **VkDevice**.

If the **descriptorType** member of **VkWriteDescriptorSet** is **VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK** then the data to write to the descriptor set is specified through a **VkWriteDescriptorSetInlineUniformBlock** structure included in the **pNext** chain of **VkWriteDescriptorSet**.

The **VkWriteDescriptorSetInlineUniformBlock** structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkWriteDescriptorSetInlineUniformBlock {
    VkStructureType sType;
    const void* pNext;
    uint32_t dataSize;
    const void* pData;
} VkWriteDescriptorSetInlineUniformBlock;
```

or the equivalent

```c
// Provided by VK_EXT_inline_uniform_block
typedef VkWriteDescriptorSetInlineUniformBlock
VkWriteDescriptorSetInlineUniformBlockEXT;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **dataSize** is the number of bytes of inline uniform block data pointed to by **pData**.
• **pData** is a pointer to **dataSize** number of bytes of data to write to the inline uniform block.

**Valid Usage**

- VUID-VkWriteDescriptorSetInlineUniformBlock-dataSize-02222
  
  **dataSize must** be an integer multiple of **4**

**Valid Usage (Implicit)**

- VUID-VkWriteDescriptorSetInlineUniformBlock-sType-sType
  
  **sType must** be **VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET_INLINE_UNIFORM_BLOCK**

- VUID-VkWriteDescriptorSetInlineUniformBlock-pData-parameter
  
  **pData must** be a valid pointer to an array of **dataSize** bytes

- VUID-VkWriteDescriptorSetInlineUniformBlock-dataSize-arraylength
  
  **dataSize must** be greater than **0**

The **VkWriteDescriptorSetAccelerationStructureKHR** structure is defined as:

```
// Provided by VK_KHR_acceleration_structure

typedef struct VkWriteDescriptorSetAccelerationStructureKHR {
    VkStructureType          sType;
    const void*              pNext;
    uint32_t                  accelerationStructureCount;
    const VkAccelerationStructureKHR*  pAccelerationStructures;
} VkWriteDescriptorSetAccelerationStructureKHR;
```

• **sType** is a **VkStructureType** value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **accelerationStructureCount** is the number of elements in **pAccelerationStructures**.

• **pAccelerationStructures** is a pointer to an array of **VkAccelerationStructureKHR** structures specifying the acceleration structures to update.

**Valid Usage**

- VUID-VkWriteDescriptorSetAccelerationStructureKHR-accelerationStructureCount-02236
  
  **accelerationStructureCount must** be equal to **descriptorCount** in the extended structure

- VUID-VkWriteDescriptorSetAccelerationStructureKHR-pAccelerationStructures-03579
  
  Each acceleration structure in **pAccelerationStructures** must have been created with a type of **VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_KHR** or **VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR**

- VUID-VkWriteDescriptorSetAccelerationStructureKHR-pAccelerationStructures-03580
  
  If the **nullDescriptor** feature is not enabled, each element of **pAccelerationStructures**
**Valid Usage (Implicit)**

- **VUID-VkWriteDescriptorSetAccelerationStructureKHR-sType-sType**
  
  `sType` **must** be `VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET_ACCELERATION_STRUCTURE_KHR`.

- **VUID-VkWriteDescriptorSetAccelerationStructureKHR-pAccelerationStructures-parameter**
  
  `pAccelerationStructures` **must** be a valid pointer to an array of `accelerationStructureCount` valid or `VK_NULL_HANDLE` `VkAccelerationStructureKHR` handles.

- **VUID-VkWriteDescriptorSetAccelerationStructureKHR-accelerationStructureCount-arraylength**
  
  `accelerationStructureCount` **must** be greater than 0.

---

The **VkWriteDescriptorSetAccelerationStructureNV** structure is defined as:

```c
// Provided by VK_NV_ray_tracing
typedef struct VkWriteDescriptorSetAccelerationStructureNV {
    VkStructureType sType;
    const void* pNext;
    uint32_t accelerationStructureCount;
    const VkAccelerationStructureNV* pAccelerationStructures;
} VkWriteDescriptorSetAccelerationStructureNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `accelerationStructureCount` is the number of elements in `pAccelerationStructures`.
- `pAccelerationStructures` is a pointer to an array of `VkAccelerationStructureNV` structures specifying the acceleration structures to update.

---

**Valid Usage**

- **VUID-VkWriteDescriptorSetAccelerationStructureNV-accelerationStructureCount-03747**
  
  `accelerationStructureCount` **must** be equal to `descriptorCount` in the extended structure.

- **VUID-VkWriteDescriptorSetAccelerationStructureNV-pAccelerationStructures-03748**
  
  Each acceleration structure in `pAccelerationStructures` **must** have been created with `VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_KHR`.

- **VUID-VkWriteDescriptorSetAccelerationStructureNV-pAccelerationStructures-03749**
  
  If the `nullDescriptor` feature is not enabled, each member of `pAccelerationStructures` **must** not be `VK_NULL_HANDLE`. 

---

**must** not be `VK_NULL_HANDLE`
Valid Usage (Implicit)

- VUID-VkWriteDescriptorSetAccelerationStructureNV-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET_ACCELERATION_STRUCTURE_NV`.

- VUID-VkWriteDescriptorSetAccelerationStructureNV-pAccelerationStructures-parameter
  `pAccelerationStructures` must be a valid pointer to an array of `accelerationStructureCount` valid or `VK_NULL_HANDLE` `VkAccelerationStructureNV` handles.

- VUID-VkWriteDescriptorSetAccelerationStructureNV-accelerationStructureCount-arraylength
  `accelerationStructureCount` must be greater than 0.

The `VkCopyDescriptorSet` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkCopyDescriptorSet {
    VkStructureType     sType;
    const void*         pNext;
    VkDescriptorSet     srcSet;
    uint32_t             srcBinding;
    uint32_t             srcArrayElement;
    VkDescriptorSet     dstSet;
    uint32_t             dstBinding;
    uint32_t             dstArrayElement;
    uint32_t             descriptorCount;
} VkCopyDescriptorSet;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `srcSet`, `srcBinding`, and `srcArrayElement` are the source set, binding, and array element, respectively. If the descriptor binding identified by `srcSet` and `srcBinding` has a descriptor type of `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK` then `srcArrayElement` specifies the starting byte offset within the binding to copy from.
- `dstSet`, `dstBinding`, and `dstArrayElement` are the destination set, binding, and array element, respectively. If the descriptor binding identified by `dstSet` and `dstBinding` has a descriptor type of `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK` then `dstArrayElement` specifies the starting byte offset within the binding to copy to.
- `descriptorCount` is the number of descriptors to copy from the source to destination. If `descriptorCount` is greater than the number of remaining array elements in the source or destination binding, those affect consecutive bindings in a manner similar to `VkWriteDescriptorSet` above. If the descriptor binding identified by `srcSet` and `srcBinding` has a descriptor type of `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK` then `descriptorCount` specifies the number of bytes to copy and the remaining array elements in the source or destination binding refer to the remaining number of bytes in those.
If the `VkDescriptorSetLayoutBinding` for `dstBinding` is `VK_DESCRIPTOR_TYPE_MUTABLE_EXT` and `srcBinding` is not `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`, the new active descriptor type becomes the descriptor type of `srcBinding`. If both `VkDescriptorSetLayoutBinding` for `srcBinding` and `dstBinding` are `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`, the active descriptor type in each source descriptor is copied into the corresponding destination descriptor. The active descriptor type can be different for each source descriptor.

**Note**
The intention is that copies to and from mutable descriptors is a simple memcpy. Copies between non-mutable and mutable descriptors are expected to require one memcpy per descriptor to handle the difference in size, but this use case with more than one `descriptorCount` is considered rare.

**Valid Usage**

- **VUID-VkCopyDescriptorSet-srcBinding-00345**
  `srcBinding` must be a valid binding within `srcSet`

- **VUID-VkCopyDescriptorSet-srcArrayElement-00346**
  The sum of `srcArrayElement` and `descriptorCount` must be less than or equal to the number of array elements in the descriptor set binding specified by `srcBinding`, and all applicable consecutive bindings, as described by `consecutive binding updates`

- **VUID-VkCopyDescriptorSet-dstBinding-00347**
  `dstBinding` must be a valid binding within `dstSet`

- **VUID-VkCopyDescriptorSet-dstArrayElement-00348**
  The sum of `dstArrayElement` and `descriptorCount` must be less than or equal to the number of array elements in the descriptor set binding specified by `dstBinding`, and all applicable consecutive bindings, as described by `consecutive binding updates`

- **VUID-VkCopyDescriptorSet-dstBinding-02632**
  The type of `dstBinding` within `dstSet` must be equal to the type of `srcBinding` within `srcSet`

- **VUID-VkCopyDescriptorSet-srcSet-00349**
  If `srcSet` is equal to `dstSet`, then the source and destination ranges of descriptors must not overlap, where the ranges may include array elements from consecutive bindings as described by `consecutive binding updates`

- **VUID-VkCopyDescriptorSet-srcBinding-02223**
  If the descriptor type of the descriptor set binding specified by `srcBinding` is `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK`, `srcArrayElement` must be an integer multiple of 4

- **VUID-VkCopyDescriptorSet-dstBinding-02224**
  If the descriptor type of the descriptor set binding specified by `dstBinding` is `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK`, `dstArrayElement` must be an integer multiple of 4

- **VUID-VkCopyDescriptorSet-srcBinding-02225**
  If the descriptor type of the descriptor set binding specified by either `srcBinding` or `dstBinding` is `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK`, `descriptorCount` must be an
integer multiple of 4

- **VUID-VkCopyDescriptorSet-srcSet-01918**
  If srcSet’s layout was created with the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` flag set, then dstSet’s layout must also have been created with the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` flag set.

- **VUID-VkCopyDescriptorSet-srcSet-04885**
  If srcSet’s layout was created with neither `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` nor `VK_DESCRIPTOR_SET_LAYOUT_CREATE_HOST_ONLY_POOL_BIT_EXT` flags set, then dstSet’s layout must have been created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` flag set.

- **VUID-VkCopyDescriptorSet-srcSet-01920**
  If the descriptor pool from which srcSet was allocated was created with the `VK_DESCRIPTOR_POOL_CREATE_UPDATE_AFTER_BIND_BIT` flag set, then the descriptor pool from which dstSet was allocated must also have been created with the `VK_DESCRIPTOR_POOL_CREATE_UPDATE_AFTER_BIND_BIT` flag set.

- **VUID-VkCopyDescriptorSet-srcSet-04887**
  If the descriptor pool from which srcSet was allocated was created with neither `VK_DESCRIPTOR_POOL_CREATE_UPDATE_AFTER_BIND_BIT` nor `VK_DESCRIPTOR_POOL_CREATE_HOST_ONLY_BIT_EXT` flags set, then the descriptor pool from which dstSet was allocated must have been created without the `VK_DESCRIPTOR_POOL_CREATE_UPDATE_AFTER_BIND_BIT` flag set.

- **VUID-VkCopyDescriptorSet-dstBinding-02753**
  If the descriptor type of the descriptor set binding specified by dstBinding is `VK_DESCRIPTOR_TYPE_SAMPLER`, then dstSet must not have been allocated with a layout that included immutable samplers for dstBinding.

- **VUID-VkCopyDescriptorSet-dstSet-04612**
  If VkDescriptorSetLayoutBinding for dstSet at dstBinding is `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`, the new active descriptor type must exist in the corresponding pMutableDescriptorTypeLists list for dstBinding if the new active descriptor type is not `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`.

- **VUID-VkCopyDescriptorSet-srcSet-04613**
  If VkDescriptorSetLayoutBinding for srcSet at srcBinding is `VK_DESCRIPTOR_TYPE_MUTABLE_EXT` and the VkDescriptorSetLayoutBinding for dstSet at dstBinding is not `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`, the active descriptor type for the source descriptor must match the descriptor type of dstBinding.

- **VUID-VkCopyDescriptorSet-dstSet-04614**
  If VkDescriptorSetLayoutBinding for dstSet at dstBinding is `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`, and the new active descriptor type is `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`, the pMutableDescriptorTypeLists for srcBinding and dstBinding must match exactly.
14.2.5. Descriptor Update Templates

A descriptor update template specifies a mapping from descriptor update information in host memory to descriptors in a descriptor set. It is designed to avoid passing redundant information to the driver when frequently updating the same set of descriptors in descriptor sets.

Descriptor update template objects are represented by `VkDescriptorUpdateTemplate` handles:

```c
// Provided by VK_VERSION_1_1
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkDescriptorUpdateTemplate)
```

or the equivalent

```c
// Provided by VK_KHR_descriptor_update_template
typedef VkDescriptorUpdateTemplate VkDescriptorUpdateTemplateKHR;
```

14.2.6. Descriptor Set Updates with Templates

Updating a large `VkDescriptorSet` array can be an expensive operation since an application must specify one `VkWriteDescriptorSet` structure for each descriptor or descriptor array to update, each of which re-specifies the same state when updating the same descriptor in multiple descriptor sets. For cases when an application wishes to update the same set of descriptors in multiple descriptor sets allocated using the same `VkDescriptorSetLayout`, `vkUpdateDescriptorSetWithTemplate` can be used as a replacement for `vkUpdateDescriptorSets`.

`VkDescriptorUpdateTemplate` allows implementations to convert a set of descriptor update operations on a single descriptor set to an internal format that, in conjunction with `vkUpdateDescriptorSetWithTemplate` or `vkCmdPushDescriptorSetWithTemplateKHR`, can be more efficient compared to calling `vkUpdateDescriptorSets` or `vkCmdPushDescriptorSetKHR`. The descriptors themselves are not specified in the `VkDescriptorUpdateTemplate`, rather, offsets into an
application provided pointer to host memory are specified, which are combined with a pointer passed to `vkUpdateDescriptorSetWithTemplate` or `vkCmdPushDescriptorSetWithTemplateKHR`. This allows large batches of updates to be executed without having to convert application data structures into a strictly-defined Vulkan data structure.

To create a descriptor update template, call:

```c
// Provided by VK_VERSION_1_1
VkResult vkCreateDescriptorUpdateTemplate(
    VkDevice device,
    const VkDescriptorUpdateTemplateCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkDescriptorUpdateTemplate* pDescriptorUpdateTemplate);
```

or the equivalent command

```c
// Provided by VK_KHR_descriptor_update_template
VkResult vkCreateDescriptorUpdateTemplateKHR(
    VkDevice device,
    const VkDescriptorUpdateTemplateCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkDescriptorUpdateTemplate* pDescriptorUpdateTemplate);
```

- `device` is the logical device that creates the descriptor update template.
- `pCreateInfo` is a pointer to a `VkDescriptorUpdateTemplateCreateInfo` structure specifying the set of descriptors to update with a single call to `vkCmdPushDescriptorSetWithTemplateKHR` or `vkUpdateDescriptorSetWithTemplate`.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pDescriptorUpdateTemplate` is a pointer to a `VkDescriptorUpdateTemplate` handle in which the resulting descriptor update template object is returned.

### Valid Usage (Implicit)

- VUID-vkCreateDescriptorUpdateTemplate-device-parameter
  - `device` must be a valid `VkDevice` handle

- VUID-vkCreateDescriptorUpdateTemplate-pCreateInfo-parameter
  - `pCreateInfo` must be a valid pointer to a valid `VkDescriptorUpdateTemplateCreateInfo` structure

- VUID-vkCreateDescriptorUpdateTemplate-pAllocator-parameter
  - If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

- VUID-vkCreateDescriptorUpdateTemplate-pDescriptorUpdateTemplate-parameter
  - `pDescriptorUpdateTemplate` must be a valid pointer to a `VkDescriptorUpdateTemplate` handle
Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The `VkDescriptorUpdateTemplateCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkDescriptorUpdateTemplateCreateInfo
{
    VkStructureType sType;
    const void* pNext;
    VkDescriptorUpdateTemplateCreateFlags flags;
    uint32_t descriptorUpdateEntryCount;
    const VkDescriptorUpdateTemplateEntry* pDescriptorUpdateEntries;
    VkDescriptorUpdateTemplateType templateType;
    VkDescriptorSetLayout descriptorSetLayout;
    VkPipelineBindPoint pipelineBindPoint;
    VkPipelineLayout pipelineLayout;
    uint32_t set;
} VkDescriptorUpdateTemplateCreateInfo;
```

or the equivalent

```c
// Provided by VK_KHR_descriptor_update_template
typedef VkDescriptorUpdateTemplateCreateInfo VkDescriptorUpdateTemplateCreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is reserved for future use.
- `descriptorUpdateEntryCount` is the number of elements in the `pDescriptorUpdateEntries` array.
- `pDescriptorUpdateEntries` is a pointer to an array of `VkDescriptorUpdateTemplateEntry` structures describing the descriptors to be updated by the descriptor update template.
- `templateType` specifies the type of the descriptor update template. If set to `VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_DESCRIPTOR_SET` it can only be used to update descriptor sets with a fixed `descriptorSetLayout`. If set to `VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_PUSH_DESCRIPTORS_KHR` it can only be used to push descriptor sets using the provided `pipelineBindPoint`, `pipelineLayout`, and `set` number.
- `descriptorSetLayout` is the descriptor set layout used to build the descriptor update template. All descriptor sets which are going to be updated through the newly created descriptor update
template **must** be created with a layout that matches (is the same as, or defined identically to) this layout. This parameter is ignored if `templateType` is not `VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_DESCRIPTOR_SET`.

- **pipelineBindPoint** is a `VkPipelineBindPoint` indicating the type of the pipeline that will use the descriptors. This parameter is ignored if `templateType` is not `VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_PUSH_DESCRIPTORS_KHR`.
- **pipelineLayout** is a `VkPipelineLayout` object used to program the bindings. This parameter is ignored if `templateType` is not `VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_PUSH_DESCRIPTORS_KHR`.
- **set** is the set number of the descriptor set in the pipeline layout that will be updated. This parameter is ignored if `templateType` is not `VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_PUSH_DESCRIPTORS_KHR`.

### Valid Usage

- **VUID-VkDescriptorUpdateTemplateCreateInfo-templateType-00350**
  If `templateType` is `VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_DESCRIPTOR_SET`, `descriptorSetLayout` must be a valid `VkDescriptorSetLayout` handle.

- **VUID-VkDescriptorUpdateTemplateCreateInfo-templateType-00351**
  If `templateType` is `VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_PUSH_DESCRIPTORS_KHR`, `pipelineBindPoint` must be a valid `VkPipelineBindPoint` value.

- **VUID-VkDescriptorUpdateTemplateCreateInfo-templateType-00352**
  If `templateType` is `VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_PUSH_DESCRIPTORS_KHR`, `pipelineLayout` must be a valid `VkPipelineLayout` handle.

- **VUID-VkDescriptorUpdateTemplateCreateInfo-templateType-00353**
  If `templateType` is `VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_PUSH_DESCRIPTORS_KHR`, `set` must be the unique set number in the pipeline layout that uses a descriptor set layout that was created with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_PUSH_DESCRIPTOR_BIT_KHR`.

- **VUID-VkDescriptorUpdateTemplateCreateInfo-templateType-04615**
  If `templateType` is `VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_DESCRIPTOR_SET`, `descriptorSetLayout` must not contain a binding with type `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`.

### Valid Usage (Implicit)

- **VUID-VkDescriptorUpdateTemplateCreateInfo-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_CREATE_INFO`.

- **VUID-VkDescriptorUpdateTemplateCreateInfo-pNext-pNext**
  `pNext` must be `NULL`.

- **VUID-VkDescriptorUpdateTemplateCreateInfo-flags-zerobitmask**
  `flags` must be `0`.

- **VUID-VkDescriptorUpdateTemplateCreateInfo-pDescriptorUpdateEntries-parameter**
  `pDescriptorUpdateEntries` must be a valid pointer to an array of `descriptorUpdateEntryCount` valid `VkDescriptorUpdateTemplateEntry` structures.
• VUID-VkDescriptorUpdateTemplateCreateInfo-templateType-parameter
templateType must be a valid VkDescriptorUpdateTemplateType value

• VUID-VkDescriptorUpdateTemplateCreateInfo-descriptorUpdateEntryCount-arraylength
descriptorUpdateEntryCount must be greater than 0

• VUID-VkDescriptorUpdateTemplateCreateInfo-commonparent
Both of descriptorSetLayout, and pipelineLayout that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice

```c
// Provided by VK_VERSION_1_1
typedef VkFlags VkDescriptorUpdateTemplateCreateFlags;
```

or the equivalent

```c
// Provided by VK_KHR_descriptor_update_template
typedef VkDescriptorUpdateTemplateCreateFlags VkDescriptorUpdateTemplateCreateFlagsKHR;
```

VkDescriptorUpdateTemplateCreateFlags is a bitmask type for setting a mask, but is currently reserved for future use.

The descriptor update template type is determined by the VkDescriptorUpdateTemplateCreateInfo ::templateType property, which takes the following values:

```c
// Provided by VK_VERSION_1_1
typedef enum VkDescriptorUpdateTemplateType {
    VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_DESCRIPTOR_SET = 0,
    // Provided by VK_VERSION_1_1 with VK_KHR_push_descriptor,
    // VK_KHR_descriptor_update_template with VK_KHR_push_descriptor
    VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_PUSH_DESCRIPTORS_KHR = 1,
    // Provided by VK_KHR_descriptor_update_template
    VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_DESCRIPTOR_SET_KHR =
    VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_DESCRIPTOR_SET,
} VkDescriptorUpdateTemplateType;
```

or the equivalent

```c
// Provided by VK_KHR_descriptor_update_template
typedef VkDescriptorUpdateTemplateType VkDescriptorUpdateTemplateTypeKHR;
```

• VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_DESCRIPTOR_SET specifies that the descriptor update template will be used for descriptor set updates only.

• VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_PUSH_DESCRIPTORS_KHR specifies that the descriptor update template will be used for push descriptor updates only.
The `VkDescriptorUpdateTemplateEntry` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkDescriptorUpdateTemplateEntry {
    uint32_t dstBinding;
    uint32_t dstArrayElement;
    uint32_t descriptorCount;
    VkDescriptorType descriptorType;
    size_t offset;
    size_t stride;
} VkDescriptorUpdateTemplateEntry;
```

or the equivalent

```c
// Provided by VK_KHR_descriptor_update_template
typedef VkDescriptorUpdateTemplateEntry VkDescriptorUpdateTemplateEntryKHR;
```

- **dstBinding** is the descriptor binding to update when using this descriptor update template.
- **dstArrayElement** is the starting element in the array belonging to **dstBinding**. If the descriptor binding identified by **dstBinding** has a descriptor type of `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK` then **dstArrayElement** specifies the starting byte offset to update.
- **descriptorCount** is the number of descriptors to update. If **descriptorCount** is greater than the number of remaining array elements in the destination binding, those affect consecutive bindings in a manner similar to `VkWriteDescriptorSet` above. If the descriptor binding identified by **dstBinding** has a descriptor type of `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK` then **descriptorCount** specifies the number of bytes to update and the remaining array elements in the destination binding refer to the remaining number of bytes in it.
- **descriptorType** is a `VkDescriptorType` specifying the type of the descriptor.
- **offset** is the offset in bytes of the first binding in the raw data structure.
- **stride** is the stride in bytes between two consecutive array elements of the descriptor update information in the raw data structure. The actual pointer `ptr` for each array element `j` of update entry `i` is computed using the following formula:

```c
const char *ptr = (const char *)pData + pDescriptorUpdateEntries[i].offset + j * pDescriptorUpdateEntries[i].stride
```

The stride is useful in case the bindings are stored in structs along with other data. If **descriptorType** is `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK` then the value of **stride** is ignored and the stride is assumed to be 1, i.e. the descriptor update information for them is always specified as a contiguous range.
Valid Usage

- VUID-VkDescriptorUpdateTemplateEntry-dstBinding-00354
  
  `dstBinding` **must** be a valid binding in the descriptor set layout implicitly specified when using a descriptor update template to update descriptors.

- VUID-VkDescriptorUpdateTemplateEntry-dstArrayElement-00355
  
  `dstArrayElement` and `descriptorCount` **must** be less than or equal to the number of array elements in the descriptor set binding implicitly specified when using a descriptor update template to update descriptors, and all applicable consecutive bindings, as described by consecutive binding updates.

- VUID-VkDescriptorUpdateTemplateEntry-descriptor-02226
  
  If `descriptor` type is `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK`, `dstArrayElement` **must** be an integer multiple of 4.

- VUID-VkDescriptorUpdateTemplateEntry-descriptor-02227
  
  If `descriptor` type is `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK`, `descriptorCount` **must** be an integer multiple of 4.

Valid Usage (Implicit)

- VUID-VkDescriptorUpdateTemplateEntry-descriptorType-parameter
  
  `descriptorType` **must** be a valid `VkDescriptorType` value.

To destroy a descriptor update template, call:

```c
// Provided by VK_VERSION_1_1
void vkDestroyDescriptorUpdateTemplate(
    VkDevice device,
    VkDescriptorUpdateTemplate descriptorUpdateTemplate,
    const VkAllocationCallbacks* pAllocator);
```

or the equivalent command:

```c
// Provided by VK_KHR_descriptor_update_template
void vkDestroyDescriptorUpdateTemplateKHR(
    VkDevice device,
    VkDescriptorUpdateTemplate descriptorUpdateTemplate,
    const VkAllocationCallbacks* pAllocator);
```

- `device` is the logical device that has been used to create the descriptor update template.
- `descriptorUpdateTemplate` is the descriptor update template to destroy.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
Valid Usage

- VUID-vkDestroyDescriptorUpdateTemplate-descriptorSetLayout-00356
  If `VkAllocationCallbacks` were provided when `descriptorUpdateTemplate` was created, a compatible set of callbacks **must** be provided here.

- VUID-vkDestroyDescriptorUpdateTemplate-descriptorSetLayout-00357
  If no `VkAllocationCallbacks` were provided when `descriptorUpdateTemplate` was created, `pAllocator` **must** be `NULL`.

Valid Usage (Implicit)

- VUID-vkDestroyDescriptorUpdateTemplate-device-parameter
  `device` **must** be a valid `VkDevice` handle.

- VUID-vkDestroyDescriptorUpdateTemplate-descriptorUpdateTemplate-parameter
  If `descriptorUpdateTemplate` is not `VK_NULL_HANDLE`, `descriptorUpdateTemplate` **must** be a valid `VkDescriptorUpdateTemplate` handle.

- VUID-vkDestroyDescriptorUpdateTemplate-pAllocator-parameter
  If `pAllocator` is not `NULL`, `pAllocator` **must** be a valid pointer to a valid `VkAllocationCallbacks` structure.

- VUID-vkDestroyDescriptorUpdateTemplate-descriptorUpdateTemplate-parent
  If `descriptorUpdateTemplate` is a valid handle, it **must** have been created, allocated, or retrieved from `device`.

Host Synchronization

- Host access to `descriptorUpdateTemplate` **must** be externally synchronized.

Once a `VkDescriptorUpdateTemplate` has been created, descriptor sets **can** be updated by calling:

```c
// Provided by VK_VERSION_1_1
void vkUpdateDescriptorSetWithTemplate(
    VkDevice device,
    VkDescriptorSet descriptorSet,
    VkDescriptorUpdateTemplate descriptorUpdateTemplate,
    const void* pData);
```

or the equivalent command

```c
// Provided by VK_KHR_descriptor_update_template
void vkUpdateDescriptorSetWithTemplateKHR(
    VkDevice device,
    VkDescriptorSet descriptorSet,
    `...`
);```

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VkDescriptorUpdateTemplate descriptorUpdateTemplate,
const void* pData);

- `device` is the logical device that updates the descriptor set.
- `descriptorSet` is the descriptor set to update
- `descriptorUpdateTemplate` is a `VkDescriptorUpdateTemplate` object specifying the update mapping between `pData` and the descriptor set to update.
- `pData` is a pointer to memory containing one or more `VkDescriptorImageInfo`, `VkDescriptorBufferInfo`, or `VkBufferView` structures or `VkAccelerationStructureKHR` or `VkAccelerationStructureNV` handles used to write the descriptors.

**Valid Usage**

- VUID-vkUpdateDescriptorSetWithTemplate-pData-01685
  `pData` must be a valid pointer to a memory containing one or more valid instances of `VkDescriptorImageInfo`, `VkDescriptorBufferInfo`, or `VkBufferView` in a layout defined by `descriptorUpdateTemplate` when it was created with `vkCreateDescriptorUpdateTemplate`

- VUID-vkUpdateDescriptorSetWithTemplate-descriptorSet-06995
  Host access to `descriptorSet` must be externally synchronized unless explicitly denoted otherwise for specific flags

**Valid Usage (Implicit)**

- VUID-vkUpdateDescriptorSetWithTemplate-device-parameter
  `device` must be a valid `VkDevice` handle

- VUID-vkUpdateDescriptorSetWithTemplate-descriptorSet-parameter
  `descriptorSet` must be a valid `VkDescriptorSet` handle

- VUID-vkUpdateDescriptorSetWithTemplate-descriptorUpdateTemplate-parameter
  `descriptorUpdateTemplate` must be a valid `VkDescriptorUpdateTemplate` handle

- VUID-vkUpdateDescriptorSetWithTemplate-descriptorSet-parent
  `descriptorSet` must have been created, allocated, or retrieved from `device`

- VUID-vkUpdateDescriptorSetWithTemplate-descriptorUpdateTemplate-parent
  `descriptorUpdateTemplate` must have been created, allocated, or retrieved from `device`

**API example**

```c
struct AppBufferView {
    VkBufferView bufferView;
    uint32_t applicationRelatedInformation;
};

struct AppDataStructure {
```
VkDescriptorImageInfo imageInfo; // a single image info
VkDescriptorBufferInfo bufferInfoArray[3]; // 3 buffer infos in an array
AppBufferView bufferView[2]; // An application defined structure

// ... some more application related data
};

const VkDescriptorUpdateTemplateEntry descriptorUpdateTemplateEntries[] =
{
    // binding to a single image descriptor
    {
        .binding = 0,
        .dstArrayElement = 0,
        .descriptorCount = 1,
        .descriptorType = VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER,
        .offset = offsetof(AppDataStructure, imageInfo),
        .stride = 0, // stride not required if descriptorCount is 1
    },

    // binding to an array of buffer descriptors
    {
        .binding = 1,
        .dstArrayElement = 0,
        .descriptorCount = 3,
        .descriptorType = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER,
        .offset = offsetof(AppDataStructure, bufferInfoArray),
        .stride = sizeof(VkDescriptorBufferInfo) // descriptor buffer infos are compact
    },

    // binding to an array of buffer views
    {
        .binding = 2,
        .dstArrayElement = 0,
        .descriptorCount = 2,
        .descriptorType = VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER,
        .offset = offsetof(AppDataStructure, bufferView) +
                  offsetof(AppBufferView, bufferView),
        .stride = sizeof(AppBufferView) // bufferViews do not have to be compact
    },
};

// create a descriptor update template for descriptor set updates
const VkDescriptorUpdateTemplateCreateInfo createInfo =
{
    .sType = VK_STRUCTURE_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_CREATE_INFO,
    .pNext = NULL,
    .flags = 0,
    .descriptorUpdateEntryCount = 3,
    .pDescriptorUpdateEntries = descriptorUpdateTemplateEntries,
\[
\text{.templateType} = \text{VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_DESCRIPTOR_SET},
\text{.descriptorSetLayout} = \text{myLayout},
\text{.pipelineBindPoint} = 0, \quad \text{// ignored by given templateType}
\text{.pipelineLayout} = 0, \quad \text{// ignored by given templateType}
\text{.set} = 0, \quad \text{// ignored by given templateType}
\}\]

\[
\text{VkDescriptorUpdateTemplate} \ \text{myDescriptorUpdateTemplate};
\text{myResult} = \text{vkCreateDescriptorUpdateTemplate}(
\text{myDevice},
\text{&createInfo},
\text{NULL},
\text{&myDescriptorUpdateTemplate});
\]

\[
\text{AppDataStructure} \ \text{appData};
\]

\[
\text{// fill appData here or cache it in your engine}
\text{vkUpdateDescriptorSetWithTemplate}(
\text{myDevice},
\text{myDescriptorSet},
\text{myDescriptorUpdateTemplate}, \text{&appData});
\]

### 14.2.7. Descriptor Set Binding

To bind one or more descriptor sets to a command buffer, call:

```c
// Provided by VK_VERSION_1_0
void \text{vkCmdBindDescriptorSets}(\text{VkCommandBuffer} \text{commandBuffer},
\text{VkPipelineBindPoint} \text{pipelineBindPoint},
\text{VkPipelineLayout} \text{layout},
\text{uint32_t} \text{firstSet},
\text{uint32_t} \text{descriptorSetCount},
\text{const} \text{VkDescriptorSet}* \text{pDescriptorSets},
\text{uint32_t} \text{dynamicOffsetCount},
\text{const} \text{uint32_t}* \text{pDynamicOffsets});
```

- \text{commandBuffer} is the command buffer that the descriptor sets will be bound to.
- \text{pipelineBindPoint} is a \text{VkPipelineBindPoint} indicating the type of the pipeline that will use the descriptors. There is a separate set of bind points for each pipeline type, so binding one does not disturb the others.
- \text{layout} is a \text{VkPipelineLayout} object used to program the bindings.
- \text{firstSet} is the set number of the first descriptor set to be bound.
- \text{descriptorSetCount} is the number of elements in the \text{pDescriptorSets} array.
- \text{pDescriptorSets} is a pointer to an array of handles to \text{VkDescriptorSet} objects describing the descriptor sets to bind to.
- \text{dynamicOffsetCount} is the number of dynamic offsets in the \text{pDynamicOffsets} array.
• `pDynamicOffsets` is a pointer to an array of `uint32_t` values specifying dynamic offsets.

`vkCmdBindDescriptorSets` binds descriptor sets `pDescriptorSets[0..descriptorSetCount-1]` to set numbers `[firstSet..firstSet+descriptorSetCount-1]` for subsequent bound pipeline commands set by `pipelineBindPoint`. Any bindings that were previously applied via these sets, or calls to `vkCmdSetDescriptorBufferOffsetsEXT` or `vkCmdBindDescriptorBufferEmbeddedSamplersEXT`, are no longer valid.

Once bound, a descriptor set affects rendering of subsequent commands that interact with the given pipeline type in the command buffer until either a different set is bound to the same set number, or the set is disturbed as described in Pipeline Layout Compatibility.

A compatible descriptor set must be bound for all set numbers that any shaders in a pipeline access, at the time that a drawing or dispatching command is recorded to execute using that pipeline. However, if none of the shaders in a pipeline statically use any bindings with a particular set number, then no descriptor set need be bound for that set number, even if the pipeline layout includes a non-trivial descriptor set layout for that set number.

When consuming a descriptor, a descriptor is considered valid if the descriptor is not undefined as described by descriptor set allocation. If the `nullDescriptor` feature is enabled, a null descriptor is also considered valid. A descriptor that was disturbed by Pipeline Layout Compatibility, or was never bound by `vkCmdBindDescriptorSets` is not considered valid. If a pipeline accesses a descriptor either statically or dynamically depending on the `VkDescriptorBindingFlagBits`, the consuming descriptor type in the pipeline must match the `VkDescriptorType` in `VkDescriptorSetLayoutCreateInfo` for the descriptor to be considered valid. If a descriptor is a mutable descriptor, the consuming descriptor type in the pipeline must match the active descriptor type for the descriptor to be considered valid.

**Note**

Further validation may be carried out beyond validation for descriptor types, e.g. Texel Input Validation.

If any of the sets being bound include dynamic uniform or storage buffers, then `pDynamicOffsets` includes one element for each array element in each dynamic descriptor type binding in each set. Values are taken from `pDynamicOffsets` in an order such that all entries for set N come before set N+1; within a set, entries are ordered by the binding numbers in the descriptor set layouts; and within a binding array, elements are in order. `dynamicOffsetCount` must equal the total number of dynamic descriptors in the sets being bound.

The effective offset used for dynamic uniform and storage buffer bindings is the sum of the relative offset taken from `pDynamicOffsets`, and the base address of the buffer plus base offset in the descriptor set. The range of the dynamic uniform and storage buffer bindings is the buffer range as specified in the descriptor set.

Each of the `pDescriptorSets` must be compatible with the pipeline layout specified by `layout`. The layout used to program the bindings must also be compatible with the pipeline used in subsequent bound pipeline commands with that pipeline type, as defined in the Pipeline Layout Compatibility section.
The descriptor set contents bound by a call to `vkCmdBindDescriptorSets` may be consumed at the following times:

- For descriptor bindings created with the `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT` bit set, the contents may be consumed when the command buffer is submitted to a queue, or during shader execution of the resulting draws and dispatches, or any time in between. Otherwise,
- during host execution of the command, or during shader execution of the resulting draws and dispatches, or any time in between.

Thus, the contents of a descriptor set binding must not be altered (overwritten by an update command, or freed) between the first point in time that it may be consumed, and when the command completes executing on the queue.

The contents of `pDynamicOffsets` are consumed immediately during execution of `vkCmdBindDescriptorSets`. Once all pending uses have completed, it is legal to update and reuse a descriptor set.

### Valid Usage

- **VUID-vkCmdBindDescriptorSets-pDescriptorSets-00358**
  Each element of `pDescriptorSets` must have been allocated with a `VkDescriptorSetLayout` that matches (is the same as, or identically defined as) the `VkDescriptorSetLayout` at set `n` in `layout`, where `n` is the sum of `firstSet` and the index into `pDescriptorSets`

- **VUID-vkCmdBindDescriptorSets-dynamicOffsetCount-00359**
  `dynamicOffsetCount` must be equal to the total number of dynamic descriptors in `pDescriptorSets`

- **VUID-vkCmdBindDescriptorSets-firstSet-00360**
  The sum of `firstSet` and `descriptorSetCount` must be less than or equal to `VkPipelineLayoutCreateInfo::setLayoutCount` provided when `layout` was created

- **VUID-vkCmdBindDescriptorSets-pipelineBindPoint-00361**
  `pipelineBindPoint` must be supported by the `commandBuffer`'s parent `VkCommandPool`'s queue family

- **VUID-vkCmdBindDescriptorSets-pDynamicOffsets-01971**
  Each element of `pDynamicOffsets` which corresponds to a descriptor binding with type `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC` must be a multiple of `VkPhysicalDeviceLimits::minUniformBufferOffsetAlignment`

- **VUID-vkCmdBindDescriptorSets-pDynamicOffsets-01972**
  Each element of `pDynamicOffsets` which corresponds to a descriptor binding with type `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC` must be a multiple of `VkPhysicalDeviceLimits::minStorageBufferOffsetAlignment`

- **VUID-vkCmdBindDescriptorSets-pDescriptorSets-01979**
  For each dynamic uniform or storage buffer binding in `pDescriptorSets`, the sum of the effective offset and the range of the binding must be less than or equal to the size of the buffer

- **VUID-vkCmdBindDescriptorSets-pDescriptorSets-06715**
For each dynamic uniform or storage buffer binding in pDescriptorSets, if the range was set with VK_WHOLE_SIZE then pDynamicOffsets which corresponds to the descriptor binding must be 0

- VUID-vkCmdBindDescriptorSets-pDescriptorSets-04616
  Each element of pDescriptorSets must not have been allocated from a VkDescriptorPool with the VK_DESCRIPTOR_POOL_CREATE_HOST_ONLY_BIT_EXT flag set

- VUID-vkCmdBindDescriptorSets-graphicsPipelineLibrary-06754
  If graphicsPipelineLibrary is not enabled, each element of pDescriptorSets must be a valid VkDescriptorSet

- VUID-vkCmdBindDescriptorSets-pDescriptorSets-08010
  Each element of pDescriptorSets must have been allocated with a VkDescriptorSetLayout which was not created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

### Valid Usage (Implicit)

- VUID-vkCmdBindDescriptorSets-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdBindDescriptorSets-pipelineBindPoint-parameter
  pipelineBindPoint must be a valid VkPipelineBindPoint value

- VUID-vkCmdBindDescriptorSets-layout-parameter
  layout must be a valid VkPipelineLayout handle

- VUID-vkCmdBindDescriptorSets-pDescriptorSets-parameter
  pDescriptorSets must be a valid pointer to an array of descriptorSetCount valid or VK_NULL_HANDLE VkDescriptorSet handles

- VUID-vkCmdBindDescriptorSets-pDynamicOffsets-parameter
  If dynamicOffsetCount is not 0, pDynamicOffsets must be a valid pointer to an array of uint32_t values

- VUID-vkCmdBindDescriptorSets-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdBindDescriptorSets-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics, or compute operations

- VUID-vkCmdBindDescriptorSets-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdBindDescriptorSets-descriptorSetCount-arraylength
  descriptorSetCount must be greater than 0

- VUID-vkCmdBindDescriptorSets-commonparent
  Each of commandBuffer, layout, and the elements of pDescriptorSets that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

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14.2.8. Push Descriptor Updates

In addition to allocating descriptor sets and binding them to a command buffer, an application can record descriptor updates into the command buffer.

To push descriptor updates into a command buffer, call:

```c
void vkCmdPushDescriptorSetKHR(
    VkCommandBuffer commandBuffer,
    VkPipelineBindPoint pipelineBindPoint,
    VkPipelineLayout layout,
    uint32_t set,
    uint32_t descriptorWriteCount,
    const VkWriteDescriptorSet* pDescriptorWrites);
```

- `commandBuffer` is the command buffer that the descriptors will be recorded in.
- `pipelineBindPoint` is a `VkPipelineBindPoint` indicating the type of the pipeline that will use the descriptors. There is a separate set of push descriptor bindings for each pipeline type, so binding one does not disturb the others.
- `layout` is a `VkPipelineLayout` object used to program the bindings.
- `set` is the set number of the descriptor set in the pipeline layout that will be updated.
- `descriptorWriteCount` is the number of elements in the `pDescriptorWrites` array.
- `pDescriptorWrites` is a pointer to an array of `VkWriteDescriptorSet` structures describing the descriptors to be updated.

*Push descriptors* are a small bank of descriptors whose storage is internally managed by the command buffer rather than being written into a descriptor set and later bound to a command buffer. Push descriptors allow for incremental updates of descriptors without managing the
lifetime of descriptor sets.

When a command buffer begins recording, all push descriptors are undefined. Push descriptors can be updated incrementally and cause shaders to use the updated descriptors for subsequent bound pipeline commands with the pipeline type set by pipelineBindPoint until the descriptor is overwritten, or else until the set is disturbed as described in Pipeline Layout Compatibility. When the set is disturbed or push descriptors with a different descriptor set layout are set, all push descriptors are undefined.

Push descriptors that are statically used by a pipeline must not be undefined at the time that a drawing or dispatching command is recorded to execute using that pipeline. This includes immutable sampler descriptors, which must be pushed before they are accessed by a pipeline (the immutable samplers are pushed, rather than the samplers in pDescriptorWrites). Push descriptors that are not statically used can remain undefined.

Push descriptors do not use dynamic offsets. Instead, the corresponding non-dynamic descriptor types can be used and the offset member of VkDescriptorBufferInfo can be changed each time the descriptor is written.

Each element of pDescriptorWrites is interpreted as in VkWriteDescriptorSet, except the dstSet member is ignored.

To push an immutable sampler, use a VkWriteDescriptorSet with dstBinding and dstArrayElement selecting the immutable sampler's binding. If the descriptor type is VK_DESCRIPTOR_TYPE_SAMPLER, the pImageInfo parameter is ignored and the immutable sampler is taken from the push descriptor set layout in the pipeline layout. If the descriptor type is VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER, the sampler member of the pImageInfo parameter is ignored and the immutable sampler is taken from the push descriptor set layout in the pipeline layout.

Valid Usage

- VUID-vkCmdPushDescriptorSetKHR-pipelineBindPoint-00363
  pipelineBindPoint must be supported by the commandBuffer's parent VkCommandPool's queue family

- VUID-vkCmdPushDescriptorSetKHR-set-00364
  set must be less than VkPipelineLayoutCreateInfo::setLayoutCount provided when layout was created

- VUID-vkCmdPushDescriptorSetKHR-set-00365
  set must be the unique set number in the pipeline layout that uses a descriptor set layout that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_PUSH_DESCRIPTOR_BIT_KHR

- VUID-vkCmdPushDescriptorSetKHR-pDescriptorWrites-06494
  For each element i where pDescriptorWrites[i].descriptorType is VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE, VK_DESCRIPTOR_TYPE_STORAGE_IMAGE, or VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT, pDescriptorWrites[i].pImageInfo must be a valid pointer to an array of pDescriptorWrites[i].descriptorCount valid VkDescriptorImageInfo structures
Valid Usage (Implicit)

- VUID-vkCmdPushDescriptorSetKHR-commandBuffer-parameter: commandBuffer must be a valid VkCommandBuffer handle
- VUID-vkCmdPushDescriptorSetKHR-pipelineBindPoint-parameter: pipelineBindPoint must be a valid VkPipelineBindPoint value
- VUID-vkCmdPushDescriptorSetKHR-layout-parameter: layout must be a valid VkPipelineLayout handle
- VUID-vkCmdPushDescriptorSetKHR-pDescriptorWrites-parameter: pDescriptorWrites must be a valid pointer to an array of descriptorWriteCount valid VkWriteDescriptorSet structures
- VUID-vkCmdPushDescriptorSetKHR-commandBuffer-recording: commandBuffer must be in the recording state
- VUID-vkCmdPushDescriptorSetKHR-commandBuffer-cmdpool: The VkCommandPool that commandBuffer was allocated from must support graphics, or compute operations
- VUID-vkCmdPushDescriptorSetKHR-videocoding: This command must only be called outside of a video coding scope
- VUID-vkCmdPushDescriptorSetKHR-descriptorWriteCount-arraylength: descriptorWriteCount must be greater than 0
- VUID-vkCmdPushDescriptorSetKHR-commonparent: Both of commandBuffer, and layout must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
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<tr>
<td>Primary</td>
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<td>Outside</td>
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<td>State</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td>Compute</td>
<td></td>
</tr>
</tbody>
</table>

14.2.9. Push Descriptor Updates with Descriptor Update Templates

It is also possible to use a descriptor update template to specify the push descriptors to update. To
do so, call:

```c
// Provided by VK_VERSION_1_1 with VK_KHR_push_descriptor,
// VK_KHR_descriptor_update_template with VK_KHR_push_descriptor
void vkCmdPushDescriptorSetWithTemplateKHR(
    VkCommandBuffer commandBuffer,
    VkDescriptorUpdateTemplate descriptorUpdateTemplate,
    VkPipelineLayout layout,
    uint32_t set,
    const void* pData);
```

- `commandBuffer` is the command buffer that the descriptors will be recorded in.
- `descriptorUpdateTemplate` is a descriptor update template defining how to interpret the descriptor information in `pData`.
- `layout` is a `VkPipelineLayout` object used to program the bindings. It **must** be compatible with the layout used to create the `descriptorUpdateTemplate` handle.
- `set` is the set number of the descriptor set in the pipeline layout that will be updated. This **must** be the same number used to create the `descriptorUpdateTemplate` handle.
- `pData` is a pointer to memory containing descriptors for the templated update.

### Valid Usage

- **VUID-vkCmdPushDescriptorSetWithTemplateKHR-commandBuffer-00366**
  The `pipelineBindPoint` specified during the creation of the descriptor update template **must** be supported by the `commandBuffer`'s parent `VkCommandPool`'s queue family

- **VUID-vkCmdPushDescriptorSetWithTemplateKHR-pData-01686**
  `pData` **must** be a valid pointer to a memory containing one or more valid instances of `VkDescriptorImageInfo`, `VkDescriptorBufferInfo`, or `VkBufferView` in a layout defined by `descriptorUpdateTemplate` when it was created with `vkCreateDescriptorUpdateTemplate`

- **VUID-vkCmdPushDescriptorSetWithTemplateKHR-layout-07993**
  `layout` **must** be compatible with the layout used to create `descriptorUpdateTemplate`

- **VUID-vkCmdPushDescriptorSetWithTemplateKHR-descriptorUpdateTemplate-07994**
  `descriptorUpdateTemplate` **must** have been created with a `templateType` of `VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_PUSH_DESCRIPTORS_KHR`

- **VUID-vkCmdPushDescriptorSetWithTemplateKHR-set-07995**
  `set` **must** be the same value used to create `descriptorUpdateTemplate`

- **VUID-vkCmdPushDescriptorSetWithTemplateKHR-set-07304**
  `set` **must** be less than `VkPipelineLayoutCreateInfo::setLayoutCount` provided when `layout` was created

- **VUID-vkCmdPushDescriptorSetWithTemplateKHR-set-07305**
  `set` **must** be the unique set number in the pipeline layout that uses a descriptor set layout that was created with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_PUSH_DESCRIPTOR_BIT_KHR`
Valid Usage (Implicit)

- **VUID-vkCmdPushDescriptorSetWithTemplateKHR-commandBuffer-parameter**
  
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- **VUID-vkCmdPushDescriptorSetWithTemplateKHR-descriptorUpdateTemplate-parameter**
  
  `descriptorUpdateTemplate` **must** be a valid `VkDescriptorUpdateTemplate` handle

- **VUID-vkCmdPushDescriptorSetWithTemplateKHR-layout-parameter**
  
  `layout` **must** be a valid `VkPipelineLayout` handle

- **VUID-vkCmdPushDescriptorSetWithTemplateKHR-commandBuffer-recording**
  
  `commandBuffer` **must** be in the recording state

- **VUID-vkCmdPushDescriptorSetWithTemplateKHR-commandBuffer-cmdpool**

  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics, or compute operations

- **VUID-vkCmdPushDescriptorSetWithTemplateKHR-videocoding**

  This command **must** only be called outside of a video coding scope

- **VUID-vkCmdPushDescriptorSetWithTemplateKHR-commonparent**

  Each of `commandBuffer`, `descriptorUpdateTemplate`, and `layout` **must** have been created, allocated, or retrieved from the same `VkDevice`

---

Host Synchronization

- Host access to `commandBuffer` **must** be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized

---

Command Properties

<table>
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<tr>
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<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

API example

```c
struct AppDataStructure
{
    VkDescriptorImageInfo imageInfo;  // a single image info
    // ... some more application related data
};

const VkDescriptorUpdateTemplateEntry descriptorUpdateTemplateEntries[] = {
```
// binding to a single image descriptor
{
  .binding = 0,
  .dstArrayElement = 0,
  .descriptorCount = 1,
  .descriptorType = VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER,
  .offset = offsetof(AppDataStructure, imageInfo),
  .stride = 0 // not required if descriptorCount is 1
};

// create a descriptor update template for push descriptor set updates
const VkDescriptorUpdateTemplateCreateInfo createInfo = {
  .sType = VK_STRUCTURE_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_CREATE_INFO,
  .pNext = NULL,
  .flags = 0,
  .descriptorUpdateEntryCount = 1,
  .pDescriptorUpdateEntries = descriptorUpdateTemplateEntries,
  .templateType = VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_PUSH_DESCRIPTORS_KHR,
  .descriptorSetLayout = 0, // ignored by given templateType
  .pipelineBindPoint = VK_PIPELINE_BIND_POINT_GRAPHICS,
  .pipelineLayout = myPipelineLayout,
  .set = 0,
};

VkDescriptorUpdateTemplate myDescriptorUpdateTemplate;
myResult = vkCreateDescriptorUpdateTemplate(
  myDevice,
  &createInfo,
  NULL,
  &myDescriptorUpdateTemplate);

AppDataStructure appData;
// fill appData here or cache it in your engine
vkCmdPushDescriptorSetWithTemplateKHR(myCmdBuffer, myDescriptorUpdateTemplate, myPipelineLayout, 0,&appData);

14.2.10. Push Constant Updates

As described above in section Pipeline Layouts, the pipeline layout defines shader push constants which are updated via Vulkan commands rather than via writes to memory or copy commands.

Note
Push constants represent a high speed path to modify constant data in pipelines that is expected to outperform memory-backed resource updates.

To update push constants, call:
void vkCmdPushConstants(
  VkCommandBuffer   commandBuffer,
  VkPipelineLayout  layout,
  VkShaderStageFlags stageFlags,
  uint32_t          offset,
  uint32_t          size,
  const void*       pValues);

- `commandBuffer` is the command buffer in which the push constant update will be recorded.
- `layout` is the pipeline layout used to program the push constant updates.
- `stageFlags` is a bitmask of `VkShaderStageFlagBits` specifying the shader stages that will use the push constants in the updated range.
- `offset` is the start offset of the push constant range to update, in units of bytes.
- `size` is the size of the push constant range to update, in units of bytes.
- `pValues` is a pointer to an array of `size` bytes containing the new push constant values.

When a command buffer begins recording, all push constant values are undefined. Reads of undefined push constant values by the executing shader return undefined values.

Push constant values can be updated incrementally, causing shader stages in `stageFlags` to read the new data from `pValues` for push constants modified by this command, while still reading the previous data for push constants not modified by this command. When a bound pipeline command is issued, the bound pipeline's layout must be compatible with the layouts used to set the values of all push constants in the pipeline layout's push constant ranges, as described in Pipeline Layout Compatibility. Binding a pipeline with a layout that is not compatible with the push constant layout does not disturb the push constant values.

**Note**
As `stageFlags` needs to include all flags the relevant push constant ranges were created with, any flags that are not supported by the queue family that the `VkCommandPool` used to allocate `commandBuffer` was created on are ignored.

**Valid Usage**

- VUID-vkCmdPushConstants-offset-01795
  For each byte in the range specified by `offset` and `size` and for each shader stage in `stageFlags`, there must be a push constant range in `layout` that includes that byte and that stage.

- VUID-vkCmdPushConstants-offset-01796
  For each byte in the range specified by `offset` and `size` and for each push constant range that overlaps that byte, `stageFlags` must include all stages in that push constant range's `VkPushConstantRange::stageFlags`.

- VUID-vkCmdPushConstants-offset-00368
offset must be a multiple of 4

- VUID-vkCmdPushConstants-size-00369
  size must be a multiple of 4

- VUID-vkCmdPushConstants-offset-00370
  offset must be less than VkPhysicalDeviceLimits::maxPushConstantsSize

- VUID-vkCmdPushConstants-size-00371
  size must be less than or equal to VkPhysicalDeviceLimits::maxPushConstantsSize minus offset

Valid Usage (Implicit)

- VUID-vkCmdPushConstants-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdPushConstants-layout-parameter
  layout must be a valid VkPipelineLayout handle

- VUID-vkCmdPushConstants-stageFlags-parameter
  stageFlags must be a valid combination of VkShaderStageFlagBits values

- VUID-vkCmdPushConstants-stageFlags-requiredbitmask
  stageFlags must not be 0

- VUID-vkCmdPushConstants-pValues-parameter
  pValues must be a valid pointer to an array of size bytes

- VUID-vkCmdPushConstants-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdPushConstants-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics, or compute operations

- VUID-vkCmdPushConstants-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdPushConstants-size-arraylength
  size must be greater than 0

- VUID-vkCmdPushConstants-commonparent
  Both of commandBuffer, and layout must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
### 14.3. Physical Storage Buffer Access

To query a 64-bit buffer device address value through which buffer memory can be accessed in a shader, call:

```c
// Provided by VK_VERSION_1_2
VkDeviceAddress vkGetBufferDeviceAddress(
    VkDevice device,
    const VkBufferDeviceAddressInfo* pInfo);
```

or the equivalent command

```c
// Provided by VK_KHR_buffer_device_address
VkDeviceAddress vkGetBufferDeviceAddressKHR(
    VkDevice device,
    const VkBufferDeviceAddressInfo* pInfo);
```

or the equivalent command

```c
// Provided by VK_EXT_buffer_device_address
VkDeviceAddress vkGetBufferDeviceAddressEXT(
    VkDevice device,
    const VkBufferDeviceAddressInfo* pInfo);
```

- `device` is the logical device that the buffer was created on.
- `pInfo` is a pointer to a `VkBufferDeviceAddressInfo` structure specifying the buffer to retrieve an address for.

The 64-bit return value is an address of the start of `pInfo->buffer`. The address range starting at this value and whose size is the size of the buffer can be used in a shader to access the memory bound to that buffer, using the `SPV_KHR_physical_storage_buffer` extension or the equivalent `SPV_EXT_physical_storage_buffer` extension and the `PhysicalStorageBuffer` storage class. For example, this value can be stored in a uniform buffer, and the shader can read the value from the uniform buffer and use it to do a dependent read/write to this buffer. A value of zero is reserved as a “null” pointer and must not be returned as a valid buffer device address. All loads, stores, and atomics in a shader through `PhysicalStorageBuffer` pointers must access addresses in the address
range of some buffer.

If the buffer was created with a non-zero value of `VkBufferOpaqueCaptureAddressCreateInfo::opaqueCaptureAddress` or `VkBufferDeviceAddressCreateInfoEXT::deviceAddress`, the return value will be the same address that was returned at capture time.

The returned address must satisfy the alignment requirement specified by `VkMemoryRequirements::alignment` for the buffer in `VkBufferDeviceAddressInfo::buffer`.

If multiple `VkBuffer` objects are bound to overlapping ranges of `VkDeviceMemory`, implementations may return address ranges which overlap. In this case, it is ambiguous which `VkBuffer` is associated with any given device address. For purposes of valid usage, if multiple `VkBuffer` objects can be attributed to a device address, a `VkBuffer` is selected such that valid usage passes, if it exists.

Valid Usage

- VUID-vkGetBufferDeviceAddress-bufferDeviceAddress-03324
  The `bufferDeviceAddress` or `VkPhysicalDeviceBufferDeviceAddressFeaturesEXT::bufferDeviceAddress` feature must be enabled.

- VUID-vkGetBufferDeviceAddress-device-03325
  If `device` was created with multiple physical devices, then the `bufferDeviceAddressMultiDevice` or `VkPhysicalDeviceBufferDeviceAddressFeaturesEXT::bufferDeviceAddressMultiDevice` feature must be enabled.

Valid Usage (Implicit)

- VUID-vkGetBufferDeviceAddress-device-parameter
  `device` must be a valid `VkDevice` handle.

- VUID-vkGetBufferDeviceAddress-pInfo-parameter
  `pInfo` must be a valid pointer to a valid `VkBufferDeviceAddressInfo` structure.

The `VkBufferDeviceAddressInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkBufferDeviceAddressInfo {
    VkStructureType sType;
    const void* pNext);
    VkBuffer buffer;
} VkBufferDeviceAddressInfo;
```

or the equivalent

```c
// Provided by VK_KHR_buffer_device_address
```
```
typedef VkBufferDeviceAddressInfo VkBufferDeviceAddressInfoKHR;
```

or the equivalent

```
// Provided by VK_EXT_buffer_device_address
typedef VkBufferDeviceAddressInfo VkBufferDeviceAddressInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `buffer` specifies the buffer whose address is being queried.

### Valid Usage

- VUID-VkBufferDeviceAddressInfo-buffer-02600
  - If `buffer` is non-sparse and was not created with the `VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT` flag, then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

- VUID-VkBufferDeviceAddressInfo-buffer-02601
  - `buffer` must have been created with `VK_BUFFER_USAGE_SHADER_DEVICE_ADDRESS_BIT`.

### Valid Usage (Implicit)

- VUID-VkBufferDeviceAddressInfo-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_BUFFER_DEVICE_ADDRESS_INFO`.

- VUID-VkBufferDeviceAddressInfo-pNext-pNext
  - `pNext` must be `NULL`.

- VUID-VkBufferDeviceAddressInfo-buffer-parameter
  - `buffer` must be a valid `VkBuffer` handle.

To query a 64-bit buffer opaque capture address, call:

```
// Provided by VK_VERSION_1_2
uint64_t vkGetBufferOpaqueCaptureAddress(
    VkDevice device,
    const VkBufferDeviceAddressInfo* pInfo);
```

or the equivalent command:

```
// Provided by VK_KHR_buffer_device_address
uint64_t vkGetBufferOpaqueCaptureAddressKHR(
    VkDevice device,
```
const VkBufferDeviceAddressInfo* pInfo);

- **device** is the logical device that the buffer was created on.
- **pInfo** is a pointer to a VkBufferDeviceAddressInfo structure specifying the buffer to retrieve an address for.

The 64-bit return value is an opaque capture address of the start of pInfo->buffer.

If the buffer was created with a non-zero value of VkBufferOpaqueCaptureAddressCreateInfo::opaqueCaptureAddress the return value must be the same address.

### Valid Usage

- VUID-vkGetBufferOpaqueCaptureAddress-None-03326
  - The bufferDeviceAddress feature must be enabled
- VUID-vkGetBufferOpaqueCaptureAddress-device-03327
  - If device was created with multiple physical devices, then the bufferDeviceAddressMultiDevice feature must be enabled

### Valid Usage (Implicit)

- VUID-vkGetBufferOpaqueCaptureAddress-device-parameter
  - device must be a valid VkDevice handle
- VUID-vkGetBufferOpaqueCaptureAddress-pInfo-parameter
  - pInfo must be a valid pointer to a valid VkBufferDeviceAddressInfo structure

## 14.4. Descriptor Buffers

If the descriptorBuffer feature is enabled, an alternative way to specify descriptor sets is via buffers, rather than descriptor set objects.

### 14.4.1. Putting descriptors in memory

Commands are provided to retrieve descriptor data, and also to locate where in memory that data must be written to match the given descriptor set layout.

To determine the amount of memory needed to store all descriptors with a given layout, call:

```c
// Provided by VK_EXT_descriptor_buffer
void vkGetDescriptorSetLayoutSizeEXT(
    VkDevice device, 
    VkDescriptorSetLayout layout, 
    VkDeviceSize* pLayoutSizeInBytes);
```
• **device** is the logical device that gets the size.
• **layout** is the descriptor set layout being queried.
• **pLayoutSizeInBytes** is a pointer to **VkDeviceSize** where the size in bytes will be written.

The size of a descriptor set layout will be at least as large as the sum total of the size of all descriptors in the layout, and may be larger. This size represents the amount of memory that will be required to store all of the descriptors for this layout in memory, when placed according to the layout's offsets as obtained by **vkGetDescriptorSetLayoutBindingOffsetEXT**.

If any **binding** in **layout** is **VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT**, the returned size includes space for the maximum **descriptorCount** descriptors as declared for that **binding**. To compute the required size of a descriptor set with a **VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT**:

\[
\text{size} = \text{offset} + \text{descriptorSize} \times \text{variableDescriptorCount}
\]

where **offset** is obtained by **vkGetDescriptorSetLayoutBindingOffsetEXT** and **descriptorSize** is the size of the relevant descriptor as obtained from **VkPhysicalDeviceDescriptorBufferPropertiesEXT**, and **variableDescriptorCount** is the equivalent of **VkDescriptorSetVariableDescriptorCountAllocateInfo::pDescriptorCounts**. For **VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK**, **variableDescriptorCount** is the size in bytes for the inline uniform block, and **descriptorSize** is 1.

If **VkPhysicalDeviceDescriptorBufferPropertiesEXT::combinedImageSamplerDescriptorSingleArray** is **VK_FALSE** and the variable descriptor type is **VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER**, **variableDescriptorCount** is always considered to be the upper bound.

### Valid Usage

- **VUID-vkGetDescriptorSetLayoutSizeEXT-None-08011**  
  The **descriptorBuffer** feature must be enabled

- **VUID-vkGetDescriptorSetLayoutSizeEXT-layout-08012**  
  **layout** must have been created with the **VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT** flag set

### Valid Usage (Implicit)

- **VUID-vkGetDescriptorSetLayoutSizeEXT-device-parameter**  
  **device** must be a valid **VkDevice** handle

- **VUID-vkGetDescriptorSetLayoutSizeEXT-layout-parameter**  
  **layout** must be a valid **VkDescriptorSetLayout** handle

- **VUID-vkGetDescriptorSetLayoutSizeEXT-pLayoutSizeInBytes-parameter**  
  **pLayoutSizeInBytes** must be a valid pointer to a **VkDeviceSize** value

- **VUID-vkGetDescriptorSetLayoutSizeEXT-layout-parent**
To get the offset of a binding within a descriptor set layout in memory, call:

```c
// Provided by VK_EXT_descriptor_buffer
void vkGetDescriptorSetLayoutBindingOffsetEXT(
    VkDevice device,
    VkDescriptorSetLayout layout,
    uint32_t binding,
    VkDeviceSize* pOffset);
```

- `device` is the logical device that gets the offset.
- `layout` is the descriptor set layout being queried.
- `binding` is the binding number being queried.
- `pOffset` is a pointer to `VkDeviceSize` where the byte offset of the binding will be written.

Each binding in a descriptor set layout is assigned an offset in memory by the implementation. When a shader accesses a resource with that binding, it will access the bound descriptor buffer from that offset to look for its descriptor. This command provides an application with that offset, so that descriptors can be placed in the correct locations. The precise location accessed by a shader for a given descriptor is as follows:

```
location = bufferAddress + setOffset + descriptorOffset + (arrayElement \times descriptorSize)
```

where `bufferAddress` and `setOffset` are the base address and offset for the identified descriptor set as specified by `vkCmdBindDescriptorBuffersEXT` and `vkCmdSetDescriptorBufferOffsetsEXT`, `descriptorOffset` is the offset for the binding returned by this command, `arrayElement` is the index into the array specified in the shader, and `descriptorSize` is the size of the relevant descriptor as obtained from `VkPhysicalDeviceDescriptorBufferPropertiesEXT`. Applications are responsible for placing valid descriptors at the expected location in order for a shader to access it. The overall offset added to `bufferAddress` to calculate `location` **must** be less than `VkPhysicalDeviceDescriptorBufferPropertiesEXT::maxSamplerDescriptorBufferRange` for samplers and `VkPhysicalDeviceDescriptorBufferPropertiesEXT::maxResourceDescriptorBufferRange` for resources.

If any `binding` in `layout` is `VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT`, that `binding` **must** have the largest offset of any `binding`.

A descriptor `binding` with type `VK_DESCRIPTOR_TYPE_MUTABLE_VALUE` **can** be used. Any potential types in `VkMutableDescriptorTypeCreateInfoVALVE::pDescriptorTypes` for `binding` share the same offset. If the size of the **mutable descriptor** is larger than the size of a concrete descriptor type being accessed, the padding area is ignored by the implementation.
Valid Usage

- VUID-vkGetDescriptorSetLayoutBindingOffsetEXT-None-08013
  The descriptorBuffer feature must be enabled

- VUID-vkGetDescriptorSetLayoutBindingOffsetEXT-layout-08014
  layout must have been created with the
  VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT flag set

Valid Usage (Implicit)

- VUID-vkGetDescriptorSetLayoutBindingOffsetEXT-device-parameter
  device must be a valid VkDevice handle

- VUID-vkGetDescriptorSetLayoutBindingOffsetEXT-layout-parameter
  layout must be a valid VkDescriptorSetLayout handle

- VUID-vkGetDescriptorSetLayoutBindingOffsetEXT-pOffset-parameter
  pOffset must be a valid pointer to a VkDeviceSize value

- VUID-vkGetDescriptorSetLayoutBindingOffsetEXT-layout-parent
  layout must have been created, allocated, or retrieved from device

To get descriptor data to place in a buffer, call:

```c
// Provided by VK_EXT_descriptor_buffer
void vkGetDescriptorEXT(  
    VkDevice device,  
    const VkDescriptorGetInfoEXT* pDescriptorInfo,  
    size_t dataSize,  
    void* pDescriptor);
```

- device is the logical device that gets the descriptor.
- pDescriptorInfo is a pointer to a VkDescriptorGetInfoEXT structure specifying the parameters of the descriptor to get.
- dataSize is the amount of the descriptor data to get in bytes.
- pDescriptor is a pointer to a user-allocated buffer where the descriptor will be written.

The size of the data for each descriptor type is determined by the value in VkPhysicalDeviceDescriptorBufferPropertiesEXT. This value also defines the stride in bytes for arrays of that descriptor type.

If the VkPhysicalDeviceDescriptorBufferPropertiesEXT::combinedImageSamplerDescriptorSingleArray property is VK_FALSE the implementation requires an array of VkDescriptorTypeCombinedImageSampler descriptors to be written into a descriptor buffer as an array of image descriptors, immediately followed by an array of sampler descriptors. Applications must write the first VkPhysicalDeviceDescriptorBufferPropertiesEXT::sampledImageDescriptorSize
bytes of the data returned through `pDescriptor` to the first array, and the remaining `VkPhysicalDeviceDescriptorBufferPropertiesEXT::samplerDescriptorSize` bytes of the data to the second array. For variable-sized descriptor bindings of `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER` descriptors, the two arrays each have a size equal to the upper bound `descriptorCount` of that binding.

A descriptor obtained by this command references the underlying `VkImageView` or `VkSampler`, and these objects must not be destroyed before the last time a descriptor is dynamically accessed. For descriptor types which consume an address instead of an object, the underlying `VkBuffer` is referenced instead.

### Valid Usage

- **VUID-vkGetDescriptorEXT-None-08015**
  The `descriptorBuffer` feature must be enabled.

- **VUID-vkGetDescriptorEXT-dataSize-08125**
  `dataSize` must equal the size of a descriptor of type `VkDescriptorGetInfoEXT::type` determined by the value in `VkPhysicalDeviceDescriptorBufferPropertiesEXT`, or `VkPhysicalDeviceDescriptorBufferDensityMapPropertiesEXT::combinedImageSamplerDensityMapDescriptorSize` if `pDescriptorInfo` specifies a `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER` whose `VkSampler` was created with `VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT` set.

- **VUID-vkGetDescriptorEXT-pDescriptor-08016**
  `pDescriptor` must be a valid pointer to an array of at least `dataSize` bytes.

### Valid Usage (Implicit)

- **VUID-vkGetDescriptorEXT-device-parameter**
  `device` must be a valid `VkDevice` handle.

- **VUID-vkGetDescriptorEXT-pDescriptorInfo-parameter**
  `pDescriptorInfo` must be a valid pointer to a valid `VkDescriptorGetInfoEXT` structure.

- **VUID-vkGetDescriptorEXT-pDescriptor-parameter**
  `pDescriptor` must be a valid pointer to an array of `dataSize` bytes.

- **VUID-vkGetDescriptorEXT-dataSize-arraylength**
  `dataSize` must be greater than 0.

Information about the descriptor to get is passed in a `VkDescriptorGetInfoEXT` structure:

```c
// Provided by VK_EXT_descriptor_buffer
typedef struct VkDescriptorGetInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkDescriptorType type;
    VkDescriptorDataEXT data;
} VkDescriptorGetInfoEXT;
```

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 VkDescriptorGetInfoEXT;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **type** is the type of descriptor to get.
- **data** is a structure containing the information needed to get the descriptor.

**Valid Usage**

- **VUID-VkDescriptorGetInfoEXT-type-08018**
  type must not be `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC`, `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC` or `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK`

- **VUID-VkDescriptorGetInfoEXT-type-08019**
  If `type` is `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`, the `pCombinedImageSampler->sampler` member of `data` must be a `VkSampler` created on `device`

- **VUID-VkDescriptorGetInfoEXT-type-08020**
  If `type` is `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`, the `pCombinedImageSampler->imageView` member of `data` must be a `VkImageView` created on `device`, or `VK_NULL_HANDLE`

- **VUID-VkDescriptorGetInfoEXT-type-08021**
  If `type` is `VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT`, the `pInputAttachmentImage->imageView` member of `data` must be a `VkImageView` created on `device`, or `VK_NULL_HANDLE`

- **VUID-VkDescriptorGetInfoEXT-type-08022**
  If `type` is `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE`, and if `pSampledImage` is not `NULL`, the `pSampledImage->imageView` member of `data` must be a `VkImageView` created on `device`, or `VK_NULL_HANDLE`

- **VUID-VkDescriptorGetInfoEXT-type-08023**
  If `type` is `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE`, and if `pStorageImage` is not `NULL`, the `pStorageImage->imageView` member of `data` must be a `VkImageView` created on `device`, or `VK_NULL_HANDLE`

- **VUID-VkDescriptorGetInfoEXT-type-08024**
  If `type` is `VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER`, `pUniformTexelBuffer` is not `NULL` and `pUniformTexelBuffer->address` is not zero, `pUniformTexelBuffer->address` must be an address within a `VkBuffer` created on `device`

- **VUID-VkDescriptorGetInfoEXT-type-08025**
  If `type` is `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER`, `pStorageTexelBuffer` is not `NULL` and `pStorageTexelBuffer->address` is not zero, `pStorageTexelBuffer->address` must be an address within a `VkBuffer` created on `device`

- **VUID-VkDescriptorGetInfoEXT-type-08026**
  If `type` is `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER`, `pUniformBuffer` is not `NULL` and `pUniformBuffer->address` is not zero, `pUniformBuffer->address` must be an address within a `VkBuffer` created on `device`
• VUID-VkDescriptorGetInfoEXT-type-08027
  If type is VK_DESCRIPTOR_TYPE_STORAGE_BUFFER, pStorageBuffer is not NULL and
  pStorageBuffer->address is not zero, pStorageBuffer->address must be an address within a
  VkBuffer created on device

• VUID-VkDescriptorGetInfoEXT-type-08028
  If type is VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR and accelerationStructure is not
  0, accelerationStructure must contain the address of a VkAccelerationStructureKHR
  created on device

• VUID-VkDescriptorGetInfoEXT-type-08029
  If type is VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_NV and accelerationStructure is not
  0, accelerationStructure must contain the handle of a VkAccelerationStructureNV created
  on device, returned by vkGetAccelerationStructureHandleNV

---

**Valid Usage (Implicit)**

• VUID-VkDescriptorGetInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_DESCRIPTOR_GET_INFO_EXT

• VUID-VkDescriptorGetInfoEXT-pNext-pNext
  pNext must be NULL

• VUID-VkDescriptorGetInfoEXT-type-parameter
  type must be a valid VkDescriptorType value

• VUID-VkDescriptorGetInfoEXT-pSampler-parameter
  If type is VK_DESCRIPTOR_TYPE_SAMPLER, the pSampler member of data must be a valid pointer
  to a valid VkSampler handle

• VUID-VkDescriptorGetInfoEXT-pCombinedImageSampler-parameter
  If type is VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER, the pCombinedImageSampler member
  of data must be a valid pointer to a valid VkDescriptorImageInfo structure

• VUID-VkDescriptorGetInfoEXT-pInputAttachmentImage-parameter
  If type is VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT, the pInputAttachmentImage member of data
  must be a valid pointer to a valid VkDescriptorImageInfo structure

• VUID-VkDescriptorGetInfoEXT-pSampledImage-parameter
  If type is VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE, and if pSampledImage is not NULL, the
  pSampledImage member of data must be a valid pointer to a valid VkDescriptorImageInfo
  structure

• VUID-VkDescriptorGetInfoEXT-pStorageImage-parameter
  If type is VK_DESCRIPTOR_TYPE_STORAGE_IMAGE, and if pStorageImage is not NULL, the
  pStorageImage member of data must be a valid pointer to a valid VkDescriptorImageInfo
  structure

• VUID-VkDescriptorGetInfoEXT-pUniformTexelBuffer-parameter
  If type is VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER, and if pUniformTexelBuffer is not NULL,
  the pUniformTexelBuffer member of data must be a valid pointer to a valid
  VkDescriptorAddressInfoEXT structure
If `type` is `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER`, and if `pStorageTexelBuffer` is not `NULL`, the `pStorageTexelBuffer` member of `data` must be a valid pointer to a valid `VkDescriptorAddressInfoEXT` structure.

If `type` is `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER`, and if `pUniformBuffer` is not `NULL`, the `pUniformBuffer` member of `data` must be a valid pointer to a valid `VkDescriptorAddressInfoEXT` structure.

If `type` is `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER`, and if `pStorageBuffer` is not `NULL`, the `pStorageBuffer` member of `data` must be a valid pointer to a valid `VkDescriptorAddressInfoEXT` structure.

Data describing the descriptor is passed in a `VkDescriptorDataEXT` structure:

```c
// Provided by VK_EXT_descriptor_buffer
typedef union VkDescriptorDataEXT {
    const VkSampler* pSampler;
    const VkDescriptorImageInfo* pCombinedImageSampler;
    const VkDescriptorImageInfo* pInputAttachmentImage;
    const VkDescriptorImageInfo* pSampledImage;
    const VkDescriptorImageInfo* pStorageImage;
    const VkDescriptorAddressInfoEXT* pUniformTexelBuffer;
    const VkDescriptorAddressInfoEXT* pStorageTexelBuffer;
    const VkDescriptorAddressInfoEXT* pUniformBuffer;
    const VkDescriptorAddressInfoEXT* pStorageBuffer;
    VkDeviceAddress accelerationStructure;
} VkDescriptorDataEXT;
```

- `pSampler` is a pointer to a `VkSampler` handle specifying the parameters of a `VK_DESCRIPTOR_TYPE_SAMPLER` descriptor.
- `pCombinedImageSampler` is a pointer to a `VkDescriptorImageInfo` structure specifying the parameters of a `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER` descriptor.
- `pInputAttachmentImage` is a pointer to a `VkDescriptorImageInfo` structure specifying the parameters of a `VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT` descriptor.
- `pSampledImage` is a pointer to a `VkDescriptorImageInfo` structure specifying the parameters of a `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE` descriptor.
- `pStorageImage` is a pointer to a `VkDescriptorImageInfo` structure specifying the parameters of a `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE` descriptor.
- `pUniformTexelBuffer` is a pointer to a `VkDescriptorAddressInfoEXT` structure specifying the parameters of a `VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER` descriptor.
- `pStorageTexelBuffer` is a pointer to a `VkDescriptorAddressInfoEXT` structure specifying the parameters of a `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER` descriptor.
- `pUniformBuffer` is a pointer to a `VkDescriptorAddressInfoEXT` structure specifying the
parameters of a VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER descriptor.

- **pStorageBuffer** is a pointer to a VkDescriptorAddressInfoEXT structure specifying the parameters of a VK_DESCRIPTOR_TYPE_STORAGE_BUFFER descriptor.

- **accelerationStructure** is the address of a VkAccelerationStructureKHR specifying the parameters of a VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR descriptor, or a VkAccelerationStructureNV handle specifying the parameters of a VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_NV descriptor.

If the nullDescriptor feature is enabled, pSampledImage, pStorageImage, pUniformTexelBuffer, pStorageTexelBuffer, pUniformBuffer, and pStorageBuffer can each be NULL. Loads from a null descriptor return zero values and stores and atomics to a null descriptor are discarded.

If the nullDescriptor feature is enabled, accelerationStructure can be 0. A null acceleration structure descriptor results in the miss shader being invoked.

### Valid Usage

- **VUID-VkDescriptorDataEXT-type-08030**
  If VkDescriptorGetInfoEXT:type is VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER, and pUniformBuffer->address is the address of a non-sparse buffer, then that buffer **must** be bound completely and contiguously to a single VkDeviceMemory object

- **VUID-VkDescriptorDataEXT-type-08031**
  If VkDescriptorGetInfoEXT:type is VK_DESCRIPTOR_TYPE_STORAGE_BUFFER, and pStorageBuffer->address is the address of a non-sparse buffer, then that buffer **must** be bound completely and contiguously to a single VkDeviceMemory object

- **VUID-VkDescriptorDataEXT-type-08032**
  If VkDescriptorGetInfoEXT:type is VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER, and pUniformTexelBuffer->address is the address of a non-sparse buffer, then that buffer **must** be bound completely and contiguously to a single VkDeviceMemory object

- **VUID-VkDescriptorDataEXT-type-08033**
  If VkDescriptorGetInfoEXT:type is VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER, and pStorageTexelBuffer->address is the address of a non-sparse buffer, then that buffer **must** be bound completely and contiguously to a single VkDeviceMemory object

- **VUID-VkDescriptorDataEXT-type-08034**
  If VkDescriptorGetInfoEXT:type is VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER, and the nullDescriptor feature is not enabled, pCombinedImageSampler->imageView **must** not be VK_NULL_HANDLE

- **VUID-VkDescriptorDataEXT-type-08035**
  If VkDescriptorGetInfoEXT:type is VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE, and the nullDescriptor feature is not enabled, pSampledImage **must** not be NULL and pSampledImage->imageView **must** not be VK_NULL_HANDLE

- **VUID-VkDescriptorDataEXT-type-08036**
  If VkDescriptorGetInfoEXT:type is VK_DESCRIPTOR_TYPE_STORAGE_IMAGE, and the nullDescriptor feature is not enabled, pStorageImage **must** not be NULL and pStorageImage->imageView **must** not be VK_NULL_HANDLE
If `VkDescriptorGetInfoEXT::type` is `VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER`, and the `nullDescriptor` feature is not enabled, `pUniformTexelBuffer` must not be NULL

If `VkDescriptorGetInfoEXT::type` is `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER`, and the `nullDescriptor` feature is not enabled, `pStorageTexelBuffer` must not be NULL

If `VkDescriptorGetInfoEXT::type` is `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER`, and the `nullDescriptor` feature is not enabled, `pUniformBuffer` must not be NULL

If `VkDescriptorGetInfoEXT::type` is `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER`, and the `nullDescriptor` feature is not enabled, `pStorageBuffer` must not be NULL

If `VkDescriptorGetInfoEXT::type` is `VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR`, and the `nullDescriptor` feature is not enabled, `accelerationStructure` must not be 0

If `VkDescriptorGetInfoEXT::type` is `VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_NV`, and the `nullDescriptor` feature is not enabled, `accelerationStructure` must not be 0

Data describing a `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER`, `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER`, `VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER`, or `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER` descriptor is passed in a `VkDescriptorAddressInfoEXT` structure:

```c
// Provided by VK_EXT_descriptor_buffer
typedef struct VkDescriptorAddressInfoEXT {
    VkStructureType sType;
    void* pNext;
    VkDeviceAddress address;
    VkDeviceSize range;
    VkFormat format;
} VkDescriptorAddressInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `address` is either 0 or a device address at an offset in a buffer, where the base address can be queried from `vkGetBufferDeviceAddress`.
- `range` is the size in bytes of the buffer or buffer view used by the descriptor.
- `format` is the format of the data elements in the buffer view and is ignored for buffers.

**Valid Usage**

- VUID-VkDescriptorAddressInfoEXT-address-08043
  If the `nullDescriptor` feature is not enabled, `address` must not be zero
If the **nullDescriptor** feature is enabled, **address can be zero.** Loads from a null descriptor return zero values and stores and atomics to a null descriptor are discarded.

Immutable samplers specified in a descriptor set layout through **pImmutableSamplers must be provided by applications when obtaining descriptor data.** Immutable samplers written in a descriptor buffer **must have identical parameters to the immutable samplers in the descriptor set layout that consumes the sampler.**

**Note**

If the descriptor set layout was created with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_EMBEDDED_IMMUTABLE_SAMPLERS_BIT_EXT`, there is no buffer backing for the immutable sampler, so this requirement does not exist. The implementation handles allocation of these descriptors internally.

**Note**

As descriptors are now in regular memory, drivers cannot hide copies of immutable samplers that end up in descriptor sets from the application. As such, applications are required to provide these samplers as if they were not provided immutably.
14.4.2. Binding descriptor buffers

Descriptor buffers have their own separate binding point on the command buffer, with buffers bound using `vkCmdBindDescriptorBuffersEXT`. `vkCmdSetDescriptorBufferOffsetsEXT` assigns pairs of buffer binding indices and buffer offsets to the same binding point on the command buffer as `vkCmdBindDescriptorSets`, allowing subsequent bound pipeline commands to use the specified descriptor buffers. Bindings applied via `vkCmdBindDescriptorSets` cannot exist simultaneously with those applied via calls to `vkCmdSetDescriptorBufferOffsetsEXT` or `vkCmdBindDescriptorBufferEmbeddedSamplersEXT`, as calls to `vkCmdSetDescriptorBufferOffsetsEXT` or `vkCmdBindDescriptorBufferEmbeddedSamplersEXT` invalidate any bindings by previous calls to `vkCmdBindDescriptorSets` and vice-versa.

To bind descriptor buffers to a command buffer, call:

```c
// Provided by VK_EXT_descriptor_buffer
void vkCmdBindDescriptorBuffersEXT(
    VkCommandBuffer commandBuffer,
    uint32_t bufferCount,
    const VkDescriptorBufferBindingInfoEXT* pBindingInfos);
```

- `commandBuffer` is the command buffer that the descriptor buffers will be bound to.
- `bufferCount` is the number of elements in the `pBindingInfos` array.
- `pBindingInfos` is a pointer to an array of `VkDescriptorBufferBindingInfoEXT` structures.

`vkCmdBindDescriptorBuffersEXT` causes any offsets previously set by `vkCmdSetDescriptorBufferOffsetsEXT` that use the bindings numbered `[0.. bufferCount-1]` to be no longer valid for subsequent bound pipeline commands. Any previously bound buffers at binding points greater than or equal to `bufferCount` are unbound.

**Valid Usage**

- VUID-vkCmdBindDescriptorBuffersEXT-None-08047
  The descriptorBuffer feature must be enabled

- VUID-vkCmdBindDescriptorBuffersEXT-maxSamplerDescriptorBufferBindings-08048
  There must be no more than `VkPhysicalDeviceDescriptorBufferPropertiesEXT::maxSamplerDescriptorBufferBindings` descriptor buffers containing sampler descriptor data bound

- VUID-vkCmdBindDescriptorBuffersEXT-maxResourceDescriptorBufferBindings-08049
  There must be no more than `VkPhysicalDeviceDescriptorBufferPropertiesEXT::maxResourceDescriptorBufferBindings` descriptor buffers containing resource descriptor data bound

- VUID-vkCmdBindDescriptorBuffersEXT-None-08050
  There must be no more than 1 descriptor buffer bound that was created with the `VK_BUFFER_USAGE_PUSH_DESCRIPTORS_DESCRIPTOR_BUFFER_BIT_EXT` bit set

- VUID-vkCmdBindDescriptorBuffersEXT-bufferCount-08051

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bufferCount must be less than or equal to VkPhysicalDeviceDescriptorBufferPropertiesEXT::maxDescriptorBufferBindings

- VUID-vkCmdBindDescriptorBuffersEXT-pBindingInfos-08052
  For any element of pBindingInfos, if the buffer from which address was queried is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdBindDescriptorBuffersEXT-pBindingInfos-08053
  For any element of pBindingInfos, the buffer from which address was queried must have been created with the VK_BUFFER_USAGE_SAMPLER_DESCRIPTOR_BUFFER_BIT_EXT bit set if it contains sampler descriptor data

- VUID-vkCmdBindDescriptorBuffersEXT-pBindingInfos-08054
  For any element of pBindingInfos, the buffer from which address was queried must have been created with the VK_BUFFER_USAGE_RESOURCE_DESCRIPTOR_BUFFER_BIT_EXT bit set if it contains resource descriptor data

- VUID-vkCmdBindDescriptorBuffersEXT-pBindingInfos-08055
  For any element of pBindingInfos, usage must match the buffer from which address was queried

### Valid Usage (Implicit)

- VUID-vkCmdBindDescriptorBuffersEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdBindDescriptorBuffersEXT-pBindingInfos-parameter
  pBindingInfos must be a valid pointer to an array of bufferCount valid VkDescriptorBufferBindingInfoEXT structures

- VUID-vkCmdBindDescriptorBuffersEXT-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdBindDescriptorBuffersEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics, or compute operations

- VUID-vkCmdBindDescriptorBuffersEXT-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdBindDescriptorBuffersEXT-bufferCount-arraylength
  bufferCount must be greater than 0

### Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
Data describing a descriptor buffer binding is passed in a `VkDescriptorBufferBindingInfoEXT` structure:

```c
// Provided by VK_EXT_descriptor_buffer
typedef struct VkDescriptorBufferBindingInfoEXT {
    VkStructureType sType;
    void* pNext;
    VkDeviceAddress address;
    VkBufferUsageFlags usage;
} VkDescriptorBufferBindingInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `address` is a `VkDeviceAddress` specifying the device address defining the descriptor buffer to be bound.
- `usage` is a bitmask of `VkBufferUsageFlagBits` specifying the `VkBufferCreateInfo::usage` for the buffer from which `address` was queried.

If a `VkPipelineCreateFlags2CreateInfoKHR` structure is present in the `pNext` chain, `VkPipelineCreateFlags2CreateInfoKHR::flags` from that structure is used instead of `flags` from this structure.

## Valid Usage

- **VUID-VkDescriptorBufferBindingInfoEXT-bufferlessPushDescriptors-08056**
  If `VkPhysicalDeviceDescriptorBufferPropertiesEXT::bufferlessPushDescriptors` is `VK_FALSE`, and `usage` contains `VK_BUFFER_USAGE_PUSH_DESCRIPTOR_BUFFER_BIT_EXT`, then the `pNext` chain must include a `VkDescriptorBufferBindingPushDescriptorBufferHandleEXT` structure.

- **VUID-VkDescriptorBufferBindingInfoEXT-address-08057**
  `address` must be aligned to `VkPhysicalDeviceDescriptorBufferPropertiesEXT::descriptorBufferOffsetAlignment`

- **VUID-VkDescriptorBufferBindingInfoEXT-usage-08122**
  If `usage` includes `VK_BUFFER_USAGE_SAMPLER_DESCRIPTOR_BUFFER_BIT_EXT`, `address` must be an address within a valid buffer that was created with `VK_BUFFER_USAGE_SAMPLER_DESCRIPTOR_BUFFER_BIT_EXT`
• VUID-VkDescriptorBufferBindingInfoEXT-usage-08123
  If `usage` includes `VK_BUFFER_USAGE_RESOURCE_DESCRIPTOR_BUFFER_BIT_EXT`, `address` must be an address within a valid buffer that was created with `VK_BUFFER_USAGE_RESOURCE_DESCRIPTOR_BUFFER_BIT_EXT`

• VUID-VkDescriptorBufferBindingInfoEXT-usage-08124
  If `usage` includes `VK_BUFFER_USAGE_PUSH_DESCRIPTORS_DESCRIPTOR_BUFFER_BIT_EXT`, `address` must be an address within a valid buffer that was created with `VK_BUFFER_USAGE_PUSH_DESCRIPTORS_DESCRIPTOR_BUFFER_BIT_EXT`

---

**Valid Usage (Implicit)**

• VUID-VkDescriptorBufferBindingInfoEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_DESCRIPTOR_BUFFER_BINDING_INFO_EXT`

• VUID-VkDescriptorBufferBindingInfoEXT-pNext-pNext
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkBufferUsageFlags2CreateInfoKHR` or `VkDescriptorBufferBindingPushDescriptorBufferHandleEXT`

• VUID-VkDescriptorBufferBindingInfoEXT-sType-unique
  The `sType` value of each struct in the `pNext` chain must be unique

• VUID-VkDescriptorBufferBindingInfoEXT-usage-parameter
  `usage` must be a valid combination of `VkBufferUsageFlagBits` values

• VUID-VkDescriptorBufferBindingInfoEXT-usage-requiredbitmask
  `usage` must not be 0

---

When the `VkPhysicalDeviceDescriptorBufferPropertiesEXT::bufferlessPushDescriptors` property is `VK_FALSE`, the `VkBuffer` handle of the buffer for push descriptors is passed in a `VkDescriptorBufferBindingPushDescriptorBufferHandleEXT` structure:

```c
// Provided by VK_EXT_descriptor_buffer
typedef struct VkDescriptorBufferBindingPushDescriptorBufferHandleEXT {
  VkStructureType sType;
  void* pNext;
  VkBuffer buffer;
} VkDescriptorBufferBindingPushDescriptorBufferHandleEXT;
```

• `sType` is a `VkStructureType` value identifying this structure.

• `pNext` is `NULL` or a pointer to a structure extending this structure.

• `buffer` is the `VkBuffer` handle of the buffer for push descriptors.

---

**Valid Usage**

• VUID-VkDescriptorBufferBindingPushDescriptorBufferHandleEXT-
Valid Usage (Implicit)

- VUID-VkDescriptorBufferBindingPushDescriptorBufferHandleEXT-sType-sType must be VK_STRUCTURE_TYPE_DESCRIPTOR_BUFFER_BINDING_PUSH_DESCRIPTOR_BUFFER_HANDLE_EXT

- VUID-VkDescriptorBufferBindingPushDescriptorBufferHandleEXT-buffer-parameter buffer must be a valid VkBuffer handle

To set descriptor buffer offsets in a command buffer, call:

```c
// Provided by VK_EXT_descriptor_buffer
void vkCmdSetDescriptorBufferOffsetsEXT(
    VkCommandBuffer commandBuffer,
    VkPipelineBindPoint pipelineBindPoint,
    VkPipelineLayout layout,
    uint32_t firstSet,
    uint32_t setCount,
    const uint32_t* pBufferIndices,
    const VkDeviceSize* pOffsets);
```

- `commandBuffer` is the command buffer in which the descriptor buffer offsets will be set.
- `pipelineBindPoint` is a VkPipelineBindPoint indicating the type of the pipeline that will use the descriptors.
- `layout` is a VkPipelineLayout object used to program the bindings.
- `firstSet` is the number of the first set to be bound.
- `setCount` is the number of elements in the pBufferIndices and pOffsets arrays.
- `pBufferIndices` is a pointer to an array of indices into the descriptor buffer binding points set by vkCmdBindDescriptorBuffersEXT.
- `pOffsets` is a pointer to an array of VkDeviceSize offsets to apply to the bound descriptor buffers.

vkCmdSetDescriptorBufferOffsetsEXT binds setCount pairs of descriptor buffers, specified by indices into the binding points bound using vkCmdBindDescriptorBuffersEXT, and buffer offsets to set numbers [firstSet..firstSet+descriptorSetCount-1] for subsequent bound pipeline commands set by pipelineBindPoint. Set [firstSet + i] is bound to the descriptor buffer at binding pBufferIndices[i] at an offset of pOffsets[i]. Any bindings that were previously applied via these sets, or calls to vkCmdBindDescriptorSets, are no longer valid. Other sets will also be invalidated upon calling this command if layout differs from the pipeline layout used to bind those other sets, as described in Pipeline Layout Compatibility.
After binding descriptors, applications can modify descriptor memory either by performing writes on the host or with device commands. When descriptor memory is updated with device commands, visibility for the shader stage accessing a descriptor is ensured with the VK_ACCESS_2_DESCRIPTOR_BUFFER_READ_BIT_EXT access flag. Implementations must not access resources referenced by these descriptors unless they are dynamically accessed by shaders. Descriptors bound with this call can be undefined if they are not dynamically accessed by shaders.

Implementations may read descriptor data for any statically accessed descriptor if the binding in layout is not declared with the VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT flag. If the binding in layout is declared with VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT, implementations must not read descriptor data that is not dynamically accessed.

Applications must ensure that any descriptor which the implementation may read must be in-bounds of the underlying descriptor buffer binding.

**Note**
Applications can freely decide how large a variable descriptor buffer binding is, so it may not be safe to read such descriptor payloads statically. The intention of these rules is to allow implementations to speculatively prefetch descriptor payloads where feasible.

Dynamically accessing a resource through descriptor data from an unbound region of a sparse partially-resident buffer will result in invalid descriptor data being read, and therefore undefined behavior.

**Note**
For descriptors written by the host, visibility is implied through the automatic visibility operation on queue submit, and there is no need to consider VK_ACCESS_2_DESCRIPTOR_BUFFER_READ_BIT. Explicit synchronization for descriptors is only required when descriptors are updated on the device.

**Note**
The requirements above imply that all descriptor bindings have been defined with the equivalent of VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT, VK_DESCRIPTOR_BINDING_UPDATE_UNUSED_WHILE_PENDING_BIT and VK_DESCRIPTOR_BINDING_PARTIALLY_BOUND_BIT, but enabling those features is not required to get this behavior.

---

**Valid Usage**

- VUID-vkCmdSetDescriptorBufferOffsetsEXT-None-08060
  The descriptorBuffer feature must be enabled

- VUID-vkCmdSetDescriptorBufferOffsetsEXT-pOffsets-08061
  The offsets in pOffsets must be aligned to VkPhysicalDeviceDescriptorBufferPropertiesEXT::descriptorBufferOffsetAlignment

- VUID-vkCmdSetDescriptorBufferOffsetsEXT-pOffsets-08063
The offsets in `pOffsets` must be small enough such that any descriptor binding referenced by `layout` without the `VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT` flag computes a valid address inside the underlying `VkBuffer`.

- **VUID-vkCmdSetDescriptorBufferOffsetsEXT-pOffsets-08126**
The offsets in `pOffsets` must be small enough such that any location accessed by a shader as a sampler descriptor must be within `VkPhysicalDeviceDescriptorBufferPropertiesEXT::maxSamplerDescriptorBufferRange` of the sampler descriptor buffer binding.

- **VUID-vkCmdSetDescriptorBufferOffsetsEXT-pOffsets-08127**
The offsets in `pOffsets` must be small enough such that any location accessed by a shader as a resource descriptor must be within `VkPhysicalDeviceDescriptorBufferPropertiesEXT::maxResourceDescriptorBufferRange` of the resource descriptor buffer binding.

- **VUID-vkCmdSetDescriptorBufferOffsetsEXT-pBufferIndices-08064**
Each element of ` pBufferIndices` must be less than `VkPhysicalDeviceDescriptorBufferPropertiesEXT::maxDescriptorBufferBindings`.

- **VUID-vkCmdSetDescriptorBufferOffsetsEXT-pBufferIndices-08065**
Each element of ` pBufferIndices` must reference a valid descriptor buffer binding set by a previous call to `vkCmdBindDescriptorBuffersEXT` in `commandBuffer`.

- **VUID-vkCmdSetDescriptorBufferOffsetsEXT-firstSet-08066**
The sum of `firstSet` and `setCount` must be less than or equal to `VkPipelineLayoutCreateInfo::setLayoutCount` provided when `layout` was created.

- **VUID-vkCmdSetDescriptorBufferOffsetsEXT-pipelineBindPoint-08067**
`pipelineBindPoint` must be supported by the `commandBuffer`'s parent `VkCommandPool`'s queue family.

- **VUID-vkCmdSetDescriptorBufferOffsetsEXT-firstSet-09006**
The `VkDescriptorSetLayout` for each set from `firstSet` to `firstSet + setCount` when `layout` was created must have been created with the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT` bit set.

---

**Valid Usage (Implicit)**

- **VUID-vkCmdSetDescriptorBufferOffsetsEXT-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- **VUID-vkCmdSetDescriptorBufferOffsetsEXT-pipelineBindPoint-parameter**
  `pipelineBindPoint` must be a valid `VkPipelineBindPoint` value.

- **VUID-vkCmdSetDescriptorBufferOffsetsEXT-layout-parameter**
  `layout` must be a valid `VkPipelineLayout` handle.

- **VUID-vkCmdSetDescriptorBufferOffsetsEXT-pBufferIndices-parameter**
  ` pBufferIndices` must be a valid pointer to an array of `setCount` `uint32_t` values.

- **VUID-vkCmdSetDescriptorBufferOffsetsEXT-pOffsets-parameter**
  `pOffsets` must be a valid pointer to an array of `setCount` `VkDeviceSize` values.

- **VUID-vkCmdSetDescriptorBufferOffsetsEXT-commandBuffer-recording**
commandBuffer must be in the recording state

- VUID-vkCmdSetDescriptorBufferOffsetsEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics, or compute operations

- VUID-vkCmdSetDescriptorBufferOffsetsEXT-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdSetDescriptorBufferOffsetsEXT-setCount-arraylength
  setCount must be greater than 0

- VUID-vkCmdSetDescriptorBufferOffsetsEXT-commonparent
  Both of commandBuffer, and layout must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Primary Secondary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics Compute</td>
<td>State</td>
</tr>
</tbody>
</table>

To bind an embedded immutable sampler set to a command buffer, call:

```c
// Provided by VK_EXT_descriptor_buffer
void vkCmdBindDescriptorBufferEmbeddedSamplersEXT(
    VkCommandBuffer commandBuffer,
    VkPipelineBindPoint pipelineBindPoint,
    VkPipelineLayout layout,
    uint32_t set);
```

- commandBuffer is the command buffer that the embedded immutable samplers will be bound to.
- pipelineBindPoint is a VkPipelineBindPoint indicating the type of the pipeline that will use the embedded immutable samplers.
- layout is a VkPipelineLayout object used to program the bindings.
- set is the number of the set to be bound.

vkCmdBindDescriptorBufferEmbeddedSamplersEXT binds the embedded immutable samplers in set of
layout to set for the command buffer for subsequent bound pipeline commands set by pipelineBindPoint. Any previous binding to this set by vkCmdSetDescriptorBufferOffsetsEXT or this command is overwritten. Any sets that were last bound by a call to vkCmdBindDescriptorSets are invalidated upon calling this command. Other sets will also be invalidated upon calling this command if layout differs from the pipeline layout used to bind those other sets, as described in Pipeline Layout Compatibility.

**Valid Usage**

- VUID-vkCmdBindDescriptorBufferEmbeddedSamplersEXT-None-08068
  The descriptorBuffer feature must be enabled

- VUID-vkCmdBindDescriptorBufferEmbeddedSamplersEXT-pipelineBindPoint-08069
  pipelineBindPoint must be supported by the commandBuffer’s parent VkCommandPool’s queue family

- VUID-vkCmdBindDescriptorBufferEmbeddedSamplersEXT-set-08070
  The VkDescriptorSetLayout at index set when layout was created must have been created with the VK_DESCRIPTOR_SET_LAYOUT_CREATE_EMBEDDED_IMMUTABLE_SAMPLERS_BIT_EXT bit set

- VUID-vkCmdBindDescriptorBufferEmbeddedSamplersEXT-set-08071
  set must be less than or equal to VkPipelineLayoutCreateInfo::setLayoutCount provided when layout was created

**Valid Usage (Implicit)**

- VUID-vkCmdBindDescriptorBufferEmbeddedSamplersEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdBindDescriptorBufferEmbeddedSamplersEXT-pipelineBindPoint-parameter
  pipelineBindPoint must be a valid VkPipelineBindPoint value

- VUID-vkCmdBindDescriptorBufferEmbeddedSamplersEXT-layout-parameter
  layout must be a valid VkPipelineLayout handle

- VUID-vkCmdBindDescriptorBufferEmbeddedSamplersEXT-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdBindDescriptorBufferEmbeddedSamplersEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics, or compute operations

- VUID-vkCmdBindDescriptorBufferEmbeddedSamplersEXT-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdBindDescriptorBufferEmbeddedSamplersEXT-commonparent
  Both of commandBuffer, and layout must have been created, allocated, or retrieved from the same VkDevice
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

<table>
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<td>Outside</td>
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<td>State</td>
</tr>
</tbody>
</table>

14.4.3. Updating descriptor buffers

Updates to descriptor data in buffers can be performed by any operation on either the host or device that can access memory.

Descriptor buffer reads can be synchronized using `VK_ACCESS_2_DESCRIPTOR_BUFFER_READ_BIT_EXT` in the relevant shader stage.

14.4.4. Push Descriptors with Descriptor Buffers

If the `descriptorBufferPushDescriptors` feature is enabled, push descriptors can be used with descriptor buffers in the same way as with descriptor sets.

The `VkPhysicalDeviceDescriptorBufferPropertiesEXT::bufferlessPushDescriptors` property indicates whether the implementation requires a buffer to back push descriptors. If the property is `VK_FALSE` then before recording any push descriptors the application must bind exactly 1 descriptor buffer that was created with the `VK_BUFFER_USAGE_PUSH_DESCRIPTORS_DESCRIPTOR_BUFFER_BIT_EXT` bit set. When this buffer is bound any previously recorded push descriptors that are required for a subsequent command must be recorded again.

14.4.5. Capture and replay

In a similar way to `bufferDeviceAddressCaptureReplay`, the `descriptorBufferCaptureReplay` feature allows the creation of opaque handles for objects at capture time that can be passed into object creation calls in a future replay, causing descriptors to be created with the same data. The opaque memory address for any memory used by these resources must have been captured using `vkGetDeviceMemoryOpaqueCaptureAddress` and be replayed using `VkMemoryOpaqueCaptureAddressAllocateInfo`.

To get the opaque descriptor data for a buffer, call:

```c
// Provided by VK_EXT_descriptor_buffer
```
VkResult `vkGetBufferOpaqueCaptureDescriptorDataEXT`

- `device` is the logical device that gets the data.
- `pInfo` is a pointer to a `VkBufferCaptureDescriptorDataInfoEXT` structure specifying the buffer.
- `pData` is a pointer to a user-allocated buffer where the data will be written.

### Valid Usage

- VUID-vkGetBufferOpaqueCaptureDescriptorDataEXT-None-08072
  The `descriptorBufferCaptureReplay` feature must be enabled
- VUID-vkGetBufferOpaqueCaptureDescriptorDataEXT-pData-08073
  `pData` must point to a buffer that is at least `VkPhysicalDeviceDescriptorBufferPropertiesEXT::bufferCaptureReplayDescriptorDataSize` bytes in size
- VUID-vkGetBufferOpaqueCaptureDescriptorDataEXT-device-08074
  If `device` was created with multiple physical devices, then the `bufferDeviceAddressMultiDevice` feature must be enabled

### Valid Usage (Implicit)

- VUID-vkGetBufferOpaqueCaptureDescriptorDataEXT-device-parameter
  `device` must be a valid `VkDevice` handle
- VUID-vkGetBufferOpaqueCaptureDescriptorDataEXT-pInfo-parameter
  `pInfo` must be a valid pointer to a valid `VkBufferCaptureDescriptorDataInfoEXT` structure
- VUID-vkGetBufferOpaqueCaptureDescriptorDataEXT-pData-parameter
  `pData` must be a pointer value

### Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

Information about the buffer to get descriptor buffer capture data for is passed in a `VkBufferCaptureDescriptorDataInfoEXT` structure:
typedef struct VkBufferCaptureDescriptorDataInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkBuffer buffer;
} VkBufferCaptureDescriptorDataInfoEXT;

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **buffer** is the *VkBuffer* handle of the buffer to get opaque capture data for.

### Valid Usage

- **VUID-VkBufferCaptureDescriptorDataInfoEXT-buffer-08075**
  - The **buffer** must have been created with `VK_BUFFER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT` set in *VkBufferCreateInfo*.

### Valid Usage (Implicit)

- **VUID-VkBufferCaptureDescriptorDataInfoEXT-sType-sType**
  - The **sType** must be `VK_STRUCTURE_TYPE_BUFFER_CAPTURE_DESCRIPTOR_DATA_INFO_EXT`.

- **VUID-VkBufferCaptureDescriptorDataInfoEXT-pNext-pNext**
  - The **pNext** must be NULL.

- **VUID-VkBufferCaptureDescriptorDataInfoEXT-buffer-parameter**
  - The **buffer** must be a valid *VkBuffer* handle.

To get the opaque capture descriptor data for an image, call:

```c
// Provided by VK_EXT_descriptor_buffer
VkResult vkGetImageOpaqueCaptureDescriptorDataEXT(
    VkDevice device, 
    const VkImageCaptureDescriptorDataInfoEXT* pInfo, 
    void* pData);
```

- **device** is the logical device that gets the data.
- **pInfo** is a pointer to a *VkImageCaptureDescriptorDataInfoEXT* structure specifying the image.
- **pData** is a pointer to a user-allocated buffer where the data will be written.

### Valid Usage

- **VUID-vkGetImageOpaqueCaptureDescriptorDataEXT-None-08076**
The `descriptorBufferCaptureReplay` feature must be enabled

- VUID-vkGetImageOpaqueCaptureDescriptorDataEXT-pData-08077
  `pData` must point to a buffer that is at least `VkPhysicalDeviceDescriptorBufferPropertiesEXT::imageCaptureReplayDescriptorDataSize` bytes in size

- VUID-vkGetImageOpaqueCaptureDescriptorDataEXT-device-08078
  If `device` was created with multiple physical devices, then the `bufferDeviceAddressMultiDevice` feature must be enabled

Valid Usage (Implicit)

- VUID-vkGetImageOpaqueCaptureDescriptorDataEXT-device-parameter
  `device` must be a valid `VkDevice` handle

- VUID-vkGetImageOpaqueCaptureDescriptorDataEXT-pInfo-parameter
  `pInfo` must be a valid pointer to a valid `VkImageCaptureDescriptorDataInfoEXT` structure

- VUID-vkGetImageOpaqueCaptureDescriptorDataEXT-pData-parameter
  `pData` must be a pointer value

Return Codes

**Success**

- VK_SUCCESS

**Failure**

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

Information about the image to get descriptor buffer capture data for is passed in a `VkImageCaptureDescriptorDataInfoEXT` structure:

```c
// Provided by VK_EXT_descriptor_buffer
typedef struct VkImageCaptureDescriptorDataInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkImage image;
} VkImageCaptureDescriptorDataInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `image` is the `VkImage` handle of the image to get opaque capture data for.
Valid Usage

- VUID-VkImageCaptureDescriptorDataInfoEXT-image-08079
  
  image must have been created with
  VK_IMAGE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT set in
  VkImageCreateInfo::flags

Valid Usage (Implicit)

- VUID-VkImageCaptureDescriptorDataInfoEXT-sType-sType
  
  sType must be VK_STRUCTURE_TYPE_IMAGE_CAPTURE_DESCRIPTOR_DATA_INFO_EXT

- VUID-VkImageCaptureDescriptorDataInfoEXT-pNext-pNext
  
  pNext must be NULL

- VUID-VkImageCaptureDescriptorDataInfoEXT-image-parameter
  
  image must be a valid VkImage handle

To get the opaque capture descriptor data for an image view, call:

```c
// Provided by VK_EXT_descriptor_buffer
VkResult vkGetImageViewOpaqueCaptureDescriptorDataEXT(
    VkDevice device,
    const VkImageViewCaptureDescriptorDataInfoEXT* pInfo,
    void* pData);
```

- `device` is the logical device that gets the data.

- `pInfo` is a pointer to a VkImageViewCaptureDescriptorDataInfoEXT structure specifying the image view.

- `pData` is a pointer to a user-allocated buffer where the data will be written.

Valid Usage

- VUID-vkGetImageViewOpaqueCaptureDescriptorDataEXT-None-08080
  
  The descriptorBufferCaptureReplay feature must be enabled

- VUID-vkGetImageViewOpaqueCaptureDescriptorDataEXT-pData-08081
  
  pData must point to a buffer that is at least
  VkPhysicalDeviceDescriptorBufferPropertiesEXT::imageViewCaptureReplayDescriptorDataSize bytes in size

- VUID-vkGetImageViewOpaqueCaptureDescriptorDataEXT-device-08082
  
  If device was created with multiple physical devices, then the
  bufferDeviceAddressMultiDevice feature must be enabled
Valid Usage (Implicit)

- VUID-vkGetImageViewOpaqueCaptureDescriptorDataEXT-device-parameter
device must be a valid VkDevice handle

- VUID-vkGetImageViewOpaqueCaptureDescriptorDataEXT-pInfo-parameter
  pInfo must be a valid pointer to a valid VkImageViewCaptureDescriptorDataInfoEXT structure

- VUID-vkGetImageViewOpaqueCaptureDescriptorDataEXT-pData-parameter
  pData must be a pointer value

Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

Information about the image view to get descriptor buffer capture data for is passed in a VkImageViewCaptureDescriptorDataInfoEXT structure:

```c
// Provided by VK_EXT_descriptor_buffer
typedef struct VkImageViewCaptureDescriptorDataInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkImageView imageView;
} VkImageViewCaptureDescriptorDataInfoEXT;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- imageView is the VkImageView handle of the image view to get opaque capture data for.

Valid Usage

- VUID-VkImageViewCaptureDescriptorDataInfoEXT-imageView-08083
  imageView must have been created with
  VK_IMAGE_VIEW_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT set in
  VkImageViewCreateInfo::flags
Valid Usage (Implicit)

- VUID-VkImageViewCaptureDescriptorDataInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_IMAGE_VIEW_CAPTURE_DESCRIPTOR_DATA_INFO_EXT

- VUID-VkImageViewCaptureDescriptorDataInfoEXT-pNext-pNext
  pNext must be NULL

- VUID-VkImageViewCaptureDescriptorDataInfoEXT-imageView-parameter
  imageView must be a valid VkImageView handle

To get the opaque capture descriptor data for a sampler, call:

```c
// Provided by VK_EXT_descriptor_buffer
VkResult vkGetSamplerOpaqueCaptureDescriptorDataEXT(
    VkDevice device,
    const VkSamplerCaptureDescriptorDataInfoEXT* pInfo,
    void* pData);
```

- `device` is the logical device that gets the data.
- `pInfo` is a pointer to a VkSamplerCaptureDescriptorDataInfoEXT structure specifying the sampler.
- `pData` is a pointer to a user-allocated buffer where the data will be written.

Valid Usage

- VUID-vkGetSamplerOpaqueCaptureDescriptorDataEXT-None-08084
  The descriptorBufferCaptureReplay feature must be enabled

- VUID-vkGetSamplerOpaqueCaptureDescriptorDataEXT-pData-08085
  `pData` must point to a buffer that is at least
  VkPhysicalDeviceDescriptorBufferPropertiesEXT::samplerCaptureReplayDescriptorDataSize bytes in size

- VUID-vkGetSamplerOpaqueCaptureDescriptorDataEXT-device-08086
  If `device` was created with multiple physical devices, then the
  bufferDeviceAddressMultiDevice feature must be enabled

Valid Usage (Implicit)

- VUID-vkGetSamplerOpaqueCaptureDescriptorDataEXT-device-parameter
  `device` must be a valid VkDevice handle

- VUID-vkGetSamplerOpaqueCaptureDescriptorDataEXT-pInfo-parameter
  `pInfo` must be a valid pointer to a valid VkSamplerCaptureDescriptorDataInfoEXT structure
Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

Information about the sampler to get descriptor buffer capture data for is passed in a VkSamplerCaptureDescriptorDataInfoEXT structure:

```c
// Provided by VK_EXT_descriptor_buffer
typedef struct VkSamplerCaptureDescriptorDataInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkSampler sampler;
} VkSamplerCaptureDescriptorDataInfoEXT;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `sampler` is the VkSampler handle of the sampler to get opaque capture data for.

Valid Usage

- VUID-VkSamplerCaptureDescriptorDataInfoEXT-sampler-08087
  `sampler` must have been created with VK_SAMPLER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT set in VkSamplerCreateInfo::flags

Valid Usage (Implicit)

- VUID-VkSamplerCaptureDescriptorDataInfoEXT-sType-sType
  `sType` must be VK_STRUCTURE_TYPE_SAMPLER_CAPTURE_DESCRIPTOR_DATA_INFO_EXT

- VUID-VkSamplerCaptureDescriptorDataInfoEXT-pNext-pNext
  `pNext` must be NULL

- VUID-VkSamplerCaptureDescriptorDataInfoEXT-sampler-parameter
  `sampler` must be a valid VkSampler handle
To get the opaque capture descriptor data for an acceleration structure, call:

```c
// Provided by VK_EXT_descriptor_buffer with VK_KHR_acceleration_structure or
// VK_NV_ray_tracing
VkResult vkGetAccelerationStructureOpaqueCaptureDescriptorDataEXT(
    VkDevice device,
    const VkAccelerationStructureCaptureDescriptorDataInfoEXT* pInfo,
    void* pData);
```

- `device` is the logical device that gets the data.
- `pInfo` is a pointer to a `VkAccelerationStructureCaptureDescriptorDataInfoEXT` structure specifying the acceleration structure.
- `pData` is a pointer to a user-allocated buffer where the data will be written.

## Valid Usage

- **VUID-vkGetAccelerationStructureOpaqueCaptureDescriptorDataEXT-None-08088**
  The `descriptorBufferCaptureReplay` feature must be enabled

- **VUID-vkGetAccelerationStructureOpaqueCaptureDescriptorDataEXT-pData-08089**
  `pData` must point to a buffer that is at least `VkPhysicalDeviceDescriptorBufferPropertiesEXT::accelerationStructureCaptureReplayDescriptorDataSize` bytes in size

- **VUID-vkGetAccelerationStructureOpaqueCaptureDescriptorDataEXT-device-08090**
  If `device` was created with multiple physical devices, then the `bufferDeviceAddressMultiDevice` feature must be enabled

## Valid Usage (Implicit)

- **VUID-vkGetAccelerationStructureOpaqueCaptureDescriptorDataEXT-device-parameter**
  `device` must be a valid `VkDevice` handle

- **VUID-vkGetAccelerationStructureOpaqueCaptureDescriptorDataEXT-pInfo-parameter**
  `pInfo` must be a valid pointer to a valid `VkAccelerationStructureCaptureDescriptorDataInfoEXT` structure

- **VUID-vkGetAccelerationStructureOpaqueCaptureDescriptorDataEXT-pData-parameter**
  `pData` must be a pointer value

## Return Codes

**Success**
- **VK_SUCCESS**
Failure

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

Information about the acceleration structure to get descriptor buffer capture data for is passed in a `VkAccelerationStructureCaptureDescriptorDataInfoEXT` structure:

```c
// Provided by VK_EXT_descriptor_buffer with VK_KHR_acceleration_structure or
// VK_NV_ray_tracing
typedef struct VkAccelerationStructureCaptureDescriptorDataInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkAccelerationStructureKHR accelerationStructure;
    VkAccelerationStructureNV accelerationStructureNV;
} VkAccelerationStructureCaptureDescriptorDataInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `accelerationStructure` is the `VkAccelerationStructureKHR` handle of the acceleration structure to get opaque capture data for.
- `accelerationStructureNV` is the `VkAccelerationStructureNV` handle of the acceleration structure to get opaque capture data for.

**Valid Usage**

- VUID-VkAccelerationStructureCaptureDescriptorDataInfoEXT-accelerationStructure-08091
  If `accelerationStructure` is not `VK_NULL_HANDLE` then `accelerationStructure` must have been created with `VK_ACCELERATION_STRUCTURE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT` set in `VkAccelerationStructureCreateInfoKHR::createFlags`

- VUID-VkAccelerationStructureCaptureDescriptorDataInfoEXT-accelerationStructureNV-08092
  If `accelerationStructureNV` is not `VK_NULL_HANDLE` then `accelerationStructureNV` must have been created with `VK_ACCELERATION_STRUCTURE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT` set in `VkAccelerationStructureCreateInfoNV::info.flags`

- VUID-VkAccelerationStructureCaptureDescriptorDataInfoEXT-accelerationStructure-08093
  If `accelerationStructure` is not `VK_NULL_HANDLE` then `accelerationStructureNV` must be `VK_NULL_HANDLE`

- VUID-VkAccelerationStructureCaptureDescriptorDataInfoEXT-accelerationStructureNV-08094
If `accelerationStructureNV` is not `VK_NULL_HANDLE` then `accelerationStructure` **must** be `VK_NULL_HANDLE`.

**Valid Usage (Implicit)**

- VUID-VkAccelerationStructureCaptureDescriptorDataInfoEXT-sType-sType must be `VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_CAPTURE_DESCRIPTOR_DATA_INFO_EXT`
- VUID-VkAccelerationStructureCaptureDescriptorDataInfoEXT-pNext-pNext must be `NULL`
- VUID-VkAccelerationStructureCaptureDescriptorDataInfoEXT-accelerationStructure-parameter
  If `accelerationStructure` is not `VK_NULL_HANDLE`, `accelerationStructure` **must** be a valid `VkAccelerationStructureKHR` handle
- VUID-VkAccelerationStructureCaptureDescriptorDataInfoEXT-accelerationStructureNV-parameter
  If `accelerationStructureNV` is not `VK_NULL_HANDLE`, `accelerationStructureNV` **must** be a valid `VkAccelerationStructureNV` handle
- VUID-VkAccelerationStructureCaptureDescriptorDataInfoEXT-commonparent
  Both of `accelerationStructure`, and `accelerationStructureNV` that are valid handles of non-ignored parameters **must** have been created, allocated, or retrieved from the same `VkDevice`

The `VkOpaqueCaptureDescriptorDataCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_descriptor_buffer
typedef struct VkOpaqueCaptureDescriptorDataCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    const void* opaqueCaptureDescriptorData;
} VkOpaqueCaptureDescriptorDataCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `opaqueCaptureDescriptorData` is a pointer to a user-allocated buffer containing opaque capture data retrieved using `vkGetBufferOpaqueCaptureDescriptorDataEXT`, `vkGetImageOpaqueCaptureDescriptorDataEXT`, `vkGetImageViewOpaqueCaptureDescriptorDataEXT`, `vkGetSamplerOpaqueCaptureDescriptorDataEXT`, or `vkGetAccelerationStructureOpaqueCaptureDescriptorDataEXT`.

During replay, opaque descriptor capture data **can** be specified by adding a `VkOpaqueCaptureDescriptorDataCreateInfoEXT` structure to the relevant `pNext` chain of a
VkBufferCreateInfo, VkImageCreateInfo, VkImageViewCreateInfo, VkSamplerCreateInfo, VkAccelerationStructureCreateInfoNV or VkAccelerationStructureCreateInfoKHR structure.

Valid Usage (Implicit)

- **VUID-VkOpaqueCaptureDescriptorDataCreateInfoEXT-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_OPAQUE_CAPTURE_DESCRIPTOR_DATA_CREATE_INFO_EXT`

- **VUID-VkOpaqueCaptureDescriptorDataCreateInfoEXT-opaqueCaptureDescriptorData- opaqueCaptureDescriptorData** must be a pointer value
Chapter 15. Shader Interfaces

When a pipeline is created, the set of shaders specified in the corresponding VkPipelineCreateInfo structure are implicitly linked at a number of different interfaces.

- Shader Input and Output Interface
- Vertex Input Interface
- Fragment Output Interface
- Fragment Tile Image Interface
- Fragment Input Attachment Interface
- Ray Tracing Pipeline Interface
- Shader Resource Interface
- Geometry Shader Passthrough

This chapter describes valid uses for a set of SPIR-V decorations. Any other use of one of these decorations is invalid, with the exception that, when using SPIR-V versions 1.4 and earlier: Block, BufferBlock, Offset, ArrayStride, and MatrixStride can also decorate types and type members used by variables in the Private and Function storage classes.

Note

In this chapter, there are references to SPIR-V terms such as the MeshNV execution model. These terms will appear even in a build of the specification which does not support any extensions. This is as intended, since these terms appear in the unified SPIR-V specification without such qualifiers.

15.1. Shader Input and Output Interfaces

When multiple stages are present in a pipeline, the outputs of one stage form an interface with the inputs of the next stage. When such an interface involves a shader, shader outputs are matched against the inputs of the next stage, and shader inputs are matched against the outputs of the previous stage.

All the variables forming the shader input and output interfaces are listed as operands to the OpEntryPoint instruction and are declared with the Input or Output storage classes, respectively, in the SPIR-V module. These generally form the interfaces between consecutive shader stages, regardless of any non-shader stages between the consecutive shader stages.

There are two classes of variables that can be matched between shader stages, built-in variables and user-defined variables. Each class has a different set of matching criteria.

Output variables of a shader stage have undefined values until the shader writes to them or uses the Initializer operand when declaring the variable.
15.1.1. Built-in Interface Block

Shader built-in variables meeting the following requirements define the built-in interface block. They must

- be explicitly declared (there are no implicit built-ins),
- be identified with a BuiltIn decoration,
- form object types as described in the Built-in Variables section, and
- be declared in a block whose top-level members are the built-ins.

There must be no more than one built-in interface block per shader per interface, except for the mesh output interface where there must be at most one built-in interface block decorated with the PerPrimitiveEXT decoration and at most one built-in interface block without this decoration.

Built-ins must not have any Location or Component decorations.

15.1.2. User-defined Variable Interface

The non-built-in variables listed by OpEntryPoint with the Input or Output storage class form the user-defined variable interface. These must have numeric type or, recursively, composite types of such types. If an implementation supports storageInputOutput16, components can have a width of 16 bits. These variables must be identified with a Location decoration and can also be identified with a Component decoration.

15.1.3. Interface Matching

An output variable, block, or structure member in a given shader stage has an interface match with an input variable, block, or structure member in a subsequent shader stage if they both adhere to the following conditions:

- They have equivalent decorations, other than:
  - XfbBuffer, XfbStride, Offset, and Stream
  - one is not decorated with Component and the other is declared with a Component of 0
  - Interpolation decorations
  - RelaxedPrecision if one is an input variable and the other an output variable
- Their types match as follows:
  - if the input is declared in a tessellation control or geometry shader as an OpTypeArray with an Element Type equivalent to the OpType* declaration of the output, and neither is a structure member; or
  - if the maintenance4 feature is enabled, they are declared as OpTypeVector variables, and the output has a Component Count value higher than that of the input but the same Component Type; or
  - if the output is declared in a mesh shader as an OpTypeArray with an Element Type equivalent to the OpType* declaration of the input, and neither is a structure member; or
If the input is decorated with `PerVertexKHR`, and is declared in a fragment shader as an `OpTypeArray` with an `Element Type` equivalent to the `OpType*` declaration of the output, and neither the input nor the output is a structure member; or

- if in any other case they are declared with an equivalent `OpType*` declaration.

- If both are structures and every member has an interface match.

**Note**

The word “structure” above refers to both variables that have an `OpTypeStruct` type and interface blocks (which are also declared as `OpTypeStruct`).

If the pipeline is compiled as separate graphics pipeline libraries and the `graphicsPipelineLibraryIndependentInterpolationDecoration` limit is not supported, matches are not found if the interpolation decorations differ between the last pre-rasterization shader stage and the fragment shader stage.

All input variables and blocks **must** have an interface match in the preceding shader stage, except for built-in variables in fragment shaders. Shaders **can** declare and write to output variables that are not declared or read by the subsequent stage.

Matching rules for *passthrough geometry shaders* are slightly different and are described in the *Passthrough Interface Matching* section.

The value of an input variable is undefined if the preceding stage does not write to a matching output variable, as described above.

### 15.1.4. Location Assignment

This section describes Location assignments for user-defined variables and how many Location slots are consumed by a given user-variable type. As mentioned above, some inputs and outputs have an additional level of arrayness relative to other shader inputs and outputs. This outer array level is removed from the type before considering how many Location slots the type consumes.

The Location value specifies an interface slot comprised of a 32-bit four-component vector conveyed between stages. The Component specifies word components within these vector Location slots. Only types with widths of 16, 32 or 64 are supported in shader interfaces.

Inputs and outputs of the following types consume a single interface Location:

- 16-bit scalar and vector types, and
- 32-bit scalar and vector types, and
- 64-bit scalar and 2-component vector types.

64-bit three- and four-component vectors consume two consecutive Location slots.

If a declared input or output is an array of size n and each element takes m Location slots, it will be assigned $m \times n$ consecutive Location slots starting with the specified Location.

If the declared input or output is an $n \times m$ 16-, 32- or 64-bit matrix, it will be assigned multiple...
Location slots starting with the specified Location. The number of Location slots assigned for each matrix will be the same as for an n-element array of m-component vectors.

An OpVariable with a structure type that is not a block must be decorated with a Location.

When an OpVariable with a structure type (either block or non-block) is decorated with a Location, the members in the structure type must not be decorated with a Location. The OpVariable’s members are assigned consecutive Location slots in declaration order, starting from the first member, which is assigned the Location decoration from the OpVariable.

When a block-type OpVariable is declared without a Location decoration, each member in its structure type must be decorated with a Location. Types nested deeper than the top-level members must not have Location decorations.

The Location slots consumed by block and structure members are determined by applying the rules above in a depth-first traversal of the instantiated members as though the structure or block member were declared as an input or output variable of the same type.

Any two inputs listed as operands on the same OpEntryPoint must not be assigned the same Location slot and Component word, either explicitly or implicitly. Any two outputs listed as operands on the same OpEntryPoint must not be assigned the same Location slot and Component word, either explicitly or implicitly.

The number of input and output Location slots available for a shader input or output interface is limited, and dependent on the shader stage as described in Shader Input and Output Locations. All variables in both the built-in interface block and the user-defined variable interface count against these limits. Each effective Location must have a value less than the number of Location slots available for the given interface, as specified in the “Locations Available” column in Shader Input and Output Locations.

Table 19. Shader Input and Output Locations

<table>
<thead>
<tr>
<th>Shader Interface</th>
<th>Locations Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>vertex input</td>
<td>maxVertexInputAttributes</td>
</tr>
<tr>
<td>vertex output</td>
<td>maxVertexOutputComponents / 4</td>
</tr>
<tr>
<td>tessellation control input</td>
<td>maxTessellationControlPerVertexInputComponents / 4</td>
</tr>
<tr>
<td>tessellation control output</td>
<td>maxTessellationControlPerVertexOutputComponents / 4</td>
</tr>
<tr>
<td>tessellation evaluation input</td>
<td>maxTessellationEvaluationInputComponents / 4</td>
</tr>
<tr>
<td>tessellation evaluation output</td>
<td>maxTessellationEvaluationOutputComponents / 4</td>
</tr>
<tr>
<td>geometry input</td>
<td>maxGeometryInputComponents / 4</td>
</tr>
<tr>
<td>geometry output</td>
<td>maxGeometryOutputComponents / 4</td>
</tr>
<tr>
<td>fragment input</td>
<td>maxFragmentInputComponents / 4</td>
</tr>
<tr>
<td>fragment output</td>
<td>maxFragmentOutputAttachments</td>
</tr>
</tbody>
</table>
### 15.1.5. Component Assignment

The Component decoration allows the Location to be more finely specified for scalars and vectors, down to the individual Component word within a Location slot that are consumed. The Component word within a Location are 0, 1, 2, and 3. A variable or block member starting at Component N will consume Component words N, N+1, N+2, … up through its size. For 16-, and 32-bit types, it is invalid if this sequence of Component words gets larger than 3. A scalar 64-bit type will consume two of these Component words in sequence, and a two-component 64-bit vector type will consume all four Component words available within a Location. A three- or four-component 64-bit vector type must not specify a non-zero Component decoration. A three-component 64-bit vector type will consume all four Component words of the first Location and Component 0 and 1 of the second Location. This leaves Component 2 and 3 available for other component-qualified declarations.

A scalar or two-component 64-bit data type must not specify a Component decoration of 1 or 3. A Component decoration must not be specified for any type that is not a scalar or vector.

A four-component 64-bit data type will consume all four Component words of the first Location and all four Component words of the second Location.

### 15.2. Vertex Input Interface

When the vertex stage is present in a pipeline, the vertex shader input variables form an interface with the vertex input attributes. The vertex shader input variables are matched by the Location and Component decorations to the vertex input attributes specified in the pVertexInputState member of the VkGraphicsPipelineCreateInfo structure.

The vertex shader input variables listed by OpEntryPoint with the Input storage class form the vertex input interface. These variables must be identified with a Location decoration and can also be identified with a Component decoration.

For the purposes of interface matching: variables declared without a Component decoration are considered to have a Component decoration of zero. The number of available vertex input Location slots is given by the maxVertexInputAttributes member of the VkPhysicalDeviceLimits structure.

See Attribute Location and Component Assignment for details.

All vertex shader inputs declared as above must have a corresponding attribute and binding in the pipeline.

### 15.3. Fragment Output Interface

When the fragment stage is present in a pipeline, the fragment shader outputs form an interface with the output attachments defined by a render pass instance. The fragment shader output
variables are matched by the \texttt{Location} and \texttt{Component} decorations to specified color attachments.

The fragment shader output variables listed by \texttt{OpEntryPoint} with the \texttt{Output} storage class form the \textit{fragment output interface}. These variables \textbf{must} be identified with a \texttt{Location} decoration. They \textbf{can} also be identified with a \texttt{Component} decoration and/or an \texttt{Index} decoration. For the purposes of interface matching: variables declared without a \texttt{Component} decoration are considered to have a \texttt{Component} decoration of zero, and variables declared without an \texttt{Index} decoration are considered to have an \texttt{Index} decoration of zero.

A fragment shader output variable identified with a \texttt{Location} decoration of \texttt{i} is associated with the color attachment indicated by \texttt{VkRenderingInfo::pColorAttachments[i]}. When using render pass objects, it is associated with the color attachment indicated by \texttt{VkSubpassDescription::pColorAttachments[i]}. Values are written to those attachments after passing through the blending unit as described in \textit{Blending}, if enabled. Locations are consumed as described in \textit{Location Assignment}. The number of available fragment output \texttt{Location} slots is given by the \texttt{maxFragmentOutputAttachments} member of the \texttt{VkPhysicalDeviceLimits} structure.

When an active fragment shader invocation finishes, the values of all fragment shader outputs are copied out and used as blend inputs or color attachments writes. If the invocation does not set a value for them, the input values to those blending or color attachment writes are undefined.

Components of the output variables are assigned as described in \textit{Component Assignment}. Output \texttt{Component} words identified as 0, 1, 2, and 3 will be directed to the R, G, B, and A inputs to the blending unit, respectively, or to the output attachment if blending is disabled. If two variables are placed within the same \texttt{Location}, they \textbf{must} have the same underlying type (floating-point or integer). \texttt{Component} words which do not correspond to any fragment shader output will also result in undefined values for blending or color attachment writes.

Fragment outputs identified with an \texttt{Index} of zero are directed to the first input of the blending unit associated with the corresponding \texttt{Location}. Outputs identified with an \texttt{Index} of one are directed to the second input of the corresponding blending unit.

There \textbf{must} be no output variable which has the same \texttt{Location}, \texttt{Component}, and \texttt{Index} as any other, either explicitly declared or implied.

Output values written by a fragment shader \textbf{must} be declared with either \texttt{OpTypeFloat} or \texttt{OpTypeInt}, and a \texttt{Width} of 32. If \texttt{storageInputOutput16} is supported, output values written by a fragment shader \textbf{can} be also declared with either \texttt{OpTypeFloat} or \texttt{OpTypeInt} and a \texttt{Width} of 16. Composites of these types are also permitted. If the color attachment has a signed or unsigned normalized fixed-point format, color values are assumed to be floating-point and are converted to fixed-point as described in \textit{Conversion from Floating-Point to Normalized Fixed-Point}; If the color attachment has an integer format, color values are assumed to be integers and converted to the bit-depth of the target. Any value that cannot be represented in the attachment’s format is undefined. For any other attachment format no conversion is performed. If the type of the values written by the fragment shader do not match the format of the corresponding color attachment, the resulting values are undefined for those components.
15.4. Legacy Dithering

The application can enable dithering to be applied to the color output of a subpass, by using the `VK_SUBPASS_DESCRIPTION_ENABLE_LEGACY_DITHERING_BIT_EXT` or the `VK_RENDERING_ENABLE_LEGACY_DITHERING_BIT_EXT` flags.

When dithering is enabled, the implementation may modify the output color value \( c \) by one ULP. This modification must only depend on the framebuffer coordinates \((x_f, y_f)\) of the sample, as well as on the value of \( c \).

The exact details of the dithering algorithm are unspecified, including the algorithm itself, the formats dithering is applied to, and the stage in which it is applied.

---

**Note**

This extension is intended only for use by OpenGL emulation layers, and as such the dithering algorithm applied to the subpass should be equivalent to the vendor's OpenGL implementation, if any.

---

15.5. Fragment Tile Image Interface

When a fragment stage is present in a pipeline, the fragment shader tile image variables decorated with `Location` form an interface with the color attachments defined by the render pass instance. The fragment shader tile image variables are matched by `Location` decorations to the color attachments specified in the `pColorAttachments` array of the `VkRenderingInfoKHR` structure describing the render pass instance the fragment shader is executed in.

The fragment shader variables listed by `OpEntryPoint` with the `TileImageEXT` storage class and a decoration of `Location` form the fragment tile image interface. These variables must be declared with a type of `OpTypeImage`, and a `Dim` operand of `TileImageDataEXT`. The `Component` decoration is not supported for these variables.

Reading from a tile image variable with a `Location` decoration of \( i \) reads from the color attachment identified by the element of `VkRenderingInfoKHR::pColorAttachments` with a `location` equal to \( i \). If the tile image variable is declared as an array of size \( N \), it consumes \( N \) consecutive tile image locations, starting with the index specified. There must not be more than one tile image variable with the same `Location` whether explicitly declared or implied by an array declaration. The number of available tile image locations is the same as the number of available fragment output locations as given by the `maxFragmentOutputAttachments` member of the `VkPhysicalDeviceLimits` structure.

The basic data type (floating-point, integer, unsigned integer) of the tile image variable must match the basic format of the corresponding color attachment, or the values read from the tile image variables are undefined.

---

15.6. Fragment Input Attachment Interface

When a fragment stage is present in a pipeline, the fragment shader subpass inputs form an interface with the input attachments of the current subpass. The fragment shader subpass input
variables are matched by `InputAttachmentIndex` decorations to the input attachments specified in the `pInputAttachments` array of the `VkSubpassDescription` structure describing the subpass that the fragment shader is executed in.

The fragment shader subpass input variables with the `UniformConstant` storage class and a decoration of `InputAttachmentIndex` that are statically used by `OpEntryPoint` form the *fragment input attachment interface*. These variables must be declared with a type of `OpTypeImage`, a `Dim` operand of `SubpassData`, an `Arrayed` operand of 0, and a `Sampled` operand of 2. The `MS` operand of the `OpTypeImage` must be 0 if the `samples` field of the corresponding `VkAttachmentDescription` is `VK_SAMPLE_COUNT_1_BIT` and `multisampled-render-to-single-sampled` is not enabled, and 1 otherwise.

A subpass input variable identified with an `InputAttachmentIndex` decoration of `i` reads from the input attachment indicated by `pInputAttachments[i]` member of `VkSubpassDescription`. If the subpass input variable is declared as an array of size `N`, it consumes `N` consecutive input attachments, starting with the index specified. There must not be more than one input variable with the same `InputAttachmentIndex` whether explicitly declared or implied by an array declaration per image aspect. A multi-aspect image (e.g. a depth/stencil format) can use the same input variable. The number of available input attachment indices is given by the `maxPerStageDescriptorInputAttachments` member of the `VkPhysicalDeviceLimits` structure.

Variables identified with the `InputAttachmentIndex` must only be used by a fragment stage. The numeric format of the subpass input must match the format of the corresponding input attachment, or the values of subpass loads from these variables are undefined. If the framebuffer attachment contains both depth and stencil aspects, the numeric format of the subpass input determines if depth or stencil aspect is accessed by the shader.

See *Input Attachment* for more details.

### 15.6.1. Fragment Input Attachment Compatibility

An input attachment that is statically accessed by a fragment shader must be backed by a descriptor that is equivalent to the `VkImageView` in the `VkFramebuffer`, except for `subresourceRange.aspectMask`. The `aspectMask` must be equal to the aspect accessed by the shader.

### 15.7. Ray Tracing Pipeline Interface

Ray tracing pipelines may have more stages than other pipelines with multiple instances of each stage and more dynamic interactions between the stages, but still have interface structures that obey the same general rules as interfaces between shader stages in other pipelines. The three types of inter-stage interface variables for ray tracing pipelines are:

- Ray payloads containing data tracked for the entire lifetime of the ray.
- Hit attributes containing data about a specific hit for the duration of its processing.
- Callable data for passing data into and out of a callable shader.

Ray payloads and callable data are used in explicit shader call instructions, so they have an incoming variant to distinguish the parameter passed to the invocation from any other payloads or data being used by subsequent shader call instructions.
An interface structure used between stages must match between the stages using it. Specifically:

- The hit attribute structure read in an any-hit or closest hit shader must be the same structure as the hit attribute structure written in the corresponding intersection shader in the same hit group.
- The incoming callable data for a callable shader must be the same structure as the callable data referenced by the execute callable instruction in the calling shader.
- The ray payload for a shader invoked by a ray tracing command must be the same structure for all shader stages using the payload for that ray.

Any shader with an incoming ray payload, incoming callable data, or hit attribute must only declare one variable of that type.

### Table 20. Ray Pipeline Shader Interface

<table>
<thead>
<tr>
<th>Shader Stage</th>
<th>Ray Payload</th>
<th>Incoming Ray Payload</th>
<th>Hit Attribute</th>
<th>Callable Data</th>
<th>Incoming Callable Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ray Generation</td>
<td>r/w</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intersection</td>
<td></td>
<td>r/w</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any-Hit</td>
<td>r/w</td>
<td>r/w</td>
<td>r</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closest Hit</td>
<td>r/w</td>
<td>r/w</td>
<td></td>
<td>r/w</td>
<td></td>
</tr>
<tr>
<td>Miss</td>
<td>r/w</td>
<td>r/w</td>
<td></td>
<td>r/w</td>
<td></td>
</tr>
<tr>
<td>Callable</td>
<td></td>
<td>r/w</td>
<td></td>
<td>r/w</td>
<td></td>
</tr>
</tbody>
</table>

### 15.8. Shader Resource Interface

When a shader stage accesses buffer or image resources, as described in the Resource Descriptors section, the shader resource variables must be matched with the pipeline layout that is provided at pipeline creation time.

The set of shader variables that form the shader resource interface for a stage are the variables statically used by that stage's OpEntryPoint with a storage class of Uniform, UniformConstant, StorageBuffer, or PushConstant. For the fragment shader, this includes the fragment input attachment interface.

The shader resource interface consists of two sub-interfaces: the push constant interface and the descriptor set interface.

### 15.8.1. Push Constant Interface

The shader variables defined with a storage class of PushConstant that are statically used by the shader entry points for the pipeline define the push constant interface. They must be:

- typed as OpTypeStruct,
• identified with a Block decoration, and
• laid out explicitly using the Offset, ArrayStride, and MatrixStride decorations as specified in Offset and Stride Assignment.

There must be no more than one push constant block statically used per shader entry point.

Each statically used member of a push constant block must be placed at an Offset such that the entire member is entirely contained within the VkPushConstantRange for each OpEntryPoint that uses it, and the stageFlags for that range must specify the appropriate VkShaderStageFlagBits for that stage. The Offset decoration for any member of a push constant block must not cause the space required for that member to extend outside the range [0, maxPushConstantsSize).

Any member of a push constant block that is declared as an array must only be accessed with dynamically uniform indices.

15.8.2. Descriptor Set Interface

The descriptor set interface is comprised of the shader variables with the storage class of StorageBuffer, Uniform or UniformConstant (including the variables in the fragment input attachment interface) that are statically used by the shader entry points for the pipeline.

These variables must have DescriptorSet and Binding decorations specified, which are assigned and matched with the VkDescriptorSetLayout objects in the pipeline layout as described in DescriptorSet and Binding Assignment.

The Image Format of an OpTypeImage declaration must not be Unknown, for variables which are used for OpImageRead, OpImageSparseRead, or OpImageWrite operations, except under the following conditions:

• For OpImageWrite, if the image format is listed in the storage without format list and if the shaderStorageImageWriteWithoutFormat feature is enabled and the shader module declares the StorageImageWriteWithoutFormat capability.
• For OpImageWrite, if the image format supports VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT and the shader module declares the StorageImageWriteWithoutFormat capability.
• For OpImageRead or OpImageSparseRead, if the image format is listed in the storage without format list and if the shaderStorageImageReadWithoutFormat feature is enabled and the shader module declares the StorageImageReadWithoutFormat capability.
• For OpImageRead or OpImageSparseRead, if the image format supports VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT and the shader module declares the StorageImageReadWithoutFormat capability.
• For OpImageRead, if Dim is SubpassData (indicating a read from an input attachment).

The Image Format of an OpTypeImage declaration must not be Unknown, for variables which are used for OpAtomic* operations.

Variables identified with the Uniform storage class are used to access transparent buffer backed resources. Such variables must be:
• typed as `OpTypeStruct`, or an array of this type,
• identified with a `Block` or `BufferBlock` decoration, and
• laid out explicitly using the `Offset`, `ArrayStride`, and `MatrixStride` decorations as specified in `Offset and Stride Assignment`.

Variables identified with the `StorageBuffer` storage class are used to access transparent buffer backed resources. Such variables **must** be:

• typed as `OpTypeStruct`, or an array of this type,
• identified with a `Block` decoration, and
• laid out explicitly using the `Offset`, `ArrayStride`, and `MatrixStride` decorations as specified in `Offset and Stride Assignment`.

The `Offset` decoration for any member of a `Block`-decorated variable in the `Uniform` storage class **must** not cause the space required for that variable to extend outside the range \([0, \text{maxUniformBufferRange})\). The `Offset` decoration for any member of a `Block`-decorated variable in the `StorageBuffer` storage class **must** not cause the space required for that variable to extend outside the range \([0, \text{maxStorageBufferRange})\).

Variables identified with the `Uniform` storage class **can** also be used to access transparent descriptor set backed resources when the variable is assigned to a descriptor set layout binding with a `descriptorType` of `VK_DESCRIPTOR_TYPE INLINE_UNIFORM_BLOCK`. In this case the variable **must** be typed as `OpTypeStruct` and **cannot** be aggregated into arrays of that type. Further, the `Offset` decoration for any member of such a variable **must** not cause the space required for that variable to extend outside the range \([0, \text{maxInlineUniformBlockSize})\).

Variables identified with a storage class of `UniformConstant` and a decoration of `InputAttachmentIndex` **must** be declared as described in `Fragment Input Attachment Interface`.

SPIR-V variables decorated with a descriptor set and binding that identify a combined image sampler descriptor **can** have a type of `OpTypeImage`, `OpTypeSampler` (`Sampled=1`), or `OpTypeSampledImage`.

Arrays of any of these types **can** be indexed with *constant integral expressions*. The following features **must** be enabled and capabilities **must** be declared in order to index such arrays with dynamically uniform or non-uniform indices:

• Storage images (except storage texel buffers and input attachments):
  • Dynamically uniform: `shaderStorageImageArrayDynamicIndexing` and `StorageImageArrayDynamicIndexing`
  • Non-uniform: `shaderStorageImageArrayNonUniformIndexing` and `StorageImageArrayNonUniformIndexing`

• Storage texel buffers:
  • Dynamically uniform: `shaderStorageTexelBufferArrayDynamicIndexing` and `StorageTexelBufferArrayDynamicIndexing`
  • Non-uniform: `shaderStorageTexelBufferArrayNonUniformIndexing` and `StorageTexelBufferArrayNonUniformIndexing`
• Input attachments:
  ◦ Dynamically uniform: shaderInputAttachmentArrayDynamicIndexing and 
    InputAttachmentArrayDynamicIndexing
  ◦ Non-uniform: shaderInputAttachmentArrayNonUniformIndexing and 
    InputAttachmentArrayNonUniformIndexing

• Sampled images (except uniform texel buffers), samplers and combined image samplers:
  ◦ Dynamically uniform: shaderSampledImageArrayDynamicIndexing and 
    SampledImageArrayDynamicIndexing
  ◦ Non-uniform: shaderSampledImageArrayNonUniformIndexing and 
    SampledImageArrayNonUniformIndexing

• Uniform texel buffers:
  ◦ Dynamically uniform: shaderUniformTexelBufferArrayDynamicIndexing and 
    UniformTexelBufferArrayDynamicIndexing
  ◦ Non-uniform: shaderUniformTexelBufferArrayNonUniformIndexing and 
    UniformTexelBufferArrayNonUniformIndexing

• Uniform buffers:
  ◦ Dynamically uniform: shaderUniformBufferArrayDynamicIndexing and 
    UniformBufferArrayDynamicIndexing
  ◦ Non-uniform: shaderUniformBufferArrayNonUniformIndexing and 
    UniformBufferArrayNonUniformIndexing

• Storage buffers:
  ◦ Dynamically uniform: shaderStorageBufferArrayDynamicIndexing and 
    StorageBufferArrayDynamicIndexing
  ◦ Non-uniform: shaderStorageBufferArrayNonUniformIndexing and 
    StorageBufferArrayNonUniformIndexing

• Acceleration structures:
  ◦ Dynamically uniform: Always supported.
  ◦ Non-uniform: Always supported.

• weight image:
  ◦ Dynamically uniform: Always supported.
  ◦ Non-uniform: Never supported.

• Block matching image:
  ◦ Dynamically uniform: Always supported.
  ◦ Non-uniform: Never supported.

If an instruction loads from or stores to a resource (including atomics and image instructions) and 
the resource descriptor being accessed is not dynamically uniform, then the corresponding non-
uniform indexing feature must be enabled and the capability must be declared. If an instruction 
loads from or stores to a resource (including atomics and image instructions) and the resource
descriptor being accessed is loaded from an array element with a non-constant index, then the corresponding dynamic or non-uniform indexing feature must be enabled and the capability must be declared.

If the combined image sampler enables sampler Y/Cb/Cr conversion or samples a subsampled image, it must be indexed only by constant integral expressions when aggregated into arrays in shader code, irrespective of the shaderSampledImageArrayDynamicIndexing feature.

Table 21. Shader Resource and Descriptor Type Correspondence

<table>
<thead>
<tr>
<th>Resource type</th>
<th>Descriptor Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>sampler</td>
<td>VK_DESCRIPTOR_TYPE_SAMPLER or VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER</td>
</tr>
<tr>
<td>sampled image</td>
<td>VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE or VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER</td>
</tr>
<tr>
<td>storage image</td>
<td>VK_DESCRIPTOR_TYPE_STORAGE_IMAGE</td>
</tr>
<tr>
<td>combined image sampler</td>
<td>VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER</td>
</tr>
<tr>
<td>uniform texel buffer</td>
<td>VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER</td>
</tr>
<tr>
<td>storage texel buffer</td>
<td>VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER</td>
</tr>
<tr>
<td>uniform buffer</td>
<td>VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER or VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC</td>
</tr>
<tr>
<td>storage buffer</td>
<td>VK_DESCRIPTOR_TYPE_STORAGE_BUFFER or VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC</td>
</tr>
<tr>
<td>input attachment</td>
<td>VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT</td>
</tr>
<tr>
<td>inline uniform block</td>
<td>VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK</td>
</tr>
<tr>
<td>acceleration structure</td>
<td>VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR or VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_NV</td>
</tr>
<tr>
<td>weight image</td>
<td>VK_DESCRIPTOR_TYPE_SAMPLE_WEIGHT_IMAGE_QCOM</td>
</tr>
<tr>
<td>block matching image</td>
<td>VK_DESCRIPTOR_TYPE_BLOCK_MATCH_IMAGE_QCOM</td>
</tr>
</tbody>
</table>

Table 22. Shader Resource and Storage Class Correspondence

<table>
<thead>
<tr>
<th>Resource type</th>
<th>Storage Class</th>
<th>Type(^1)</th>
<th>Decoration(s)(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>sampler</td>
<td>UniformConstant</td>
<td>OpTypeSampler</td>
<td></td>
</tr>
<tr>
<td>sampled image</td>
<td>UniformConstant</td>
<td>OpTypeImage (Sampled=1)</td>
<td></td>
</tr>
<tr>
<td>storage image</td>
<td>UniformConstant</td>
<td>OpTypeImage (Sampled=2)</td>
<td></td>
</tr>
<tr>
<td>combined image sampler</td>
<td>UniformConstant</td>
<td>OpTypeSampledImage</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>OpTypeImage (Sampled=1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>OpTypeSampler</td>
<td></td>
</tr>
<tr>
<td>uniform texel buffer</td>
<td>UniformConstant</td>
<td>OpTypeImage (Dim=Buffer, Sampled=1)</td>
<td></td>
</tr>
<tr>
<td>storage texel buffer</td>
<td>UniformConstant</td>
<td>OpTypeImage (Dim=Buffer, Sampled=2)</td>
<td></td>
</tr>
<tr>
<td>Resource type</td>
<td>Storage Class</td>
<td>Type(^1)</td>
<td>Decoration(s)(^2)</td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------------</td>
<td>------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>uniform buffer</td>
<td>Uniform</td>
<td>OpTypeStruct</td>
<td>Block, Offset, (ArrayStride), (MatrixStride)</td>
</tr>
<tr>
<td>storage buffer</td>
<td>Uniform</td>
<td>OpTypeStruct</td>
<td>BufferBlock, Offset, (ArrayStride), (MatrixStride)</td>
</tr>
<tr>
<td>StorageBuffer</td>
<td></td>
<td></td>
<td>Block, Offset, (ArrayStride), (MatrixStride)</td>
</tr>
<tr>
<td>input attachment</td>
<td>UniformConstant</td>
<td>OpTypeImage (Dim =SubpassData, Sampled=2)</td>
<td>InputAttachmentIndex</td>
</tr>
<tr>
<td>inline uniform block</td>
<td>Uniform</td>
<td>OpTypeStruct</td>
<td>Block, Offset, (ArrayStride), (MatrixStride)</td>
</tr>
<tr>
<td>acceleration structure</td>
<td>UniformConstant</td>
<td>OpTypeAccelerationStruct ureKHR</td>
<td></td>
</tr>
<tr>
<td>sample weight image</td>
<td>UniformConstant</td>
<td>OpTypeImage (Depth=0, Dim =2D, Arrayed=1, MS=0, Sampled=1)</td>
<td>WeightTextureQCOM</td>
</tr>
<tr>
<td>block matching image</td>
<td>UniformConstant</td>
<td>OpTypeImage (Depth=0, Dim =2D, Arrayed=0, MS=0, Sampled=1)</td>
<td>BlockMatchTextureQCOM</td>
</tr>
</tbody>
</table>

1

Where `OpTypeImage` is referenced, the `Dim` values `Buffer` and `Subpassdata` are only accepted where they are specifically referenced. They do not correspond to resource types where a generic `OpTypeImage` is specified.

2

In addition to `DescriptorSet` and `Binding`.

### 15.8.3. DescriptorSet and Binding Assignment

A variable decorated with a `DescriptorSet` decoration of s and a `Binding` decoration of b indicates that this variable is associated with the `VkDescriptorSetLayoutBinding` that has a binding equal to b in `pSetLayouts[s]` that was specified in `VkPipelineLayoutCreateInfo`.

`DescriptorSet` decoration values **must** be between zero and `maxBoundDescriptorSets` minus one, inclusive. `Binding` decoration values **can** be any 32-bit unsigned integer value, as described in `Descriptor Set Layout`. Each descriptor set has its own binding name space.

If the `Binding` decoration is used with an array, the entire array is assigned that binding value. The array **must** be a single-dimensional array and size of the array **must** be no larger than the number of descriptors in the binding. If the array is runtime-sized, then array elements greater than or equal to the size of that binding in the bound descriptor set **must** not be used. If the array is runtime-sized, the `runtimeDescriptorArray` feature **must** be enabled and the `RuntimeDescriptorArray`
capability **must** be declared. The index of each element of the array is referred to as the **arrayElement**. For the purposes of interface matching and descriptor set operations, if a resource variable is not an array, it is treated as if it has an arrayElement of zero.

There is a limit on the number of resources of each type that **can** be accessed by a pipeline stage as shown in **Shader Resource Limits**. The “Resources Per Stage” column gives the limit on the number each type of resource that **can** be statically used for an entry point in any given stage in a pipeline. The “Resource Types” column lists which resource types are counted against the limit. Some resource types count against multiple limits. The **VK_DESCRIPTOR_TYPE_MUTABLE_EXT** descriptor type counts as one individual resource and one for every unique resource limit per descriptor set type that is present in the associated binding’s **VkMutableDescriptorTypeListEXT**. If multiple descriptor types in **VkMutableDescriptorTypeListEXT** map to the same resource limit, only one descriptor is consumed for purposes of computing resource limits.

The pipeline layout **may** include descriptor sets and bindings which are not referenced by any variables statically used by the entry points for the shader stages in the binding’s **stageFlags**.

However, if a variable assigned to a given **DescriptorSet** and **Binding** is statically used by the entry point for a shader stage, the pipeline layout **must** contain a descriptor set binding in that descriptor set layout and for that binding number, and that binding’s **stageFlags** **must** include the appropriate **VkShaderStageFlagBits** for that stage. The variable **must** be of a valid resource type determined by its SPIR-V type and storage class, as defined in **Shader Resource and Storage Class Correspondence**. The descriptor set layout binding **must** be of a corresponding descriptor type, as defined in **Shader Resource and Descriptor Type Correspondence**.

**Note**

There are no limits on the number of shader variables that can have overlapping set and binding values in a shader; but which resources are statically used has an impact. If any shader variable identifying a resource is statically used in a shader, then the underlying descriptor bound at the declared set and binding must support the declared type in the shader when the shader executes.

If multiple shader variables are declared with the same set and binding values, and with the same underlying descriptor type, they can all be statically used within the same shader. However, accesses are not automatically synchronized, and **Aliased** decorations should be used to avoid data hazards (see section 2.18.2 **Aliasing in the SPIR-V specification**).

If multiple shader variables with the same set and binding values are declared in a single shader, but with different declared types, where any of those are not supported by the relevant bound descriptor, that shader can only be executed if the variables with the unsupported type are not statically used.

A noteworthy example of using multiple statically-used shader variables sharing the same descriptor set and binding values is a descriptor of type **VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER** that has multiple corresponding shader variables in the **UniformConstant** storage class, where some could be **OpTypeImage** (Sampled=1), some could be **OpTypeSampler**, and some could be **OpTypeSampledImage**.
### Table 23. Shader Resource Limits

<table>
<thead>
<tr>
<th>Resources per Stage</th>
<th>Resource Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>maxPerStageDescriptorSamplers or maxPerStageDescriptorUpdateAfterBindSamplers</td>
<td>sampler</td>
</tr>
<tr>
<td>maxPerStageDescriptorSampledImages or maxPerStageDescriptorUpdateAfterBindSampledImages</td>
<td>combined image sampler</td>
</tr>
<tr>
<td>maxPerStageDescriptorSampledImages or maxPerStageDescriptorUpdateAfterBindSampledImages</td>
<td>sampled image</td>
</tr>
<tr>
<td>maxPerStageDescriptorSampledImages or maxPerStageDescriptorUpdateAfterBindSampledImages</td>
<td>combined image sampler</td>
</tr>
<tr>
<td>maxPerStageDescriptorSampledImages or maxPerStageDescriptorUpdateAfterBindSampledImages</td>
<td>uniform texel buffer</td>
</tr>
<tr>
<td>maxPerStageDescriptorSampledImages or maxPerStageDescriptorUpdateAfterBindSampledImages</td>
<td>sample weight image</td>
</tr>
<tr>
<td>maxPerStageDescriptorSampledImages or maxPerStageDescriptorUpdateAfterBindSampledImages</td>
<td>block matching image</td>
</tr>
<tr>
<td>maxPerStageDescriptorStorageImages or maxPerStageDescriptorUpdateAfterBindStorageImages</td>
<td>storage image</td>
</tr>
<tr>
<td>maxPerStageDescriptorStorageImages or maxPerStageDescriptorUpdateAfterBindStorageImages</td>
<td>storage texel buffer</td>
</tr>
<tr>
<td>maxPerStageDescriptorStorageImages or maxPerStageDescriptorUpdateAfterBindStorageImages</td>
<td>uniform buffer</td>
</tr>
<tr>
<td>maxPerStageDescriptorStorageImages or maxPerStageDescriptorUpdateAfterBindStorageImages</td>
<td>uniform buffer dynamic</td>
</tr>
<tr>
<td>maxPerStageDescriptorStorageImages or maxPerStageDescriptorUpdateAfterBindStorageImages</td>
<td>storage buffer</td>
</tr>
<tr>
<td>maxPerStageDescriptorStorageImages or maxPerStageDescriptorUpdateAfterBindStorageImages</td>
<td>storage buffer dynamic</td>
</tr>
<tr>
<td>maxPerStageDescriptorInputAttachments or maxPerStageDescriptorUpdateAfterBindInputAttachments</td>
<td>input attachment¹</td>
</tr>
<tr>
<td>maxPerStageDescriptorInlineUniformBlocks or maxPerStageDescriptorUpdateAfterBindInlineUniformBlocks</td>
<td>inline uniform block</td>
</tr>
<tr>
<td>VkPhysicalDeviceRayTracingPropertiesNV::maxDescriptorSetAccelerationStructures or maxPerStageDescriptorAccelerationStructures or maxPerStageDescriptorUpdateAfterBindAccelerationStructures</td>
<td>acceleration structure</td>
</tr>
</tbody>
</table>

1

Input attachments can only be used in the fragment shader stage

### 15.8.4. Offset and Stride Assignment

Certain objects must be explicitly laid out using the Offset, ArrayStride, and MatrixStride, as described in SPIR-V explicit layout validation rules. All such layouts also must conform to the following requirements.

**Note**

The numeric order of Offset decorations does not need to follow member declaration order.
Alignment Requirements

There are different alignment requirements depending on the specific resources and on the features enabled on the device.

Matrix types are defined in terms of arrays as follows:

- A column-major matrix with C columns and R rows is equivalent to a C element array of vectors with R components.
- A row-major matrix with C columns and R rows is equivalent to an R element array of vectors with C components.

The scalar alignment of the type of an OpTypeStruct member is defined recursively as follows:

- A scalar of size N has a scalar alignment of N.
- A vector type has a scalar alignment equal to that of its component type.
- An array type has a scalar alignment equal to that of its element type.
- A structure has a scalar alignment equal to the largest scalar alignment of any of its members.
- A matrix type inherits scalar alignment from the equivalent array declaration.

The base alignment of the type of an OpTypeStruct member is defined recursively as follows:

- A scalar has a base alignment equal to its scalar alignment.
- A two-component vector has a base alignment equal to twice its scalar alignment.
- A three- or four-component vector has a base alignment equal to four times its scalar alignment.
- An array has a base alignment equal to the base alignment of its element type.
- A structure has a base alignment equal to the largest base alignment of any of its members. An empty structure has a base alignment equal to the size of the smallest scalar type permitted by the capabilities declared in the SPIR-V module. (e.g., for a 1 byte aligned empty struct in the StorageBuffer storage class, StorageBuffer8BitAccess or UniformAndStorageBuffer8BitAccess must be declared in the SPIR-V module.)
- A matrix type inherits base alignment from the equivalent array declaration.

The extended alignment of the type of an OpTypeStruct member is similarly defined as follows:

- A scalar or vector type has an extended alignment equal to its base alignment.
- An array or structure type has an extended alignment equal to the largest extended alignment of any of its members, rounded up to a multiple of 16.
- A matrix type inherits extended alignment from the equivalent array declaration.

A member is defined to improperly straddle if either of the following are true:

- It is a vector with total size less than or equal to 16 bytes, and has Offset decorations placing its first byte at F and its last byte at L, where floor(F / 16) != floor(L / 16).
- It is a vector with total size greater than 16 bytes and has its Offset decorations placing its first
Standard Buffer Layout

Every member of an OpTypeStruct that is required to be explicitly laid out must be aligned according to the first matching rule as follows. If the struct is contained in pointer types of multiple storage classes, it must satisfy the requirements for every storage class used to reference it.

1. If the scalarBlockLayout feature is enabled on the device and the storage class is Uniform, StorageBuffer, PhysicalStorageBuffer, ShaderRecordBufferKHR, or PushConstant then every member must be aligned according to its scalar alignment.

2. If the workgroupMemoryExplicitLayoutScalarBlockLayout feature is enabled on the device and the storage class is Workgroup then every member must be aligned according to its scalar alignment.

3. All vectors must be aligned according to their scalar alignment.

4. If the uniformBufferStandardLayout feature is not enabled on the device, then any member of an OpTypeStruct with a storage class of Uniform and a decoration of Block must be aligned according to its extended alignment.

5. Every other member must be aligned according to its base alignment.

Note

Even if scalar alignment is supported, it is generally more performant to use the base alignment.

The memory layout must obey the following rules:

- The Offset decoration of any member must be a multiple of its alignment.
- Any ArrayStride or MatrixStride decoration must be a multiple of the alignment of the array or matrix as defined above.

If one of the conditions below applies

- The storage class is Uniform, StorageBuffer, PhysicalStorageBuffer, ShaderRecordBufferKHR, or PushConstant, and the scalarBlockLayout feature is not enabled on the device.
- The storage class is Workgroup, and either the struct member is not part of a Block or the workgroupMemoryExplicitLayoutScalarBlockLayout feature is not enabled on the device.
- The storage class is any other storage class.

the memory layout must also obey the following rules:

- Vectors must not improperly straddle, as defined above.
- The Offset decoration of a member must not place it between the end of a structure, an array or a matrix and the next multiple of the alignment of that structure, array or matrix.

Note

The std430 layout in GLSL satisfies these rules for types using the base alignment. The std140 layout satisfies the rules for types using the extended alignment.
15.9. Built-In Variables

Built-in variables are accessed in shaders by declaring a variable decorated with a \texttt{BuiltIn SPIR-V} decoration. The meaning of each \texttt{BuiltIn} decoration is as follows. In the remainder of this section, the name of a built-in is used interchangeably with a term equivalent to a variable decorated with that particular built-in. Built-ins that represent integer values \textbf{can} be declared as either signed or unsigned 32-bit integers.

As mentioned above, some inputs and outputs have an additional level of arrayness relative to other shader inputs and outputs. This level of arrayness is not included in the type descriptions below, but must be included when declaring the built-in.

\textbf{BaryCoordKHR}

The \texttt{BaryCoordKHR} decoration \textbf{can} be used to decorate a fragment shader input variable. This variable will contain a three-component floating-point vector with barycentric weights that indicate the location of the fragment relative to the screen-space locations of vertices of its primitive, obtained using perspective interpolation.

\textbf{Valid Usage}

- \texttt{VUID-BaryCoordKHR-BaryCoordKHR-04154}
  The \texttt{BaryCoordKHR} decoration \textbf{must} be used only within the \texttt{Fragment Execution Model}
- \texttt{VUID-BaryCoordKHR-BaryCoordKHR-04155}
  The variable decorated with \texttt{BaryCoordKHR} \textbf{must} be declared using the \texttt{Input Storage Class}
- \texttt{VUID-BaryCoordKHR-BaryCoordKHR-04156}
  The variable decorated with \texttt{BaryCoordKHR} \textbf{must} be declared as a three-component vector of 32-bit floating-point values

\textbf{BaryCoordNoPerspAMD}

The \texttt{BaryCoordNoPerspAMD} decoration \textbf{can} be used to decorate a fragment shader input variable. This variable will contain the (I,J) pair of the barycentric coordinates corresponding to the fragment evaluated using linear interpolation at the fragment’s center. The K coordinate of the barycentric coordinates \textbf{can} be derived given the identity $I + J + K = 1.0$.

\textbf{Valid Usage}

- \texttt{VUID-BaryCoordNoPerspAMD-BaryCoordNoPerspAMD-04157}
  The \texttt{BaryCoordNoPerspAMD} decoration \textbf{must} be used only within the \texttt{Fragment Execution Model}
- \texttt{VUID-BaryCoordNoPerspAMD-BaryCoordNoPerspAMD-04158}
  The variable decorated with \texttt{BaryCoordNoPerspAMD} \textbf{must} be declared using the \texttt{Input Storage Class}
- \texttt{VUID-BaryCoordNoPerspAMD-BaryCoordNoPerspAMD-04159}
  The variable decorated with \texttt{BaryCoordNoPerspAMD} \textbf{must} be declared as a two-component vector of 32-bit floating-point values
BaryCoordNoPerspKHR

The BaryCoordNoPerspKHR decoration can be used to decorate a fragment shader input variable. This variable will contain a three-component floating-point vector with barycentric weights that indicate the location of the fragment relative to the screen-space locations of vertices of its primitive, obtained using linear interpolation.

Valid Usage

• VUID-BaryCoordNoPerspKHR-BaryCoordNoPerspKHR-04160
  The BaryCoordNoPerspKHR decoration must be used only within the Fragment Execution Model

• VUID-BaryCoordNoPerspKHR-BaryCoordNoPerspKHR-04161
  The variable decorated with BaryCoordNoPerspKHR must be declared using the Input Storage Class

• VUID-BaryCoordNoPerspKHR-BaryCoordNoPerspKHR-04162
  The variable decorated with BaryCoordNoPerspKHR must be declared as a three-component vector of 32-bit floating-point values

BaryCoordNoPerspCentroidAMD

The BaryCoordNoPerspCentroidAMD decoration can be used to decorate a fragment shader input variable. This variable will contain the (I,J) pair of the barycentric coordinates corresponding to the fragment evaluated using linear interpolation at the centroid. The K coordinate of the barycentric coordinates can be derived given the identity \( I + J + K = 1.0 \).

Valid Usage

• VUID-BaryCoordNoPerspCentroidAMD-BaryCoordNoPerspCentroidAMD-04163
  The BaryCoordNoPerspCentroidAMD decoration must be used only within the Fragment Execution Model

• VUID-BaryCoordNoPerspCentroidAMD-BaryCoordNoPerspCentroidAMD-04164
  The variable decorated with BaryCoordNoPerspCentroidAMD must be declared using the Input Storage Class

• VUID-BaryCoordNoPerspCentroidAMD-BaryCoordNoPerspCentroidAMD-04165
  The variable decorated with BaryCoordNoPerspCentroidAMD must be declared as a three-component vector of 32-bit floating-point values

BaryCoordNoPerspSampleAMD

The BaryCoordNoPerspSampleAMD decoration can be used to decorate a fragment shader input variable. This variable will contain the (I,J) pair of the barycentric coordinates corresponding to the fragment evaluated using linear interpolation at each covered sample. The K coordinate of the barycentric coordinates can be derived given the identity \( I + J + K = 1.0 \).

Valid Usage

The `BaryCoordNoPerspSampleAMD` decoration **must** be used only within the Fragment Execution Model.

The variable decorated with `BaryCoordNoPerspSampleAMD` must be declared using the Input Storage Class.

The variable decorated with `BaryCoordNoPerspSampleAMD` must be declared as a two-component vector of 32-bit floating-point values.

---

**BaryCoordPullModelAMD**

The `BaryCoordPullModelAMD` decoration can be used to decorate a fragment shader input variable. This variable will contain \((1/W, 1/I, 1/J)\) evaluated at the fragment center and can be used to calculate gradients and then interpolate I, J, and W at any desired sample location.

---

### Valid Usage

- **VUID-BaryCoordPullModelAMD-BaryCoordPullModelAMD-04169**
  The `BaryCoordPullModelAMD` decoration must be used only within the Fragment Execution Model.

- **VUID-BaryCoordPullModelAMD-BaryCoordPullModelAMD-04170**
  The variable decorated with `BaryCoordPullModelAMD` must be declared using the Input Storage Class.

- **VUID-BaryCoordPullModelAMD-BaryCoordPullModelAMD-04171**
  The variable decorated with `BaryCoordPullModelAMD` must be declared as a three-component vector of 32-bit floating-point values.

---

**BaryCoordSmoothAMD**

The `BaryCoordSmoothAMD` decoration can be used to decorate a fragment shader input variable. This variable will contain the \((I,J)\) pair of the barycentric coordinates corresponding to the fragment evaluated using perspective interpolation at the fragment's center. The K coordinate of the barycentric coordinates can be derived given the identity \(I + J + K = 1.0\).

---

### Valid Usage

- **VUID-BaryCoordSmoothAMD-BaryCoordSmoothAMD-04172**
  The `BaryCoordSmoothAMD` decoration must be used only within the Fragment Execution Model.

- **VUID-BaryCoordSmoothAMD-BaryCoordSmoothAMD-04173**
  The variable decorated with `BaryCoordSmoothAMD` must be declared using the Input Storage Class.

- **VUID-BaryCoordSmoothAMD-BaryCoordSmoothAMD-04174**
  The variable decorated with `BaryCoordSmoothAMD` must be declared as a two-component vector of 32-bit floating-point values.
BaryCoordSmoothCentroidAMD

The `BaryCoordSmoothCentroidAMD` decoration can be used to decorate a fragment shader input variable. This variable will contain the (I,J) pair of the barycentric coordinates corresponding to the fragment evaluated using perspective interpolation at the centroid. The K coordinate of the barycentric coordinates can be derived given the identity I + J + K = 1.0.

**Valid Usage**

- VUID-BaryCoordSmoothCentroidAMD-BaryCoordSmoothCentroidAMD-04175
  The `BaryCoordSmoothCentroidAMD` decoration must be used only within the Fragment Execution Model

- VUID-BaryCoordSmoothCentroidAMD-BaryCoordSmoothCentroidAMD-04176
  The variable decorated with `BaryCoordSmoothCentroidAMD` must be declared using the Input Storage Class

- VUID-BaryCoordSmoothCentroidAMD-BaryCoordSmoothCentroidAMD-04177
  The variable decorated with `BaryCoordSmoothCentroidAMD` must be declared as a two-component vector of 32-bit floating-point values

BaryCoordSmoothSampleAMD

The `BaryCoordSmoothSampleAMD` decoration can be used to decorate a fragment shader input variable. This variable will contain the (I,J) pair of the barycentric coordinates corresponding to the fragment evaluated using perspective interpolation at each covered sample. The K coordinate of the barycentric coordinates can be derived given the identity I + J + K = 1.0.

**Valid Usage**

- VUID-BaryCoordSmoothSampleAMD-BaryCoordSmoothSampleAMD-04178
  The `BaryCoordSmoothSampleAMD` decoration must be used only within the Fragment Execution Model

- VUID-BaryCoordSmoothSampleAMD-BaryCoordSmoothSampleAMD-04179
  The variable decorated with `BaryCoordSmoothSampleAMD` must be declared using the Input Storage Class

- VUID-BaryCoordSmoothSampleAMD-BaryCoordSmoothSampleAMD-04180
  The variable decorated with `BaryCoordSmoothSampleAMD` must be declared as a two-component vector of 32-bit floating-point values

BaseInstance

Decorating a variable with the `BaseInstance` built-in will make that variable contain the integer value corresponding to the first instance that was passed to the command that invoked the current vertex shader invocation. `BaseInstance` is the `firstInstance` parameter to a direct drawing command or the `firstInstance` member of a structure consumed by an indirect drawing command.
Valid Usage

• VUID-BaseInstance-BaseInstance-04181
  The `BaseInstance` decoration **must** be used only within the Vertex Execution Model

• VUID-BaseInstance-BaseInstance-04182
  The variable decorated with `BaseInstance` **must** be declared using the Input Storage Class

• VUID-BaseInstance-BaseInstance-04183
  The variable decorated with `BaseInstance` **must** be declared as a scalar 32-bit integer value

BaseVertex

Decorating a variable with the `BaseVertex` built-in will make that variable contain the integer value corresponding to the first vertex or vertex offset that was passed to the command that invoked the current vertex shader invocation. For non-indexed drawing commands, this variable is the firstVertex parameter to a direct drawing command or the firstVertex member of the structure consumed by an indirect drawing command. For indexed drawing commands, this variable is the vertexOffset parameter to a direct drawing command or the vertexOffset member of the structure consumed by an indirect drawing command.

Valid Usage

• VUID-BaseVertex-BaseVertex-04184
  The `BaseVertex` decoration **must** be used only within the Vertex Execution Model

• VUID-BaseVertex-BaseVertex-04185
  The variable decorated with `BaseVertex` **must** be declared using the Input Storage Class

• VUID-BaseVertex-BaseVertex-04186
  The variable decorated with `BaseVertex` **must** be declared as a scalar 32-bit integer value

ClipDistance

Decorating a variable with the `ClipDistance` built-in decoration will make that variable contain the mechanism for controlling user clipping. `ClipDistance` is an array such that the i\(^{th}\) element of the array specifies the clip distance for plane i. A clip distance of 0 means the vertex is on the plane, a positive distance means the vertex is inside the clip half-space, and a negative distance means the vertex is outside the clip half-space.

**Note**

The array variable decorated with `ClipDistance` is explicitly sized by the shader.

**Note**

In the last pre-rasterization shader stage, these values will be linearly interpolated across the primitive and the portion of the primitive with interpolated distances less than 0 will be considered outside the clip volume. If `ClipDistance` is then used by a fragment shader, `ClipDistance` contains these linearly interpolated values.
Valid Usage

- VUID-ClipDistance-ClipDistance-04187
  The ClipDistance decoration **must** be used only within the MeshEXT, MeshNV, Vertex, Fragment, TessellationControl, TessellationEvaluation, or Geometry Execution Model.

- VUID-ClipDistance-ClipDistance-04188
  The variable decorated with ClipDistance within the MeshEXT, MeshNV, or Vertex Execution Model **must** be declared using the Output Storage Class.

- VUID-ClipDistance-ClipDistance-04189
  The variable decorated with ClipDistance within the Fragment Execution Model **must** be declared using the Input Storage Class.

- VUID-ClipDistance-ClipDistance-04190
  The variable decorated with ClipDistance within the TessellationControl, TessellationEvaluation, or Geometry Execution Model **must** not be declared in a Storage Class other than Input or Output.

- VUID-ClipDistance-ClipDistance-04191
  The variable decorated with ClipDistance **must** be declared as an array of 32-bit floating-point values.

ClipDistancePerViewNV

Decorating a variable with the ClipDistancePerViewNV built-in decoration will make that variable contain the per-view clip distances. The per-view clip distances have the same semantics as ClipDistance.

Valid Usage

- VUID-ClipDistancePerViewNV-ClipDistancePerViewNV-04192
  The ClipDistancePerViewNV decoration **must** be used only within the MeshNV Execution Model.

- VUID-ClipDistancePerViewNV-ClipDistancePerViewNV-04193
  The variable decorated with ClipDistancePerViewNV **must** be declared using the Output Storage Class.

- VUID-ClipDistancePerViewNV-ClipDistancePerViewNV-04194
  The variable decorated with ClipDistancePerViewNV **must** also be decorated with the PerViewNV decoration.

- VUID-ClipDistancePerViewNV-ClipDistancePerViewNV-04195
  The variable decorated with ClipDistancePerViewNV **must** be declared as a two-dimensional array of 32-bit floating-point values.

ClusterIDHUAWEI

The ClusterIDHUAWEI decoration can be used to decorate a cluster culling shader output variable, this variable will contain an integer value that specifies the id of cluster being rendered by this drawing command. When Cluster Culling Shader enable, ClusterIDHUAWEI will replace gl_DrawID pass to vertex shader for cluster-related information fetching.
Valid Usage

• VUID-ClusterIDHUAWEI-ClusterIDHUAWEI-07797
  The ClusterIDHUAWEI decoration must be used only within the ClusterCullingHUAWEI Execution Model

• VUID-ClusterIDHUAWEI-ClusterIDHUAWEI-07798
  The variable decorated with ClusterIDHUAWEI must be declared as a scalar 32-bit integer value

CullDistance

Decorating a variable with the CullDistance built-in decoration will make that variable contain the mechanism for controlling user culling. If any member of this array is assigned a negative value for all vertices belonging to a primitive, then the primitive is discarded before rasterization.

Note

In fragment shaders, the values of the CullDistance array are linearly interpolated across each primitive.

Note

If CullDistance decorates an input variable, that variable will contain the corresponding value from the CullDistance decorated output variable from the previous shader stage.

Valid Usage

• VUID-CullDistance-CullDistance-04196
  The CullDistance decoration must be used only within the MeshEXT, MeshNV, Vertex, Fragment, TessellationControl, TessellationEvaluation, or Geometry Execution Model

• VUID-CullDistance-CullDistance-04197
  The variable decorated with CullDistance within the MeshEXT, MeshNV or Vertex Execution Model must be declared using the Output Storage Class

• VUID-CullDistance-CullDistance-04198
  The variable decorated with CullDistance within the Fragment Execution Model must be declared using the Input Storage Class

• VUID-CullDistance-CullDistance-04199
  The variable decorated with CullDistance within the TessellationControl, TessellationEvaluation, or Geometry Execution Model must not be declared using a Storage Class other than Input or Output

• VUID-CullDistance-CullDistance-04200
  The variable decorated with CullDistance must be declared as an array of 32-bit floating-point values
CullDistancePerViewNV

Decorating a variable with the `CullDistancePerViewNV` built-in decoration will make that variable contain the per-view cull distances. The per-view cull distances have the same semantics as `CullDistance`.

**Valid Usage**

- VUID-CullDistancePerViewNV-CullDistancePerViewNV-04201
  The `CullDistancePerViewNV` decoration **must** be used only within the MeshNV Execution Model

- VUID-CullDistancePerViewNV-CullDistancePerViewNV-04202
  The variable decorated with `CullDistancePerViewNV` **must** be declared using the Output Storage Class

- VUID-CullDistancePerViewNV-CullDistancePerViewNV-04203
  The variable decorated with `CullDistancePerViewNV` **must** also be decorated with the PerViewNV decoration

- VUID-CullDistancePerViewNV-CullDistancePerViewNV-04204
  The variable decorated with `CullDistancePerViewNV` **must** be declared as a two-dimensional array of 32-bit floating-point values

CullPrimitiveEXT

Decorating a variable with the `CullPrimitiveEXT` built-in decoration will make that variable contain the culling state of output primitives. If the per-primitive boolean value is `true`, the primitive will be culled, if it is `false` it will not be culled.

**Valid Usage**

- VUID-CullPrimitiveEXT-CullPrimitiveEXT-07034
  The `CullPrimitiveEXT` decoration **must** be used only within the MeshEXT Execution Model

- VUID-CullPrimitiveEXT-CullPrimitiveEXT-07035
  The variable decorated with `CullPrimitiveEXT` **must** be declared using the Output Storage Class

- VUID-CullPrimitiveEXT-CullPrimitiveEXT-07036
  The variable decorated with `CullPrimitiveEXT` **must** be declared as an array of boolean values

- VUID-CullPrimitiveEXT-CullPrimitiveEXT-07037
  The size of the array decorated with `CullPrimitiveEXT` **must** match the value specified by OutputPrimitivesEXT

- VUID-CullPrimitiveEXT-CullPrimitiveEXT-07038
  The variable decorated with `CullPrimitiveEXT` within the MeshEXT Execution Model **must** also be decorated with the PerPrimitiveEXT decoration

CullMaskKHR

A variable decorated with the `CullMaskKHR` decoration will specify the cull mask of the ray being
processed. The value is given by the Cull Mask parameter passed into one of the OpTrace* instructions.

Valid Usage

- VUID-CullMaskKHR-CullMaskKHR-06735
  The CullMaskKHR decoration must be used only within the IntersectionKHR, AnyHitKHR, ClosestHitKHR, or MissKHR Execution Model

- VUID-CullMaskKHR-CullMaskKHR-06736
  The variable decorated with CullMaskKHR must be declared using the Input Storage Class

- VUID-CullMaskKHR-CullMaskKHR-06737
  The variable decorated with CullMaskKHR must be declared as a scalar 32-bit integer value

CurrentRayTimeNV
A variable decorated with the CurrentRayTimeNV decoration contains the time value passed in to OpTraceRayMotionNV which called this shader.

Valid Usage

- VUID-CurrentRayTimeNV-CurrentRayTimeNV-04942
  The CurrentRayTimeNV decoration must be used only within the IntersectionKHR, AnyHitKHR, ClosestHitKHR, or MissKHR Execution Model

- VUID-CurrentRayTimeNV-CurrentRayTimeNV-04943
  The variable decorated with CurrentRayTimeNV must be declared using the Input Storage Class

- VUID-CurrentRayTimeNV-CurrentRayTimeNV-04944
  The variable decorated with CurrentRayTimeNV must be declared as a scalar 32-bit floating-point value

DeviceIndex
The DeviceIndex decoration can be applied to a shader input which will be filled with the device index of the physical device that is executing the current shader invocation. This value will be in the range \( [0, \max(1, \text{physicalDeviceCount})] \), where physicalDeviceCount is the physicalDeviceCount member of VkDeviceGroupDeviceCreateInfo.

Valid Usage

- VUID-DeviceIndex-DeviceIndex-04205
  The variable decorated with DeviceIndex must be declared using the Input Storage Class

- VUID-DeviceIndex-DeviceIndex-04206
  The variable decorated with DeviceIndex must be declared as a scalar 32-bit integer value
**DrawIndex**

Decorating a variable with the `DrawIndex` built-in will make that variable contain the integer value corresponding to the zero-based index of the draw that invoked the current task, mesh, or vertex shader invocation. For *indirect drawing commands*, `DrawIndex` begins at zero and increments by one for each draw executed. The number of draws is given by the `drawCount` parameter. For *direct drawing commands*, if `vkCmdDrawMultiEXT` or `vkCmdDrawMultiIndexedEXT` is used, this variable contains the integer value corresponding to the zero-based index of the draw. Otherwise `DrawIndex` is always zero. `DrawIndex` is dynamically uniform.

When task or mesh shaders are used, only the first active stage will have proper access to the variable. The value read by other stages is undefined.

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**Valid Usage**

- **VUID-DrawIndex-DrawIndex-04207**
  The `DrawIndex` decoration must be used only within the `Vertex`, `MeshEXT`, `TaskEXT`, `MeshNV`, or `TaskNV Execution Model`

- **VUID-DrawIndex-DrawIndex-04208**
  The variable decorated with `DrawIndex` must be declared using the `Input Storage Class`

- **VUID-DrawIndex-DrawIndex-04209**
  The variable decorated with `DrawIndex` must be declared as a scalar 32-bit integer value

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**FirstIndexHUAWEI**

The `FirstIndexHUAWEI` decoration can be used to decorate a cluster culling shader output variable, this indexed mode specific variable will contain an integer value that specifies the base index within the index buffer corresponding to a cluster.

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**Valid Usage**

- **VUID-FirstIndexHUAWEI-FirstIndexHUAWEI-07799**
  The `FirstIndexHUAWEI` decoration must be used only within the `ClusterCullingHUAWEI Execution Model`

- **VUID-FirstIndexHUAWEI-FirstIndexHUAWEI-07800**
  The variable decorated with `FirstIndexHUAWEI` must be declared as a scalar 32-bit integer value

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**FragCoord**

Decorating a variable with the `FragCoord` built-in decoration will make that variable contain the framebuffer coordinate \((x, y, z, w)\) of the fragment being processed. The \((x,y)\) coordinate \((0,0)\) is the upper left corner of the upper left pixel in the framebuffer.

When Sample Shading is enabled, the x and y components of `FragCoord` reflect the location of one of the samples corresponding to the shader invocation.
Otherwise, the x and y components of FragCoord reflect the location of the center of the fragment.

The z component of FragCoord is the interpolated depth value of the primitive.

The w component is the interpolated \( \frac{1}{w} \).

The Centroid interpolation decoration is ignored, but allowed, on FragCoord.

**Valid Usage**

- VUID-FragCoord-FragCoord-04210
  The FragCoord decoration must be used only within the Fragment Execution Model

- VUID-FragCoord-FragCoord-04211
  The variable decorated with FragCoord must be declared using the Input Storage Class

- VUID-FragCoord-FragCoord-04212
  The variable decorated with FragCoord must be declared as a four-component vector of 32-bit floating-point values

**FragDepth**

To have a shader supply a fragment-depth value, the shader must declare the DepthReplacing execution mode. Such a shader’s fragment-depth value will come from the variable decorated with the FragDepth built-in decoration.

This value will be used for any subsequent depth testing performed by the implementation or writes to the depth attachment. See fragment shader depth replacement for details.

**Valid Usage**

- VUID-FragDepth-FragDepth-04213
  The FragDepth decoration must be used only within the Fragment Execution Model

- VUID-FragDepth-FragDepth-04214
  The variable decorated with FragDepth must be declared using the Output Storage Class

- VUID-FragDepth-FragDepth-04215
  The variable decorated with FragDepth must be declared as a scalar 32-bit floating-point value

- VUID-FragDepth-FragDepth-04216
  If the shader dynamically writes to the variable decorated with FragDepth, the DepthReplacing Execution Mode must be declared

**FirstInstanceHUawei**

The FirstInstanceHUawei decoration can be used to decorate a cluster culling shader output variable, this variable will contain an integer value that specifies the instance ID of the first instance to draw.
Valid Usage

- VUID-FirstInstanceHUAWEI-FirstInstanceHUAWEI-07801
  The `FirstInstanceHUAWEI` decoration **must** be used only within the `ClusterCullingHUAWEI` Execution Model

- VUID-FirstInstanceHUAWEI-FirstInstanceHUAWEI-07802
  The variable decorated with `FirstInstanceHUAWEI` **must** be declared as a scalar 32-bit integer value

FirstVertexHUAWEI

The `FirstVertexHUAWEI` decoration can be used to decorate a cluster culling shader output variable, this non-indexed mode specific variable will contain an integer value that specifies the index of the first vertex in a cluster to draw.

Valid Usage

- VUID-FirstVertexHUAWEI-FirstVertexHUAWEI-07803
  The `FirstVertexHUAWEI` decoration **must** be used only within the `FirstVertexHUAWEI` Execution Model

- VUID-FirstVertexHUAWEI-FirstVertexHUAWEI-07804
  The variable decorated with `FirstVertexHUAWEI` **must** be declared as a scalar 32-bit integer value

FragInvocationCountEXT

Decorating a variable with the `FragInvocationCountEXT` built-in decoration will make that variable contain the maximum number of fragment shader invocations for the fragment, as determined by `minSampleShading`.

If Sample Shading is not enabled, `FragInvocationCountEXT` will be filled with a value of 1.

Valid Usage

- VUID-FragInvocationCountEXT-FragInvocationCountEXT-04217
  The `FragInvocationCountEXT` decoration **must** be used only within the Fragment Execution Model

- VUID-FragInvocationCountEXT-FragInvocationCountEXT-04218
  The variable decorated with `FragInvocationCountEXT` **must** be declared using the Input Storage Class

- VUID-FragInvocationCountEXT-FragInvocationCountEXT-04219
  The variable decorated with `FragInvocationCountEXT` **must** be declared as a scalar 32-bit integer value
**FragSizeEXT**

Decorating a variable with the `FragSizeEXT` built-in decoration will make that variable contain the dimensions in pixels of the area that the fragment covers for that invocation.

If fragment density map is not enabled, `FragSizeEXT` will be filled with a value of (1,1).

**Valid Usage**

- **VUID-FragSizeEXT-FragSizeEXT-04220**
  The `FragSizeEXT` decoration must be used only within the Fragment Execution Model

- **VUID-FragSizeEXT-FragSizeEXT-04221**
  The variable decorated with `FragSizeEXT` must be declared using the Input Storage Class

- **VUID-FragSizeEXT-FragSizeEXT-04222**
  The variable decorated with `FragSizeEXT` must be declared as a two-component vector of 32-bit integer values

**FragStencilRefEXT**

Decorating a variable with the `FragStencilRefEXT` built-in decoration will make that variable contain the new stencil reference value for all samples covered by the fragment. This value will be used as the stencil reference value used in stencil testing.

To write to `FragStencilRefEXT`, a shader must declare the `StencilRefReplacingEXT` execution mode. If a shader declares the `StencilRefReplacingEXT` execution mode and there is an execution path through the shader that does not set `FragStencilRefEXT`, then the fragment's stencil reference value is undefined for executions of the shader that take that path.

Only the least significant \( s \) bits of the integer value of the variable decorated with `FragStencilRefEXT` are considered for stencil testing, where \( s \) is the number of bits in the stencil framebuffer attachment, and higher order bits are discarded.

See fragment shader stencil reference replacement for more details.

**Valid Usage**

- **VUID-FragStencilRefEXT-FragStencilRefEXT-04223**
  The `FragStencilRefEXT` decoration must be used only within the Fragment Execution Model

- **VUID-FragStencilRefEXT-FragStencilRefEXT-04224**
  The variable decorated with `FragStencilRefEXT` must be declared using the Output Storage Class

- **VUID-FragStencilRefEXT-FragStencilRefEXT-04225**
  The variable decorated with `FragStencilRefEXT` must be declared as a scalar integer value

**FragmentSizeNV**

Decorating a variable with the `FragmentSizeNV` built-in decoration will make that variable contain the width and height of the fragment.
Valid Usage

- VUID-FragmentSizeNV-FragmentSizeNV-04226
  The FragmentSizeNV decoration must be used only within the Fragment Execution Model

- VUID-FragmentSizeNV-FragmentSizeNV-04227
  The variable decorated with FragmentSizeNV must be declared using the Input Storage Class

- VUID-FragmentSizeNV-FragmentSizeNV-04228
  The variable decorated with FragmentSizeNV must be declared as a two-component vector of 32-bit integer values

FrontFacing

Decorating a variable with the FrontFacing built-in decoration will make that variable contain whether the fragment is front or back facing. This variable is non-zero if the current fragment is considered to be part of a front-facing polygon primitive or of a non-polygon primitive and is zero if the fragment is considered to be part of a back-facing polygon primitive.

Valid Usage

- VUID-FrontFacing-FrontFacing-04229
  The FrontFacing decoration must be used only within the Fragment Execution Model

- VUID-FrontFacing-FrontFacing-04230
  The variable decorated with FrontFacing must be declared using the Input Storage Class

- VUID-FrontFacing-FrontFacing-04231
  The variable decorated with FrontFacing must be declared as a boolean value

FullyCoveredEXT

Decorating a variable with the FullyCoveredEXT built-in decoration will make that variable indicate whether the fragment area is fully covered by the generating primitive. This variable is non-zero if conservative rasterization is enabled and the current fragment area is fully covered by the generating primitive, and is zero if the fragment is not covered or partially covered, or conservative rasterization is disabled.

Valid Usage

- VUID-FullyCoveredEXT-FullyCoveredEXT-04232
  The FullyCoveredEXT decoration must be used only within the Fragment Execution Model

- VUID-FullyCoveredEXT-FullyCoveredEXT-04233
  The variable decorated with FullyCoveredEXT must be declared using the Input Storage Class

- VUID-FullyCoveredEXT-FullyCoveredEXT-04234
  The variable decorated with FullyCoveredEXT must be declared as a boolean value
If \texttt{VkPhysicalDeviceConservativeRasterizationPropertiesEXT}::\texttt{conservativeRasterizationPostDepthCoverage} is not supported the \texttt{PostDepthCoverage} Execution Mode \textbf{must} not be declared, when a variable with the \texttt{FullyCoveredEXT} decoration is declared

### GlobalInvocationId

Decorating a variable with the \texttt{GlobalInvocationId} built-in decoration will make that variable contain the location of the current invocation within the global workgroup. Each component is equal to the index of the local workgroup multiplied by the size of the local workgroup plus \texttt{LocalInvocationId}.

### Valid Usage

- \textbf{VUID-GlobalInvocationId-GlobalInvocationId-04236}
  The \texttt{GlobalInvocationId} decoration \textbf{must} be used only within the \texttt{GLCompute}, \texttt{MeshEXT}, \texttt{TaskEXT}, \texttt{MeshNV}, or \texttt{TaskNV} Execution Model
- \textbf{VUID-GlobalInvocationId-GlobalInvocationId-04237}
  The variable decorated with \texttt{GlobalInvocationId} \textbf{must} be declared using the Input Storage Class
- \textbf{VUID-GlobalInvocationId-GlobalInvocationId-04238}
  The variable decorated with \texttt{GlobalInvocationId} \textbf{must} be declared as a three-component vector of 32-bit integer values

### HelperInvocation

Decorating a variable with the \texttt{HelperInvocation} built-in decoration will make that variable contain whether the current invocation is a helper invocation. This variable is non-zero if the current fragment being shaded is a helper invocation and zero otherwise. A helper invocation is an invocation of the shader that is produced to satisfy internal requirements such as the generation of derivatives.

\begin{itemize}
  \item Note
    It is very likely that a helper invocation will have a value of \texttt{SampleMask} fragment shader input value that is zero.
\end{itemize}

### Valid Usage

- \textbf{VUID-HelperInvocation-HelperInvocation-04239}
  The \texttt{HelperInvocation} decoration \textbf{must} be used only within the Fragment Execution Model
- \textbf{VUID-HelperInvocation-HelperInvocation-04240}
  The variable decorated with \texttt{HelperInvocation} \textbf{must} be declared using the Input Storage Class
- \textbf{VUID-HelperInvocation-HelperInvocation-04241}

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The variable decorated with HelperInvocation must be declared as a boolean value

**HitKindKHR**

A variable decorated with the HitKindKHR decoration will describe the intersection that triggered the execution of the current shader. The values are determined by the intersection shader. For user-defined intersection shaders this is the value that was passed to the “Hit Kind” operand of OpReportIntersectionKHR. For triangle intersection candidates, this will be one of HitKindFrontFacingTriangleKHR or HitKindBackFacingTriangleKHR.

**Valid Usage**

- VUID-HitKindKHR-HitKindKHR-04242
  The HitKindKHR decoration must be used only within the AnyHitKHR or ClosestHitKHR Execution Model
- VUID-HitKindKHR-HitKindKHR-04243
  The variable decorated with HitKindKHR must be declared using the Input Storage Class
- VUID-HitKindKHR-HitKindKHR-04244
  The variable decorated with HitKindKHR must be declared as a scalar 32-bit integer value

**HitTNV**

A variable decorated with the HitTNV decoration is equivalent to a variable decorated with the RayTmaxKHR decoration.

**Valid Usage**

- VUID-HitTNV-HitTNV-04245
  The HitTNV decoration must be used only within the AnyHitNV or ClosestHitNV Execution Model
- VUID-HitTNV-HitTNV-04246
  The variable decorated with HitTNV must be declared using the Input Storage Class
- VUID-HitTNV-HitTNV-04247
  The variable decorated with HitTNV must be declared as a scalar 32-bit floating-point value

**HitTriangleVertexPositionsKHR**

A variable decorated with the HitTriangleVertexPositionsKHR decoration will specify the object space vertices of the triangle at the current intersection in application-provided order. The positions returned are transformed by the geometry transform, which is performed at standard floating point precision, but without a specifically defined order of floating point operations to perform the matrix multiplication.
Valid Usage

• VUID-HitTriangleVertexPositionsKHR-HitTriangleVertexPositionsKHR-08747
  The HitTriangleVertexPositionsKHR decoration must be used only within the AnyHitKHR or ClosestHitKHR Execution Model

• VUID-HitTriangleVertexPositionsKHR-HitTriangleVertexPositionsKHR-08748
  The variable decorated with HitTriangleVertexPositionsKHR must be declared using the Input Storage Class

• VUID-HitTriangleVertexPositionsKHR-HitTriangleVertexPositionsKHR-08749
  The variable decorated with HitTriangleVertexPositionsKHR must be declared as an array of three vectors of three 32-bit float values

• VUID-HitTriangleVertexPositionsKHR-HitTriangleVertexPositionsKHR-08750
  The variable decorated with HitTriangleVertexPositionsKHR must be used only if the value of HitKindKHR is HitKindFrontFacingTriangleKHR or HitKindBackFacingTriangleKHR

• VUID-HitTriangleVertexPositionsKHR-None-08751
  The acceleration structure corresponding to the current intersection must have been built with VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_DATA_ACCESS_KHR

IncomingRayFlagsKHR

A variable with the IncomingRayFlagsKHR decoration will contain the ray flags passed in to the trace call that invoked this particular shader. Setting pipeline flags on the raytracing pipeline must not cause any corresponding flags to be set in variables with this decoration.

Valid Usage

• VUID-IncomingRayFlagsKHR-IncomingRayFlagsKHR-04248
  The IncomingRayFlagsKHR decoration must be used only within the IntersectionKHR, AnyHitKHR, ClosestHitKHR, or MissKHR Execution Model

• VUID-IncomingRayFlagsKHR-IncomingRayFlagsKHR-04249
  The variable decorated with IncomingRayFlagsKHR must be declared using the Input Storage Class

• VUID-IncomingRayFlagsKHR-IncomingRayFlagsKHR-04250
  The variable decorated with IncomingRayFlagsKHR must be declared as a scalar 32-bit integer value

IndexCountHUAWEI

The IndexCountHUAWEI decoration can be used to decorate a cluster culling shader output variable, this indexed mode specific variable will contain an integer value that specifies the number of indexed vertices in a cluster to draw.

Valid Usage

• VUID-IndexCountHUAWEI-IndexCountHUAWEI-07805
The `IndexCountHUAWEI` decoration must be used only within the `ClusterCullingHUAWEI Execution Model`.

- VUID-IndexCountHUAWEI-IndexCountHUAWEI-07806
  The variable decorated with `IndexCountHUAWEI` must be declared as a scalar 32-bit integer value.

**InstanceCountHUAWEI**

The `InstanceCountHUAWEI` decoration can be used to decorate a cluster culling shader output variable, this variable will contain an integer value that specifies the number of instances to draw in a cluster.

**Valid Usage**

- VUID-InstanceCountHUAWEI-InstanceCountHUAWEI-07807
  The `InstanceCountHUAWEI` decoration must be used only within the `ClusterCullingHUAWEI Execution Model`.

- VUID-InstanceCountHUAWEI-InstanceCountHUAWEI-07808
  The variable decorated with `InstanceCountHUAWEI` must be declared as a scalar 32-bit integer value.

**InstanceCustomIndexKHR**

A variable decorated with the `InstanceCustomIndexKHR` decoration will contain the application-defined value of the instance that intersects the current ray. This variable contains the value that was specified in `VkAccelerationStructureInstanceKHR::instanceCustomIndex` for the current acceleration structure instance in the lower 24 bits and the upper 8 bits will be zero.

**Valid Usage**

- VUID-InstanceCustomIndexKHR-InstanceCustomIndexKHR-04251
  The `InstanceCustomIndexKHR` decoration must be used only within the `IntersectionKHR, AnyHitKHR, or ClosestHitKHR Execution Model`.

- VUID-InstanceCustomIndexKHR-InstanceCustomIndexKHR-04252
  The variable decorated with `InstanceCustomIndexKHR` must be declared using the `Input Storage Class`.

- VUID-InstanceCustomIndexKHR-InstanceCustomIndexKHR-04253
  The variable decorated with `InstanceCustomIndexKHR` must be declared as a scalar 32-bit integer value.

**InstanceId**

Decorating a variable in an intersection, any-hit, or closest hit shader with the `InstanceId` decoration will make that variable contain the index of the instance that intersects the current ray.
Valid Usage

• VUID-InstanceId-InstanceId-04254
  The `InstanceId` decoration must be used only within the `IntersectionKHR`, `AnyHitKHR`, or `ClosestHitKHR` Execution Model

• VUID-InstanceId-InstanceId-04255
  The variable decorated with `InstanceId` must be declared using the `Input Storage Class`

• VUID-InstanceId-InstanceId-04256
  The variable decorated with `InstanceId` must be declared as a scalar 32-bit integer value

InvocationId

Decorating a variable with the `InvocationId` built-in decoration will make that variable contain the index of the current shader invocation in a geometry shader, or the index of the output patch vertex in a tessellation control shader.

In a geometry shader, the index of the current shader invocation ranges from zero to the number of instances declared in the shader minus one. If the instance count of the geometry shader is one or is not specified, then `InvocationId` will be zero.

Valid Usage

• VUID-InvocationId-InvocationId-04257
  The `InvocationId` decoration must be used only within the `TessellationControl` or `Geometry Execution Model`

• VUID-InvocationId-InvocationId-04258
  The variable decorated with `InvocationId` must be declared using the `Input Storage Class`

• VUID-InvocationId-InvocationId-04259
  The variable decorated with `InvocationId` must be declared as a scalar 32-bit integer value

InvocationsPerPixelNV

Decorating a variable with the `InvocationsPerPixelNV` built-in decoration will make that variable contain the maximum number of fragment shader invocations per pixel, as derived from the effective shading rate for the fragment. If a primitive does not fully cover a pixel, the number of fragment shader invocations for that pixel may be less than the value of `InvocationsPerPixelNV`. If the shading rate indicates a fragment covering multiple pixels, then `InvocationsPerPixelNV` will be one.

Valid Usage

• VUID-InvocationsPerPixelNV-InvocationsPerPixelNV-04260
  The `InvocationsPerPixelNV` decoration must be used only within the `Fragment Execution Model`
The variable decorated with `InvocationsPerPixelNV` must be declared using the Input Storage Class.

The variable decorated with `InvocationsPerPixelNV` must be declared as a scalar 32-bit integer value.

**InstanceIndex**

Decorating a variable in a vertex shader with the `InstanceIndex` built-in decoration will make that variable contain the index of the instance that is being processed by the current vertex shader invocation. `InstanceIndex` begins at the `firstInstance` parameter to `vkCmdDraw` or `vkCmdDrawIndexed` or at the `firstInstance` member of a structure consumed by `vkCmdDrawIndirect` or `vkCmdDrawIndexedIndirect`.

**Valid Usage**

- **VUID-InstanceIndex-InstanceIndex-04263**
  The `InstanceIndex` decoration must be used only within the Vertex Execution Model.

- **VUID-InstanceIndex-InstanceIndex-04264**
  The variable decorated with `InstanceIndex` must be declared using the Input Storage Class.

- **VUID-InstanceIndex-InstanceIndex-04265**
  The variable decorated with `InstanceIndex` must be declared as a scalar 32-bit integer value.

**LaunchIdKHR**

A variable decorated with the `LaunchIdKHR` decoration will specify the index of the work item being processed. One work item is generated for each of the `width` × `height` × `depth` items dispatched by a `vkCmdTraceRaysKHR` command. All shader invocations inherit the same value for variables decorated with `LaunchIdKHR`.

**Valid Usage**

- **VUID-LaunchIdKHR-LaunchIdKHR-04266**
  The `LaunchIdKHR` decoration must be used only within the RayGenerationKHR, IntersectionKHR, AnyHitKHR, ClosestHitKHR, MissKHR, or CallableKHR Execution Model.

- **VUID-LaunchIdKHR-LaunchIdKHR-04267**
  The variable decorated with `LaunchIdKHR` must be declared using the Input Storage Class.

- **VUID-LaunchIdKHR-LaunchIdKHR-04268**
  The variable decorated with `LaunchIdKHR` must be declared as a three-component vector of 32-bit integer values.

**LaunchSizeKHR**

A variable decorated with the `LaunchSizeKHR` decoration will contain the `width`, `height`, and `depth`.
dimensions passed to the `vkCmdTraceRaysKHR` command that initiated this shader execution. The \textit{width} is in the first component, the \textit{height} is in the second component, and the \textit{depth} is in the third component.

**Valid Usage**

- VUID-LaunchSizeKHR-LaunchSizeKHR-04269
  The \textbf{LaunchSizeKHR} decoration \textbf{must} be used only within the \textbf{RayGenerationKHR}, \textbf{IntersectionKHR}, \textbf{AnyHitKHR}, \textbf{ClosestHitKHR}, \textbf{MissKHR}, or \textbf{CallableKHR} Execution Model.

- VUID-LaunchSizeKHR-LaunchSizeKHR-04270
  The variable decorated with \textbf{LaunchSizeKHR} \textbf{must} be declared using the \textbf{Input Storage Class}.

- VUID-LaunchSizeKHR-LaunchSizeKHR-04271
  The variable decorated with \textbf{LaunchSizeKHR} \textbf{must} be declared as a three-component vector of 32-bit integer values.

**Layer**

Decorating a variable with the \textit{Layer} built-in decoration will make that variable contain the select layer of a multi-layer framebuffer attachment.

In a mesh, vertex, tessellation evaluation, or geometry shader, any variable decorated with \textit{Layer} can be written with the framebuffer layer index to which the primitive produced by that shader will be directed.

The last active \textbf{pre-rasterization shader stage} (in pipeline order) controls the \textit{Layer} that is used. Outputs in previous shader stages are not used, even if the last stage fails to write the \textit{Layer}.

If the last active \textbf{pre-rasterization shader stage} shader entry point's interface does not include a variable decorated with \textit{Layer}, then the first layer is used. If a \textbf{pre-rasterization shader stage} shader entry point's interface includes a variable decorated with \textit{Layer}, it \textbf{must} write the same value to \textit{Layer} for all output vertices of a given primitive. If the \textit{Layer} value is less than 0 or greater than or equal to the number of layers in the framebuffer, then primitives \textbf{may} still be rasterized, fragment shaders \textbf{may} be executed, and the framebuffer values for all layers are undefined. In a mesh shader this also applies when the \textit{Layer} value is greater than or equal to the \textit{maxMeshOutputLayers} limit.

If a variable with the \textit{Layer} decoration is also decorated with \textbf{ViewportRelativeNV}, then the \textbf{ViewportIndex} is added to the layer that is used for rendering and that is made available in the fragment shader.

If the shader writes to a variable decorated \textbf{ViewportMaskNV}, then the layer selected has a different value for each viewport a primitive is rendered to.

In a fragment shader, a variable decorated with \textit{Layer} contains the layer index of the primitive that the fragment invocation belongs to.
Valid Usage

- VUID-Layer-Layer-04272
  The Layer decoration **must** be used only within the MeshEXT, MeshNV, Vertex, TessellationEvaluation, Geometry, or Fragment Execution Model.

- VUID-Layer-Layer-04273
  If the shaderOutputLayer feature is not enabled then the Layer decoration **must** be used only within the Geometry or Fragment Execution Model.

- VUID-Layer-Layer-04274
  The variable decorated with Layer within the MeshEXT, MeshNV, Vertex, TessellationEvaluation, or Geometry Execution Model **must** be declared using the Output Storage Class.

- VUID-Layer-Layer-04275
  The variable decorated with Layer within the Fragment Execution Model **must** be declared using the Input Storage Class.

- VUID-Layer-Layer-04276
  The variable decorated with Layer **must** be declared as a scalar 32-bit integer value.

- VUID-Layer-Layer-07039
  The variable decorated with Layer within the MeshEXT Execution Model **must** also be decorated with the PerPrimitiveEXT decoration.

LayerPerViewNV

Decorating a variable with the LayerPerViewNV built-in decoration will make that variable contain the per-view layer information. The per-view layer has the same semantics as Layer, for each view.

Valid Usage

- VUID-LayerPerViewNV-LayerPerViewNV-04277
  The LayerPerViewNV decoration **must** be used only within the MeshNV Execution Model.

- VUID-LayerPerViewNV-LayerPerViewNV-04278
  The variable decorated with LayerPerViewNV **must** be declared using the Output Storage Class.

- VUID-LayerPerViewNV-LayerPerViewNV-04279
  The variable decorated with LayerPerViewNV **must** also be decorated with the PerViewNV decoration.

- VUID-LayerPerViewNV-LayerPerViewNV-04280
  The variable decorated with LayerPerViewNV **must** be declared as an array of scalar 32-bit integer values.

LocalInvocationId

Decorating a variable with the LocalInvocationId built-in decoration will make that variable
contain the location of the current cluster culling, task, mesh, or compute shader invocation within the local workgroup. Each component ranges from zero through to the size of the workgroup in that dimension minus one.

**Note**

If the size of the workgroup in a particular dimension is one, then the `LocalInvocationId` in that dimension will be zero. If the workgroup is effectively two-dimensional, then `LocalInvocationId.z` will be zero. If the workgroup is effectively one-dimensional, then both `LocalInvocationId.y` and `LocalInvocationId.z` will be zero.

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**Valid Usage**

- **VUID-LocalInvocationId-LocalInvocationId-04281**
  The `LocalInvocationId` decoration must be used only within the `GLCompute`, `MeshEXT`, `TaskEXT`, `MeshNV`, or `TaskNV` Execution Model

- **VUID-LocalInvocationId-LocalInvocationId-04282**
  The variable decorated with `LocalInvocationId` must be declared using the Input Storage Class

- **VUID-LocalInvocationId-LocalInvocationId-04283**
  The variable decorated with `LocalInvocationId` must be declared as a three-component vector of 32-bit integer values

**LocalInvocationIndex**

Decorating a variable with the `LocalInvocationIndex` built-in decoration will make that variable contain a one-dimensional representation of `LocalInvocationId`. This is computed as:

```cpp
LocalInvocationIndex = (LocalInvocationId.z * WorkgroupSize.x * WorkgroupSize.y + LocalInvocationId.y * WorkgroupSize.x + LocalInvocationId.x);
```

---

**Valid Usage**

- **VUID-LocalInvocationIndex-LocalInvocationIndex-04284**
  The `LocalInvocationIndex` decoration must be used only within the `GLCompute`, `MeshEXT`, `TaskEXT`, `MeshNV`, or `TaskNV` Execution Model

- **VUID-LocalInvocationIndex-LocalInvocationIndex-04285**
  The variable decorated with `LocalInvocationIndex` must be declared using the Input Storage Class

- **VUID-LocalInvocationIndex-LocalInvocationIndex-04286**
  The variable decorated with `LocalInvocationIndex` must be declared as a scalar 32-bit integer value
MeshViewCountNV

Decorating a variable with the MeshViewCountNV built-in decoration will make that variable contain the number of views processed by the current mesh or task shader invocations.

Valid Usage

- VUID-MeshViewCountNV-MeshViewCountNV-04287
  The MeshViewCountNV decoration must be used only within the MeshNV or TaskNV Execution Model

- VUID-MeshViewCountNV-MeshViewCountNV-04288
  The variable decorated with MeshViewCountNV must be declared using the Input Storage Class

- VUID-MeshViewCountNV-MeshViewCountNV-04289
  The variable decorated with MeshViewCountNV must be declared as a scalar 32-bit integer value

MeshViewIndicesNV

Decorating a variable with the MeshViewIndicesNV built-in decoration will make that variable contain the mesh view indices. The mesh view indices is an array of values where each element holds the view number of one of the views being processed by the current mesh or task shader invocations. The values of array elements with indices greater than or equal to MeshViewCountNV are undefined. If the value of MeshViewIndicesNV[i] is j, then any outputs decorated with PerViewNV will take on the value of array element i when processing primitives for view index j.

Valid Usage

- VUID-MeshViewIndicesNV-MeshViewIndicesNV-04290
  The MeshViewIndicesNV decoration must be used only within the MeshNV or TaskNV Execution Model

- VUID-MeshViewIndicesNV-MeshViewIndicesNV-04291
  The variable decorated with MeshViewIndicesNV must be declared using the Input Storage Class

- VUID-MeshViewIndicesNV-MeshViewIndicesNV-04292
  The variable decorated with MeshViewIndicesNV must be declared as an array of scalar 32-bit integer values

NumSubgroups

Decorating a variable with the NumSubgroups built-in decoration will make that variable contain the number of subgroups in the local workgroup.

Valid Usage

- VUID-NumSubgroups-NumSubgroups-04293
The NumSubgroups decoration must be used only within the GLCompute, MeshEXT, TaskEXT, MeshNV, or TaskNV Execution Model

- VUID-NumSubgroups-NumSubgroups-04294
  The variable decorated with NumSubgroups must be declared using the Input Storage Class
- VUID-NumSubgroups-NumSubgroups-04295
  The variable decorated with NumSubgroups must be declared as a scalar 32-bit integer value

NumWorkgroups

Decorating a variable with the NumWorkgroups built-in decoration will make that variable contain the number of local workgroups that are part of the dispatch that the invocation belongs to. Each component is equal to the values of the workgroup count parameters passed into the dispatching commands.

Valid Usage

- VUID-NumWorkgroups-NumWorkgroups-04296
  The NumWorkgroups decoration must be used only within the GLCompute, MeshEXT, or TaskEXT Execution Model
- VUID-NumWorkgroups-NumWorkgroups-04297
  The variable decorated with NumWorkgroups must be declared using the Input Storage Class
- VUID-NumWorkgroups-NumWorkgroups-04298
  The variable decorated with NumWorkgroups must be declared as a three-component vector of 32-bit integer values

ObjectRayDirectionKHR

A variable decorated with the ObjectRayDirectionKHR decoration will specify the direction of the ray being processed, in object space.

Valid Usage

- VUID-ObjectRayDirectionKHR-ObjectRayDirectionKHR-04299
  The ObjectRayDirectionKHR decoration must be used only within the IntersectionKHR, AnyHitKHR, or ClosestHitKHR Execution Model
- VUID-ObjectRayDirectionKHR-ObjectRayDirectionKHR-04300
  The variable decorated with ObjectRayDirectionKHR must be declared using the Input Storage Class
- VUID-ObjectRayDirectionKHR-ObjectRayDirectionKHR-04301
  The variable decorated with ObjectRayDirectionKHR must be declared as a three-component vector of 32-bit floating-point values
ObjectRayOriginKHR

A variable decorated with the ObjectRayOriginKHR decoration will specify the origin of the ray being processed, in object space.

Valid Usage

- VUID-ObjectRayOriginKHR-ObjectRayOriginKHR-04302
  The ObjectRayOriginKHR decoration must be used only within the IntersectionKHR, AnyHitKHR, or ClosestHitKHR Execution Model

- VUID-ObjectRayOriginKHR-ObjectRayOriginKHR-04303
  The variable decorated with ObjectRayOriginKHR must be declared using the Input Storage Class

- VUID-ObjectRayOriginKHR-ObjectRayOriginKHR-04304
  The variable decorated with ObjectRayOriginKHR must be declared as a three-component vector of 32-bit floating-point values

ObjectToWorldKHR

A variable decorated with the ObjectToWorldKHR decoration will contain the current object-to-world transformation matrix, which is determined by the instance of the current intersection.

Valid Usage

- VUID-ObjectToWorldKHR-ObjectToWorldKHR-04305
  The ObjectToWorldKHR decoration must be used only within the IntersectionKHR, AnyHitKHR, or ClosestHitKHR Execution Model

- VUID-ObjectToWorldKHR-ObjectToWorldKHR-04306
  The variable decorated with ObjectToWorldKHR must be declared using the Input Storage Class

- VUID-ObjectToWorldKHR-ObjectToWorldKHR-04307
  The variable decorated with ObjectToWorldKHR must be declared as a matrix with four columns of three-component vectors of 32-bit floating-point values

PatchVertices

Decorating a variable with the PatchVertices built-in decoration will make that variable contain the number of vertices in the input patch being processed by the shader. In a Tessellation Control Shader, this is the same as the name:patchControlPoints member of VkPipelineTessellationStateCreateInfo. In a Tessellation Evaluation Shader, PatchVertices is equal to the tessellation control output patch size. When the same shader is used in different pipelines where the patch sizes are configured differently, the value of the PatchVertices variable will also differ.

Valid Usage
The `PatchVertices` decoration must be used only within the `TessellationControl` or `TessellationEvaluation` Execution Model.

The variable decorated with `PatchVertices` must be declared using the `Input Storage Class`.

The variable decorated with `PatchVertices` must be declared as a scalar 32-bit integer value.

**PointCoord**

Decorating a variable with the `PointCoord` built-in decoration will make that variable contain the coordinate of the current fragment within the point being rasterized, normalized to the size of the point with origin in the upper left corner of the point, as described in Basic Point Rasterization. If the primitive the fragment shader invocation belongs to is not a point, then the variable decorated with `PointCoord` contains an undefined value.

*Note*

Depending on how the point is rasterized, `PointCoord` may never reach (0,0) or (1,1).

**Valid Usage**

**PointSize**

Decorating a variable with the `PointSize` built-in decoration will make that variable contain the size of point primitives or the final rasterization of polygons if the `polygon mode` is `VK_POLYGON_MODE_POINT` when `VkPhysicalDeviceMaintenance5PropertiesKHR::polygonModePointSize` is set to `VK_TRUE`. The value written to the variable decorated with `PointSize` by the last pre-rasterization shader stage in the pipeline is used as the framebuffer-space size of points produced by rasterization. If `maintenance5` is enabled and a value is not written to a variable decorated with `PointSize`, a value of 1.0 is used as the size of points.

*Note*

When `PointSize` decorates a variable in the `Input Storage Class`, it contains the data written to the output variable decorated with `PointSize` from the previous shader stage.
Valid Usage

- VUID-PointSize-PointSize-04314
  The `PointSize` decoration must be used only within the `MeshEXT`, `MeshNV`, `Vertex`, `TessellationControl`, `TessellationEvaluation`, or `Geometry Execution Model`

- VUID-PointSize-PointSize-04315
  The variable decorated with `PointSize` within the `MeshEXT`, `MeshNV`, or `Vertex Execution Model` must be declared using the `Output Storage Class`

- VUID-PointSize-PointSize-04316
  The variable decorated with `PointSize` within the `TessellationControl`, `TessellationEvaluation`, or `Geometry Execution Model` must not be declared using a `Storage Class` other than `Input` or `Output`

- VUID-PointSize-PointSize-04317
  The variable decorated with `PointSize` must be declared as a scalar 32-bit floating-point value

**Position**

Decorating a variable with the `Position` built-in decoration will make that variable contain the position of the current vertex. In the last pre-rasterization shader stage, the value of the variable decorated with `Position` is used in subsequent primitive assembly, clipping, and rasterization operations.

*Note*

When `Position` decorates a variable in the `Input Storage Class`, it contains the data written to the output variable decorated with `Position` from the previous shader stage.

Valid Usage

- VUID-Position-Position-04318
  The `Position` decoration must be used only within the `MeshEXT`, `MeshNV`, `Vertex`, `TessellationControl`, `TessellationEvaluation`, or `Geometry Execution Model`

- VUID-Position-Position-04319
  The variable decorated with `Position` within the `MeshEXT`, `MeshNV`, or `Vertex Execution Model` must be declared using the `Output Storage Class`

- VUID-Position-Position-04320
  The variable decorated with `Position` within the `TessellationControl`, `TessellationEvaluation`, or `Geometry Execution Model` must not be declared using a `Storage Class` other than `Input` or `Output`

- VUID-Position-Position-04321
  The variable decorated with `Position` must be declared as a four-component vector of 32-bit floating-point values
PositionPerViewNV
Decorating a variable with the PositionPerViewNV built-in decoration will make that variable contain the position of the current vertex, for each view.

Elements of the array correspond to views in a multiview subpass, and those elements corresponding to views in the view mask of the subpass the shader is compiled against will be used as the position value for those views. For the final pre-rasterization shader stage in the pipeline, values written to an output variable decorated with PositionPerViewNV are used in subsequent primitive assembly, clipping, and rasterization operations, as with Position. PositionPerViewNV output in an earlier pre-rasterization shader stage is available as an input in the subsequent pre-rasterization shader stage.

If a shader is compiled against a subpass that has the VK_SUBPASS_DESCRIPTION_PER_VIEW_POSITION_X_ONLY_BIT_NVX bit set, then the position values for each view must not differ in any component other than the X component. If the values do differ, one will be chosen in an implementation-dependent manner.

Valid Usage
- VUID-PositionPerViewNV-PositionPerViewNV-04322
  The PositionPerViewNV decoration must be used only within the MeshNV, Vertex, TessellationControl, TessellationEvaluation, or Geometry Execution Model
- VUID-PositionPerViewNV-PositionPerViewNV-04323
  The variable decorated with PositionPerViewNV within the Vertex, or MeshNV Execution Model must be declared using the Output Storage Class
- VUID-PositionPerViewNV-PositionPerViewNV-04324
  The variable decorated with PositionPerViewNV within the TessellationControl, TessellationEvaluation, or Geometry Execution Model must not be declared using a Storage Class other than Input or Output
- VUID-PositionPerViewNV-PositionPerViewNV-04325
  The variable decorated with PositionPerViewNV must be declared as an array of four-component vector of 32-bit floating-point values with at least as many elements as the maximum view in the subpass's view mask plus one
- VUID-PositionPerViewNV-PositionPerViewNV-04326
  The array variable decorated with PositionPerViewNV must only be indexed by a constant or specialization constant

PrimitiveCountNV
Decorating a variable with the PrimitiveCountNV decoration will make that variable contain the primitive count. The primitive count specifies the number of primitives in the output mesh produced by the mesh shader that will be processed by subsequent pipeline stages.

Valid Usage
- VUID-PrimitiveCountNV-PrimitiveCountNV-04327
The PrimitiveCountNV decoration must be used only within the MeshNV Execution Model

- VUID-PrimitiveCountNV-PrimitiveCountNV-04328
  The variable decorated with PrimitiveCountNV must be declared using the Output Storage Class

- VUID-PrimitiveCountNV-PrimitiveCountNV-04329
  The variable decorated with PrimitiveCountNV must be declared as a scalar 32-bit integer value

**PrimitiveId**

Decorating a variable with the PrimitiveId built-in decoration will make that variable contain the index of the current primitive.

The index of the first primitive generated by a drawing command is zero, and the index is incremented after every individual point, line, or triangle primitive is processed.

For triangles drawn as points or line segments (see Polygon Mode), the primitive index is incremented only once, even if multiple points or lines are eventually drawn.

Variables decorated with PrimitiveId are reset to zero between each instance drawn.

Restarting a primitive topology using primitive restart has no effect on the value of variables decorated with PrimitiveId.

In tessellation control and tessellation evaluation shaders, it will contain the index of the patch within the current set of rendering primitives that corresponds to the shader invocation.

In a geometry shader, it will contain the number of primitives presented as input to the shader since the current set of rendering primitives was started.

In a fragment shader, it will contain the primitive index written by the mesh shader if a mesh shader is present, or the primitive index written by the geometry shader if a geometry shader is present, or with the value that would have been presented as input to the geometry shader had it been present.

In an intersection, any-hit, or closest hit shader, it will contain the index within the geometry of the triangle or bounding box being processed.

**Note**

When the PrimitiveId decoration is applied to an output variable in the mesh shader or geometry shader, the resulting value is seen through the PrimitiveId decorated input variable in the fragment shader.

The fragment shader using PrimitiveId will need to declare either the MeshShadingNV, MeshShadingEXT, Geometry or Tessellation capability to satisfy the requirement SPIR-V has to use PrimitiveId.
Valid Usage

- VUID-PrimitiveId-PrimitiveId-04330
  The PrimitiveId decoration must be used only within the MeshEXT, MeshNV, IntersectionKHR, AnyHitKHR, ClosestHitKHR, TessellationControl, TessellationEvaluation, Geometry, or Fragment Execution Model

- VUID-PrimitiveId-Fragment-04331
  If pipeline contains both the Fragment and Geometry Execution Model and a variable decorated with PrimitiveId is read from Fragment shader, then the Geometry shader must write to the output variables decorated with PrimitiveId in all execution paths

- VUID-PrimitiveId-Fragment-04332
  If pipeline contains both the Fragment and MeshEXT or MeshNV Execution Model and a variable decorated with PrimitiveId is read from Fragment shader, then the MeshEXT or MeshNV shader must write to the output variables decorated with PrimitiveId in all execution paths

- VUID-PrimitiveId-Fragment-04333
  If Fragment Execution Model contains a variable decorated with PrimitiveId, then either the MeshShadingEXT, MeshShadingNV, Geometry or Tessellation capability must also be declared

- VUID-PrimitiveId-PrimitiveId-04334
  The variable decorated with PrimitiveId within the TessellationControl, TessellationEvaluation, Fragment, IntersectionKHR, AnyHitKHR, or ClosestHitKHR Execution Model must be declared using the Input Storage Class

- VUID-PrimitiveId-PrimitiveId-04335
  The variable decorated with PrimitiveId within the Geometry Execution Model must be declared using the Input or Output Storage Class

- VUID-PrimitiveId-PrimitiveId-04336
  The variable decorated with PrimitiveId within the MeshEXT or MeshNV Execution Model must be declared using the Output Storage Class

- VUID-PrimitiveId-PrimitiveId-04337
  The variable decorated with PrimitiveId must be declared as a scalar 32-bit integer value

- VUID-PrimitiveId-PrimitiveId-07040
  The variable decorated with PrimitiveId within the MeshEXT Execution Model must also be decorated with the PerPrimitiveEXT decoration

PrimitiveIndicesNV

Decorating a variable with the PrimitiveIndicesNV decoration will make that variable contain the output array of vertex index values. Depending on the output primitive type declared using the execution mode, the indices are split into groups of one (OutputPoints), two (OutputLinesNV), or three (OutputTriangles) indices and each group generates a primitive.

Valid Usage

- VUID-PrimitiveIndicesNV-PrimitiveIndicesNV-04338
The PrimitiveIndicesNV decoration must be used only within the MeshNV Execution Model

- VUID-PrimitiveIndicesNV-PrimitiveIndicesNV-04339
  The variable decorated with PrimitiveIndicesNV must be declared using the Output Storage Class

- VUID-PrimitiveIndicesNV-PrimitiveIndicesNV-04340
  The variable decorated with PrimitiveIndicesNV must be declared as an array of scalar 32-bit integer values

- VUID-PrimitiveIndicesNV-PrimitiveIndicesNV-04341
  All index values of the array decorated with PrimitiveIndicesNV must be in the range [0, N-1], where N is the value specified by the OutputVertices Execution Mode

- VUID-PrimitiveIndicesNV-OutputPoints-04342
  If the Execution Mode is OutputPoints, then the array decorated with PrimitiveIndicesNV must be the size of the value specified by OutputPrimitivesNV

- VUID-PrimitiveIndicesNV-OutputLinesNV-04343
  If the Execution Mode is OutputLinesNV, then the array decorated with PrimitiveIndicesNV must be the size of two times the value specified by OutputPrimitivesNV

- VUID-PrimitiveIndicesNV-OutputTrianglesNV-04344
  If the Execution Mode is OutputTrianglesNV, then the array decorated with PrimitiveIndicesNV must be the size of three times the value specified by OutputPrimitivesNV

PrimitivePointIndicesEXT

Decorating a variable with the PrimitivePointIndicesEXT decoration will make that variable contain the output array of vertex index values for point primitives.

Valid Usage

- VUID-PrimitivePointIndicesEXT-PrimitivePointIndicesEXT-07041
  The PrimitivePointIndicesEXT decoration must be used only within the MeshEXT Execution Model

- VUID-PrimitivePointIndicesEXT-PrimitivePointIndicesEXT-07042
  The PrimitivePointIndicesEXT decoration must be used with the OutputPoints Execution Mode

- VUID-PrimitivePointIndicesEXT-PrimitivePointIndicesEXT-07043
  The variable decorated with PrimitivePointIndicesEXT must be declared using the Output Storage Class

- VUID-PrimitivePointIndicesEXT-PrimitivePointIndicesEXT-07044
  The variable decorated with PrimitivePointIndicesEXT must be declared as an array of scalar 32-bit integer values

- VUID-PrimitivePointIndicesEXT-PrimitivePointIndicesEXT-07045
  All index values of the array decorated with PrimitivePointIndicesEXT must be in the range [0, N-1], where N is the value specified by the OutputVertices Execution Mode
The size of the array decorated with `PrimitivePointIndicesEXT` must match the value specified by `OutputPrimitivesEXT`.

**PrimitiveLineIndicesEXT**

Decorating a variable with the `PrimitiveLineIndicesEXT` decoration will make that variable contain the output array of vertex index values for line primitives.

**Valid Usage**

- VUID-PrimitiveLineIndicesEXT-PrimitiveLineIndicesEXT-07047
  The `PrimitiveLineIndicesEXT` decoration must be used only within the `MeshEXT Execution Model`.

- VUID-PrimitiveLineIndicesEXT-PrimitiveLineIndicesEXT-07048
  The `PrimitiveLineIndicesEXT` decoration must be used with the `OutputLinesEXT Execution Mode`.

- VUID-PrimitiveLineIndicesEXT-PrimitiveLineIndicesEXT-07049
  The variable decorated with `PrimitiveLineIndicesEXT` must be declared using the `Output Storage Class`.

- VUID-PrimitiveLineIndicesEXT-PrimitiveLineIndicesEXT-07050
  The variable decorated with `PrimitiveLineIndicesEXT` must be declared as an array of two component vector 32-bit integer values.

- VUID-PrimitiveLineIndicesEXT-PrimitiveLineIndicesEXT-07051
  All index values of the array decorated with `PrimitiveLineIndicesEXT` must be in the range [0, N-1], where N is the value specified by the `OutputVertices Execution Mode`.

- VUID-PrimitiveLineIndicesEXT-PrimitiveLineIndicesEXT-07052
  The size of the array decorated with `PrimitiveLineIndicesEXT` must match the value specified by `OutputPrimitivesEXT`.

**PrimitiveTriangleIndicesEXT**

Decorating a variable with the `PrimitiveTriangleIndicesEXT` decoration will make that variable contain the output array of vertex index values for triangle primitives.

**Valid Usage**

- VUID-PrimitiveTriangleIndicesEXT-PrimitiveTriangleIndicesEXT-07053
  The `PrimitiveTriangleIndicesEXT` decoration must be used only within the `MeshEXT Execution Model`.

- VUID-PrimitiveTriangleIndicesEXT-PrimitiveTriangleIndicesEXT-07054
  The `PrimitiveTriangleIndicesEXT` decoration must be used with the `OutputTrianglesEXT Execution Mode`.

- VUID-PrimitiveTriangleIndicesEXT-PrimitiveTriangleIndicesEXT-07055
  The variable decorated with `PrimitiveTriangleIndicesEXT` must be declared using the
Output Storage Class

- VUID-PrimitiveTriangleIndicesEXT-PrimitiveTriangleIndicesEXT-07056
  The variable decorated with PrimitiveTriangleIndicesEXT must be declared as an array of three component vector 32-bit integer values.

- VUID-PrimitiveTriangleIndicesEXT-PrimitiveTriangleIndicesEXT-07057
  All index values of the array decorated with PrimitiveTriangleIndicesEXT must be in the range [0, N-1], where N is the value specified by the OutputVertices Execution Mode.

- VUID-PrimitiveTriangleIndicesEXT-PrimitiveTriangleIndicesEXT-07058
  The size of the array decorated with PrimitiveTriangleIndicesEXT must match the value specified by OutputPrimitivesEXT.

PrimitiveShadingRateKHR

Decorating a variable with the PrimitiveShadingRateKHR built-in decoration will make that variable contain the primitive fragment shading rate. The value written to the variable decorated with PrimitiveShadingRateKHR by the last pre-rasterization shader stage in the pipeline is used as the primitive fragment shading rate. Outputs in previous shader stages are ignored.

If the last active pre-rasterization shader stage shader entry point's interface does not include a variable decorated with PrimitiveShadingRateKHR, then it is as if the shader specified a fragment shading rate value of 0, indicating a horizontal and vertical rate of 1 pixel.

If a shader has PrimitiveShadingRateKHR in the output interface and there is an execution path through the shader that does not write to it, its value is undefined for executions of the shader that take that path.

Valid Usage

- VUID-PrimitiveShadingRateKHR-PrimitiveShadingRateKHR-04484
  The PrimitiveShadingRateKHR decoration must be used only within the MeshEXT, MeshNV, Vertex, or Geometry Execution Model.

- VUID-PrimitiveShadingRateKHR-PrimitiveShadingRateKHR-04485
  The variable decorated with PrimitiveShadingRateKHR must be declared using the Output Storage Class.

- VUID-PrimitiveShadingRateKHR-PrimitiveShadingRateKHR-04486
  The variable decorated with PrimitiveShadingRateKHR must be declared as a scalar 32-bit integer value.

- VUID-PrimitiveShadingRateKHR-PrimitiveShadingRateKHR-04487
  The value written to PrimitiveShadingRateKHR must include no more than one of Vertical2Pixels and Vertical4Pixels.

- VUID-PrimitiveShadingRateKHR-PrimitiveShadingRateKHR-04488
  The value written to PrimitiveShadingRateKHR must include no more than one of Horizontal2Pixels and Horizontal4Pixels.
The value written to PrimitiveShadingRateKHR must not have any bits set other than those defined by Fragment Shading Rate Flags enumerants in the SPIR-V specification.

The variable decorated with PrimitiveShadingRateKHR within the MeshEXT Execution Model must also be decorated with the PerPrimitiveEXT decoration.

RayGeometryIndexKHR

A variable decorated with the RayGeometryIndexKHR decoration will contain the geometry index for the acceleration structure geometry currently being shaded.

Valid Usage

- VUID-RayGeometryIndexKHR-RayGeometryIndexKHR-04345
  The RayGeometryIndexKHR decoration must be used only within the IntersectionKHR, AnyHitKHR, or ClosestHitKHR Execution Model.

- VUID-RayGeometryIndexKHR-RayGeometryIndexKHR-04346
  The variable decorated with RayGeometryIndexKHR must be declared using the Input Storage Class.

- VUID-RayGeometryIndexKHR-RayGeometryIndexKHR-04347
  The variable decorated with RayGeometryIndexKHR must be declared as a scalar 32-bit integer value.

RayTmaxKHR

A variable decorated with the RayTmaxKHR decoration will contain the parametric $t_{\text{max}}$ value of the ray being processed. The value is independent of the space in which the ray origin and direction exist. The value is initialized to the parameter passed into OpTraceRayKHR.

The $t_{\text{max}}$ value changes throughout the lifetime of the ray that produced the intersection. In the closest hit shader, the value reflects the closest distance to the intersected primitive. In the any-hit shader, it reflects the distance to the primitive currently being intersected. In the intersection shader, it reflects the distance to the closest primitive intersected so far or the initial value. The value can change in the intersection shader after calling OpReportIntersectionKHR if the corresponding any-hit shader does not ignore the intersection. In a miss shader, the value is identical to the parameter passed into OpTraceRayKHR.

Valid Usage

- VUID-RayTmaxKHR-RayTmaxKHR-04348
  The RayTmaxKHR decoration must be used only within the IntersectionKHR, AnyHitKHR, ClosestHitKHR, or MissKHR Execution Model.

- VUID-RayTmaxKHR-RayTmaxKHR-04349
  The variable decorated with RayTmaxKHR must be declared using the Input Storage Class.

- VUID-RayTmaxKHR-RayTmaxKHR-04350
  The variable decorated with RayTmaxKHR must be declared as a scalar 32-bit integer value.
The variable decorated with `RayTmaxKHR` must be declared as a scalar 32-bit floating-point value.

**RayTminKHR**

A variable decorated with the `RayTminKHR` decoration will contain the parametric $t_{\text{min}}$ value of the ray being processed. The value is independent of the space in which the ray origin and direction exist. The value is the parameter passed into `OpTraceRayKHR`.

The $t_{\text{min}}$ value remains constant for the duration of the ray query.

### Valid Usage

- VUID-RayTminKHR-RayTminKHR-04351
  The `RayTminKHR` decoration must be used only within the `IntersectionKHR`, `AnyHitKHR`, `ClosestHitKHR`, or `MissKHR` Execution Model

- VUID-RayTminKHR-RayTminKHR-04352
  The variable decorated with `RayTminKHR` must be declared using the Input Storage Class

- VUID-RayTminKHR-RayTminKHR-04353
  The variable decorated with `RayTminKHR` must be declared as a scalar 32-bit floating-point value

**SampleId**

Decorating a variable with the `SampleId` built-in decoration will make that variable contain the coverage index for the current fragment shader invocation. `SampleId` ranges from zero to the number of samples in the framebuffer minus one. If a fragment shader entry point's interface includes an input variable decorated with `SampleId`, Sample Shading is considered enabled with a `minSampleShading` value of 1.0.

### Valid Usage

- VUID-SampleId-SampleId-04354
  The `SampleId` decoration must be used only within the Fragment Execution Model

- VUID-SampleId-SampleId-04355
  The variable decorated with `SampleId` must be declared using the Input Storage Class

- VUID-SampleId-SampleId-04356
  The variable decorated with `SampleId` must be declared as a scalar 32-bit integer value

**SampleMask**

Decorating a variable with the `SampleMask` built-in decoration will make any variable contain the sample mask for the current fragment shader invocation.

A variable in the Input storage class decorated with `SampleMask` will contain a bitmask of the set of samples covered by the primitive generating the fragment during rasterization. It has a sample bit set if and only if the sample is considered covered for this fragment shader.
invocation. $\text{SampleMask}[]$ is an array of integers. Bits are mapped to samples in a manner where bit B of mask M ($\text{SampleMask}[M]$) corresponds to sample $32 \times M + B$.

A variable in the Output storage class decorated with $\text{SampleMask}$ is an array of integers forming a bit array in a manner similar to an input variable decorated with $\text{SampleMask}$, but where each bit represents coverage as computed by the shader. This computed $\text{SampleMask}$ is combined with the generated coverage mask in the multisample coverage operation.

Variables decorated with $\text{SampleMask}$ must be either an unsized array, or explicitly sized to be no larger than the implementation-dependent maximum sample-mask (as an array of 32-bit elements), determined by the maximum number of samples.

If a fragment shader entry point's interface includes an output variable decorated with $\text{SampleMask}$, the sample mask will be undefined for any array elements of any fragment shader invocations that fail to assign a value. If a fragment shader entry point's interface does not include an output variable decorated with $\text{SampleMask}$, the sample mask has no effect on the processing of a fragment.

### Valid Usage

- VUID-SampleMask-SampleMask-04357
  The $\text{SampleMask}$ decoration must be used only within the Fragment Execution Model

- VUID-SampleMask-SampleMask-04358
  The variable decorated with $\text{SampleMask}$ must be declared using the Input or Output Storage Class

- VUID-SampleMask-SampleMask-04359
  The variable decorated with $\text{SampleMask}$ must be declared as an array of 32-bit integer values

### SamplePosition

Decorating a variable with the $\text{SamplePosition}$ built-in decoration will make that variable contain the sub-pixel position of the sample being shaded. The top left of the pixel is considered to be at coordinate (0,0) and the bottom right of the pixel is considered to be at coordinate (1,1).

If the render pass has a fragment density map attachment, the variable will instead contain the sub-fragment position of the sample being shaded. The top left of the fragment is considered to be at coordinate (0,0) and the bottom right of the fragment is considered to be at coordinate (1,1) for any fragment area.

If a fragment shader entry point's interface includes an input variable decorated with $\text{SamplePosition}$, Sample Shading is considered enabled with a $\text{minSampleShading}$ value of 1.0.

If the current pipeline uses custom sample locations the value of any variable decorated with the $\text{SamplePosition}$ built-in decoration is undefined.
Valid Usage

• VUID-SamplePosition-SamplePosition-04360
  The SamplePosition decoration must be used only within the Fragment Execution Model

• VUID-SamplePosition-SamplePosition-04361
  The variable decorated with SamplePosition must be declared using the Input Storage Class

• VUID-SamplePosition-SamplePosition-04362
  The variable decorated with SamplePosition must be declared as a two-component vector of 32-bit floating-point values

ShadingRateKHR

Decorating a variable with the ShadingRateKHR built-in decoration will make that variable contain the fragment shading rate for the current fragment invocation.

Valid Usage

• VUID-ShadingRateKHR-ShadingRateKHR-04490
  The ShadingRateKHR decoration must be used only within the Fragment Execution Model

• VUID-ShadingRateKHR-ShadingRateKHR-04491
  The variable decorated with ShadingRateKHR must be declared using the Input Storage Class

• VUID-ShadingRateKHR-ShadingRateKHR-04492
  The variable decorated with ShadingRateKHR must be declared as a scalar 32-bit integer value

SMCountNV

Decorating a variable with the SMCountNV built-in decoration will make that variable contain the number of SMs on the device.

Valid Usage

• VUID-SMCountNV-SMCountNV-04363
  The variable decorated with SMCountNV must be declared using the Input Storage Class

• VUID-SMCountNV-SMCountNV-04364
  The variable decorated with SMCountNV must be declared as a scalar 32-bit integer value

SMIDNV

Decorating a variable with the SMIDNV built-in decoration will make that variable contain the ID of the SM on which the current shader invocation is running. This variable is in the range [0, SMCountNV-1].
Valid Usage

- VUID-SMIDNV-SMIDNV-04365
  The variable decorated with SMIDNV must be declared using the Input Storage Class

- VUID-SMIDNV-SMIDNV-04366
  The variable decorated with SMIDNV must be declared as a scalar 32-bit integer value

SubgroupId

Decorating a variable with the SubgroupId built-in decoration will make that variable contain the index of the subgroup within the local workgroup. This variable is in range \([0, \text{NumSubgroups}-1]\).

Valid Usage

- VUID-SubgroupId-SubgroupId-04367
  The SubgroupId decoration must be used only within the GLCompute, MeshEXT, TaskEXT, MeshNV, or TaskNV Execution Model

- VUID-SubgroupId-SubgroupId-04368
  The variable decorated with SubgroupId must be declared using the Input Storage Class

- VUID-SubgroupId-SubgroupId-04369
  The variable decorated with SubgroupId must be declared as a scalar 32-bit integer value

SubgroupEqMask

Decorating a variable with the SubgroupEqMask builtin decoration will make that variable contain the subgroup mask of the current subgroup invocation. The bit corresponding to the SubgroupLocalInvocationId is set in the variable decorated with SubgroupEqMask. All other bits are set to zero.

SubgroupEqMaskKHR is an alias of SubgroupEqMask.

Valid Usage

- VUID-SubgroupEqMask-SubgroupEqMask-04370
  The variable decorated with SubgroupEqMask must be declared using the Input Storage Class

- VUID-SubgroupEqMask-SubgroupEqMask-04371
  The variable decorated with SubgroupEqMask must be declared as a four-component vector of 32-bit integer values

SubgroupGeMask

Decorating a variable with the SubgroupGeMask built-in decoration will make that variable contain the subgroup mask of the current subgroup invocation. The bits corresponding to the invocations greater than or equal to SubgroupLocalInvocationId through SubgroupSize-1 are set in the variable decorated with SubgroupGeMask. All other bits are set to zero.
SubgroupGeMaskKHR is an alias of SubgroupGeMask.

Valid Usage

• VUID-SubgroupGeMask-SubgroupGeMask-04372
  The variable decorated with SubgroupGeMask must be declared using the Input Storage Class

• VUID-SubgroupGeMask-SubgroupGeMask-04373
  The variable decorated with SubgroupGeMask must be declared as a four-component vector of 32-bit integer values

SubgroupGtMask

Decorating a variable with the SubgroupGtMask builtin decoration will make that variable contain the subgroup mask of the current subgroup invocation. The bits corresponding to the invocations greater than SubgroupLocalInvocationId through SubgroupSize-1 are set in the variable decorated with SubgroupGtMask. All other bits are set to zero.

SubgroupGtMaskKHR is an alias of SubgroupGtMask.

Valid Usage

• VUID-SubgroupGtMask-SubgroupGtMask-04374
  The variable decorated with SubgroupGtMask must be declared using the Input Storage Class

• VUID-SubgroupGtMask-SubgroupGtMask-04375
  The variable decorated with SubgroupGtMask must be declared as a four-component vector of 32-bit integer values

SubgroupLeMask

Decorating a variable with the SubgroupLeMask builtin decoration will make that variable contain the subgroup mask of the current subgroup invocation. The bits corresponding to the invocations less than or equal to SubgroupLocalInvocationId through SubgroupLocalInvocationId are set in the variable decorated with SubgroupLeMask. All other bits are set to zero.

SubgroupLeMaskKHR is an alias of SubgroupLeMask.

Valid Usage

• VUID-SubgroupLeMask-SubgroupLeMask-04376
  The variable decorated with SubgroupLeMask must be declared using the Input Storage Class

• VUID-SubgroupLeMask-SubgroupLeMask-04377
  The variable decorated with SubgroupLeMask must be declared as a four-component vector of 32-bit integer values
**SubgroupLtMask**

Decorating a variable with the `SubgroupLtMask` builtin decoration will make that variable contain the *subgroup mask* of the current subgroup invocation. The bits corresponding to the invocations less than `SubgroupLocalInvocationId` are set in the variable decorated with `SubgroupLtMask`. All other bits are set to zero.

`SubgroupLtMaskKHR` is an alias of `SubgroupLtMask`.

**Valid Usage**

- VUID-SubgroupLtMask-SubgroupLtMask-04378
  The variable decorated with `SubgroupLtMask` must be declared using the `Input Storage Class`

- VUID-SubgroupLtMask-SubgroupLtMask-04379
  The variable decorated with `SubgroupLtMask` must be declared as a four-component vector of 32-bit integer values

**SubgroupLocalInvocationId**

Decorating a variable with the `SubgroupLocalInvocationId` builtin decoration will make that variable contain the index of the invocation within the subgroup. This variable is in range [0, `SubgroupSize`-1].

If `VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT` is specified, or if module declares SPIR-V version 1.6 or higher, and the local workgroup size in the X dimension of the stage is a multiple of `SubgroupSize`, full subgroups are enabled for that pipeline stage. When full subgroups are enabled, subgroups must be launched with all invocations active, i.e., there is an active invocation with `SubgroupLocalInvocationId` for each value in range [0, `SubgroupSize`-1].

**Note**

There is no direct relationship between `SubgroupLocalInvocationId` and `LocalInvocationId` or `LocalInvocationIndex`. If the pipeline or shader object was created with full subgroups applications can compute their own local invocation index to serve the same purpose:

\[ \text{index} = \text{SubgroupLocalInvocationId} + \text{SubgroupId} \times \text{SubgroupSize} \]

If full subgroups are not enabled, some subgroups may be dispatched with inactive invocations that do not correspond to a local workgroup invocation, making the value of index unreliable.

**Note**

`VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT` and `VK_SHADER_CREATE_REQUIRE_FULL_SUBGROUPS_BIT_EXT` are effectively deprecated when compiling SPIR-V 1.6 shaders, as this behavior is the default for Vulkan with SPIR-V 1.6. This is more aligned with developer expectations, and avoids applications unexpectedly breaking in the future.
Valid Usage

- VUID-SubgroupLocalInvocationId-SubgroupLocalInvocationId-04380
  The variable decorated with SubgroupLocalInvocationId must be declared using the Input Storage Class

- VUID-SubgroupLocalInvocationId-SubgroupLocalInvocationId-04381
  The variable decorated with SubgroupLocalInvocationId must be declared as a scalar 32-bit integer value

SubgroupSize

Decorating a variable with the SubgroupSize builtin decoration will make that variable contain the implementation-dependent number of invocations in a subgroup. This value must be a power-of-two integer.

If the pipeline was created with the VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT flag set, or the shader object was created with the VK_SHADER_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT_EXT flag set, or the SPIR-V module is at least version 1.6, the SubgroupSize decorated variable will contain the subgroup size for each subgroup that gets dispatched. This value must be between minSubgroupSize and maxSubgroupSize and must be uniform with subgroup scope. The value may vary across a single draw call, and for fragment shaders may vary across a single primitive. In compute dispatches, SubgroupSize must be uniform with command scope.

If the pipeline was created with a chained VkPipelineShaderStageRequiredSubgroupSizeCreateInfo structure, or the shader object was created with a chained VkShaderRequiredSubgroupSizeCreateInfoEXT structure, the SubgroupSize decorated variable will match requiredSubgroupSize.

If SPIR-V module is less than version 1.6 and the pipeline was not created with the VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT flag set and no VkPipelineShaderStageRequiredSubgroupSizeCreateInfo structure was chained, and the shader was not created with the VK_SHADER_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT_EXT flag set and no VkShaderRequiredSubgroupSizeCreateInfoEXT structure was chained, the variable decorated with SubgroupSize will match subgroupSize.

The maximum number of invocations that an implementation can support per subgroup is 128.

Note

The old behavior for SubgroupSize is considered deprecated as certain compute algorithms cannot be easily implemented without the guarantees of VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT and VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT.

Valid Usage

- VUID-SubgroupSize-SubgroupSize-04382

The old behavior for SubgroupSize is considered deprecated as certain compute algorithms cannot be easily implemented without the guarantees of VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT and VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT.
The variable decorated with `SubgroupSize` must be declared using the `Input Storage Class`

- VUID-SubgroupSize-SubgroupSize-04383
  The variable decorated with `SubgroupSize` must be declared as a scalar 32-bit integer value

**TaskCountNV**

Decorating a variable with the `TaskCountNV` decoration will make that variable contain the task count. The task count specifies the number of subsequent mesh shader workgroups that get generated upon completion of the task shader.

**Valid Usage**

- VUID-TaskCountNV-TaskCountNV-04384
  The `TaskCountNV` decoration must be used only within the `TaskNV Execution Model`

- VUID-TaskCountNV-TaskCountNV-04385
  The variable decorated with `TaskCountNV` must be declared using the `Output Storage Class`

- VUID-TaskCountNV-TaskCountNV-04386
  The variable decorated with `TaskCountNV` must be declared as a scalar 32-bit integer value

**TessCoord**

Decorating a variable with the `TessCoord` built-in decoration will make that variable contain the three-dimensional (u,v,w) barycentric coordinate of the tessellated vertex within the patch. u, v, and w are in the range [0,1] and vary linearly across the primitive being subdivided. For the tessellation modes of `Quads` or `IsoLines`, the third component is always zero.

**Valid Usage**

- VUID-TessCoord-TessCoord-04387
  The `TessCoord` decoration must be used only within the `Tessellation Evaluation Execution Model`

- VUID-TessCoord-TessCoord-04388
  The variable decorated with `TessCoord` must be declared using the `Input Storage Class`

- VUID-TessCoord-TessCoord-04389
  The variable decorated with `TessCoord` must be declared as a three-component vector of 32-bit floating-point values

**TessLevelOuter**

Decorating a variable with the `TessLevelOuter` built-in decoration will make that variable contain the outer tessellation levels for the current patch.

In tessellation control shaders, the variable decorated with `TessLevelOuter` can be written to, controlling the tessellation factors for the resulting patch. These values are used by the tessellator to control primitive tessellation and can be read by tessellation evaluation shaders.
In tessellation evaluation shaders, the variable decorated with `TessLevelOuter can` read the values written by the tessellation control shader.

### Valid Usage

- VUID-TessLevelOuter-TessLevelOuter-04390
  The `TessLevelOuter` decoration must be used only within the TessellationControl or TessellationEvaluation Execution Model

- VUID-TessLevelOuter-TessLevelOuter-04391
  The variable decorated with `TessLevelOuter` within the TessellationControl Execution Model must be declared using the Output Storage Class

- VUID-TessLevelOuter-TessLevelOuter-04392
  The variable decorated with `TessLevelOuter` within the TessellationEvaluation Execution Model must be declared using the Input Storage Class

- VUID-TessLevelOuter-TessLevelOuter-04393
  The variable decorated with `TessLevelOuter` must be declared as an array of size four, containing 32-bit floating-point values

### TessLevelInner

Decorating a variable with the `TessLevelInner` built-in decoration will make that variable contain the inner tessellation levels for the current patch.

In tessellation control shaders, the variable decorated with `TessLevelInner can` be written to, controlling the tessellation factors for the resulting patch. These values are used by the tessellator to control primitive tessellation and can be read by tessellation evaluation shaders.

In tessellation evaluation shaders, the variable decorated with `TessLevelInner can` read the values written by the tessellation control shader.

### Valid Usage

- VUID-TessLevelInner-TessLevelInner-04394
  The `TessLevelInner` decoration must be used only within the TessellationControl or TessellationEvaluation Execution Model

- VUID-TessLevelInner-TessLevelInner-04395
  The variable decorated with `TessLevelInner` within the TessellationControl Execution Model must be declared using the Output Storage Class

- VUID-TessLevelInner-TessLevelInner-04396
  The variable decorated with `TessLevelInner` within the TessellationEvaluation Execution Model must be declared using the Input Storage Class

- VUID-TessLevelInner-TessLevelInner-04397
  The variable decorated with `TessLevelInner` must be declared as an array of size two, containing 32-bit floating-point values
**VertexCountHUAWEI**

The `VertexCountHUAWEI` decoration can be used to decorate a cluster culling shader output variable, this non-indexed mode specific variable will contain an integer value that specifies the number of vertices in a cluster to draw.

<table>
<thead>
<tr>
<th>Valid Usage</th>
</tr>
</thead>
</table>
| - VUID-VertexCountHUAWEI-VertexCountHUAWEI-07809
  The `VertexCountHUAWEI` decoration must be used only within the `ClusterCullingHUAWEI` Execution Model |
| - VUID-VertexCountHUAWEI-VertexCountHUAWEI-07810
  The variable decorated with `VertexCountHUAWEI` must be declared as a scalar 32-bit integer value |

**VertexIndex**

Decorating a variable with the `VertexIndex` built-in decoration will make that variable contain the index of the vertex that is being processed by the current vertex shader invocation. For non-indexed draws, this variable begins at the `firstVertex` parameter to `vkCmdDraw` or the `firstVertex` member of a structure consumed by `vkCmdDrawIndirect` and increments by one for each vertex in the draw. For indexed draws, its value is the content of the index buffer for the vertex plus the `vertexOffset` parameter to `vkCmdDrawIndexed` or the `vertexOffset` member of the structure consumed by `vkCmdDrawIndexedIndirect`.

*Note*

`VertexIndex` starts at the same starting value for each instance.

<table>
<thead>
<tr>
<th>Valid Usage</th>
</tr>
</thead>
</table>
| - VUID-VertexIndex-VertexIndex-04398
  The `VertexIndex` decoration must be used only within the `Vertex` Execution Model |
| - VUID-VertexIndex-VertexIndex-04399
  The variable decorated with `VertexIndex` must be declared using the `Input Storage Class` |
| - VUID-VertexIndex-VertexIndex-04400
  The variable decorated with `VertexIndex` must be declared as a scalar 32-bit integer value |

**VertexOffsetHUAWEI**

The `VertexOffsetHUAWEI` decoration can be used to decorate a cluster culling shader output variable, this indexed mode specific variable will contain an integer value that specifies a offset value added to the vertex index of a cluster before indexing into the vertex buffer.

<table>
<thead>
<tr>
<th>Valid Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>- VUID-VertexOffsetHUAWEI-VertexOffsetHUAWEI-07811</td>
</tr>
</tbody>
</table>
The `VertexOffsetHUAWEI` decoration **must** be used only within the `ClusterCullingHUAWEI` Execution Model

- VUID-VertexOffsetHUAWEI-VertexOffsetHUAWEI-07812
  The variable decorated with `VertexOffsetHUAWEI` **must** be declared as a scalar 32-bit integer value

**ViewIndex**

The `ViewIndex` decoration **can** be applied to a shader input which will be filled with the index of the view that is being processed by the current shader invocation.

If multiview is enabled in the render pass, this value will be one of the bits set in the view mask of the subpass the pipeline is compiled against. If multiview is not enabled in the render pass, this value will be zero.

**Valid Usage**

- VUID-ViewIndex-ViewIndex-04401
  The `ViewIndex` decoration **must** be used only within the `MeshEXT, Vertex, Geometry, TessellationControl, TessellationEvaluation` or `Fragment Execution Model`

- VUID-ViewIndex-ViewIndex-04402
  The variable decorated with `ViewIndex` **must** be declared using the `Input Storage Class`

- VUID-ViewIndex-ViewIndex-04403
  The variable decorated with `ViewIndex` **must** be declared as a scalar 32-bit integer value

**ViewportIndex**

Decorating a variable with the `ViewportIndex` built-in decoration will make that variable contain the index of the viewport.

In a mesh, vertex, tessellation evaluation, or geometry shader, the variable decorated with `ViewportIndex` can be written to with the viewport index to which the primitive produced by that shader will be directed.

The selected viewport index is used to select the viewport transform, scissor rectangle, and exclusive scissor rectangle.

The last active **pre-rasterization shader stage** (in pipeline order) controls the `ViewportIndex` that is used. Outputs in previous shader stages are not used, even if the last stage fails to write the `ViewportIndex`.

If the last active **pre-rasterization shader stage** shader entry point’s interface does not include a variable decorated with `ViewportIndex`, and if `multiviewPerViewViewports` is not enabled, then the first viewport is used. If a **pre-rasterization shader stage** shader entry point’s interface includes a variable decorated with `ViewportIndex`, it **must** write the same value to `ViewportIndex` for all output vertices of a given primitive.

In a fragment shader, the variable decorated with `ViewportIndex` contains the viewport index of
the primitive that the fragment invocation belongs to.

If `multiviewPerViewViewports` is enabled, and if the last active pre-rasterization shader stage shader entry point's interface does not include a variable decorated with `ViewportIndex`, then the value of `ViewIndex` is used as an index to select the viewport transform and scissor rectangle, and the value of `ViewportIndex` in the fragment shader is undefined:

**Valid Usage**

- **VUID-ViewportIndex-ViewportIndex-04404**
  The `ViewportIndex` decoration must be used only within the `MeshEXT`, `MeshNV`, `Vertex`, `TessellationEvaluation`, `Geometry`, or `Fragment Execution Model`

- **VUID-ViewportIndex-ViewportIndex-04405**
  If the `shaderOutputViewportIndex` feature is not enabled then the `ViewportIndex` decoration must be used only within the `Geometry` or `Fragment Execution Model`

- **VUID-ViewportIndex-ViewportIndex-04406**
  The variable decorated with `ViewportIndex` within the `MeshEXT`, `MeshNV`, `Vertex`, `TessellationEvaluation`, or `Geometry Execution Model` must be declared using the `Output Storage Class`

- **VUID-ViewportIndex-ViewportIndex-04407**
  The variable decorated with `ViewportIndex` within the `Fragment Execution Model` must be declared using the `Input Storage Class`

- **VUID-ViewportIndex-ViewportIndex-04408**
  The variable decorated with `ViewportIndex` must be declared as a scalar 32-bit integer value

- **VUID-ViewportIndex-ViewportIndex-07060**
  The variable decorated with `ViewportIndex` within the `MeshEXT Execution Model` must also be decorated with the `PerPrimitiveEXT` decoration

**ViewportMaskNV**

Decorating a variable with the `ViewportMaskNV` built-in decoration will make that variable contain the viewport mask.

In a mesh, vertex, tessellation evaluation, or geometry shader, the variable decorated with `ViewportMaskNV` can be written to with the mask of which viewports the primitive produced by that shader will directed.

The `ViewportMaskNV` variable must be an array that has `VkPhysicalDeviceLimits::maxViewports / 32` elements. When a shader writes to this variable, bit `B` of element `M` controls whether a primitive is emitted to viewport `32 × M + B`. The viewports indicated by the mask are used to select the viewport transform, scissor rectangle, and exclusive scissor rectangle that a primitive will be transformed by.

The last active pre-rasterization shader stage (in pipeline order) controls the `ViewportMaskNV` that is used. Outputs in previous shader stages are not used, even if the last stage fails to write the `ViewportMaskNV`. When `ViewportMaskNV` is written by the final pre-rasterization shader stage, any
variable decorated with \texttt{ViewportIndex} in the fragment shader will have the index of the viewport that was used in generating that fragment.

If a pre-rasterization shader stage shader entry point's interface includes a variable decorated with \texttt{ViewportMaskNV}, it \textbf{must} write the same value to \texttt{ViewportMaskNV} for all output vertices of a given primitive.

\begin{center}
\begin{tcolorbox}
\textbf{Valid Usage}

- VUID-ViewportMaskNV-ViewportMaskNV-04409
  The \texttt{ViewportMaskNV} decoration \textbf{must} be used only within the \texttt{Vertex}, \texttt{MeshNV}, \texttt{TessellationEvaluation}, or \texttt{Geometry Execution Model}

- VUID-ViewportMaskNV-ViewportMaskNV-04410
  The variable decorated with \texttt{ViewportMaskNV} \textbf{must} be declared using the \texttt{Output Storage Class}

- VUID-ViewportMaskNV-ViewportMaskNV-04411
  The variable decorated with \texttt{ViewportMaskNV} \textbf{must} be declared as an array of 32-bit integer values

\end{tcolorbox}
\end{center}

\texttt{ViewportMaskPerViewNV}

Decorating a variable with the \texttt{ViewportMaskPerViewNV} built-in decoration will make that variable contain the mask of viewports primitives are broadcast to, for each view.

The value written to an element of \texttt{ViewportMaskPerViewNV} in the last pre-rasterization shader stage is a bitmask indicating which viewports the primitive will be directed to. The primitive will be broadcast to the viewport corresponding to each non-zero bit of the bitmask, and that viewport index is used to select the viewport transform, scissor rectangle, and exclusive scissor rectangle, for each view. The same values \textbf{must} be written to all vertices in a given primitive, or else the set of viewports used for that primitive is undefined.

Elements of the array correspond to views in a multiview subpass, and those elements corresponding to views in the view mask of the subpass the shader is compiled against will be used as the viewport mask value for those views. \texttt{ViewportMaskPerViewNV} output in an earlier pre-rasterization shader stage is not available as an input in the subsequent pre-rasterization shader stage.

Although \texttt{ViewportMaskNV} is an array, \texttt{ViewportMaskPerViewNV} is not a two-dimensional array. Instead, \texttt{ViewportMaskPerViewNV} is limited to 32 viewports.

\begin{center}
\begin{tcolorbox}
\textbf{Valid Usage}

- VUID-ViewportMaskPerViewNV-ViewportMaskPerViewNV-04412
  The \texttt{ViewportMaskPerViewNV} decoration \textbf{must} be used only within the \texttt{Vertex}, \texttt{MeshNV}, \texttt{TessellationControl}, \texttt{TessellationEvaluation}, or \texttt{Geometry Execution Model}

- VUID-ViewportMaskPerViewNV-ViewportMaskPerViewNV-04413
  The variable decorated with \texttt{ViewportMaskPerViewNV} \textbf{must} be declared using the \texttt{Output Storage Class}

\end{tcolorbox}
\end{center}
**Storage Class**

- VUID-ViewportMaskPerViewNV-ViewportMaskPerViewNV-04414
  The variable decorated with `ViewportMaskPerViewNV` **must** be declared as an array of 32-bit integer values

- VUID-ViewportMaskPerViewNV-ViewportMaskPerViewNV-04415
  The array decorated with `ViewportMaskPerViewNV` **must** be a size less than or equal to 32

- VUID-ViewportMaskPerViewNV-ViewportMaskPerViewNV-04416
  The array decorated with `ViewportMaskPerViewNV` **must** be a size greater than the maximum view in the subpass's view mask

- VUID-ViewportMaskPerViewNV-ViewportMaskPerViewNV-04417
  The array variable decorated with `ViewportMaskPerViewNV` **must** only be indexed by a constant or specialization constant

**WarpsPerSMNV**

Decorating a variable with the `WarpsPerSMNV` built-in decoration will make that variable contain the maximum number of warps executing on a SM.

**Valid Usage**

- VUID-WarpsPerSMNV-WarpsPerSMNV-04418
  The variable decorated with `WarpsPerSMNV` **must** be declared using the Input Storage Class

- VUID-WarpsPerSMNV-WarpsPerSMNV-04419
  The variable decorated with `WarpsPerSMNV` **must** be declared as a scalar 32-bit integer value

**WarpIDNV**

Decorating a variable with the `WarpIDNV` built-in decoration will make that variable contain the ID of the warp on a SM on which the current shader invocation is running. This variable is in the range [0, `WarpsPerSMNV`-1].

**Valid Usage**

- VUID-WarpIDNV-WarpIDNV-04420
  The variable decorated with `WarpIDNV` **must** be declared using the Input Storage Class

- VUID-WarpIDNV-WarpIDNV-04421
  The variable decorated with `WarpIDNV` **must** be declared as a scalar 32-bit integer value

**WorkgroupId**

Decorating a variable with the `WorkgroupId` built-in decoration will make that variable contain the global workgroup that the current invocation is a member of. Each component ranges from a base value to a base + count value, based on the parameters passed into the dispatching commands.
Valid Usage

• VUID-WorkgroupId-WorkgroupId-04422
  The WorkgroupId decoration **must** be used only within the GLCompute, MeshEXT, TaskEXT, MeshNV, or TaskNV Execution Model

• VUID-WorkgroupId-WorkgroupId-04423
  The variable decorated with WorkgroupId **must** be declared using the Input Storage Class

• VUID-WorkgroupId-WorkgroupId-04424
  The variable decorated with WorkgroupId **must** be declared as a three-component vector of 32-bit integer values

**WorkgroupSize**

*Note*

SPIR-V 1.6 deprecated WorkgroupSize in favor of using the LocalSizeId Execution Mode instead. Support for LocalSizeId was added with VK_KHR_maintenance4 and promoted to core in Version 1.3.

Decorating an object with the WorkgroupSize built-in decoration will make that object contain the dimensions of a local workgroup. If an object is decorated with the WorkgroupSize decoration, this takes precedence over any LocalSize or LocalSizeId execution mode.

Valid Usage

• VUID-WorkgroupSize-WorkgroupSize-04425
  The WorkgroupSize decoration **must** be used only within the GLCompute, MeshEXT, TaskEXT, MeshNV, or TaskNV Execution Model

• VUID-WorkgroupSize-WorkgroupSize-04426
  The variable decorated with WorkgroupSize **must** be a specialization constant or a constant

• VUID-WorkgroupSize-WorkgroupSize-04427
  The variable decorated with WorkgroupSize **must** be declared as a three-component vector of 32-bit integer values

**WorldRayDirectionKHR**

A variable decorated with the WorldRayDirectionKHR decoration will specify the direction of the ray being processed, in world space. The value is the parameter passed into OpTraceRayKHR.

Valid Usage

• VUID-WorldRayDirectionKHR-WorldRayDirectionKHR-04428
  The WorldRayDirectionKHR decoration **must** be used only within the IntersectionKHR, AnyHitKHR, ClosestHitKHR, or MissKHR Execution Model

• VUID-WorldRayDirectionKHR-WorldRayDirectionKHR-04429
The variable decorated with `WorldRayDirectionKHR` **must** be declared using the `Input Storage Class`.

- VUID-WorldRayDirectionKHR-WorldRayDirectionKHR-04430
  The variable decorated with `WorldRayDirectionKHR` **must** be declared as a three-component vector of 32-bit floating-point values.

**WorldRayOriginKHR**

A variable decorated with the `WorldRayOriginKHR` decoration will specify the origin of the ray being processed, in world space. The value is the parameter passed into `OpTraceRayKHR`.

**Valid Usage**

- VUID-WorldRayOriginKHR-WorldRayOriginKHR-04431
  The `WorldRayOriginKHR` decoration **must** be used only within the `IntersectionKHR`, `AnyHitKHR`, `ClosestHitKHR`, or `MissKHR` Execution Model.

- VUID-WorldRayOriginKHR-WorldRayOriginKHR-04432
  The variable decorated with `WorldRayOriginKHR` **must** be declared using the `Input Storage Class`.

- VUID-WorldRayOriginKHR-WorldRayOriginKHR-04433
  The variable decorated with `WorldRayOriginKHR` **must** be declared as a three-component vector of 32-bit floating-point values.

**WorldToObjectKHR**

A variable decorated with the `WorldToObjectKHR` decoration will contain the current world-to-object transformation matrix, which is determined by the instance of the current intersection.

**Valid Usage**

- VUID-WorldToObjectKHR-WorldToObjectKHR-04434
  The `WorldToObjectKHR` decoration **must** be used only within the `IntersectionKHR`, `AnyHitKHR`, `ClosestHitKHR`, or `MissKHR` Execution Model.

- VUID-WorldToObjectKHR-WorldToObjectKHR-04435
  The variable decorated with `WorldToObjectKHR` **must** be declared using the `Input Storage Class`.

- VUID-WorldToObjectKHR-WorldToObjectKHR-04436
  The variable decorated with `WorldToObjectKHR` **must** be declared as a matrix with four columns of three-component vectors of 32-bit floating-point values.

**CoreCountARM**

Decorating a variable with the `CoreCountARM` built-in decoration will make that variable contain the number of cores on the device.
### CoreCountARM

Decorating a variable with the `CoreCountARM` built-in decoration will make that variable contain the number of shader cores in the device on which the current shader invocation is running.

**Valid Usage**

- VUID-CoreCountARM-CoreCountARM-07595
  The variable decorated with `CoreCountARM` **must** be declared using the Input Storage Class
- VUID-CoreCountARM-CoreCountARM-07596
  The variable decorated with `CoreCountARM` **must** be declared as a scalar 32-bit integer value

### CoreMaxIDARM

Decorating a variable with the `CoreMaxIDARM` built-in decoration will make that variable contain the max ID of any shader core on the device on which the current shader invocation is running.

**Valid Usage**

- VUID-CoreMaxIDARM-CoreMaxIDARM-07597
  The variable decorated with `CoreMaxIDARM` **must** be declared using the Input Storage Class
- VUID-CoreMaxIDARM-CoreMaxIDARM-07598
  The variable decorated with `CoreMaxIDARM` **must** be declared as a scalar 32-bit integer value

### CoreIDARM

Decorating a variable with the `CoreIDARM` built-in decoration will make that variable contain the ID of the core on which the current shader invocation is running. This variable is in the range $[0, \text{CoreMaxIDARM}]$.

**Valid Usage**

- VUID-CoreIDARM-CoreIDARM-07599
  The variable decorated with `CoreIDARM` **must** be declared using the Input Storage Class
- VUID-CoreIDARM-CoreIDARM-07600
  The variable decorated with `CoreIDARM` **must** be declared as a scalar 32-bit integer value

### WarpMaxIDARM

Decorating a variable with the `WarpMaxIDARM` built-in decoration will make that variable contain the maximum warp ID for the core on which the current invocation is running.

**Valid Usage**

- VUID-WarpMaxIDARM-WarpMaxIDARM-07601
  The variable decorated with `WarpMaxIDARM` **must** be declared using the Input Storage Class
- VUID-WarpMaxIDARM-WarpMaxIDARM-07602
  The variable decorated with `WarpMaxIDARM` **must** be declared as a scalar 32-bit integer value
WarpIDARM

Decorating a variable with the WarpIDARM built-in decoration will make that variable contain the ID of the warp on a core on which the current shader invocation is running. This variable is in the range \([0, \text{WarpMaxIDARM}]\).

Valid Usage

- VUID-WarpIDARM-WarpIDARM-07603
  The variable decorated with WarpIDARM must be declared using the Input Storage Class
- VUID-WarpIDARM-WarpIDARM-07604
  The variable decorated with WarpIDARM must be declared as a scalar 32-bit integer value

CoalescedInputCountAMDX

Decorating a variable with the CoalescedInputCountAMDX built-in decoration will make that variable contain the number of node dispatches that the implementation coalesced into the input for the current shader. This variable will take a value in the range \([1, \text{arraySize})\), where arraySize is the maximum size of the input payload array for the shader.

Valid Usage

- VUID-CoalescedInputCountAMDX-CoalescedInputCountAMDX-09172
  The variable decorated with CoalescedInputCountAMDX must be declared using the Input Storage Class
- VUID-CoalescedInputCountAMDX-CoalescedInputCountAMDX-09173
  If a variable is decorated with CoalescedInputCountAMDX, the CoalescingAMDX execution mode must be declared
- VUID-CoalescedInputCountAMDX-CoalescedInputCountAMDX-09174
  The variable decorated with CoalescedInputCountAMDX must be declared as a scalar 32-bit integer value

ShaderIndexAMDX

Decorating a variable with the ShaderIndexAMDX built-in decoration will make that variable contain the index of the shader specified when it was compiled, either via VkPipelineShaderStageNodeCreateInfoAMDX::index or by the ShaderIndexAMDX execution mode.

Valid Usage

- VUID-ShaderIndexAMDX-ShaderIndexAMDX-09175
  The variable decorated with ShaderIndexAMDX must be declared using the Input Storage Class
- VUID-ShaderIndexAMDX-ShaderIndexAMDX-09176
The variable decorated with ShaderIndexAMDX **must** be declared as a scalar 32-bit integer value.
Chapter 16. Image Operations

16.1. Image Operations Overview

Vulkan Image Operations are operations performed by those SPIR-V Image Instructions which take an `OpTypeImage` (representing a `VkImageView`) or `OpTypeSampledImage` (representing a `(VkImageView, VkSampler)` pair). Read, write, and atomic operations also take texel coordinates as operands, and return a value based on a neighborhood of texture elements (texels) within the image. Query operations return properties of the bound image or of the lookup itself. The “Depth” operand of `OpTypeImage` is ignored.

**Note**
Texel is a term which is a combination of the words texture and element. Early interactive computer graphics supported texture operations on textures, a small subset of the image operations on images described here. The discrete samples remain essentially equivalent, however, so we retain the historical term texel to refer to them.

Image Operations include the functionality of the following SPIR-V Image Instructions:

- `OpImageSample*` and `OpImageSparseSample*` read one or more neighboring texels of the image, and filter the texel values based on the state of the sampler.
  - Instructions with `ImplicitLod` in the name determine the LOD used in the sampling operation based on the coordinates used in neighboring fragments.
  - Instructions with `ExplicitLod` in the name determine the LOD used in the sampling operation based on additional coordinates.
  - Instructions with `Proj` in the name apply homogeneous projection to the coordinates.
- `OpImageFetch` and `OpImageSparseFetch` return a single texel of the image. No sampler is used.
- `OpImage*Gather` and `OpImageSparse*Gather` read neighboring texels and return a single component of each.
- `OpImageRead` (and `OpImageSparseRead`) and `OpImageWrite` read and write, respectively, a texel in the image. No sampler is used.
- `OpImageSampleFootprintNV` identifies and returns information about the set of texels in the image that would be accessed by an equivalent `OpImageSample*` instruction.
- `OpImage*Dref*` instructions apply depth comparison on the texel values.
- `OpImageSparse*` instructions additionally return a sparse residency code.
- `OpImageQueryLod` returns the LOD parameters that would be used in a sample operation. The actual operation is not performed.
- `OpImageWeightedSampleQCOM` reads a 2D neighborhood of texels and computes a weighted average using weight values from a separate weight texture.
• `opImageBlockMatchSADQCOM` and `opTextureBlockMatchSSD` compare 2D neighborhoods of texels from two textures.

• `OpImageBoxFilterQCOM` reads a 2D neighborhood of texels and computes a weighted average of the texels.

• `opImageBlockMatchWindowSADQCOM` and `opImageBlockMatchWindowSSDQCOM` compare 2D neighborhoods of texels from two textures with the comparison repeated across a window region in the target texture.

• `opImageBlockMatchGatherSADQCOM` and `opImageBlockMatchWindowSSDQCOM` compares four 2D neighborhoods of texels from a target texture with a single 2D neighborhood in the reference texture. The R component of each comparison is gathered and returned in the output.

### 16.1.1. Texel Coordinate Systems

Images are addressed by *texel coordinates*. There are three *texel coordinate systems*:

- normalized texel coordinates $[0.0, 1.0]$
- unnormalized texel coordinates $[0.0, \text{width} / \text{height} / \text{depth}]$
- integer texel coordinates $[0, \text{width} / \text{height} / \text{depth}]$


Other image instructions can use either normalized or unnormalized texel coordinates (selected by the `unnormalizedCoordinates` state of the sampler used in the instruction), but there are limitations on what operations, image state, and sampler state is supported. Normalized coordinates are logically converted to unnormalized as part of image operations, and certain steps are only performed on normalized coordinates. The array layer coordinate is always treated as unnormalized even when other coordinates are normalized.

Normalized texel coordinates are referred to as $(s,t,r,q,a)$, with the coordinates having the following meanings:

- $s$: Coordinate in the first dimension of an image.
- $t$: Coordinate in the second dimension of an image.
- $r$: Coordinate in the third dimension of an image.
  - $(s,t,r)$ are interpreted as a direction vector for Cube images.
- $q$: Fourth coordinate, for homogeneous (projective) coordinates.
- $a$: Coordinate for array layer.

The coordinates are extracted from the SPIR-V operand based on the dimensionality of the image variable and type of instruction. For `Proj` instructions, the components are in order $(s, [t], [r], q)$, with $t$ and $r$ being conditionally present based on the `Dim` of the image. For non-`Proj` instructions, the coordinates are $(s, [t], [r], [a])$, with $t$ and $r$ being conditionally present based on the `Dim` of the image and $a$ being conditionally present based on the `Arrayed` property of the image. Projective
Unnormalized texel coordinates are referred to as (u,v,w,a), with the coordinates having the following meanings:

- **u**: Coordinate in the first dimension of an image.
- **v**: Coordinate in the second dimension of an image.
- **w**: Coordinate in the third dimension of an image.
- **a**: Coordinate for array layer.

Only the u and v coordinates are directly extracted from the SPIR-V operand, because only 1D and 2D (non-Arrayed) dimensionalities support unnormalized coordinates. The components are in order (u [,v]), with v being conditionally present when the dimensionality is 2D. When normalized coordinates are converted to unnormalized coordinates, all four coordinates are used.

Integer texel coordinates are referred to as (i,j,k,l,n), with the coordinates having the following meanings:

- **i**: Coordinate in the first dimension of an image.
- **j**: Coordinate in the second dimension of an image.
- **k**: Coordinate in the third dimension of an image.
- **l**: Coordinate for array layer.
- **n**: Index of the sample within the texel.

They are extracted from the SPIR-V operand in order (i [,j] [,k] [,l] [,n]), with j and k conditionally present based on the Dim of the image, and l conditionally present based on the Arrayed property of the image. n is conditionally present and is taken from the Sample image operand.

If an accessed image was created from a view using VkImageViewSlicedCreateInfoEXT and accessed through a VK_DESCRIPTOR_TYPE_STORAGE_IMAGE descriptor, then the value of k is incremented by VkImageViewSlicedCreateInfoEXT::sliceOffset, giving k ← sliceOffset + k. The image's accessible range in the third dimension is k < sliceOffset + sliceCount. If VkImageViewSlicedCreateInfoEXT::sliceCount is VK_REMAINING_3D_SLICES_EXT, the range is inherited from the image's depth extent as specified by Image Mip Level Sizing.

For all coordinate types, unused coordinates are assigned a value of zero.
The Texel Coordinate Systems - For the example shown of an 8×4 texel two dimensional image.

- Normalized texel coordinates:
  - The s coordinate goes from 0.0 to 1.0.
  - The t coordinate goes from 0.0 to 1.0.

- Unnormalized texel coordinates:
  - The u coordinate within the range 0.0 to 8.0 is within the image, otherwise it is outside the image.
  - The v coordinate within the range 0.0 to 4.0 is within the image, otherwise it is outside the image.

- Integer texel coordinates:
  - The i coordinate within the range 0 to 7 addresses texels within the image, otherwise it is outside the image.
  - The j coordinate within the range 0 to 3 addresses texels within the image, otherwise it is outside the image.

- Also shown for linear filtering:
  - Given the unnormalized coordinates (u,v), the four texels selected are \( i_0j_0 \), \( i_1j_0 \), \( i_0j_1 \), and \( i_1j_1 \).
  - The fractions \( \alpha \) and \( \beta \).
  - Given the offset \( \Delta_i \) and \( \Delta_j \), the four texels selected by the offset are \( i_0j'_0 \), \( i_1j'_0 \), \( i_0j'_1 \), and \( i_1j'_1 \).

**Note**

For formats with reduced-resolution components, \( \Delta_i \) and \( \Delta_j \) are relative to the resolution of the highest-resolution component, and therefore may be divided by two relative to the unnormalized coordinate space of the lower-resolution
The Texel Coordinate Systems - For the example shown of an 8×4 texel two dimensional image.

- Texel coordinates as above. Also shown for nearest filtering:
  - Given the unnormalized coordinates \((u,v)\), the texel selected is \(ij\).
  - Given the offset \(\Delta_i\) and \(\Delta_j\), the texel selected by the offset is \(ij'\).

For corner-sampled images, the texel samples are located at the grid intersections instead of the texel centers.
### 16.2. Conversion Formulas

#### 16.2.1. RGB to Shared Exponent Conversion

An RGB color (red, green, blue) is transformed to a shared exponent color \((\text{red}_{\text{shared}}, \text{green}_{\text{shared}}, \text{blue}_{\text{shared}}, \text{exp}_{\text{shared}})\) as follows:

First, the components (red, green, blue) are clamped to \((\text{red}_{\text{clamped}}, \text{green}_{\text{clamped}}, \text{blue}_{\text{clamped}})\) as:

- \[\text{red}_{\text{clamped}} = \max(0, \min(\text{sharedexp}_{\text{max}}, \text{red}))\]
- \[\text{green}_{\text{clamped}} = \max(0, \min(\text{sharedexp}_{\text{max}}, \text{green}))\]
- \[\text{blue}_{\text{clamped}} = \max(0, \min(\text{sharedexp}_{\text{max}}, \text{blue}))\]

where:

- \[N = 9\]
- \[B = 15\]
- \[E_{\text{max}} = 31\]
- \[\text{sharedexp}_{\text{max}} = \frac{(2^N - 1)}{2^N} \times 2^{(E_{\text{max}} - B)}\]

**Note**

NaN, if supported, is handled as in...
IEEE 754-2008 \textit{minNum()} and \textit{maxNum()}. This results in any NaN being mapped to zero.

The largest clamped component, $\max_{\text{clamped}}$ is determined:

$$\max_{\text{clamped}} = \max(\text{red}_{\text{clamped}}, \text{green}_{\text{clamped}}, \text{blue}_{\text{clamped}})$$

A preliminary shared exponent $\exp'$ is computed:

$$\exp' = \begin{cases} 
\lfloor \log_2(\max_{\text{clamped}}) \rfloor + (B + 1) & \text{for } \max_{\text{clamped}} > 2^{-(B + 1)} \\
0 & \text{for } \max_{\text{clamped}} \leq 2^{-(B + 1)} 
\end{cases}$$

The shared exponent $\exp_{\text{shared}}$ is computed:

$$\max_{\text{shared}} = \left\lfloor \frac{\max_{\text{clamped}}}{2^{(\exp' - B - N)}} + \frac{1}{2} \right\rfloor$$

$$\exp_{\text{shared}} = \begin{cases} 
\exp' & \text{for } 0 \leq \max_{\text{shared}} < 2^N \\
\exp' + 1 & \text{for } \max_{\text{shared}} = 2^N 
\end{cases}$$

Finally, three integer values in the range $0$ to $2^N$ are computed:

$$\text{red}_{\text{shared}} = \left\lfloor \frac{\text{red}_{\text{clamped}}}{2^{(\exp_{\text{shared}} - B - N)}} + \frac{1}{2} \right\rfloor$$

$$\text{green}_{\text{shared}} = \left\lfloor \frac{\text{green}_{\text{clamped}}}{2^{(\exp_{\text{shared}} - B - N)}} + \frac{1}{2} \right\rfloor$$

$$\text{blue}_{\text{shared}} = \left\lfloor \frac{\text{blue}_{\text{clamped}}}{2^{(\exp_{\text{shared}} - B - N)}} + \frac{1}{2} \right\rfloor$$

### 16.2.2. Shared Exponent to RGB

A shared exponent color ($\text{red}_{\text{shared}}, \text{green}_{\text{shared}}, \text{blue}_{\text{shared}}, \exp_{\text{shared}}$) is transformed to an RGB color (red, green, blue) as follows:

$$\text{red} = \text{red}_{\text{shared}} \times 2^{(\exp_{\text{shared}} - B - N)}$$

$$\text{green} = \text{green}_{\text{shared}} \times 2^{(\exp_{\text{shared}} - B - N)}$$

$$\text{blue} = \text{blue}_{\text{shared}} \times 2^{(\exp_{\text{shared}} - B - N)}$$

where:
16.3. Texel Input Operations

*Texel input instructions* are SPIR-V image instructions that read from an image. *Texel input operations* are a set of steps that are performed on state, coordinates, and texel values while processing a texel input instruction, and which are common to some or all texel input instructions. They include the following steps, which are performed in the listed order:

- **Validation operations**
  - Instruction/Sampler/Image validation
  - Coordinate validation
  - Sparse validation
  - Layout validation
- **Format conversion**
- **Texel replacement**
- **Depth comparison**
- **Conversion to RGBA**
- **Component swizzle**
- **Chroma reconstruction**
- **Y'CbCr conversion**

For texel input instructions involving multiple texels (for sampling or gathering), these steps are applied for each texel that is used in the instruction. Depending on the type of image instruction, other steps are conditionally performed between these steps or involving multiple coordinate or texel values.

If Chroma Reconstruction is implicit, Texel Filtering instead takes place during chroma reconstruction, before sampler Y'CbCr conversion occurs.

The operations described in block matching and weight image sampling are performed before Conversion to RGBA and Component swizzle.

16.3.1. Texel Input Validation Operations

*Texel input validation operations* inspect instruction/image/sampler state or coordinates, and in certain circumstances cause the texel value to be replaced or become undefined. There are a series of validations that the texel undergoes.
Instruction/Sampler/Image View Validation

There are a number of cases where a SPIR-V instruction can mismatch with the sampler, the image view, or both, and a number of further cases where the sampler can mismatch with the image view. In such cases the value of the texel returned is undefined.

These cases include:

- The sampler `borderColor` is an integer type and the image view format is not one of the `VkFormat` integer types or a stencil component of a depth/stencil format.
- The sampler `borderColor` is a float type and the image view format is not one of the `VkFormat` float types or a depth component of a depth/stencil format.
- The sampler `borderColor` is one of the opaque black colors (`VK_BORDER_COLOR_FLOAT_OPAQUE_BLACK` or `VK_BORDER_COLOR_INT_OPAQUE_BLACK`) and the image view `VkComponentSwizzle` for any of the `VkComponentMapping` components is not the identity swizzle, and `VkPhysicalDeviceBorderColorSwizzleFeaturesEXT::borderColorSwizzleFromImage` feature is not enabled, and `VkSamplerBorderColorComponentMappingCreateInfoEXT` is not specified.
- `VkSamplerBorderColorComponentMappingCreateInfoEXT::components`, if specified, has a component swizzle that does not match the component swizzle of the image view, and either component swizzle is not a form of identity swizzle.
- `VkSamplerBorderColorComponentMappingCreateInfoEXT::srgb`, if specified, does not match the sRGB encoding of the image view.
- The sampler `borderColor` is a custom color (`VK_BORDER_COLOR_FLOAT_CUSTOM_EXT` or `VK_BORDER_COLOR_INT_CUSTOM_EXT`) and the supplied `VkSamplerCustomBorderColorCreateInfoEXT::customBorderColor` is outside the bounds of the values representable in the image view's format.
- The sampler `borderColor` is a custom color (`VK_BORDER_COLOR_FLOAT_CUSTOM_EXT` or `VK_BORDER_COLOR_INT_CUSTOM_EXT`) and the image view `VkComponentSwizzle` for any of the `VkComponentMapping` components is not the identity swizzle, and `VkPhysicalDeviceBorderColorSwizzleFeaturesEXT::borderColorSwizzleFromImage` feature is not enabled, and `VkSamplerBorderColorComponentMappingCreateInfoEXT` is not specified.
- The `VkImageLayout` of any subresource in the image view does not match the `VkDescriptorImageInfo::imageLayout` used to write the image descriptor.
- The SPIR-V Image Format is not compatible with the image view's format.
- The sampler `unnormalizedCoordinates` is `VK_TRUE` and any of the limitations of unnormalized coordinates are violated.
- The sampler was created with flags containing `VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT` and the image was not created with flags containing `VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT`.
- The sampler was not created with flags containing `VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT` and the image was created with flags containing `VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT`.
- The sampler was created with flags containing `VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT` and is used with a function that is not `OpImageSampleImplicitLod` or `OpImageSampleExplicitLod`, or is used with operands `Offset` or `ConstOffsets`.
- The SPIR-V instruction is one of the `OpImage*Dref*` instructions and the sampler `compareEnable` is
• The SPIR-V instruction is not one of the `OpImage*Dref*` instructions and the sampler `compareEnable` is `VK_TRUE`.

• The SPIR-V instruction is one of the `OpImage*Dref*` instructions, the image view `format` is one of the depth/stencil formats, and the image view aspect is not `VK_IMAGE_ASPECT_DEPTH_BIT`.

• The SPIR-V instruction's image variable's properties are not compatible with the image view:
  
  ◦ Rules for `viewType`:
    
    ▪ `VK_IMAGE_VIEW_TYPE_1D` must have `Dim = 1D, Arrayed = 0, MS = 0.`
    
    ▪ `VK_IMAGE_VIEW_TYPE_2D` must have `Dim = 2D, Arrayed = 0.`
    
    ▪ `VK_IMAGE_VIEW_TYPE_3D` must have `Dim = 3D, Arrayed = 0, MS = 0.`
    
    ▪ `VK_IMAGE_VIEW_TYPE_CUBE` must have `Dim = Cube, Arrayed = 0, MS = 0.`
    
    ▪ `VK_IMAGE_VIEW_TYPE_1D_ARRAY` must have `Dim = 1D, Arrayed = 1, MS = 0.`
    
    ▪ `VK_IMAGE_VIEW_TYPE_2D_ARRAY` must have `Dim = 2D, Arrayed = 1.`
    
    ▪ `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY` must have `Dim = Cube, Arrayed = 1, MS = 0.`
  
  ◦ If the image was created with `VkImageCreateInfo::samples` equal to `VK_SAMPLE_COUNT_1_BIT`, the instruction must have `MS = 0.`

  ◦ If the image was created with `VkImageCreateInfo::samples` not equal to `VK_SAMPLE_COUNT_1_BIT`, the instruction must have `MS = 1.`

  ◦ If the `Sampled Type` of the `OpTypeImage` does not match the SPIR-V `Type`.

  ◦ If the signedness of any read or sample operation does not match the signedness of the image's `format`.

  • If the image was created with `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV`, the sampler `addressing modes` must only use a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

  • The SPIR-V instruction is `OpImageSampleFootprintNV` with `Dim = 2D` and `addressModeU` or `addressModeV` in the sampler is not `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

  • The SPIR-V instruction is `OpImageSampleFootprintNV` with `Dim = 3D` and `addressModeU`, `addressModeV`, or `addressModeW` in the sampler is not `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

  • The sampler was created with a specified `VkSamplerCustomBorderColorCreateInfoEXT::format` which does not match the `VkFormat` of the image view(s) it is sampling.

  • The sampler is sampling an image view of `VK_FORMAT_B4G4R4A4_UNORM_PACK16`, `VK_FORMAT_B5G6R5_UNORM_PACK16`, or `VK_FORMAT_B5G5R5A1_UNORM_PACK16` format without a specified `VkSamplerCustomBorderColorCreateInfoEXT::format`.

Only `OpImageSample*` and `OpImageSparseSample*` can be used with a sampler or image view that enables `sampler Y’CbCr` conversion.

`OpImageFetch`, `OpImageSparseFetch`, `OpImage*Gather`, and `OpImageSparse*Gather` must not be used with a sampler or image view that enables `sampler Y’CbCr` conversion.

The `ConstOffset` and `Offset` operands must not be used with a sampler or image view that enables
sampler Y'CbCr conversion.

**Integer Texel Coordinate Validation**

Integer texel coordinates are validated against the size of the image level, and the number of layers and number of samples in the image. For SPIR-V instructions that use integer texel coordinates, this is performed directly on the integer coordinates. For instructions that use normalized or unnormalized texel coordinates, this is performed on the coordinates that result after conversion to integer texel coordinates.

If the integer texel coordinates do not satisfy all of the conditions

\[
0 \leq i < w_s \\
0 \leq j < h_s \\
0 \leq k < d_s \\
0 \leq l < \text{layers} \\
0 \leq n < \text{samples}
\]

where:

\[
w_s = \text{width of the image level} \\
h_s = \text{height of the image level} \\
d_s = \text{depth of the image level} \\
\text{layers} = \text{number of layers in the image} \\
\text{samples} = \text{number of samples per texel in the image}
\]

then the texel fails integer texel coordinate validation.

There are four cases to consider:

1. **Valid Texel Coordinates**
If the texel coordinates pass validation (that is, the coordinates lie within the image), then the texel value comes from the value in image memory.

2. Border Texel
   - If the texel coordinates fail validation, and
   - If the read is the result of an image sample instruction or image gather instruction, and
   - If the image is not a cube image, or if a sampler created with `VK_SAMPLER_CREATE_NON_SEAMLESS_CUBE_MAP_BIT_EXT` is used,
   then the texel is a border texel and texel replacement is performed.

3. Invalid Texel
   - If the texel coordinates fail validation, and
   - If the read is the result of an image fetch instruction, image read instruction, or atomic instruction,
   then the texel is an invalid texel and texel replacement is performed.

4. Cube Map Edge or Corner
   Otherwise the texel coordinates lie beyond the edges or corners of the selected cube map face, and Cube map edge handling is performed.

Cube Map Edge Handling
If the texel coordinates lie beyond the edges or corners of the selected cube map face (as described in the prior section), the following steps are performed. Note that this does not occur when using `VK_FILTER_NEAREST` filtering within a mip level, since `VK_FILTER_NEAREST` is treated as using `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

- Cube Map Edge Texel
  - If the texel lies beyond the selected cube map face in either only $i$ or only $j$, then the coordinates $(i,j)$ and the array layer $l$ are transformed to select the adjacent texel from the appropriate neighboring face.

- Cube Map Corner Texel
  - If the texel lies beyond the selected cube map face in both $i$ and $j$, then there is no unique neighboring face from which to read that texel. The texel should be replaced by the average of the three values of the adjacent texels in each incident face. However, implementations may replace the cube map corner texel by other methods. The methods are subject to the constraint that for linear filtering if the three available texels have the same value, the resulting filtered texel must have that value, and for cubic filtering if the twelve available samples have the same value, the resulting filtered texel must have that value.

Sparse Validation
If the texel reads from an unbound region of a sparse image, the texel is a sparse unbound texel, and processing continues with texel replacement.
Layout Validation

If all planes of a disjoint multi-planar image are not in the same image layout, the image must not be sampled with sampler Y'CbCr conversion enabled.

16.3.2. Format Conversion

Texels undergo a format conversion from the VkFormat of the image view to a vector of either floating point or signed or unsigned integer components, with the number of components based on the number of components present in the format.

- Color formats have one, two, three, or four components, according to the format.
- Depth/stencil formats are one component. The depth or stencil component is selected by the aspectMask of the image view.

Each component is converted based on its type and size (as defined in the Format Definition section for each VkFormat), using the appropriate equations in 16-Bit Floating-Point Numbers, Unsigned 11-Bit Floating-Point Numbers, Unsigned 10-Bit Floating-Point Numbers, Fixed-Point Data Conversion, and Shared Exponent to RGB. Signed integer components smaller than 32 bits are sign-extended.

If the image view format is sRGB, the color components are first converted as if they are UNORM, and then sRGB to linear conversion is applied to the R, G, and B components as described in the “sRGB EOTF” section of the Khronos Data Format Specification. The A component, if present, is unchanged.

If VkSamplerYcbcrConversionYcbcrDegammaCreateInfoQCOM::enableYDegamma is equal to VK_TRUE, then sRGB to linear conversion is applied to the G component as described in the “sRGB EOTF” section of the Khronos Data Format Specification. If VkSamplerYcbcrConversionYcbcrDegammaCreateInfoQCOM::enableCbCrDegamma is equal to VK_TRUE, then sRGB to linear conversion is applied to the R and B components as described in the “sRGB EOTF” section of the Khronos Data Format Specification. The A component, if present, is unchanged.

If the image view format is block-compressed, then the texel value is first decoded, then converted based on the type and number of components defined by the compressed format.

16.3.3. Texel Replacement

A texel is replaced if it is one (and only one) of:

- a border texel,
- an invalid texel, or
- a sparse unbound texel.

Border texels are replaced with a value based on the image format and the borderColor of the sampler. The border color is:

Table 24. Border Color B, Custom Border Color VkSamplerCustomBorderColorCreateInfoEXT
The custom border color (U) may be rounded by implementations prior to texel replacement, but the error introduced by such a rounding must not exceed one ULP of the image’s format.

This is substituted for the texel value by replacing the number of components in the image format.

### Table 25. Border Texel Components After Replacement

<table>
<thead>
<tr>
<th>Texel Aspect or Format</th>
<th>Component Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth aspect</td>
<td>D = B_r</td>
</tr>
<tr>
<td>Stencil aspect</td>
<td>S = B_g†</td>
</tr>
<tr>
<td>One component color format</td>
<td>Color_r = B_r</td>
</tr>
<tr>
<td>Two component color format</td>
<td>[Color_r,Color_g] = [B_r,B_g]</td>
</tr>
<tr>
<td>Three component color format</td>
<td>[Color_r,Color_g,Color_b] = [B_r,B_g,B_b]</td>
</tr>
<tr>
<td>Four component color format</td>
<td>[Color_r,Color_g,Color_b,Color_a] = [B_r,B_g,B_b,B_a]</td>
</tr>
<tr>
<td>Single component alpha format</td>
<td>[Color_r,Color_g,Color_b,Color_a] = [0,0,0,B_a]</td>
</tr>
</tbody>
</table>

† S = B_g may be substituted as the replacement method by the implementation when VkSamplerCreateInfo::borderColor is VK_BORDER_COLOR_INT_CUSTOM_EXT and VkSamplerCustomBorderColorCreateInfoEXT::format is VK_FORMAT_UNDEFINED. Implementations should use S = B_g as the replacement method.

The value returned by a read of an invalid texel is undefined, unless that read operation is from a buffer resource and the robustBufferAccess feature is enabled. In that case, an invalid texel is replaced as described by the robustBufferAccess feature. If the access is to an image resource and
the x, y, z, or layer coordinate validation fails and the robustImageAccess feature is enabled, then zero must be returned for the R, G, and B components, if present. Either zero or one must be returned for the A component, if present. If the robustImageAccess2 feature is enabled, zero values must be returned. If only the sample index was invalid, the values returned are undefined.

Additionally, if the robustImageAccess feature is enabled, but the robustImageAccess2 feature is not, any invalid texels may be expanded to four components prior to texel replacement. This means that components not present in the image format may be replaced with 0 or may undergo conversion to RGBA as normal.

Loads from a null descriptor return a four component color value of all zeros. However, for storage images and storage texel buffers using an explicit SPIR-V Image Format, loads from a null descriptor may return an alpha value of 1 (float or integer, depending on format) if the format does not include alpha.

If the VkPhysicalDeviceSparseProperties::residencyNonResidentStrict property is VK_TRUE, a sparse unbound texel is replaced with 0 or 0.0 values for integer and floating-point components of the image format, respectively.

If residencyNonResidentStrict is VK_FALSE, the value of the sparse unbound texel is undefined.

16.3.4. Depth Compare Operation

If the image view has a depth/stencil format, the depth component is selected by the aspectMask, and the operation is an OpImage*Dref* instruction, a depth comparison is performed. The result is 1.0 if the comparison evaluates to true, and 0.0 otherwise. This value replaces the depth component D.

The compare operation is selected by the VkCompareOp value set by VkSamplerCreateInfo::compareOp. The reference value from the SPIR-V operand D_ref and the texel depth value D_text are used as the reference and test values, respectively, in that operation.

If the image being sampled has an unsigned normalized fixed-point format, then D_ref is clamped to [0,1] before the compare operation.

16.3.5. Conversion to RGBA

The texel is expanded from one, two, or three components to four components based on the image base color:

Table 26. Texel Color After Conversion To RGBA

<table>
<thead>
<tr>
<th>Texel Aspect or Format</th>
<th>RGBA Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth aspect</td>
<td>[Color_r,Color_g,Color_b,Color_a] = [D,0,0,one]</td>
</tr>
<tr>
<td>Stencil aspect</td>
<td>[Color_r,Color_g,Color_b,Color_a] = [S,0,0,one]</td>
</tr>
<tr>
<td>One component color format</td>
<td>[Color_r,Color_g,Color_b,Color_a] = [Color_r,0,one]</td>
</tr>
<tr>
<td>Two component color format</td>
<td>[Color_r,Color_g,Color_b,Color_a] = [Color_r,Color_g,0,one]</td>
</tr>
<tr>
<td>Three component color format</td>
<td>[Color_r,Color_g,Color_b,Color_a] = [Color_r,Color_g,Color_b,one]</td>
</tr>
<tr>
<td>Four component color format</td>
<td>[Color_r,Color_g,Color_b,Color_a] = [Color_r,Color_g,Color_b,Color_a]</td>
</tr>
</tbody>
</table>
### Texel Aspect or Format

<table>
<thead>
<tr>
<th>RGBA Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>One alpha component color format</td>
</tr>
<tr>
<td>[Color_r, Color_g, Color_b, Color_a] = [0,0,0,Color_a]</td>
</tr>
</tbody>
</table>

where \( \text{one} = 1.0f \) for floating-point formats and depth aspects, and \( \text{one} = 1 \) for integer formats and stencil aspects.

## 16.3.6. Component Swizzle

All texel input instructions apply a **swizzle** based on:

- the `VkComponentSwizzle` enums in the `components` member of the `VkImageViewCreateInfo` structure for the image being read if **sampler Y’C_bC_r conversion** is not enabled, and
- the `VkComponentSwizzle` enums in the `components` member of the `VkSamplerYcbcrConversionCreateInfo` structure for the **sampler Y’C_bC_r conversion** if **sampler Y’C_bC_r conversion** is enabled.

The swizzle can rearrange the components of the texel, or substitute zero or one for any components. It is defined as follows for each color component:

\[
\begin{align*}
\text{Color}'_{\text{component}} &= \begin{cases} 
\text{Color}_r & \text{for RED swizzle} \\
\text{Color}_g & \text{for GREEN swizzle} \\
\text{Color}_b & \text{for BLUE swizzle} \\
\text{Color}_a & \text{for ALPHA swizzle} \\
0 & \text{for ZERO swizzle} \\
\text{one} & \text{for ONE swizzle} \\
\text{identity} & \text{for IDENTITY swizzle}
\end{cases}
\end{align*}
\]

where:

\[
\begin{align*}
\text{one} &= \begin{cases} 
1.0f & \text{for floating point components} \\
1 & \text{for integer components}
\end{cases} \\
\text{identity} &= \begin{cases} 
\text{Color}_r & \text{for component} = r \\
\text{Color}_g & \text{for component} = g \\
\text{Color}_b & \text{for component} = b \\
\text{Color}_a & \text{for component} = a
\end{cases}
\end{align*}
\]

If the border color is one of the `VK_BORDER_COLOR_*_OPAQUE_BLACK` enums and the `VkComponentSwizzle` is not the `identity swizzle` for all components, the value of the texel after swizzle is undefined.

If the image view has a depth/stencil format and the `VkComponentSwizzle` is `VK_COMPONENT_SWIZZLE_ONE`, and `VkPhysicalDeviceMaintenance5PropertiesKHR::depthStencilSwizzleOneSupport` is not set to `VK_TRUE`, the value of the texel after swizzle is undefined.
16.3.7. Sparse Residency

OpImageSparse* instructions return a structure which includes a residency code indicating whether any texels accessed by the instruction are sparse unbound texels. This code can be interpreted by the OpImageSparseTexelsResident instruction which converts the residency code to a boolean value.

16.3.8. Chroma Reconstruction

In some color models, the color representation is defined in terms of monochromatic light intensity (often called “luma”) and color differences relative to this intensity, often called “chroma”. It is common for color models other than RGB to represent the chroma components at lower spatial resolution than the luma component. This approach is used to take advantage of the eye’s lower spatial sensitivity to color compared with its sensitivity to brightness. Less commonly, the same approach is used with additive color, since the green component dominates the eye’s sensitivity to light intensity and the spatial sensitivity to color introduced by red and blue is lower.

Lower-resolution components are “downsampled” by resizing them to a lower spatial resolution than the component representing luminance. This process is also commonly known as “chroma subsampling”. There is one luminance sample in each texture texel, but each chrominance sample may be shared among several texels in one or both texture dimensions.

- “_444” formats do not spatially downsample chroma values compared with luma: there are unique chroma samples for each texel.
- “_422” formats have downsampling in the x dimension (corresponding to \( u \) or \( s \) coordinates): they are sampled at half the resolution of luma in that dimension.
- “_420” formats have downsampling in the x dimension (corresponding to \( u \) or \( s \) coordinates) and the y dimension (corresponding to \( v \) or \( t \) coordinates): they are sampled at half the resolution of luma in both dimensions.

The process of reconstructing a full color value for texture access involves accessing both chroma and luma values at the same location. To generate the color accurately, the values of the lower-resolution components at the location of the luma samples must be reconstructed from the lower-resolution sample locations, an operation known here as “chroma reconstruction” irrespective of the actual color model.

The location of the chroma samples relative to the luma coordinates is determined by the \( xChromaOffset \) and \( yChromaOffset \) members of the VkSamplerYcbcrConversionCreateInfo structure used to create the sampler \( Y’C_BC_R \) conversion.

The following diagrams show the relationship between unnormalized \((u,v)\) coordinates and \((i,j)\) integer texel positions in the luma component (shown in black, with circles showing integer sample positions) and the texel coordinates of reduced-resolution chroma components, shown as crosses in red.

Note

If the chroma values are reconstructed at the locations of the luma samples by means of interpolation, chroma samples from outside the image bounds are needed; these are determined according to Wrapping Operation. These diagrams
represent this by showing the bounds of the “chroma texel” extending beyond the image bounds, and including additional chroma sample positions where required for interpolation. The limits of a sample for **NEAREST** sampling is shown as a grid.

**Figure 6. 422 downsampling, xChromaOffset=COSITED_EVEN**

**Figure 7. 422 downsampling, xChromaOffset=MIDPOINT**
Figure 8. 420 downsampling, $xChromaOffset=\text{COSITED\_EVEN}$, $yChromaOffset=\text{COSITED\_EVEN}$

Figure 9. 420 downsampling, $xChromaOffset=\text{MIDPOINT}$, $yChromaOffset=\text{COSITED\_EVEN}$
Reconstruction is implemented in one of two ways:

If the format of the image that is to be sampled sets `VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_BIT`, or the `VkSamplerYcbcrConversionCreateInfo`’s `forceExplicitReconstruction` is set to `VK_TRUE`, reconstruction is performed as an explicit step independent of filtering, described in the *Explicit Reconstruction* section.

If the format of the image that is to be sampled does not set `VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_BIT` and if the
VkSamplerYcbcrConversionCreateInfo’s `forceExplicitReconstruction` is set to VK_FALSE, reconstruction is performed as an implicit part of filtering prior to color model conversion, with no separate post-conversion texel filtering step, as described in the Implicit Reconstruction section.

**Explicit Reconstruction**

- If the `chromaFilter` member of the `VkSamplerYcbcrConversionCreateInfo` structure is VK_FILTER_NEAREST:
  - If the format’s R and B components are reduced in resolution in just width by a factor of two relative to the G component (i.e. this is a “_422” format), the $\tau_{ijk}[\text{level}]$ values accessed by texel filtering are reconstructed as follows:
    \[
    \begin{align*}
    \tau_R'(i, j) &= \tau_R([i \times 0.5], j)[\text{level}] \\
    \tau_B'(i, j) &= \tau_B([i \times 0.5], j)[\text{level}]
    \end{align*}
    \]
  - If the format’s R and B components are reduced in resolution in width and height by a factor of two relative to the G component (i.e. this is a “_420” format), the $\tau_{ijk}[\text{level}]$ values accessed by texel filtering are reconstructed as follows:
    \[
    \begin{align*}
    \tau_R'(i, j) &= \tau_R([i \times 0.5], [j \times 0.5])[\text{level}] \\
    \tau_B'(i, j) &= \tau_B([i \times 0.5], [j \times 0.5])[\text{level}]
    \end{align*}
    \]

  - **Note**
    - `xChromaOffset` and `yChromaOffset` have no effect if `chromaFilter` is VK_FILTER_NEAREST for explicit reconstruction.

- If the `chromaFilter` member of the `VkSamplerYcbcrConversionCreateInfo` structure is VK_FILTER_LINEAR:
  - If the format’s R and B components are reduced in resolution in just width by a factor of two relative to the G component (i.e. this is a “_422” format):
    - If `xChromaOffset` is VK_CHROMA_LOCATION_COSITED_EVEN:
      \[
      \tau_{RB}'(i, j) = \begin{cases} 
      \tau_{RB}([i \times 0.5], [j \times 0.5])[\text{level}], & 0.5 \times i = [0.5 \times i] \\
      0.5 \times \tau_{RB}([i \times 0.5], [j \times 0.5])[\text{level}] + 0.5 \times \tau_{RB}([i \times 0.5] + 1, [j \times 0.5])[\text{level}], & 0.5 \times i \neq [0.5 \times i]
      \end{cases}
      \]
    - If `xChromaOffset` is VK_CHROMA_LOCATION_MIDPOINT:
      \[
      \tau_{RB}'(i, j) = \begin{cases} 
      0.25 \times \tau_{RB}([i \times 0.5] - 1, [j \times 0.5])[\text{level}] + 0.75 \times \tau_{RB}([i \times 0.5], [j \times 0.5])[\text{level}], & 0.5 \times i = [0.5 \times i] \\
      0.75 \times \tau_{RB}([i \times 0.5], [j \times 0.5])[\text{level}] + 0.25 \times \tau_{RB}([i \times 0.5] + 1, [j \times 0.5])[\text{level}], & 0.5 \times i \neq [0.5 \times i]
      \end{cases}
      \]
  - If the format’s R and B components are reduced in resolution in width and height by a factor of two relative to the G component (i.e. this is a “_420” format), a similar relationship applies. Due to the number of options, these formulae are expressed more concisely as follows:
In the case where the texture itself is bilinearly interpolated as described in Texel Filtering, thus requiring four full-color samples for the filtering operation, and where the reconstruction of these samples uses bilinear interpolation in the chroma components due to `chromaFilter=VK_FILTER_LINEAR`, up to nine chroma samples may be required, depending on the sample location.

**Implicit Reconstruction**

Implicit reconstruction takes place by the samples being interpolated, as required by the filter settings of the sampler, except that `chromaFilter` takes precedence for the chroma samples.

If `chromaFilter` is `VK_FILTER_NEAREST`, an implementation *may* behave as if `xChromaOffset` and `yChromaOffset` were both `VK_CHROMA_LOCATION_MIDPOINT`, irrespective of the values set.

**Note**

This will not have any visible effect if the locations of the luma samples coincide with the location of the samples used for rasterization.

The sample coordinates are adjusted by the downsample factor of the component (such that, for example, the sample coordinates are divided by two if the component has a downsample factor of two relative to the luma component):

\[
\begin{align*}
    i_{RB} &= \begin{cases} 0.5 \times (i) & \text{xChromaOffset=COSITED_EVEN} \\
                           0.5 \times (i - 0.5) & \text{xChromaOffset=MIDPOINT} \end{cases} \\
    j_{RB} &= \begin{cases} 0.5 \times (j) & \text{yChromaOffset=COSITED_EVEN} \\
                           0.5 \times (j - 0.5) & \text{yChromaOffset=MIDPOINT} \end{cases}
\end{align*}
\]

\[
\begin{align*}
    i_{floor} &= \lfloor i_{RB} \rfloor \\
    j_{floor} &= \lfloor j_{RB} \rfloor \\
    i_{frac} &= i_{RB} - i_{floor} \\
    j_{frac} &= j_{RB} - j_{floor}
\end{align*}
\]

\[
\begin{align*}
    \tau_{RB'}(i,j) &= \tau_{RB}(i_{floor}, j_{floor})[\text{level}] \times (1 - i_{frac}) \times (1 - j_{frac}) + \\
                    \tau_{RB}(1 + i_{floor}, j_{floor})[\text{level}] \times i_{frac} \times (1 - j_{frac}) + \\
                    \tau_{RB}(i_{floor}, 1 + j_{floor})[\text{level}] \times (1 - i_{frac}) \times j_{frac} + \\
                    \tau_{RB}(1 + i_{floor}, 1 + j_{floor})[\text{level}] \times i_{frac} \times j_{frac}
\end{align*}
\]

**Sampler Y'C_B'C_R Conversion**

Sampler Y'C_B'C_R conversion performs the following operations, which an implementation *may*
combine into a single mathematical operation:

- Sampler $Y'C_bC_r$ Range Expansion
- Sampler $Y'C_bC_R$ Model Conversion

**Sampler $Y'C_bC_r$ Range Expansion**

Sampler $Y'C_bC_r$ range expansion is applied to color component values after all texel input operations which are not specific to sampler $Y'C_bC_r$ conversion. For example, the input values to this stage have been converted using the normal format conversion rules.

The input values to this stage may have been converted using sRGB to linear conversion if $ycbcrDegamma$ is enabled.

Sampler $Y'C_bC_r$ range expansion is not applied if $ycbcrModel$ is $VK_SAMPLER_YCBCR_MODEL_CONVERSION_RGB_IDENTITY$. That is, the shader receives the vector $C'_rgba$ as output by the Component Swizzle stage without further modification.

For other values of $ycbcrModel$, range expansion is applied to the texel component values output by the Component Swizzle defined by the $components$ member of $VkSamplerYcbcrConversionCreateInfo$. Range expansion applies independently to each component of the image. For the purposes of range expansion and $Y'C_bC_r$ model conversion, the R and B components contain color difference (chroma) values and the G component contains luma. The A component is not modified by sampler $Y'C_bC_r$ range expansion.

The range expansion to be applied is defined by the $ycbcrRange$ member of the $VkSamplerYcbcrConversionCreateInfo$ structure:

- If $ycbcrRange$ is $VK_SAMPLER_YCBCR_RANGE_ITU_FULL$, the following transformations are applied:

\[
Y' = C'_{rgba}[G] \\
C_B = C'_{rgba}[B] - \frac{2^{(n-1)}}{(2^n) - 1} \\
C_R = C'_{rgba}[R] - \frac{2^{(n-1)}}{(2^n) - 1}
\]

**Note**

These formulae correspond to the “full range” encoding in the “Quantization schemes” chapter of the Khronos Data Format Specification.

Should any future amendments be made to the ITU specifications from which these equations are derived, the formulae used by Vulkan may also be updated to maintain parity.

- If $ycbcrRange$ is $VK_SAMPLER_YCBCR_RANGE_ITU_NARROW$, the following transformations are applied:
\[ Y' = \frac{C'_{rgb} [G] \times (2^n - 1) - 16 \times 2^n - 8}{219 \times 2^n - 8} \]

\[ C_B = \frac{C'_{rgb} [B] \times (2^n - 1) - 128 \times 2^n - 8}{224 \times 2^n - 8} \]

\[ C_R = \frac{C'_{rgb} [R] \times (2^n - 1) - 128 \times 2^n - 8}{224 \times 2^n - 8} \]

**Note**

These formulae correspond to the “narrow range” encoding in the “Quantization schemes” chapter of the Khronos Data Format Specification.

- \( n \) is the bit-depth of the components in the format.

The precision of the operations performed during range expansion **must** be at least that of the source format.

An implementation **may** clamp the results of these range expansion operations such that \( Y' \) falls in the range \([0,1]\), and/or such that \( C_B \) and \( C_R \) fall in the range \([-0.5,0.5]\).

**Sampler Y'CbCr Model Conversion**

The range-expanded values are converted between color models, according to the color model conversion specified in the `ycbcrModel` member:

**VK_SAMPLER_YCBCR_MODEL_CONVERSION_RGB_IDENTITY**

The color components are not modified by the color model conversion since they are assumed already to represent the desired color model in which the shader is operating; \( Y'C_bC_R \) range expansion is also ignored.

**VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_IDENTITY**

The color components are not modified by the color model conversion and are assumed to be treated as though in \( Y'C_bC_R \) form both in memory and in the shader; \( Y'C_bC_R \) range expansion is applied to the components as for other \( Y'C_bC_R \) models, with the vector \((C_R,Y',C_B,A)\) provided to the shader.

**VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_709**

The color components are transformed from a \( Y'C_bC_R \) representation to an R'G'B' representation as described in the “BT.709 Y'CbCr conversion” section of the Khronos Data Format Specification.

**VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_601**

The color components are transformed from a \( Y'C_bC_R \) representation to an R'G'B' representation as described in the “BT.601 Y'CbCr conversion” section of the Khronos Data Format Specification.

**VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_2020**

The color components are transformed from a \( Y'C_bC_R \) representation to an R'G'B' representation as described in the “BT.2020 Y'CbCr conversion” section of the Khronos Data Format Specification.
In this operation, each output component is dependent on each input component.

An implementation may clamp the R'G'B' results of these conversions to the range [0,1].

The precision of the operations performed during model conversion must be at least that of the source format.

The alpha component is not modified by these model conversions.

**Note**
Sampling operations in a non-linear color space can introduce color and intensity shifts at sharp transition boundaries. To avoid this issue, the technically precise color correction sequence described in the “Introduction to Color Conversions” chapter of the *Khronos Data Format Specification* may be performed as follows:

- Calculate the unnormalized texel coordinates corresponding to the desired sample position.
- For a `minFilter` or `magFilter` of `VK_FILTER_NEAREST`:
  1. Calculate \((i,j)\) for the sample location as described under the “nearest filtering” formulae in *(u,v,w,a) to (i,j,k,l,n)* Transformation And Array Layer Selection
  2. Calculate the normalized texel coordinates corresponding to these integer coordinates.
  3. Sample using `sampler Y'CbCr conversion` at this location.
- For a `minFilter` or `magFilter` of `VK_FILTER_LINEAR`:
  1. Calculate \((i_{[0,1]}, j_{[0,1]})\) for the sample location as described under the “linear filtering” formulae in *(u,v,w,a) to (i,j,k,l,n)* Transformation And Array Layer Selection
  2. Calculate the normalized texel coordinates corresponding to these integer coordinates.
  3. Sample using `sampler Y'CbCr conversion` at each of these locations.
  4. Convert the non-linear A'R'G'B' outputs of the Y'CbCr conversions to linear ARGB values as described in the “Transfer Functions” chapter of the *Khronos Data Format Specification*.
  5. Interpolate the linear ARGB values using the \(\alpha\) and \(\beta\) values described in the “linear filtering” section of *(u,v,w,a) to (i,j,k,l,n)* Transformation And Array Layer Selection and the equations in Texel Filtering.

The additional calculations and, especially, additional number of sampling operations in the `VK_FILTER_LINEAR` case can be expected to have a performance impact compared with using the outputs directly. Since the variations from “correct” results are subtle for most content, the application author should determine whether a more costly implementation is strictly necessary.

If `chromaFilter`, and `minFilter` or `magFilter` are both `VK_FILTER_NEAREST`, these
operations are redundant and sampling using sampler \( Y'\text{C}_b\text{C}_r \) conversion at the desired sample coordinates will produce the “correct” results without further processing.

16.4. Texel Output Operations

*Texel output instructions* are SPIR-V image instructions that write to an image. *Texel output operations* are a set of steps that are performed on state, coordinates, and texel values while processing a texel output instruction, and which are common to some or all texel output instructions. They include the following steps, which are performed in the listed order:

- Validation operations
  - Format validation
  - Type validation
  - Coordinate validation
  - Sparse validation
- Texel output format conversion

16.4.1. Texel Output Validation Operations

*Texel output validation operations* inspect instruction/image state or coordinates, and in certain circumstances cause the write to have no effect. There are a series of validations that the texel undergoes.

**Texel Format Validation**

If the image format of the \( \text{OpTypeImage} \) is not compatible with the \( \text{VkImageView} \)'s format, the write causes the contents of the image’s memory to become undefined.

**Texel Type Validation**

If the \( \text{Sampled Type} \) of the \( \text{OpTypeImage} \) does not match the SPIR-V Type, the write causes the value of the texel to become undefined. For integer types, if the signedness of the access does not match the signedness of the accessed resource, the write causes the value of the texel to become undefined.

16.4.2. Integer Texel Coordinate Validation

The integer texel coordinates are validated according to the same rules as for texel input coordinate validation.

If the texel fails integer texel coordinate validation, then the write has no effect.

16.4.3. Sparse Texel Operation

If the texel attempts to write to an unbound region of a sparse image, the texel is a sparse unbound texel. In such a case, if the \( \text{VkPhysicalDeviceSparseProperties::residencyNonResidentStrict} \) property is \( \text{VK_TRUE} \), the sparse unbound texel write has no effect. If \( \text{residencyNonResidentStrict} \) is \( \text{VK_FALSE} \),
the write **may** have a side effect that becomes visible to other accesses to unbound texels in any resource, but will not be visible to any device memory allocated by the application.

### 16.4.4. Texel Output Format Conversion

If the image format is sRGB, a linear to sRGB conversion is applied to the R, G, and B components as described in the “sRGB EOTF” section of the *Khronos Data Format Specification*. The A component, if present, is unchanged.

Texels then undergo a format conversion from the floating point, signed, or unsigned integer type of the texel data to the `VkFormat` of the image view. If the number of components in the texel data is larger than the number of components in the format, additional components are discarded.

Each component is converted based on its type and size (as defined in the *Format Definition* section for each `VkFormat`). Floating-point outputs are converted as described in *Floating-Point Format Conversions* and *Fixed-Point Data Conversion*. Integer outputs are converted such that their value is preserved. The converted value of any integer that cannot be represented in the target format is undefined.

### 16.5. Normalized Texel Coordinate Operations

If the image sampler instruction provides normalized texel coordinates, some of the following operations are performed.

#### 16.5.1. Projection Operation

For **Proj** image operations, the normalized texel coordinates \((s, t, r, q, a)\) and (if present) the \(D_{\text{ref}}\) coordinate are transformed as follows:

\[
\begin{align*}
  s &= \frac{s}{q}, \quad \text{for 1D, 2D, or 3D image} \\
  t &= \frac{t}{q}, \quad \text{for 2D or 3D image} \\
  r &= \frac{r}{q}, \quad \text{for 3D image} \\
  D_{\text{ref}} &= \frac{D_{\text{ref}}}{q}, \quad \text{if provided}
\end{align*}
\]

#### 16.5.2. Derivative Image Operations

Derivatives are used for LOD selection. These derivatives are either implicit (in an `ImplicitLod` image instruction in a fragment shader) or explicit (provided explicitly by shader to the image instruction in any shader).

For implicit derivatives image instructions, the derivatives of texel coordinates are calculated in the same manner as *derivative operations*. That is:
\[ \frac{\partial s}{\partial x} = dPdx(s), \quad \frac{\partial s}{\partial y} = dPdy(s), \quad \text{for 1D, 2D, Cube, or 3D image} \]
\[ \frac{\partial t}{\partial x} = dPdx(t), \quad \frac{\partial t}{\partial y} = dPdy(t), \quad \text{for 2D, Cube, or 3D image} \]
\[ \frac{\partial r}{\partial x} = dPdx(r), \quad \frac{\partial r}{\partial y} = dPdy(r), \quad \text{for Cube or 3D image} \]

Partial derivatives not defined above for certain image dimensionalities are set to zero.

For explicit LOD image instructions, if the \textbf{optional} SPIR-V operand \texttt{Grad} is provided, then the operand values are used for the derivatives. The number of components present in each derivative for a given image dimensionality matches the number of partial derivatives computed above.

If the \textbf{optional} SPIR-V operand \texttt{Lod} is provided, then derivatives are set to zero, the cube map derivative transformation is skipped, and the scale factor operation is skipped. Instead, the floating point scalar coordinate is directly assigned to \( \lambda_{\text{base}} \) as described in LOD Operation.

If the image or sampler object used by an implicit derivative image instruction is not uniform across the quad and \texttt{quadDivergentImplicitLod} is not supported, then the derivative and LOD values are undefined. Implicit derivatives are well-defined when the image and sampler and control flow are uniform across the quad, even if they diverge between different quads.

If \texttt{quadDivergentImplicitLod} is supported, then derivatives and implicit LOD values are well-defined even if the image or sampler object are not uniform within a quad. The derivatives are computed as specified above, and the implicit LOD calculation proceeds for each shader invocation using its respective image and sampler object.

16.5.3. Cube Map Face Selection and Transformations

For cube map image instructions, the \((s,t,r)\) coordinates are treated as a direction vector \((r_x,r_y,r_z)\). The direction vector is used to select a cube map face. The direction vector is transformed to a per-face texel coordinate system \((s_{\text{face}},t_{\text{face}})\). The direction vector is also used to transform the derivatives to per-face derivatives.

16.5.4. Cube Map Face Selection

The direction vector selects one of the cube map’s faces based on the largest magnitude coordinate direction (the major axis direction). Since two or more coordinates can have identical magnitude, the implementation \textbf{must} have rules to disambiguate this situation.

The rules \textbf{should} have as the first rule that \( r_z \) wins over \( r_y \) and \( r_x \), and the second rule that \( r_y \) wins over \( r_x \). An implementation \textbf{may} choose other rules, but the rules \textbf{must} be deterministic and depend only on \((r_x,r_y,r_z)\).

The layer number (corresponding to a cube map face), the coordinate selections for \( s_c, t_c, r_c \), and the selection of derivatives, are determined by the major axis direction as specified in the following two tables.

\textit{Table 27. Cube map face and coordinate selection}
<table>
<thead>
<tr>
<th>Major Axis Direction</th>
<th>Layer Number</th>
<th>Cube Map Face</th>
<th>$s_c$</th>
<th>$t_c$</th>
<th>$r_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$+r_x$</td>
<td>0</td>
<td>Positive X</td>
<td>$-r_z$</td>
<td>$-r_y$</td>
<td>$r_x$</td>
</tr>
<tr>
<td>$-r_x$</td>
<td>1</td>
<td>Negative X</td>
<td>$+r_z$</td>
<td>$-r_y$</td>
<td>$r_x$</td>
</tr>
<tr>
<td>$+r_y$</td>
<td>2</td>
<td>Positive Y</td>
<td>$+r_x$</td>
<td>$+r_z$</td>
<td>$r_y$</td>
</tr>
<tr>
<td>$-r_y$</td>
<td>3</td>
<td>Negative Y</td>
<td>$+r_x$</td>
<td>$-r_z$</td>
<td>$r_y$</td>
</tr>
<tr>
<td>$+r_z$</td>
<td>4</td>
<td>Positive Z</td>
<td>$+r_x$</td>
<td>$-r_y$</td>
<td>$r_z$</td>
</tr>
<tr>
<td>$-r_z$</td>
<td>5</td>
<td>Negative Z</td>
<td>$-r_x$</td>
<td>$-r_y$</td>
<td>$r_z$</td>
</tr>
</tbody>
</table>

Table 28. Cube map derivative selection

<table>
<thead>
<tr>
<th>Major Axis Direction</th>
<th>$\partial s_c / \partial x$</th>
<th>$\partial s_c / \partial y$</th>
<th>$\partial t_c / \partial x$</th>
<th>$\partial t_c / \partial y$</th>
<th>$\partial r_c / \partial x$</th>
<th>$\partial r_c / \partial y$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$+r_x$</td>
<td>$-\partial r_x / \partial x$</td>
<td>$-\partial r_x / \partial y$</td>
<td>$-\partial r_y / \partial x$</td>
<td>$-\partial r_y / \partial y$</td>
<td>$+\partial r_x / \partial x$</td>
<td>$+\partial r_x / \partial y$</td>
</tr>
<tr>
<td>$-r_x$</td>
<td>$+\partial r_x / \partial x$</td>
<td>$+\partial r_x / \partial y$</td>
<td>$-\partial r_y / \partial x$</td>
<td>$-\partial r_y / \partial y$</td>
<td>$-\partial r_z / \partial x$</td>
<td>$-\partial r_z / \partial y$</td>
</tr>
<tr>
<td>$+r_y$</td>
<td>$+\partial r_x / \partial x$</td>
<td>$+\partial r_x / \partial y$</td>
<td>$+\partial r_z / \partial x$</td>
<td>$+\partial r_z / \partial y$</td>
<td>$+\partial r_y / \partial x$</td>
<td>$+\partial r_y / \partial y$</td>
</tr>
<tr>
<td>$-r_y$</td>
<td>$+\partial r_x / \partial x$</td>
<td>$+\partial r_x / \partial y$</td>
<td>$-\partial r_z / \partial x$</td>
<td>$-\partial r_z / \partial y$</td>
<td>$-\partial r_y / \partial x$</td>
<td>$-\partial r_y / \partial y$</td>
</tr>
<tr>
<td>$+r_z$</td>
<td>$+\partial r_x / \partial x$</td>
<td>$+\partial r_x / \partial y$</td>
<td>$-\partial r_y / \partial x$</td>
<td>$-\partial r_y / \partial y$</td>
<td>$+\partial r_z / \partial x$</td>
<td>$+\partial r_z / \partial y$</td>
</tr>
<tr>
<td>$-r_z$</td>
<td>$-\partial r_x / \partial x$</td>
<td>$-\partial r_x / \partial y$</td>
<td>$-\partial r_y / \partial x$</td>
<td>$-\partial r_y / \partial y$</td>
<td>$-\partial r_z / \partial x$</td>
<td>$-\partial r_z / \partial y$</td>
</tr>
</tbody>
</table>

16.5.5. Cube Map Coordinate Transformation

\[
s_{\text{face}} = \frac{1}{2} \times \frac{s_c}{|r_c|} + \frac{1}{2}
\]
\[
t_{\text{face}} = \frac{1}{2} \times \frac{t_c}{|r_c|} + \frac{1}{2}
\]

16.5.6. Cube Map Derivative Transformation

\[
\frac{\partial s_{\text{face}}}{\partial x} = \frac{\partial}{\partial x} \left( \frac{1}{2} \times \frac{s_c}{|r_c|} + \frac{1}{2} \right)
\]
\[
\frac{\partial s_{\text{face}}}{\partial x} = \frac{1}{2} \times \frac{\partial}{\partial x} \left( \frac{s_c}{|r_c|} \right)
\]
\[
\frac{\partial s_{\text{face}}}{\partial x} = \frac{1}{2} \times \frac{|r_c| \times \partial s_c / \partial x - s_c \times \partial r_c / \partial x}{(r_c)^2}
\]
16.5.7. Scale Factor Operation, LOD Operation and Image Level(s) Selection

LOD selection can be either explicit (provided explicitly by the image instruction) or implicit (determined from a scale factor calculated from the derivatives). The LOD must be computed with `mipmapPrecisionBits` of accuracy.

Scale Factor Operation

The magnitude of the derivatives are calculated by:

\[
\begin{align*}
\frac{\partial s_{\text{face}}}{\partial y} & = \frac{1}{2} \times \left( \frac{|r_c| \times \partial s_c / \partial y - s_c \times \partial r_c / \partial y}{(r_c)^2} \right) \\
\frac{\partial t_{\text{face}}}{\partial x} & = \frac{1}{2} \times \left( \frac{|r_c| \times \partial t_c / \partial x - t_c \times \partial r_c / \partial x}{(r_c)^2} \right) \\
\frac{\partial t_{\text{face}}}{\partial y} & = \frac{1}{2} \times \left( \frac{|r_c| \times \partial t_c / \partial y - t_c \times \partial r_c / \partial y}{(r_c)^2} \right)
\end{align*}
\]

where:

\[
\partial t/\partial x = \partial t/\partial y = 0 \text{ (for 1D images)}
\]

\[
\partial r/\partial x = \partial r/\partial y = 0 \text{ (for 1D, 2D or Cube images)}
\]

and:

\[
w_{\text{base}} = \text{image.w}
\]
h_{base} = image.h

d_{base} = image.d

(for the baseMipLevel, from the image descriptor).

For corner-sampled images, the w_{base}, h_{base}, and d_{base} are instead:

w_{base} = image.w - 1

h_{base} = image.h - 1

d_{base} = image.d - 1

A point sampled in screen space has an elliptical footprint in texture space. The minimum and maximum scale factors (\rho_{min}, \rho_{max}) should be the minor and major axes of this ellipse.

The scale factors \rho_x and \rho_y, calculated from the magnitude of the derivatives in x and y, are used to compute the minimum and maximum scale factors.

\rho_x and \rho_y may be approximated with functions f_x and f_y, subject to the following constraints:

- \( f_x \) is continuous and monotonically increasing in each of \( m_{ux}, m_{vx}, \) and \( m_{wx} \)
- \( f_y \) is continuous and monotonically increasing in each of \( m_{uy}, m_{vy}, \) and \( m_{wy} \)

\[
\max(|m_{ux}|, |m_{vx}|, |m_{wx}|) \leq f_x \leq \sqrt{2}(|m_{ux}| + |m_{vx}| + |m_{wx}|) \\
\max(|m_{uy}|, |m_{vy}|, |m_{wy}|) \leq f_y \leq \sqrt{2}(|m_{uy}| + |m_{vy}| + |m_{wy}|)
\]

The minimum and maximum scale factors (\rho_{min},\rho_{max}) are determined by:

\[
\rho_{max} = \max(\rho_x, \rho_y)
\]

\[
\rho_{min} = \min(\rho_x, \rho_y)
\]

The ratio of anisotropy is determined by:

\[
\eta = \min(\rho_{max}/\rho_{min}, \text{max}_{\text{Aniso}})
\]

where:
sampler.maxAniso = maxAnisotropy (from sampler descriptor)

limits.maxAniso = maxSamplerAnisotropy (from physical device limits)

maxAniso = min(sampler.maxAniso, limits.maxAniso)

If ρ_max = ρ_min = 0, then all the partial derivatives are zero, the fragment’s footprint in texel space is a point, and η should be treated as 1. If ρ_max ≠ 0 and ρ_min = 0 then all partial derivatives along one axis are zero, the fragment’s footprint in texel space is a line segment, and η should be treated as maxAniso. However, anytime the footprint is small in texel space the implementation may use a smaller value of η, even when ρ_min is zero or close to zero. If either VkPhysicalDeviceFeatures::samplerAnisotropy or VkSamplerCreateInfo::anisotropyEnable are VK_FALSE, maxAniso is set to 1.

If η = 1, sampling is isotropic. If η > 1, sampling is anisotropic.

The sampling rate (N) is derived as:

\[ N = \lceil \eta \rceil \]

An implementation may round N up to the nearest supported sampling rate. An implementation may use the value of N as an approximation of η.

**LOD Operation**

The LOD parameter λ is computed as follows:

\[
\lambda_{base}(x, y) = \begin{cases} 
  \text{shaderOp.Lod} & \text{(from optional SPIR-V operand)} \\
  \log_2\left(\frac{P_{max}}{\eta}\right) & \text{otherwise}
\end{cases}
\]

\[
\lambda'(x, y) = \lambda_{base} + \text{clamp}(\text{sampler.bias} + \text{shaderOp.bias}, -\text{maxSamplerLodBias}, \text{maxSamplerLodBias})
\]

\[
\lambda = \begin{cases} 
  \text{lod}_\text{max}, & \lambda' > \text{lod}_\text{max} \\
  \lambda', & \text{lod}_\text{min} \leq \lambda' \leq \text{lod}_\text{max} \\
  \text{lod}_\text{min}, & \lambda' < \text{lod}_\text{min} \\
  \text{undefined}, & \text{lod}_\text{min} > \text{lod}_\text{max}
\end{cases}
\]

where:

- \text{sampler.bias} = \text{mipLodBias} (from sampler descriptor)
- \text{shaderOp.bias} = \begin{cases} 
  \text{Bias} & \text{(from optional SPIR-V operand)} \\
  0 & \text{otherwise}
\end{cases}
- \text{sampler.lod}_\text{min} = \text{minLod} (from sampler descriptor)
- \text{shaderOp.lod}_\text{min} = \begin{cases} 
  \text{MinLod} & \text{(from optional SPIR-V operand)} \\
  0 & \text{otherwise}
\end{cases}

\[
\text{lod}_\text{min} = \max(\text{sampler.lod}_\text{min}, \text{shaderOp.lod}_\text{min}) \\
\text{lod}_\text{max} = \maxLod
\]

and maxSamplerLodBias is the value of the VkPhysicalDeviceLimits feature maxSamplerLodBias.
**Image Level(s) Selection**

The image level(s) \( d, d_{hi}, \) and \( d_{lo} \) which texels are read from are determined by an image-level parameter \( d_l \), which is computed based on the LOD parameter, as follows:

\[
d_l = \begin{cases} 
\text{nearest}(d'), & \text{mipmapMode is VK_SAMPLER_MIPMAP_MODE_NEAREST} \\
\text{otherwise} & 
\end{cases} 
\]

where:

\[
d' = \max(\text{level}_{base} + \text{clamp}(\lambda, 0, q), \text{minLod}_{imageView})
\]

\[
\text{nearest}(d') = \begin{cases} 
[d' + 0.5] - 1, & \text{preferred} \\
[d' + 0.5], & \text{alternative} 
\end{cases}
\]

and:

\[
\text{minLod}_{imageView} = \begin{cases} 
\text{minLod}_{Float}_{imageView}, & \text{preferred} \\
\text{minLod}_{Integer}_{imageView}, & \text{alternative} 
\end{cases}
\]

\[
\text{level}_{base} = \text{baseMipLevel} \\
q = \text{levelCount} - 1
\]

\( \text{baseMipLevel} \) and \( \text{levelCount} \) are taken from the subresourceRange of the image view.

\( \text{minLod}_{imageView} \) must be less or equal to \( \text{level}_{base} + q \).

If the sampler's \( \text{mipmapMode} \) is \( \text{VK_SAMPLER_MIPMAP_MODE_NEAREST} \), then the level selected is \( d = d_l \).

If the sampler's \( \text{mipmapMode} \) is \( \text{VK_SAMPLER_MIPMAP_MODE_LINEAR} \), two neighboring levels are selected:

\[
d_{hi} = \lfloor d_l \rfloor \\
d_{lo} = \min(d_{hi} + 1, \text{level}_{base} + q) \\
\delta = d_l - d_{hi}
\]

\( \delta \) is the fractional value, quantized to the number of mipmap precision bits, used for linear filtering between levels.

**16.5.8. (s,t,r,q,a) to (u,v,w,a) Transformation**

The normalized texel coordinates are scaled by the image level dimensions and the array layer is selected.

This transformation is performed once for each level used in filtering (either \( d \), or \( d_{hi} \) and \( d_{lo} \)).
where:

\[ u(x, y) = s(x, y) \times \text{width}_{\text{scale}} + \Delta_i \]

\[ v(x, y) = \begin{cases} 
0 & \text{for 1D images} \\
t(x, y) \times \text{height}_{\text{scale}} + \Delta_j & \text{otherwise}
\end{cases} \]

\[ w(x, y) = \begin{cases} 
0 & \text{for 2D or Cube images} \\
r(x, y) \times \text{depth}_{\text{scale}} + \Delta_k & \text{otherwise}
\end{cases} \]

\[ a(x, y) = \begin{cases} 
a(x, y) & \text{for array images} \\
0 & \text{otherwise}
\end{cases} \]

\[ \text{width}_{\text{scale}} = \text{width}_{\text{level}} - 1 \]

\[ \text{height}_{\text{scale}} = \text{height}_{\text{level}} - 1 \]

\[ \text{depth}_{\text{scale}} = \text{depth}_{\text{level}} - 1 \]

for corner-sampled images.

and where \((\Delta_i, \Delta_j, \Delta_k)\) are taken from the image instruction if it includes a ConstOffset or Offset operand, otherwise they are taken to be zero.

Operations then proceed to Unnormalized Texel Coordinate Operations.

16.6. Unnormalized Texel Coordinate Operations

16.6.1. \((u,v,w,a)\) to \((i,j,k,l,n)\) Transformation And Array Layer Selection

The unnormalized texel coordinates are transformed to integer texel coordinates relative to the selected mipmap level.

The layer index \(l\) is computed as:
\[ l = \text{clamp}(\text{RNE}(a), 0, \text{layerCount} - 1) + \text{baseArrayLayer} \]

where \text{layerCount} is the number of layers in the image subresource range of the image view, \text{baseArrayLayer} is the first layer from the subresource range, and where:

\[
\text{RNE}(a) = \begin{cases} 
\text{roundTiesToEven}(a) & \text{preferred, from IEEE Std 754-2008 Floating-Point Arithmetic} \\
\lfloor a + 0.5 \rfloor & \text{alternative}
\end{cases}
\]

The sample index \( n \) is assigned the value 0.

Nearest filtering (\text{VK_FILTER_NEAREST}) computes the integer texel coordinates that the unnormalized coordinates lie within:

\[
i = \lfloor u + \text{shift} \rfloor \\
j = \lfloor v + \text{shift} \rfloor \\
k = \lfloor w + \text{shift} \rfloor
\]

where:

\[
\text{shift} = 0.0
\]

for conventional images, and:

\[
\text{shift} = 0.5
\]

for corner-sampled images.

Linear filtering (\text{VK_FILTER_LINEAR}) computes a set of neighboring coordinates which bound the unnormalized coordinates. The integer texel coordinates are combinations of \( i_0 \) or \( i_1 \), \( j_0 \) or \( j_1 \), \( k_0 \) or \( k_1 \), as well as weights \( \alpha \), \( \beta \), and \( \gamma \).

\[
i_0 = \lfloor u - \text{shift} \rfloor \\
i_1 = i_0 + 1 \\
j_0 = \lfloor v - \text{shift} \rfloor \\
j_1 = j_0 + 1 \\
k_0 = \lfloor w - \text{shift} \rfloor \\
k_1 = k_0 + 1
\]

\[
\alpha = \text{frac}(u - \text{shift}) \\
\beta = \text{frac}(v - \text{shift}) \\
\gamma = \text{frac}(w - \text{shift})
\]

where:
shift = 0.5
for conventional images, and:

shift = 0.0
for corner-sampled images, and where:

$$\text{frac}(x) = x - \lfloor x \rfloor$$

where the number of fraction bits retained is specified by VkPhysicalDeviceLimits::subTexelPrecisionBits.

Cubic filtering (VK_FILTER_CUBIC_EXT) computes a set of neighboring coordinates which bound the unnormalized coordinates. The integer texel coordinates are combinations of \(i_0, i_1, i_2\) or \(i_3, j_0, j_1, j_2\) or \(j_3, k_0, k_1, k_2\) or \(k_3\), as well as weights \(\alpha, \beta,\) and \(\gamma\).

\[
\begin{align*}
  i_0 &= \lfloor u - \frac{3}{2} \rfloor \\
  i_1 &= i_0 + 1 \\
  i_2 &= i_1 + 1 \\
  i_3 &= i_2 + 1 \\
  j_0 &= \lfloor v - \frac{3}{2} \rfloor \\
  j_1 &= j_0 + 1 \\
  j_2 &= j_1 + 1 \\
  j_3 &= j_2 + 1 \\
  k_0 &= \lfloor w - \frac{3}{2} \rfloor \\
  k_1 &= k_0 + 1 \\
  k_2 &= k_1 + 1 \\
  k_3 &= k_2 + 1 \\
 \end{align*}
\]

\[
\begin{align*}
  \alpha &= \text{frac}\left( u - \frac{1}{2} \right) \\
  \beta &= \text{frac}\left( v - \frac{1}{2} \right) \\
  \gamma &= \text{frac}\left( w - \frac{1}{2} \right) \\
\end{align*}
\]

where:

$$\text{frac}(x) = x - \lfloor x \rfloor$$

where the number of fraction bits retained is specified by VkPhysicalDeviceLimits::subTexelPrecisionBits.

### 16.7. Integer Texel Coordinate Operations

Integer texel coordinate operations may supply a LOD which texels are to be read from or written to using the optional SPIR-V operand Lod. If the Lod is provided then it must be an integer.

The image level selected is:
\[ d = level_{base} + \begin{cases} Lod & \text{(from optional SPIR-V operand)} \\ 0 & \text{otherwise} \end{cases} \]

If \( d \) does not lie in the range \([\text{baseMipLevel}, \text{baseMipLevel} + \text{levelCount})\) or \( d \) is less than \( \text{minLodInteger}_{\text{imageView}} \), then any values fetched are zero if the \text{robustImageAccess2} feature is enabled, otherwise are undefined, and any writes (if supported) are discarded.

### 16.8. Image Sample Operations

#### 16.8.1. Wrapping Operation

If the used sampler was created without \text{VK_SAMPLER_CREATE_NON_SEAMLESS_CUBE_MAP_BIT_EXT}, Cube images ignore the wrap modes specified in the sampler. Instead, if \text{VK_FILTER_NEAREST} is used within a mip level then \text{VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE} is used, and if \text{VK_FILTER_LINEAR} is used within a mip level then sampling at the edges is performed as described earlier in the \text{Cube map edge handling} section.

The first integer texel coordinate \( i \) is transformed based on the \text{addressModeU} parameter of the sampler.

\[
i = \begin{cases} 
  i \mod \text{size} \\
  (\text{size} - 1) - \text{mirror}((i \mod (2 \times \text{size})) - \text{size}) & \text{for repeat} \\
  \text{clamp}(i, 0, \text{size} - 1) & \text{for mirrored repeat} \\
  \text{clamp}(i, -1, \text{size}) & \text{for clamp to edge} \\
  \text{clamp}(\text{mirror}(i), 0, \text{size} - 1) & \text{for clamp to border} \\
  \text{clamp}(\text{mirror}(i), 0, \text{size} - 1) & \text{for mirror clamp to edge} 
\end{cases}
\]

where:

\[
\text{mirror}(n) = \begin{cases} 
  n & \text{for } n \geq 0 \\
  -(1 + n) & \text{otherwise} 
\end{cases}
\]

\( j \) (for 2D and Cube image) and \( k \) (for 3D image) are similarly transformed based on the \text{addressModeV} and \text{addressModeW} parameters of the sampler, respectively.

#### 16.8.2. Texel Gathering

SPIR-V instructions with \text{Gather} in the name return a vector derived from 4 texels in the base level of the image view. The rules for the \text{VK_FILTER_LINEAR} minification filter are applied to identify the four selected texels. Each texel is then converted to an RGBA value according to \text{conversion to RGBA} and then \text{swizzled}. A four-component vector is then assembled by taking the component indicated by the \text{Component} value in the instruction from the swizzled color value of the four texels. If the operation does not use the \text{ConstOffsets} image operand then the four texels form the \( 2 \times 2 \) rectangle used for texture filtering:
If the operation does use the `ConstOffsets` image operand then the offsets allow a custom filter to be defined:

\[
\begin{align*}
\tau[R] &= \tau_{i_0,j_0}[\text{level}_{\text{base}}][\text{comp}] + \Delta_0 \cdot \text{level}_{\text{base}} \cdot \text{comp} \\
\tau[G] &= \tau_{i_0,j_0}[\text{level}_{\text{base}}][\text{comp}] + \Delta_1 \cdot \text{level}_{\text{base}} \cdot \text{comp} \\
\tau[B] &= \tau_{i_0,j_0}[\text{level}_{\text{base}}][\text{comp}] + \Delta_2 \cdot \text{level}_{\text{base}} \cdot \text{comp} \\
\tau[A] &= \tau_{i_0,j_0}[\text{level}_{\text{base}}][\text{comp}] + \Delta_3 \cdot \text{level}_{\text{base}} \cdot \text{comp}
\end{align*}
\]

where:

\[
\tau[\text{level}_{\text{base}}][\text{comp}] = \begin{cases} 
\tau[\text{level}_{\text{base}}][R], & \text{for comp} = 0 \\
\tau[\text{level}_{\text{base}}][G], & \text{for comp} = 1 \\
\tau[\text{level}_{\text{base}}][B], & \text{for comp} = 2 \\
\tau[\text{level}_{\text{base}}][A], & \text{for comp} = 3
\end{cases}
\]

Comp from SPIR-V operand Component

`OpImage*Gather` must not be used on a sampled image with `sampler Y\text{C}_b\text{C}_s` conversion enabled.

If `level_{\text{base}} < \text{minLodInteger}_{\text{imageView}}`, then any values fetched are zero if `robustImageAccess2` is enabled. Otherwise values are undefined.

### 16.8.3. Texel Filtering

Texel filtering is first performed for each level (either \(d\) or \(d_{\text{hi}}\) and \(d_{\text{lo}}\)).

If \(\lambda\) is less than or equal to zero, the texture is said to be **magnified**, and the filter mode within a mip level is selected by the `magFilter` in the sampler. If \(\lambda\) is greater than zero, the texture is said to be **minified**, and the filter mode within a mip level is selected by the `minFilter` in the sampler.

**Texel Nearest Filtering**

Within a mip level, VK\_FILTER\_NEAREST filtering selects a single value using the (i, j, k) texel coordinates, with all texels taken from layer l.

\[
\tau[\text{level}] = \begin{cases} 
\tau_{i,j,k}[\text{level}], & \text{for 3D image} \\
\tau_{i,j}[\text{level}], & \text{for 2D or Cube image} \\
\tau_{i,j}[\text{level}], & \text{for 1D image}
\end{cases}
\]

**Texel Linear Filtering**

Within a mip level, VK\_FILTER\_LINEAR filtering combines 8 (for 3D), 4 (for 2D or Cube), or 2 (for 1D)
 texel values, together with their linear weights. The linear weights are derived from the fractions computed earlier:

\[
    \begin{align*}
        w_{i_0} &= (1 - \alpha) \\
        w_{i_1} &= (\alpha) \\
        w_{j_0} &= (1 - \beta) \\
        w_{j_1} &= (\beta) \\
        w_{k_0} &= (1 - \gamma) \\
        w_{k_1} &= (\gamma)
    \end{align*}
\]

The values of multiple texels, together with their weights, are combined to produce a filtered value.

The `VkSamplerReductionModeCreateInfo::reductionMode` can control the process by which multiple texels, together with their weights, are combined to produce a filtered texture value.

When the `reductionMode` is set (explicitly or implicitly) to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE`, a weighted average is computed:

\[
    \begin{align*}
        \tau_{3D} &= \sum_{k = k_0}^{k_1} \sum_{j = j_0}^{j_1} \sum_{i = i_0}^{i_1} (w_i)(w_j)(w_k)\tau_{i,j,k} \\
        \tau_{2D} &= \sum_{j = j_0}^{j_1} \sum_{i = i_0}^{i_1} (w_i)(w_j)\tau_{i,j} \\
        \tau_{1D} &= \sum_{i = i_0}^{i_1} (w_i)\tau_{i}
    \end{align*}
\]

However, if the reduction mode is `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX`, the process operates on the above set of multiple texels, together with their weights, computing a component-wise minimum or maximum, respectively, of the components of the set of texels with non-zero weights.

**Texel Cubic Filtering**

Within a mip level, `VK_FILTER_CUBIC_EXT`, filtering computes a weighted average of 64 (for 3D), 16 (for 2D), or 4 (for 1D) texel values, together with their Catmull-Rom, Zero Tangent Cardinal, B-Spline, or Mitchell-Netravali weights as specified by `VkSamplerCubicWeightsCreateInfoQCOM`.

Catmull-Rom weights specified by `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM` are derived from the fractions computed earlier.
Zero Tangent Cardinal weights specified by `VK_CUBIC_FILTER_WEIGHTS_ZERO_TANGENT_CARDINAL_QCOM` are derived from the fractions computed earlier.

\[
\begin{bmatrix}
  w_{i_0} & w_{i_1} & w_{i_2} & w_{i_3}
\end{bmatrix} = \frac{1}{2} \begin{bmatrix}
  1 & \alpha & \alpha^2 & \alpha^3
\end{bmatrix} \begin{bmatrix}
  0 & 2 & 0 & 0 \\
  -1 & 0 & 1 & 0 \\
  2 & -5 & 4 & -1 \\
  -1 & 3 & -3 & 1
\end{bmatrix}
\]

\[
\begin{bmatrix}
  w_{j_0} & w_{j_1} & w_{j_2} & w_{j_3}
\end{bmatrix} = \frac{1}{2} \begin{bmatrix}
  1 & \beta & \beta^2 & \beta^3
\end{bmatrix} \begin{bmatrix}
  0 & 2 & 0 & 0 \\
  -1 & 0 & 1 & 0 \\
  2 & -5 & 4 & -1 \\
  -1 & 3 & -3 & 1
\end{bmatrix}
\]

\[
\begin{bmatrix}
  w_{k_0} & w_{k_1} & w_{k_2} & w_{k_3}
\end{bmatrix} = \frac{1}{2} \begin{bmatrix}
  1 & \gamma & \gamma^2 & \gamma^3
\end{bmatrix} \begin{bmatrix}
  0 & 2 & 0 & 0 \\
  -1 & 0 & 1 & 0 \\
  2 & -5 & 4 & -1 \\
  -1 & 3 & -3 & 1
\end{bmatrix}
\]

B-Spline weights specified by `VK_CUBIC_FILTER_WEIGHTS_B_SPLINE_QCOM` are derived from the fractions computed earlier.

\[
\begin{bmatrix}
  w_{i_0} & w_{i_1} & w_{i_2} & w_{i_3}
\end{bmatrix} = \frac{1}{6} \begin{bmatrix}
  1 & \alpha & \alpha^2 & \alpha^3
\end{bmatrix} \begin{bmatrix}
  1 & 4 & 1 & 0 \\
  -3 & 0 & 3 & 0 \\
  3 & -6 & 3 & 0 \\
  -1 & 3 & -3 & 1
\end{bmatrix}
\]

\[
\begin{bmatrix}
  w_{j_0} & w_{j_1} & w_{j_2} & w_{j_3}
\end{bmatrix} = \frac{1}{6} \begin{bmatrix}
  1 & \beta & \beta^2 & \beta^3
\end{bmatrix} \begin{bmatrix}
  1 & 4 & 1 & 0 \\
  -3 & 0 & 3 & 0 \\
  3 & -6 & 3 & 0 \\
  -1 & 3 & -3 & 1
\end{bmatrix}
\]

\[
\begin{bmatrix}
  w_{k_0} & w_{k_1} & w_{k_2} & w_{k_3}
\end{bmatrix} = \frac{1}{6} \begin{bmatrix}
  1 & \gamma & \gamma^2 & \gamma^3
\end{bmatrix} \begin{bmatrix}
  1 & 4 & 1 & 0 \\
  -3 & 0 & 3 & 0 \\
  3 & -6 & 3 & 0 \\
  -1 & 3 & -3 & 1
\end{bmatrix}
\]

Mitchell-Netravali weights specified by `VK_CUBIC_FILTER_WEIGHTS_MITCHELL_NETRAVALI_QCOM` are derived from the fractions computed earlier.
The values of multiple texels, together with their weights, are combined to produce a filtered value. The `VkSamplerReductionModeCreateInfo::reductionMode` can control the process by which multiple texels, together with their weights, are combined to produce a filtered texture value.

When the `reductionMode` is set (explicitly or implicitly) to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE` or `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`, a weighted average is computed:

\[
\tau_{3D} = \sum_{k=j_0}^{k} \sum_{j=j_0}^{j} \sum_{i=i_0}^{i} (w_i)(w_j)(w_k) \tau_{ijk}
\]

\[
\tau_{2D} = \sum_{j=j_0}^{j} \sum_{i=i_0}^{i} (w_i)(w_j) \tau_{ij}
\]

\[
\tau_{1D} = \sum_{i=i_0}^{i} (w_i) \tau_i
\]

However, if the reduction mode is `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX`, the process operates on the above set of multiple texels, together with their weights, computing a component-wise minimum or maximum, respectively, of the components of the set of texels with non-zero weights.

**Texel Range Clamp**

When the `reductionMode` is set to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`, the weighted average is clamped to be within the component-wise minimum and maximum of the set of texels with non-zero weights.

**Texel Mipmap Filtering**

`VK_SAMPLER_MIPMAP_MODE_NEAREST` filtering returns the value of a single mipmap level,

\[ \tau = \tau[d]. \]

`VK_SAMPLER_MIPMAP_MODE_LINEAR` filtering combines the values of multiple mipmap levels (\(\tau[hi]\) and
\( \tau(I_0) \), together with their linear weights.

The linear weights are derived from the fraction computed earlier:

\[
\begin{align*}
w_{hi} &= (1 - \delta) \\
w_{lo} &= (\delta)
\end{align*}
\]

The values of multiple mipmap levels, together with their weights, are combined to produce a final filtered value.

The `VkSamplerReductionModeCreateInfo::reductionMode` can control the process by which multiple texels, together with their weights, are combined to produce a filtered texture value.

When the `reductionMode` is set (explicitly or implicitly) to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE`, a weighted average is computed:

\[
\tau = (w_{hi})\tau[h] + (w_{lo})\tau[l]
\]

However, if the reduction mode is `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX`, the process operates on the above values, together with their weights, computing a component-wise minimum or maximum, respectively, of the components of the values with non-zero weights.

**Texel Anisotropic Filtering**

Anisotropic filtering is enabled by the `anisotropyEnable` in the sampler. When enabled, the image filtering scheme accounts for a degree of anisotropy.

The particular scheme for anisotropic texture filtering is implementation-dependent. Implementations should consider the `magFilter`, `minFilter` and `mipmapMode` of the sampler to control the specifics of the anisotropic filtering scheme used. In addition, implementations should consider `minLod` and `maxLod` of the sampler.

**Note**

For historical reasons, vendor implementations of anisotropic filtering interpret these sampler parameters in different ways, particularly in corner cases such as `magFilter`, `minFilter` of `NEAREST` or `maxAnisotropy` equal to 1.0. Applications should not expect consistent behavior in such cases, and should use anisotropic filtering only with parameters which are expected to give a quality improvement relative to `LINEAR` filtering.

The following describes one particular approach to implementing anisotropic filtering for the 2D Image case; implementations may choose other methods:

Given a `magFilter`, `minFilter` of `VK_FILTER_LINEAR` and a `mipmapMode` of `VK_SAMPLER_MIPMAP_MODE_NEAREST`:

Instead of a single isotropic sample, \( N \) isotropic samples are sampled within the image footprint of the image level \( d \) to approximate an anisotropic filter. The sum \( \tau_{2Daniso} \) is defined using the single isotropic \( \tau_{2D}(u,v) \) at level \( d \).
When \( \text{VkSamplerReductionModeCreateInfo}::\text{reductionMode} \) is set to \( \text{VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE} \), the above summation is used. However, if the reduction mode is \( \text{VK_SAMPLER_REDUCTION_MODE_MIN} \) or \( \text{VK_SAMPLER_REDUCTION_MODE_MAX} \), the process operates on the above values, together with their weights, computing a component-wise minimum or maximum, respectively, of the components of the values with non-zero weights.

16.9. Texel Footprint Evaluation

The SPIR-V instruction \( \text{OpImageSampleFootprintNV} \) evaluates the set of texels from a single mip level that would be accessed during a texel filtering operation. In addition to the inputs that would be accepted by an equivalent \( \text{OpImageSample*} \) instruction, \( \text{OpImageSampleFootprintNV} \) accepts two additional inputs. The \text{Granularity} input is an integer identifying the size of texel groups used to evaluate the footprint. Each bit in the returned footprint mask corresponds to an aligned block of texels whose size is given by the following table:

\[
\tau_{2\text{Dan}iso} = \frac{1}{N} \sum_{i=1}^{N} \tau_{2\text{D}}(u(x - \frac{1}{2} + \frac{i}{N + 1}, y), v(x - \frac{1}{2} + \frac{i}{N + 1}, y)), \quad \text{when } \rho_x > \rho_y
\]

\[
\tau_{2\text{Dan}iso} = \frac{1}{N} \sum_{i=1}^{N} \tau_{2\text{D}}(u(x, y - \frac{1}{2} + \frac{i}{N + 1}), v(x, y - \frac{1}{2} + \frac{i}{N + 1})), \quad \text{when } \rho_y \geq \rho_x
\]

When \( \text{VkSamplerReductionModeCreateInfo}::\text{reductionMode} \) is set to \( \text{VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE} \), the above summation is used. However, if the reduction mode is \( \text{VK_SAMPLER_REDUCTION_MODE_MIN} \) or \( \text{VK_SAMPLER_REDUCTION_MODE_MAX} \), the process operates on the above values, together with their weights, computing a component-wise minimum or maximum, respectively, of the components of the values with non-zero weights.

<table>
<thead>
<tr>
<th>Granularity</th>
<th>( \text{Dim = 2D} )</th>
<th>( \text{Dim = 3D} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>unsupported</td>
<td>unsupported</td>
</tr>
<tr>
<td>1</td>
<td>2x2</td>
<td>2x2x2</td>
</tr>
<tr>
<td>2</td>
<td>4x2</td>
<td>unsupported</td>
</tr>
<tr>
<td>3</td>
<td>4x4</td>
<td>4x4x2</td>
</tr>
<tr>
<td>4</td>
<td>8x4</td>
<td>unsupported</td>
</tr>
<tr>
<td>5</td>
<td>8x8</td>
<td>unsupported</td>
</tr>
<tr>
<td>6</td>
<td>16x8</td>
<td>unsupported</td>
</tr>
<tr>
<td>7</td>
<td>16x16</td>
<td>unsupported</td>
</tr>
<tr>
<td>8</td>
<td>unsupported</td>
<td>unsupported</td>
</tr>
<tr>
<td>9</td>
<td>unsupported</td>
<td>unsupported</td>
</tr>
<tr>
<td>10</td>
<td>unsupported</td>
<td>16x16x16</td>
</tr>
<tr>
<td>11</td>
<td>64x64</td>
<td>32x16x16</td>
</tr>
<tr>
<td>12</td>
<td>128x64</td>
<td>32x32x16</td>
</tr>
<tr>
<td>13</td>
<td>128x128</td>
<td>32x32x32</td>
</tr>
<tr>
<td>14</td>
<td>256x128</td>
<td>64x32x32</td>
</tr>
<tr>
<td>15</td>
<td>256x256</td>
<td>unsupported</td>
</tr>
</tbody>
</table>

The \text{Coarse} input is used to select between the two mip levels that \text{may} be accessed during texel
filtering when using a `mipmapMode` of `VK_SAMPLER_MIPMAP_MODE_LINEAR`. When filtering between two mip levels, a `Coarse` value of `true` requests the footprint in the lower-resolution mip level (higher level number), while `false` requests the footprint in the higher-resolution mip level. If texel filtering would access only a single mip level, the footprint in that level would be returned when `Coarse` is set to `false`; an empty footprint would be returned when `Coarse` is set to `true`.

The footprint for `OpImageSampleFootprintNV` is returned in a structure with six members:

- The first member is a boolean value that is true if the texel filtering operation would access only a single mip level.
- The second member is a two- or three-component integer vector holding the footprint anchor location. For two-dimensional images, the returned components are in units of eight texel groups. For three-dimensional images, the returned components are in units of four texel groups.
- The third member is a two- or three-component integer vector holding a footprint offset relative to the anchor. All returned components are in units of texel groups.
- The fourth member is a two-component integer vector mask, which holds a bitfield identifying the set of texel groups in an 8x8 or 4x4x4 neighborhood relative to the anchor and offset.
- The fifth member is an integer identifying the mip level containing the footprint identified by the anchor, offset, and mask.
- The sixth member is an integer identifying the granularity of the returned footprint.

For footprints in two-dimensional images (`Dim2D`), the mask returned by `OpImageSampleFootprintNV` indicates whether each texel group in a 8x8 local neighborhood of texel groups would have one or more texels accessed during texel filtering. In the mask, the texel group with local group coordinates `(l\text{gx}, l\text{gy})` is considered covered if and only if

\[
0 \neq ((\text{mask}.x + (\text{mask}.y << 32))\&(1<<(l\text{gy} \times 8 + l\text{gx})))
\]

where:

- \(0 \leq l\text{gx}<8\) and \(0 \leq l\text{gy}<8\); and
- `mask` is the returned two-component mask.

The local group with coordinates `(l\text{gx}, l\text{gy})` in the mask is considered covered if and only if the texel filtering operation would access one or more texels `τ\text{ij}` in the returned mip level where:

\[
\begin{align*}
i_0 &= \begin{cases} 
gran.x \times (8 \times \text{anchor}.x + l\text{gx}), & \text{if } l\text{gx} + \text{offset}.x < 8 \\
gran.x \times (8 \times (\text{anchor}.x - 1) + l\text{gx}), & \text{otherwise}
\end{cases} \\
i_1 &= i_0 + \gran.x - 1 \\
j_0 &= \begin{cases} 
gran.y \times (8 \times \text{anchor}.y + l\text{gy}), & \text{if } l\text{gy} + \text{offset}.y < 8 \\
gran.y \times (8 \times (\text{anchor}.y - 1) + l\text{gy}), & \text{otherwise}
\end{cases} \\
j_1 &= j_0 + \gran.y - 1
\end{align*}
\]

and
\begin{itemize}
\item \(0 \leq i \leq i_1\) and \(0 \leq j \leq j_1\);
\item \texttt{gran} is a two-component vector holding the width and height of the texel group identified by the granularity;
\item \texttt{anchor} is the returned two-component anchor vector; and
\item \texttt{offset} is the returned two-component offset vector.
\end{itemize}

For footprints in three-dimensional images (Dim3D), the mask returned by \texttt{OpImageSampleFootprintNV} indicates whether each texel group in a 4x4x4 local neighborhood of texel groups would have one or more texels accessed during texel filtering. In the mask, the texel group with local group coordinates \((l_{gx}, l_{gy}, l_{gz})\), is considered covered if and only if:

\[
0 \neq (\texttt{mask}.x + (\texttt{mask}.y << 32)) \& (1 << (l_{gz} \times 16 + l_{gy} \times 4 + l_{gx})])
\]

where:
\begin{itemize}
\item \(0 \leq l_{gx} < 4, 0 \leq l_{gy} < 4,\) and \(0 \leq l_{gz} < 4\); and
\item \texttt{mask} is the returned two-component mask.
\end{itemize}

The local group with coordinates \((l_{gx}, l_{gy}, l_{gz})\) in the mask is considered covered if and only if the texel filtering operation would access one or more texels \(\tau_{i,j,k}\) in the returned mip level where:

\[
i_0 = \begin{cases} 
\text{gran}.x \times (4 \times \text{anchor}.x + l_{gx}), & \text{if } l_{gx} + \text{offset}.x < 4 \\
\text{gran}.x \times (4 \times (\text{anchor}.x - 1) + l_{gx}), & \text{otherwise}
\end{cases}
\]

\[
i_1 = i_0 + \text{gran}.x - 1
\]

\[
j_0 = \begin{cases} 
\text{gran}.y \times (4 \times \text{anchor}.y + l_{gy}), & \text{if } l_{gy} + \text{offset}.y < 4 \\
\text{gran}.y \times (4 \times (\text{anchor}.y - 1) + l_{gy}), & \text{otherwise}
\end{cases}
\]

\[
j_1 = j_0 + \text{gran}.y - 1
\]

\[
k_0 = \begin{cases} 
\text{gran}.z \times (4 \times \text{anchor}.z + l_{gz}), & \text{if } l_{gz} + \text{offset}.z < 4 \\
\text{gran}.z \times (4 \times (\text{anchor}.z - 1) + l_{gz}), & \text{otherwise}
\end{cases}
\]

\[
k_1 = k_0 + \text{gran}.z - 1
\]

and
\begin{itemize}
\item \(0 \leq i \leq i_1, j_0 \leq j \leq j_1, k_0 \leq k \leq k_1\);
\item \texttt{gran} is a three-component vector holding the width, height, and depth of the texel group identified by the granularity;
\item \texttt{anchor} is the returned three-component anchor vector; and
\item \texttt{offset} is the returned three-component offset vector.
\end{itemize}

If the sampler used by \texttt{OpImageSampleFootprintNV} enables anisotropic texel filtering via \texttt{anisotropyEnable}, it is possible that the set of texel groups accessed in a mip level may be too large to be expressed using an 8x8 or 4x4x4 mask using the granularity requested in the instruction. In this case, the implementation uses a texel group larger than the requested granularity. When a larger texel group size is used, \texttt{OpImageSampleFootprintNV} returns an integer granularity value that can be interpreted in the same manner as the granularity value provided to the instruction to
determine the texel group size used. If anisotropic texel filtering is disabled in the sampler, or if an anisotropic footprint can be represented as an 8x8 or 4x4x4 mask with the requested granularity, \texttt{OpImageSampleFootprintNV} will use the requested granularity as-is and return a granularity value of zero.

\texttt{OpImageSampleFootprintNV} supports only two- and three-dimensional image accesses (\texttt{Dim2D} and \texttt{Dim3D}), and the footprint returned is undefined if a sampler uses an addressing mode other than \texttt{VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE}.

### 16.10. Weight Image Sampling

The SPIR-V instruction \texttt{OpImageWeightedSampleQCOM} specifies a texture sampling operation involving two images: the \textit{sampled image} and the \textit{weight image}. It is similar to bilinear filtering except more than 2x2 texels may participate in the filter and the filter weights are user-specified rather than computed by fixed-function hardware. The weight image view defines a 2D kernel weights used during sampling.

The \texttt{OpImageWeightedSampleQCOM} support normalized or unnormalized texel coordinates. In addition to the inputs that would be accepted by an equivalent \texttt{OpImageSample*} instruction, \texttt{OpImageWeightedSampleQCOM} accepts a \texttt{weight} input that specifies the view of a sample weight image.

The input \texttt{weight} must be a view of a 2D or 1D image with \texttt{miplevels} equal to 1, \texttt{samples} equal to \texttt{VK_SAMPLE_COUNT_1_BIT}, created with an identity swizzle, and created with \texttt{usage} that includes \texttt{VK_IMAGE_USAGE_SAMPLE_WEIGHT_BIT_QCOM}. The \texttt{VkImageViewSampleWeightCreateInfoQCOM} specifies additional parameters of the view: \texttt{filterCenter}, \texttt{filterSize}, and \texttt{numPhases}, described in more detail below.

The \texttt{weight} view defines a filtering kernel that is a region of view's subresource range. The kernel spans a region from integer texel coordinate \((0,0)\) to \((\text{filterSize.x}-1, \text{filterSize.y}-1)\). It is valid for the view's subresource to have dimensions larger than the kernel but the texels with integer coordinates greater than \((\text{filterSize.width}-1, \text{filterSize.height}-1)\) are ignored by weight sampling. The value returned by queries \texttt{OpImageQuerySize}, \texttt{OpImageQuerySizeLod}, \texttt{OpImageQueryLevels}, and \texttt{OpImageQuerySamples} return for a weight image is undefined.

\texttt{filterCenter} designates an integer texel coordinate within the filter kernel as being the 'center' of the kernel. The center must be in the range \((0,0)\) to \((\text{filterSize.x}-1, \text{filterSize.y}-1)\). \texttt{numPhases} describes the number of filter phases used to provide sub-pixel filtering. Both are described in more detail below.

### 16.10.1. Weight Image Layout

The weight image specifies filtering kernel weight values. A 2D image view can be used to specify a 2D matrix of filter weights. For separable filers, a 1D image view can be used to specify the horizontal and vertical weights.

#### 2D Non-Separable Weight Filters

A 2D image view defined with \texttt{VkImageViewSampleWeightCreateInfoQCOM} describes a 2D matrix
(filterSize.width × filterSize.height) of weight elements with filter's center point at filterCenter. Note that filterSize can be smaller than the view's subresource, but the filter will always be located starting at integer texel coordinate (0,0).

The following figure illustrates a 2D convolution filter having filterSize of (4,3) and filterCenter at (1, 1).

![2D Convolution Filter](image)

*Figure 12. 2D Convolution Filter*

For a 2D weight filter, the phases are stored as layers of a 2D array image. The width and height of the view's subresource range must be less than or equal to VkPhysicalDeviceImageProcessingPropertiesQCOM::maxWeightFilterDimension. The layers are stored in horizontal phase major order. Expressed as a formula, the layer index for each filter phase is computed as:

```
layerIndex(horizPhase, vertPhase, horizPhaseCount) = (vertPhase * horizPhaseCount) + horizPhase
```

1D Separable Weight Filters

A separable weight filter is a 2D filter that can be specified by two 1D filters in the x and y directions such that their product yields the 2D filter. The following example shows a 2D filter and its associated separable 1D horizontal and vertical filters.
A 1D array image view defined with `VkImageViewSampleWeightCreateInfoQCOM` and with `layerCount` equal to '2' describes a separable weight filter. The horizontal weights are specified in slice '0' and the vertical weights in slice '1'. The `filterSize` and `filterCenter` specify the size and origin of the of the horizontal and vertical filters. For many use cases, 1D separable filters can offer a performance advantage over 2D filters.

For a 1D separable weight filter, the phases are arranged into a 1D array image with two layers. The horizontal weights are stored in layer 0 and the vertical weights in layer 1. Within each layer of the 1D array image, the weights are arranged into groups of 4, and then arranged by phase. Expressed as a formula, the 1D texel offset for each weight within each layer is computed as:

```cpp
// Let horizontal weights have a weightIndex of [0, filterSize.width - 1]
// Let vertical weights have a weightIndex of [0, filterSize.height - 1]
// Let phaseCount be the number of phases in either the vertical or horizontal
direction.

texelOffset(phaseIndex, weightIndex, phaseCount) = (phaseCount * 4 * (weightIndex / 4)) + (phaseIndex * 4) + (weightIndex % 4)
```

### 16.10.2. Weight Sampling Phases

When using weight image sampling, the texture coordinates may not align with a texel center in the sampled image. In this case, the filter weights can be adjusted based on the subpixel location. This is termed “subpixel filtering” to indicate that the origin of the filter lies at a subpixel location other than the texel center. Conceptually, this means that the weight filter is positioned such that filter taps do not align with sampled texels exactly. In such a case, modified filter weights may be needed to adjust for the off-center filter taps. Unlike bilinear filtering where the subpixel weights are computed by the implementation, subpixel weight image sampling requires that the per-phase filter weights are pre-computed by the application and stored in an array where each slice of the array is a “filter phase”. The array is indexed by the implementation based on subpixel positioning. Rather than a single 2D kernel of filter weights, the application provides an array of kernels, one set
of filter weights per phase.

The number of phases are restricted by following requirements, which apply to both separable and non-separable filters:

- The number of phases in the vertical direction, \( \text{phaseCount}_{\text{vert}} \), must be a power of two (i.e., 1, 2, 4, etc.).
- The number of phases in the horizontal direction \( \text{phaseCount}_{\text{horiz}} \), must equal \( \text{phaseCount}_{\text{vert}} \).
- The total number of phases, \( \text{phaseCount}_{\text{vert}} \times \text{phaseCount}_{\text{horiz}} \), must be less than or equal to \( \text{VkPhysicalDeviceImageProcessingPropertiesQCOM}:\text{maxWeightFilterPhases} \).

### 16.10.3. Weight Sampler Parameters

Weight sampling requires \( \text{VkSamplerCreateInfo} \) \( \text{addressModeU} \) and \( \text{addressModeV} \) must be set to \( \text{VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE} \) or \( \text{VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_BORDER} \). If \( \text{VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_BORDER} \) is used, then the border color must be set to transparent black.

### 16.10.4. Weight Sampling Operation

The 2D unnormalized texel coordinates \((u, v)\) are transformed by \( \text{filterCenter} \) to specify coordinates \(i_0, j_0\).

\[
i_0 = \lfloor u - \text{filterCenter}_x \rfloor \\
j_0 = \lfloor v - \text{filterCenter}_y \rfloor
\]

where \( \text{filterCenter} \) is specified by \( \text{VkImageViewSampleWeightCreateInfoQCOM}:\text{filterCenter} \).

Two sets of neighboring integer 2D texel coordinates are generated. The first set is used for selecting texels from the sampled image \( \tau \) and the second set used for selecting texels from the weight image \( w \). The first set of neighboring coordinates are combinations of \( i_0 \) to \( i_{\text{filterWidth} - 1} \) and \( j_0 \) to \( j_{\text{filterHeight} - 1} \). The second set of neighboring coordinates are combinations of \( k_0 \) to \( k_{\text{filterWidth} - 1} \) and \( l_0 \) to \( l_{\text{filterHeight} - 1} \). The first and second sets each contain \((\text{filterWidth} \times \text{filterHeight})\) of pairs of \((i, j)\) and \((k, l)\) coordinates respectively.

\[
\{i_q\}_q = 0 \quad q = \text{filterWidth} - 1 = i_0 + q \\
\{j_q\}_q = 0 \quad q = \text{filterHeight} - 1 = j_0 + q \\
\{k_q\}_q = 0 \quad q = \text{filterWidth} - 1 \\
\{l_q\}_q = 0 \quad q = \text{filterHeight} - 1
\]

where \( \text{filterWidth} \) and \( \text{filterHeight} \) are specified by \( \text{VkImageViewSampleWeightCreateInfoQCOM}:\text{filterSize} \).

Each of the generated integer coordinates \((i_q, j_q)\) is transformed by texture wrapping operation,
followed by integer texel coordinate validation. If any coordinate fails coordinate validation, it is a Border Texel and texel replacement is performed.

The phase index $\psi$ is computed from the fraction bits of the unnormalized 2D texel coordinates:

\[
\begin{align*}
    \text{phaseCount}_h &= \sqrt{\text{numPhases}} \\
    hPhase &= \lfloor \text{frac}(u) \times \text{phaseCount}_h \rfloor \\
    vPhase &= \lfloor \text{frac}(v) \times \text{phaseCount}_v \rfloor \\
    \psi &= (vPhase \times \text{phaseCount}_h) + hPhase
\end{align*}
\]

where the number of fraction bits retained is $\log_2(\text{numPhases})$ specified by \text{VkImageViewSampleWeightCreateInfoQCOM::numPhases}.

Each pair of texel coordinates $(i, j)$ in the first set selects a single texel value $\tau_{ij}$ from the sampled image. Each pair of texel coordinates $(k, l)$ in the second set, combined with phaseIndex $\psi$, selects a single weight from the weight image $w(k, l, \psi)$.

\[
w(k, l, \psi) = \begin{cases} 
    w_{k\psi} \quad (\psi \text{ as layer index}) & \text{for 2D array view (non-separable filter)} \\
    \text{weight}_h \times \text{weight}_v & \text{for 1D array view (separable filter)}
\end{cases}
\]

If $w$ is a 2D array view, then non-separable filtering is specified, and integer coordinates $(k, l)$ are used to select texels from layer $\psi$ of $w$. If $w$ is a 1D array view, then separable filtering is specified and integer coordinates $(k, l)$ are transformed to $(k_{\text{packed}}, l_{\text{packed}})$, and used to select horizontal weight ($\text{weight}_h$) and vertical weight ($\text{weight}_v$) texels from layer 0 and layer 1 of $w$ respectively.

\[
\begin{align*}
    k_{\text{packed}} &= (\text{phaseCount}_h \times 4 \lfloor k/4 \rfloor) + (hPhase \times 4) + (k \mod 4) \\
    l_{\text{packed}} &= (\text{phaseCount}_v \times 4 \lfloor l/4 \rfloor) + (vPhase \times 4) + (l \mod 4)
\end{align*}
\]

\[
\begin{align*}
    \text{weight}_h &= w_{k_{\text{packed}}[0]} \\
    \text{weight}_v &= w_{l_{\text{packed}}[1]}
\end{align*}
\]

(Vertical weights packed in layer 1)

Where $\%$ refers to the integer modulo operator.

The values of multiple texels, together with their weights, are combined to produce a filtered value.

\[
\tau_{\text{weightSampling}} = \sum_{j = j_0}^{j_{\text{blockHeight}-1}} \sum_{i = i_0}^{i_{\text{blockHeight}-1}} w(k, l, \psi)\tau_{ij}
\]

When \text{VkSamplerReductionModeCreateInfo::reductionMode} is set to \text{VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE}, the above summation is used. However, if the reduction mode is \text{VK_SAMPLER_REDUCTION_MODE_MIN} or \text{VK_SAMPLER_REDUCTION_MODE_MAX}, the process operates on the above values, computing a component-wise minimum or maximum of the texels with non-zero weights. If the reduction mode is \text{VK_SAMPLER_REDUCTION_MODE_MIN} or \text{VK_SAMPLER_REDUCTION_MODE_MAX}, each $w(k, l, \psi)$ weight must be equal to 0.0 or 1.0, otherwise the
Finally, the operations described in Conversion to RGBA and Component swizzle are performed and the final result is returned to the shader.

16.11. Block Matching

The SPIR-V instruction `opImageBlockMatchSAD` and `opImageBlockMatchSSD` specify texture block matching operations where a block or region of texels within a target image is compared with a same-sized region a reference image. The instructions make use of two image views: the target view and the reference view. The target view and reference view can be the same view, allowing block matching of two blocks within a single image.

Similar to an equivalent `OpImageFetch` instruction, `opImageBlockMatchSAD` and `opImageBlockMatchSSD` specify a image and an integer texel coordinate which describes the bottom-left texel of the target block. There are three additional inputs. The reference and refCoordinate specifies bottom-left texel of the reference block. The blockSize specifies the integer width and height of the target and reference blocks to be compared, and must not be greater than `VkPhysicalDeviceImageProcessingPropertiesQCOM.maxBlockMatchRegion`.

`opImageBlockMatchWindowSAD` and `opImageBlockMatchWindowSSD` take the same input parameters as the corresponding non-window instructions. The block matching comparison is performed for all pixel values within a 2D window whose dimensions are specified in the sampler.

16.11.1. Block Matching Sampler Parameters

For `opImageBlockMatchSAD` and `opImageBlockMatchSSD`, the input sampler must be created with addressModeU and addressModeV, equal to `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`, or `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_BORDER` with `VK_BORDER_COLOR_FLOAT_TRANSPARENT_BLACK`. The input sampler must be created with unnormalizedCoordinates equal to `VK_TRUE`. The input sampler must be created with components equal to `VK_COMPONENT_SWIZZLE_IDENTITY`.

For `opImageBlockMatchWindowSAD` and `opImageBlockMatchWindowSSD` instructions, the target sampler must have been created with `VkSamplerBlockMatchWindowCreateInfoQCOM` in the pNext chain.

For `opImageBlockMatchWindowSAD`, `opImageBlockMatchWindowSSD`, `opImageBlockMatchGatherSAD`, or `opImageBlockMatchGatherSSD` instructions, the input sampler must be created with addressModeU and addressModeV, equal to `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_BORDER` with `VK_BORDER_COLOR_FLOAT_TRANSPARENT_BLACK`.

Other sampler states are ignored.

16.11.2. Block Matching Operation

Block matching SPIR-V instructions `opImageBlockMatchSAD` and `opImageBlockMatchSSD` specify two sets of 2D integer texel coordinates: target coordinates \((u, v)\) and reference coordinates \((s, t)\).

The coordinates define the bottom-left texel of the target block \((i_0, j_0)\) and the reference block \((k_0, l_0)\).
For the target block, a set of neighboring integer texel coordinates are generated. The neighboring coordinates are combinations of \( i_0 \) to \( i_{\text{blockWidth}-1} \) and \( j_0 \) to \( j_{\text{blockHeight}-1} \). The set is of size \( \text{blockWidth} \times \text{blockHeight} \).

\[
\begin{align*}
\{ i_q \}_{q=0}^{\text{blockWidth}-1} &= i_0 + q \\
\{ j_q \}_{q=0}^{\text{blockHeight}-1} &= j_0 + q
\end{align*}
\]

where \( \text{blockWidth} \) and \( \text{blockHeight} \) is specified by the \( \text{blockSize} \) operand.

If any target integer texel coordinate \((i, j)\) in the set fails integer texel coordinate validation, then the texel is an invalid texel and texel replacement is performed.

Similarly for the reference block, a set of neighboring integer texel coordinates are generated.

\[
\begin{align*}
\{ k_q \}_{q=0}^{\text{blockWidth}-1} &= k_0 + q \\
\{ l_q \}_{q=0}^{\text{blockHeight}-1} &= l_0 + q
\end{align*}
\]

Each reference texel coordinate \((k, l)\) in the set must not fail integer texel coordinate validation. To avoid undefined behavior, application shader should guarantee that the reference block is fully within the bounds of the reference image.

Each pair of texel coordinates \((i, j)\) in the set selects a single texel value from the target image \( \tau_{ij} \). Each pair of texel coordinates \((k, l)\) in the set selects a single texel value from the reference image \( v_{kl} \).

The difference between target and reference texel values is summed to compute a difference metric. The \text{opTextureBlockMatchSAD} computes the sum of absolute differences.

\[
\tau_{\text{SAD}} = \sum_{j=j_0}^{j_{\text{blockHeight}-1}} \sum_{l=l_0}^{l_{\text{blockHeight}-1}} |v_{kl} - \tau_{ij}|
\]

The \text{opImageBlockMatchSSD} computes the sum of the squared differences.
When `VkSamplerReductionModeCreateInfo::reductionMode` is set to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE`, the above summation is used. However, if the reduction mode is `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX`, the process operates on the above values, computing a component-wise minimum or maximum of $|v_{k_l} - \tau_{i,j}|$, respectively. For $\tau_{SAD}$, the minimum or maximum difference is computed and for $\tau_{SSD}$, the square of the minimum or maximum is computed.

Finally, the operations described in Conversion to RGBA and Component swizzle are performed and the final result is returned to the shader. The component swizzle is specified by the target image descriptor; any swizzle specified by the reference image descriptor is ignored.

**Block Matching Window Operation**

Window block matching SPIR-V instructions `opImageBlockMatchWindowSAD` and `opImageBlockMatchWindowSSD` specify two sets of 2D integer texel coordinates: target coordinates $(u, v)$ and reference coordinates $(s, t)$. The block matching operation is performed repeatedly, for multiple sets of target integer coordinates within the specified window. These instructions effectively search a region or “window” within the target texture and identify the window coordinates where the minimum or maximum error metric is found. These instructions only support single component image formats.

The target coordinates are combinations of coordinates from $(u, v)$ to $(u + \text{windowWidth} - 1, v + \text{windowHeight} - 1)$ where `windowHeight` and `windowWidth` are specified by `VkSamplerBlockMatchWindowCreateInfoQCOM::windowExtent`. At each each target coordinate, a block matching operation is performed, resulting in a difference metric. The the reference coordinate $(s, t)$ is fixed. The block matching operation is repeated `windowWidth \times windowHeight` times.

The resulting minimum or maximum error is returned in the R component of the output. The integer window coordinates $(x, y)$ are returned in the G and B components of the output. The A component is 0. The minimum or maximum behavior is selected by `VkSamplerBlockMatchWindowCreateInfoQCOM::windowCompareMode`.

The following pseudo-code describes the operation `opImageBlockMatchWindowSAD`. The pseudo-code for `opImageBlockMatchWindowSSD` follows an identical pattern.

```cpp
vec4 opImageBlockMatchGatherSAD( sampler2D target,
                                  uvec2 targetCoord,
                                  sampler2D reference,
                                  uvec2 refCoord,
                                  uvec2 blockSize) {
    // Two parameters are sourced from the VkSampler associated with
    // 'target':
```
// compareMode (which can be either 'MIN' or 'MAX')
// uvec2 window (which defines the search window)

minSAD = INF;
maxSAD = -INF;
ivec2 minCoord;
ivec2 maxCoord;

for (uint x=0, x<window.width; x++) {
    for (uint y=0; y<window.height; y++) {
        float SAD = textureBlockMatchSAD(target,
                                            targetCoord + ivec2(x, y),
                                            reference,
                                            refCoord,
                                            blocksize).x;

        if (SAD < minSAD) {
            minSAD = SAD;
            minCoord = ivec2(x,y);
        }
        if (SAD > maxSAD) {
            maxSAD = SAD;
            maxCoord = ivec2(x,y);
        }
    }
}

if (compareMode==MIN) {
    return vec4(minSAD, minCoord.x, minCoord.y, 0.0);
} else {
    return vec4(maxSAD, maxCoord.x, maxCoord.y, 0.0);
}

Block Matching Gather Operation

Block matching Gather SPIR-V instructions opImageBlockMatchGatherSAD and opImageBlockMatchGatherSSD specify two sets of 2D integer texel coordinates: target coordinates \((u, v)\) and reference coordinates \((s, t)\).

These instructions perform the block matching operation 4 times, using integer target coordinates \((u, v), (u+1, v), (u+2, v), \) and \((u+3, v)\). The R component from each of those 4 operations is gathered and returned in the R, G, B, and A components of the output respectively. For each block match operation, the reference coordinate is \((s, t)\). For each block match operation, only the R component of the target and reference images are compared. The following pseudocode describes the operation opImageBlockMatchGatherSAD. The pseudocode for opImageBlockMatchGatherSSD follows an identical pattern.

```
vec4 opImageBlockMatchGatherSAD(sampler2D target,
                                ivec2 targetCoord,
                                sampler2D reference,
                                uint
```
vec4 out;
vec2 refCoord,
vec2 blocksize) {
for (uint x=0, x<4; x++) {
    float SAD = textureBlockMatchSAD(target,
        targetCoord + uvec2(x, 0),
        reference,
        refCoord,
        blocksize).x;
    if (x == 0) {
        out.x = SAD;
    }
    if (x == 1) {
        out.y = SAD;
    }
    if (x == 2) {
        out.z = SAD;
    }
    if (x == 3) {
        out.w = SAD;
    }
}
    return out;
}

16.12. Box Filter Sampling

The SPIR-V instruction OpImageBoxFilterQCOM specifies texture box filtering operation where a weighted average of a region of texels is computed, with the weights proportional to the coverage of each of the texels.

In addition to the inputs that would be accepted by an equivalent OpImageSample* instruction, OpImageBoxFilterQCOM accepts one additional input, boxSize which specifies the width and height in texels of the region to be averaged.

The figure below shows an example of using OpImageBoxFilterQCOM to sample from a 8 × 4 texel two-dimensional image, with unnormalized texture coordinates (4.125, 2.625) and boxSize of (2.75, 2.25). The filter will read 12 texel values and compute a weights based portion off each texel covered by the box.
If \textit{boxSize} has height and width both equal to 1.0, then this instruction will behave as traditional bilinear filtering. The \textit{boxSize} parameter \textbf{must} be greater than or equal to 1.0 and \textbf{must} not be greater than \texttt{VkPhysicalDeviceImageProcessingPropertiesQCOM\_maxBoxFilterBlockSize}.

\subsection*{16.12.1. Box Filter Sampler Parameters}

The input \texttt{sampler} \textbf{must} be created with \texttt{addressModeU} and \texttt{addressModeV}, equal to \texttt{VK\_SAMPLER\_ADDRESS\_MODE\_CLAMP\_TO\_EDGE}, or \texttt{VK\_SAMPLER\_ADDRESS\_MODE\_CLAMP\_TO\_BORDER} with \texttt{VK\_BORDER\_COLOR\_FLOAT\_TRANSPARENT\_BLACK}.

\subsection*{16.12.2. Box Filter Operation}

The 2D unnormalized texel coordinates \((u, v)\) are transformed by \textit{boxSize} to specify integer texel coordinates \((i_0, j_0)\) of the bottom left texel for the filter.

\begin{align*}
i_0 &= \lfloor u - \frac{boxWidth}{2} \rfloor \\
j_0 &= \lfloor v - \frac{boxHeight}{2} \rfloor
\end{align*}

where \textit{boxWidth} and \textit{boxHeight} are specified by the code\((x,y)\) components of the \textit{boxSize} operand.

The filter dimensions \((filterWidth \times filterHeight)\) are computed from the fractional portion of the \((u, v)\) coordinates and the \textit{boxSize}.
\begin{align*}
    \text{startFrac}U &= \text{frac}\left(u - \frac{\text{boxWidth}}{2}\right) \\
    \text{startFrac}V &= \text{frac}\left(v - \frac{\text{boxHeight}}{2}\right) \\
    \text{endFrac}U &= \text{frac}(\text{startFrac}U + \text{boxWidth}) \\
    \text{endFrac}V &= \text{frac}(\text{startFrac}V + \text{boxHeight}) \\
    \text{filterWidth} &= \lfloor\text{startFrac}U + \text{boxWidth}\rfloor \\
    \text{filterHeight} &= \lfloor\text{startFrac}V + \text{boxHeight}\rfloor
\end{align*}

where the number of fraction bits retained by \text{frac()} is specified by \text{VkPhysicalDeviceLimits::subTexelPrecisionBits}.

A set of neighboring integer texel coordinates are generated. The neighboring coordinates are combinations of \(i_0\) to \(i_{\text{filterWidth} - 1}\) and \(j_0\) to \(j_{\text{filterHeight} - 1}\), with \(i_0, j_0\) being the top-left coordinate of this set. The set is of size \((\text{filterWidth} \times \text{filterHeight})\).

\begin{align*}
    \{i_q\}_q = \text{filterWidth} - 1 &= i_0 + q \\
    \{j_q\}_q = \text{filterHeight} - 1 &= j_0 + q
\end{align*}

Each of the generated integer coordinates \((i_q, j_q)\) is transformed by texture wrapping operation, followed by integer texel coordinate validation. If any coordinate fails coordinate validation, it is a Border Texel and texel replacement is performed.

Horizontal weights \(\text{horizWeight}_0\) to \(\text{horizWeight}_{\text{boxWidth} - 1}\) and vertical weights \(\text{vertWeight}_0\) to \(\text{vertWeight}_{\text{boxHeight} - 1}\) are computed. Texels that are fully covered by the box will have a horizontal and vertical weight of 1. Texels partially covered by the box will have will have a reduced weights proportional to the coverage.

\begin{align*}
    \text{horizWeight}_i &= \begin{cases} 
        (1 - \text{startFrac}U), & \text{for}(i = 0) \\
        (\text{endFrac}U), & \text{for}(i = \text{filterWidth} - 1)\text{and}(\text{endFrac}U! = 0) \\
        (1), & \text{otherwise}
    \end{cases} \\
    \text{vertWeight}_j &= \begin{cases} 
        (1 - \text{startFrac}V), & \text{for}(j = 0) \\
        (\text{endFrac}V), & \text{for}(j = \text{filterHeight} - 1)\text{and}(\text{endFrac}V! = 0) \\
        (1), & \text{otherwise}
    \end{cases}
\end{align*}

The values of multiple texels, together with their horizontal and vertical weights, are combined to produce a box filtered value.

\[\tau_{\text{boxFilter}} = \frac{1}{\text{boxHeight} \times \text{boxWidth}} \sum_{j = j_0}^{\text{filterHeight} - 1} \sum_{i = i_0}^{\text{filterWidth} - 1} (\text{horizWeight}_i)(\text{vertWeight}_j)\tau_{i,j}\]

When \text{VkSamplerReductionModeCreateInfo::reductionMode} is set to
VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE, the above summation is used. However, if the reduction mode is VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX, the process operates on the above values, computing a component-wise minimum or maximum of the texels.

16.13. Image Operation Steps

Each step described in this chapter is performed by a subset of the image instructions:

- Texel Input Validation Operations, Format Conversion, Texel Replacement, Conversion to RGBA, and Component Swizzle: Performed by all instructions except OpImageWrite.
- Depth Comparison: Performed by OpImage*Dref instructions.
- All Texel output operations: Performed by OpImageWrite.
- Projection: Performed by all OpImage*Proj instructions.
- Derivative Image Operations, Cube Map Operations, Scale Factor Operation, LOD Operation and Image Level(s) Selection, and Texel Anisotropic Filtering: Performed by all OpImageSample* and OpImageSparseSample* instructions.
- (s,t,r,q,a) to (u,v,w,a) Transformation, Wrapping, and (u,v,w,a) to (i,j,k,l,n) Transformation And Array Layer Selection: Performed by all OpImageSample, OpImageSparseSample, and OpImage*Gather instructions.
- Texel Filtering: Performed by all OpImageSample* and OpImageSparseSample* instructions.
- Sparse Residency: Performed by all OpImageSparse* instructions.
- (s,t,r,q,a) to (u,v,w,a) Transformation, Wrapping, and Weight Image Sampling: Performed by OpImageWeightedSample* instructions.
- (s,t,r,q,a) to (u,v,w,a) Transformation, Wrapping, and Block Matching: Performed by OpImageBlockMatch* instructions.
- (s,t,r,q,a) to (u,v,w,a) Transformation, Wrapping, and Box Filter Sampling: Performed by OpImageBoxFilter* instructions.


16.14.1. Image Property Queries

OpImageQuerySize, OpImageQuerySizeLod, OpImageQueryLevels, and OpImageQuerySamples query properties of the image descriptor that would be accessed by a shader image operation. They return 0 if the bound descriptor is a null descriptor.

OpImageQuerySizeLod returns the size of the image level identified by the Level of Detail operand. If that level does not exist in the image, and the descriptor is not null, then the value returned is undefined.
16.14.2. Lod Query

OpImageQueryLod returns the Lod parameters that would be used in an image operation with the given image and coordinates. If the descriptor that would be accessed is a null descriptor then (0,0) is returned. Otherwise, the steps described in this chapter are performed as if for OpImageSampleImplicitLod, up to Scale Factor Operation, LOD Operation and Image Level(s) Selection. The return value is the vector \((\lambda', d)\). These values may be subject to implementation-specific maxima and minima for very large, out-of-range values.
Chapter 17. Fragment Density Map Operations

17.1. Fragment Density Map Operations Overview

When a fragment is generated in a render pass that has a fragment density map attachment, its area is determined by the properties of the local framebuffer region that the fragment occupies. The framebuffer is divided into a uniform grid of these local regions, and their fragment area property is derived from the density map with the following operations:

- Fetch density value
  - Component swizzle
  - Component mapping
- Fragment area conversion
  - Fragment area filter
  - Fragment area clamp

17.2. Fetch Density Value

Each local framebuffer region at center coordinate \((x, y)\) fetches a texel from the fragment density map.

First, the local framebuffer region center coordinate \((x, y)\) is offset by the value specified in VkSubpassFragmentDensityMapOffsetEndInfoQCOM. If no offset is specified, then the default offset \((0, 0)\) is used. The offsetted coordinate \((x', y')\) is computed as follows:

\[
x' = \text{clamp}(x + p\text{FragmentDensityOffsets}[layer]_x, 0, \text{framebuffer}_width - 1)
y' = \text{clamp}(y + p\text{FragmentDensityOffsets}[layer]_y, 0, \text{framebuffer}_height - 1)
\]

The offsetted coordinate \((x', y')\) fetches a texel from the fragment density map at integer coordinates:

\[
i = \left\lfloor \frac{x'}{\text{framebufferWidth}} \right\rfloor
\]
\[
j = \left\lfloor \frac{y'}{\text{framebufferHeight}} \right\rfloor
\]

Where the size of each region in the framebuffer is:

\[
\text{fragmentDensityTexelSize}_{\text{width}} = 2^{\left\lfloor \log_2\left(\frac{\text{framebufferWidth}}{\text{fragmentDensityMapWidth}}\right) \right\rfloor}
\]

\[
\text{fragmentDensityTexelSize}_{\text{height}} = 2^{\left\lfloor \log_2\left(\frac{\text{framebufferHeight}}{\text{fragmentDensityMapHeight}}\right) \right\rfloor}
\]
This region is subject to the limits in VkPhysicalDeviceFragmentDensityMapPropertiesEXT and therefore the final region size is clamped:

\[
\text{fragmentDensityTexelSize}_{\text{h}} = \frac{\text{fragmentbuffer}_{\text{height}}}{\log_2(\text{FragmentDensityMapHeight})}
\]

\[
\text{fragmentDensityTexelSize}_{\text{w, ext}} = \text{clamp}(\text{fragmentDensityTexelSize}_{\text{w, ext}}, \text{minFragmentDensityTexelSize}_{\text{w, ext}}, \text{maxFragmentDensityTexelSize}_{\text{w, ext}})
\]

\[
\text{fragmentDensityTexelSize}_{\text{v, ext}} = \text{clamp}(\text{fragmentDensityTexelSize}_{\text{v, ext}}, \text{minFragmentDensityTexelSize}_{\text{v, ext}}, \text{maxFragmentDensityTexelSize}_{\text{v, ext}})
\]

When multiview is enabled for the render pass and the fragment density map attachment view was created with layerCount greater than 1, the layer used for offsets and for fetching from the fragment density map is:

\[
layer = baseArrayLayer + \text{ViewIndex}
\]

Otherwise:

\[
layer = baseArrayLayer
\]

The texel fetched from the density map at (i,j,layer) is next converted to density with the following operations.

17.2.1. Component Swizzle

The components member of VkImageViewCreateInfo is applied to the fetched texel as defined in Image component swizzle.

17.2.2. Component Mapping

The swizzled texel’s components are mapped to a density value:

\[
densityValue_{xy} = (C’r, C’y)
\]

17.3. Fragment Area Conversion

Fragment area for the framebuffer region is undefined if the density fetched is not a normalized floating-point value greater than 0.0. Otherwise, the fetched fragment area for that region is derived as:

\[
\text{fragmentArea}_{wh} = \frac{1.0}{densityValue_{xy}}
\]
17.3.1. Fragment Area Filter

Optionally, the implementation may fetch additional density map texels in an implementation defined window around (i,j). The texels follow the standard conversion steps up to and including fragment area conversion.

A single fetched fragment area for the framebuffer region is chosen by the implementation and must have an area between the min and max areas of the fetched set.

17.3.2. Fragment Area Clamp

The implementation may clamp the fetched fragment area to one that it supports. The clamped fragment area must have a size less than or equal to the original fetched value. Implementations may vary the supported set of fragment areas per framebuffer region. Fragment area (1,1) must always be in the supported set.

Note

For example, if the fetched fragment area is (1,4) but the implementation only supports areas of {(1,1),(2,2)}, it could choose to clamp the area to (2,2) since it has the same size as (1,4). While this would produce fragments that have lower quality strictly in the x-axis, the overall density is maintained.

The clamped fragment area is assigned to the corresponding framebuffer region.
Chapter 18. Queries

Queries provide a mechanism to return information about the processing of a sequence of Vulkan commands. Query operations are asynchronous, and as such, their results are not returned immediately. Instead, their results, and their availability status are stored in a Query Pool. The state of these queries can be read back on the host, or copied to a buffer object on the device.

The supported query types are Occlusion Queries, Pipeline Statistics Queries, Result Status Queries, Video Encode Feedback Queries and Timestamp Queries. Performance Queries are supported if the associated extension is available. Transform Feedback Queries are supported if the associated extension is available. Intel performance queries are supported if the associated extension is available. Mesh Shader Queries are supported if the associated extension is available.

Several additional queries with specific purposes associated with ray tracing are available if the corresponding extensions are supported, as described for VkQueryType.

18.1. Query Pools

Queries are managed using query pool objects. Each query pool is a collection of a specific number of queries of a particular type.

Query pools are represented by VkQueryPool handles:

```c
// Provided by VK_VERSION_1_0
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkQueryPool)
```

To create a query pool, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkCreateQueryPool(
    VkDevice device,                // Logical device that creates the query pool.
    const VkQueryPoolCreateInfo* pCreateInfo,  // Pointer to a VkQueryPoolCreateInfo structure containing the number and type of queries to be managed by the pool.
    const VkAllocationCallbacks* pAllocator,  // Controls host memory allocation as described in the Memory Allocation chapter.
    VkQueryPool* pQueryPool);  // Pointer to a VkQueryPool handle in which the resulting query pool object is returned.
```

- **device** is the logical device that creates the query pool.
- **pCreateInfo** is a pointer to a VkQueryPoolCreateInfo structure containing the number and type of queries to be managed by the pool.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
- **pQueryPool** is a pointer to a VkQueryPool handle in which the resulting query pool object is returned.

Valid Usage (Implicit)

- VUID-vkCreateQueryPool-device-parameter
device must be a valid VkDevice handle

- VUID-vkCreateQueryPool-pCreateInfo-parameter
  pCreateInfo must be a valid pointer to a valid VkQueryPoolCreateInfo structure

- VUID-vkCreateQueryPool-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkCreateQueryPool-pQueryPool-parameter
  pQueryPool must be a valid pointer to a VkQueryPool handle

### Return Codes

**Success**

- VK_SUCCESS

**Failure**

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkQueryPoolCreateInfo structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkQueryPoolCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkQueryPoolCreateFlags flags;
    VkQueryType queryType;
    uint32_t queryCount;
    VkQueryPipelineStatisticFlags pipelineStatistics;
} VkQueryPoolCreateInfo;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **queryType** is a VkQueryType value specifying the type of queries managed by the pool.
- **queryCount** is the number of queries managed by the pool.
- **pipelineStatistics** is a bitmask of VkQueryPipelineStatisticFlagBits specifying which counters will be returned in queries on the new pool, as described below in Pipeline Statistics Queries.

pipelineStatistics is ignored if queryType is not VK_QUERY_TYPE_PIPELINE_STATISTICS.
Valid Usage

- VUID-VkQueryPoolCreateInfo-queryType-00791
  If the pipelineStatisticsQuery feature is not enabled, queryType must not be VK_QUERY_TYPE_PIPELINE_STATISTICS

- VUID-VkQueryPoolCreateInfo-meshShaderQueries-07068
  If the meshShaderQueries feature is not enabled, queryType must not be VK_QUERY_TYPE_MESH_PRIMITIVES_GENERATED_EXT

- VUID-VkQueryPoolCreateInfo-meshShaderQueries-07069
  If the meshShaderQueries feature is not enabled, and queryType is VK_QUERY_TYPE_PIPELINE_STATISTICS, pipelineStatistics must not contain VK_QUERY_PIPELINE_STATISTIC_TASK_SHADER_INVOCATIONS_BIT_EXT or VK_QUERY_PIPELINE_STATISTIC_MESH_SHADER_INVOCATIONS_BIT_EXT

- VUID-VkQueryPoolCreateInfo-queryType-00792
  If queryType is VK_QUERY_TYPE_PIPELINE_STATISTICS, pipelineStatistics must be a valid combination of VkQueryPipelineStatisticFlagBits values

- VUID-VkQueryPoolCreateInfo-queryType-03222
  If queryType is VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR, the pNext chain must include a VkQueryPoolPerformanceCreateInfoKHR structure

- VUID-VkQueryPoolCreateInfo-queryCount-02763
  queryCount must be greater than 0

- VUID-VkQueryPoolCreateInfo-queryType-07133
  If queryType is VK_QUERY_TYPE_VIDEO_ENCODE_FEEDBACK_KHR, then the pNext chain must include a VkVideoProfileInfoKHR structure with videoCodecOperation specifying an encode operation

- VUID-VkQueryPoolCreateInfo-queryType-07906
  If queryType is VK_QUERY_TYPE_VIDEO_ENCODE_FEEDBACK_KHR, then the pNext chain must include a VkQueryPoolVideoEncodeFeedbackCreateInfoKHR structure

- VUID-VkQueryPoolCreateInfo-queryType-07907
  If queryType is VK_QUERY_TYPE_VIDEO_ENCODE_FEEDBACK_KHR, and the pNext chain includes a VkVideoProfileInfoKHR structure and a VkQueryPoolVideoEncodeFeedbackCreateInfoKHR structure, then VkQueryPoolVideoEncodeFeedbackCreateInfoKHR::encodeFeedbackFlags must not contain any bits that are not set in VkVideoEncodeCapabilitiesKHR::supportedEncodeFeedbackFlags, as returned by vkGetPhysicalDeviceVideoCapabilitiesKHR for the video profile described by VkVideoProfileInfoKHR and its pNext chain

Valid Usage (Implicit)

- VUID-VkQueryPoolCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPEQUERY_POOL_CREATE_INFO

- VUID-VkQueryPoolCreateInfo-pNext-pNext
Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkQueryPoolPerformanceCreateInfoKHR`, `VkQueryPoolVideoEncodeFeedbackCreateInfoKHR`, `VkVideoDecodeH264ProfileInfoKHR`, `VkVideoDecodeH265ProfileInfoKHR`, `VkVideoEncodeH264ProfileInfoKHR`, `VkVideoEncodeH265ProfileInfoKHR`, `VkVideoEncodeUsageInfoKHR`, or `VkVideoProfileInfoKHR`

- `VUID-VkQueryPoolCreateInfo-sType-unique` The `sType` value of each struct in the `pNext` chain must be unique
- `VUID-VkQueryPoolCreateInfo-flags-zero bitmask` `flags` must be 0
- `VUID-VkQueryPoolCreateInfo-queryType-parameter` `queryType` must be a valid `VkQueryType` value

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkQueryPoolCreateFlags;
```

`VkQueryPoolCreateFlags` is a bitmask type for setting a mask, but is currently reserved for future use.

The `VkQueryPoolPerformanceCreateInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_performance_query
typedef struct VkQueryPoolPerformanceCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t queueFamilyIndex;
    uint32_t counterIndexCount;
    const uint32_t* pCounterIndices;
} VkQueryPoolPerformanceCreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `queueFamilyIndex` is the queue family index to create this performance query pool for.
- `counterIndexCount` is the length of the `pCounterIndices` array.
- `pCounterIndices` is a pointer to an array of indices into the `vkEnumeratePhysicalDeviceQueueFamilyPerformanceQueryCountersKHR::pCounters` to enable in this performance query pool.

### Valid Usage

- `VUID-VkQueryPoolPerformanceCreateInfoKHR-queueFamilyIndex-03236` `queueFamilyIndex` must be a valid queue family index of the device
- `VUID-VkQueryPoolPerformanceCreateInfoKHR-performanceCounterQueryPools-03237`
The `performanceCounterQueryPools` feature must be enabled

- VUID-VkQueryPoolPerformanceCreateInfoKHR-pCounterIndices-03321
  Each element of `pCounterIndices` must be in the range of counters reported by `vkEnumeratePhysicalDeviceQueueFamilyPerformanceQueryCountersKHR` for the queue family specified in `queueFamilyIndex`

### Valid Usage (Implicit)

- VUID-VkQueryPoolPerformanceCreateInfoKHR-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_QUERY_POOL_PERFORMANCE_CREATE_INFO_KHR`

- VUID-VkQueryPoolPerformanceCreateInfoKHR-pCounterIndices-parameter
  `pCounterIndices` must be a valid pointer to an array of `counterIndexCount` `uint32_t` values

- VUID-VkQueryPoolPerformanceCreateInfoKHR-counterIndexCount-arraylength
  `counterIndexCount` must be greater than 0

To query the number of passes required to query a performance query pool on a physical device, call:

```c
// Provided by VK_KHR_performance_query
void vkGetPhysicalDeviceQueueFamilyPerformanceQueryPassesKHR(
    VkPhysicalDevice physicalDevice, 
    const VkQueryPoolPerformanceCreateInfoKHR* pPerformanceQueryCreateInfo, 
    uint32_t* pNumPasses);
```

- `physicalDevice` is the handle to the physical device whose queue family performance query counter properties will be queried.

- `pPerformanceQueryCreateInfo` is a pointer to a `VkQueryPoolPerformanceCreateInfoKHR` of the performance query that is to be created.

- `pNumPasses` is a pointer to an integer related to the number of passes required to query the performance query pool, as described below.

The `pPerformanceQueryCreateInfo` member `VkQueryPoolPerformanceCreateInfoKHR::queueFamilyIndex` must be a queue family of `physicalDevice`. The number of passes required to capture the counters specified in the `pPerformanceQueryCreateInfo` member `VkQueryPoolPerformanceCreateInfoKHR::pCounters` is returned in `pNumPasses`.

### Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceQueueFamilyPerformanceQueryPassesKHR-physicalDevice-parameter
  `physicalDevice` must be a valid `VkPhysicalDevice` handle

- VUID-vkGetPhysicalDeviceQueueFamilyPerformanceQueryPassesKHR-pPerformanceQueryCreateInfo-parameter

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PerformanceQueryCreateInfo must be a valid pointer to a valid VkQueryPoolPerformanceCreateInfoKHR structure

- VUID-vkGetPhysicalDeviceQueueFamilyPerformanceQueryPassesKHR-pNumPasses-parameter
  pNumPasses must be a valid pointer to a uint32_t value

To destroy a query pool, call:

```c
// Provided by VK_VERSION_1_0
void vkDestroyQueryPool(
  VkDevice device,
  VkQueryPool queryPool,
  const VkAllocationCallbacks* pAllocator);
```

- device is the logical device that destroys the query pool.
- queryPool is the query pool to destroy.
- pAllocator controls host memory allocation as described in the Memory Allocation chapter.

Valid Usage

- VUID-vkDestroyQueryPool-queryPool-00793
  All submitted commands that refer to queryPool must have completed execution

- VUID-vkDestroyQueryPool-queryPool-00794
  If VkAllocationCallbacks were provided when queryPool was created, a compatible set of callbacks must be provided here

- VUID-vkDestroyQueryPool-queryPool-00795
  If no VkAllocationCallbacks were provided when queryPool was created, pAllocator must be NULL

Note

Applications can verify that queryPool can be destroyed by checking that vkGetQueryPoolResults() without the VK_QUERY_RESULT_PARTIAL_BIT flag returns VK_SUCCESS for all queries that are used in command buffers submitted for execution.

Valid Usage (Implicit)

- VUID-vkDestroyQueryPool-device-parameter
device must be a valid VkDevice handle

- VUID-vkDestroyQueryPool-queryPool-parameter
  If queryPool is not VK_NULL_HANDLE, queryPool must be a valid VkQueryPool handle

- VUID-vkDestroyQueryPool-pAllocator-parameter
If `pAllocator` is not `NULL`, `pAllocator` **must** be a valid pointer to a valid `VkAllocationCallbacks` structure.

- VUID-vkDestroyQueryPool-queryPool-parent
  If `queryPool` is a valid handle, it **must** have been created, allocated, or retrieved from `device`.

### Host Synchronization

- Host access to `queryPool` **must** be externally synchronized.

Possible values of `VkQueryPoolCreateInfo::queryType`, specifying the type of queries managed by the pool, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkQueryType {
    VK_QUERY_TYPE_OCCLUSION = 0,
    VK_QUERY_TYPE_PIPELINE_STATISTICS = 1,
    VK_QUERY_TYPE_TIMESTAMP = 2,
    // Provided by VK_KHR_video_queue
    VK_QUERY_TYPE_RESULT_STATUS_ONLY_KHR = 1000023000,
    // Provided by VK_EXT_transform_feedback
    VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT_KHR = 1000028004,
    // Provided by VK_KHR_performance_query
    VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR = 1000116000,
    // Provided by VK_KHR_acceleration_structure
    VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_KHR = 1000150000,
    // Provided by VK_KHR_acceleration_structure
    VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_SIZE_KHR = 1000150001,
    // Provided by VK_NV_ray_tracing
    VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_NV = 1000165000,
    // Provided by VK_INTEL_performance_query
    VK_QUERY_TYPE_PERFORMANCE_QUERY_INTEL = 1000210000,
    #ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_KHR_video_encode_queue
    VK_QUERY_TYPE_VIDEO_ENCODE_FEEDBACK_KHR = 1000299000,
    #endif
    // Provided by VK_EXT_mesh_shader
    VK_QUERY_TYPE_MESH_PRIMITIVES_GENERATED_EXT = 1000328000,
    // Provided by VK_EXT_primitives_generated_query
    VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT = 1000382000,
    // Provided by VK_KHR_ray_tracing_maintenance1
    VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_BOTTOM_LEVEL_POINTERS_KHR = 1000386000,
    // Provided by VK_KHR_ray_tracing_maintenance1
    VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SIZE_KHR = 1000386001,
    // Provided by VK_EXT_opacity_micromap
    VK_QUERY_TYPE_MICROMAP_SERIALIZATION_SIZE_EXT = 1000396000,
}
```
18.2. Query Operation

The operation of queries is controlled by the commands `vkCmdBeginQuery`, `vkCmdEndQuery`, `vkCmdBeginQueryIndexedEXT`, `vkCmdEndQueryIndexedEXT`, `vkCmdResetQueryPool`, `vkCmdCopyQueryPoolResults`, `vkCmdWriteAccelerationStructuresPropertiesKHR`, and `vkCmdWriteAccelerationStructuresPropertiesNV`, and `vkCmdWriteTimestamp2` or `vkCmdWriteTimestamp`.

In order for a `VkCommandBuffer` to record query management commands, the queue family for which its `VkCommandPool` was created must support the appropriate type of operations (graphics, compute) suitable for the query type of a given query pool.

Each query in a query pool has a status that is either unavailable or available, and also has state to store the numerical results of a query operation of the type requested when the query pool was created. Resetting a query via `vkCmdResetQueryPool` or `vkResetQueryPool` sets the status to unavailable and makes the numerical results undefined. A query is made available by the operation of `vkCmdEndQuery`, `vkCmdEndQueryIndexedEXT`, `vkCmdWriteTimestamp2`, or
vkCmdWriteTimestamp. Both the availability status and numerical results can be retrieved by calling either vkGetQueryPoolResults or vkCmdCopyQueryPoolResults.

After query pool creation, each query must be reset before it is used. Queries must also be reset between uses.

If a logical device includes multiple physical devices, then each command that writes a query must execute on a single physical device, and any call to vkCmdBeginQuery must execute the corresponding vkCmdEndQuery command on the same physical device.

To reset a range of queries in a query pool on a queue, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdResetQueryPool(
    VkCommandBuffer commandBuffer,
    VkQueryPool queryPool,
    uint32_t firstQuery,
    uint32_t queryCount);
```

- `commandBuffer` is the command buffer into which this command will be recorded.
- `queryPool` is the handle of the query pool managing the queries being reset.
- `firstQuery` is the initial query index to reset.
- `queryCount` is the number of queries to reset.

When executed on a queue, this command sets the status of query indices `[firstQuery, firstQuery + queryCount - 1]` to unavailable.

This command defines an execution dependency between other query commands that reference the same query.

The first synchronization scope includes all commands which reference the queries in `queryPool` indicated by `firstQuery` and `queryCount` that occur earlier in submission order.

The second synchronization scope includes all commands which reference the queries in `queryPool` indicated by `firstQuery` and `queryCount` that occur later in submission order.

The operation of this command happens after the first scope and happens before the second scope.

If the `queryType` used to create `queryPool` was `VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR`, this command sets the status of query indices `[firstQuery, firstQuery + queryCount - 1]` to unavailable for each pass of `queryPool`, as indicated by a call to vkGetPhysicalDeviceQueueFamilyPerformanceQueryPassesKHR.

Note

Because vkCmdResetQueryPool resets all the passes of the indicated queries, applications must not record a vkCmdResetQueryPool command for a `queryPool` created with `VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR` in a command buffer that needs to be submitted multiple times as indicated by a call to
vkGetPhysicalDeviceQueueFamilyPerformanceQueryPassesKHR.

Otherwise applications will never be able to complete the recorded queries.

### Valid Usage

- **VUID-vkCmdResetQueryPool-firstQuery-00796**
  - `firstQuery` **must** be less than the number of queries in `queryPool`

- **VUID-vkCmdResetQueryPool-firstQuery-00797**
  - The sum of `firstQuery` and `queryCount` **must** be less than or equal to the number of queries in `queryPool`

- **VUID-vkCmdResetQueryPool-None-02841**
  - All queries used by the command **must** not be active

- **VUID-vkCmdResetQueryPool-firstQuery-02862**
  - If `queryPool` was created with `VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR`, this command **must** not be recorded in a command buffer that, either directly or through secondary command buffers, also contains begin commands for a query from the set of queries `[firstQuery, firstQuery + queryCount - 1]`

### Valid Usage (Implicit)

- **VUID-vkCmdResetQueryPool-commandBuffer-parameter**
  - `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- **VUID-vkCmdResetQueryPool-queryPool-parameter**
  - `queryPool` **must** be a valid `VkQueryPool` handle

- **VUID-vkCmdResetQueryPool-commandBuffer-recording**
  - `commandBuffer` **must** be in the recording state

- **VUID-vkCmdResetQueryPool-commandBuffer-cmdpool**
  - The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics, compute, decode, encode, or optical flow operations

- **VUID-vkCmdResetQueryPool-renderpass**
  - This command **must** only be called outside of a render pass instance

- **VUID-vkCmdResetQueryPool-videocoding**
  - This command **must** only be called outside of a video coding scope

- **VUID-vkCmdResetQueryPool-commonparent**
  - Both of `commandBuffer`, and `queryPool` **must** have been created, allocated, or retrieved from the same `VkDevice`

### Host Synchronization

- Host access to `commandBuffer` **must** be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized
To reset a range of queries in a query pool on the host, call:

```c
// Provided by VK_VERSION_1_2
void vkResetQueryPool(
    VkDevice device,
    VkQueryPool queryPool,
    uint32_t firstQuery,
    uint32_t queryCount);
```

or the equivalent command

```c
// Provided by VK_EXT_host_query_reset
void vkResetQueryPoolEXT(
    VkDevice device,
    VkQueryPool queryPool,
    uint32_t firstQuery,
    uint32_t queryCount);
```

- `device` is the logical device that owns the query pool.
- `queryPool` is the handle of the query pool managing the queries being reset.
- `firstQuery` is the initial query index to reset.
- `queryCount` is the number of queries to reset.

This command sets the status of query indices `[firstQuery, firstQuery + queryCount - 1]` to unavailable.

If `queryPool` is `VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR` this command sets the status of query indices `[firstQuery, firstQuery + queryCount - 1]` to unavailable for each pass.
Valid Usage

• VUID-vkResetQueryPool-None-02665
  The hostQueryReset feature must be enabled

• VUID-vkResetQueryPool-firstQuery-02666
  firstQuery must be less than the number of queries in queryPool

• VUID-vkResetQueryPool-firstQuery-02667
  The sum of firstQuery and queryCount must be less than or equal to the number of queries in queryPool

• VUID-vkResetQueryPool-firstQuery-02741
  Submitted commands that refer to the range specified by firstQuery and queryCount in queryPool must have completed execution

• VUID-vkResetQueryPool-firstQuery-02742
  The range of queries specified by firstQuery and queryCount in queryPool must not be in use by calls to vkGetQueryPoolResults or vkResetQueryPool in other threads

Valid Usage (Implicit)

• VUID-vkResetQueryPool-device-parameter
  device must be a valid VkDevice handle

• VUID-vkResetQueryPool-queryPool-parameter
  queryPool must be a valid VkQueryPool handle

• VUID-vkResetQueryPool-queryPool-parent
  queryPool must have been created, allocated, or retrieved from device

Once queries are reset and ready for use, query commands can be issued to a command buffer. Occlusion queries and pipeline statistics queries count events - drawn samples and pipeline stage invocations, respectively - resulting from commands that are recorded between a vkCmdBeginQuery command and a vkCmdEndQuery command within a specified command buffer, effectively scoping a set of drawing and/or dispatching commands. Timestamp queries write timestamps to a query pool. Performance queries record performance counters to a query pool. Performance queries record performance counters to a query pool.

A query must begin and end in the same command buffer, although if it is a primary command buffer, and the inheritedQueries feature is enabled, it can execute secondary command buffers during the query operation. For a secondary command buffer to be executed while a query is active, it must set the occlusionQueryEnable, queryFlags, and/or pipelineStatistics members of VkCommandBufferInheritanceInfo to conservative values, as described in the Command Buffer Recording section. A query must either begin and end inside the same subpass of a render pass instance, or must both begin and end outside of a render pass instance (i.e. contain entire render pass instances).

If queries are used while executing a render pass instance that has multiview enabled, the query uses N consecutive query indices in the query pool (starting at query) where N is the number of bits set in the view mask in the subpass the query is used in. How the numerical results of the query are
distributed among the queries is implementation-dependent. For example, some implementations may write each view's results to a distinct query, while other implementations may write the total result to the first query and write zero to the other queries. However, the sum of the results in all the queries must accurately reflect the total result of the query summed over all views. Applications can sum the results from all the queries to compute the total result.

Queries used with multiview rendering must not span subpasses, i.e. they must begin and end in the same subpass.

A query must either begin and end inside the same video coding scope, or must both begin and end outside of a video coding scope and must not contain entire video coding scopes.

To begin a query, call:

```
// Provided by VK_VERSION_1_0
void vkCmdBeginQuery(
    VkCommandBuffer commandBuffer,
    VkQueryPool queryPool,
    uint32_t query,
    VkQueryControlFlags flags);
```

- commandBuffer is the command buffer into which this command will be recorded.
- queryPool is the query pool that will manage the results of the query.
- query is the query index within the query pool that will contain the results.
- flags is a bitmask of VkQueryControlFlagBits specifying constraints on the types of queries that can be performed.

If the queryType of the pool is VK_QUERY_TYPE_OCCLUSION and flags contains VK_QUERY_CONTROL_PRECISE_BIT, an implementation must return a result that matches the actual number of samples passed. This is described in more detail in Occlusion Queries.

Calling vkCmdBeginQuery is equivalent to calling vkCmdBeginQueryIndexedEXT with the index parameter set to zero.

After beginning a query, that query is considered active within the command buffer it was called in until that same query is ended. Queries active in a primary command buffer when secondary command buffers are executed are considered active for those secondary command buffers.

Furthermore, if the query is started within a video coding scope, the following command buffer states are initialized for the query type:

- The active_query_index is set to the value specified by query.
- The last activatable query index is also set to the value specified by query.

Each video coding operation stores a result to the query corresponding to the current active query index, followed by incrementing the active query index. If the active query index gets incremented past the last activatable query index, issuing any further video coding operations results in undefined behavior.
Note
In practice, this means that currently no more than a single video coding operation must be issued between a begin and end query pair.

This command defines an execution dependency between other query commands that reference the same query.

The first synchronization scope includes all commands which reference the queries in queryPool indicated by query that occur earlier in submission order.

The second synchronization scope includes all commands which reference the queries in queryPool indicated by query that occur later in submission order.

The operation of this command happens after the first scope and happens before the second scope.

### Valid Usage

- VUID-vkCmdBeginQuery-None-00807
  All queries used by the command must be unavailable

- VUID-vkCmdBeginQuery-queryType-02804
  The queryType used to create queryPool must not be VK_QUERY_TYPE_TIMESTAMP

- VUID-vkCmdBeginQuery-queryType-04728
  The queryType used to create queryPool must not be
  
  - VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_KHR
  
  - VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIALIZATION_SIZE_KHR

- VUID-vkCmdBeginQuery-queryType-06741
  The queryType used to create queryPool must not be
  
  - VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SIZE_KHR
  
  - VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_BOTTOM_LEVEL_POINTERS_KHR

- VUID-vkCmdBeginQuery-queryType-04729
  The queryType used to create queryPool must not be
  
  - VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_NV

- VUID-vkCmdBeginQuery-queryType-00800
  If the occlusionQueryPrecise feature is not enabled, or the queryType used to create queryPool was not VK_QUERY_TYPE_OCCLUSION, flags must not contain VK_QUERY_CONTROL_PRECISE_BIT

- VUID-vkCmdBeginQuery-query-00802
  query must be less than the number of queries in queryPool

- VUID-vkCmdBeginQuery-queryType-00803
  If the queryType used to create queryPool was VK_QUERY_TYPE_PIPELINE_STATISTICS and any of the pipelineStatistics indicate graphics operations, the VkCommandPool that

- VUID-vkCmdBeginQuery-queryType-00804
  If the queryType used to create queryPool was VK_QUERY_TYPE_PIPELINE_STATISTICS and any of the pipelineStatistics indicate graphics operations, the VkCommandPool that
commandBuffer was allocated from **must** support graphics operations

- VUID-vkCmdBeginQuery-queryType-00805
  If the queryType used to create queryPool was VK_QUERY_TYPE_PIPELINE_STATISTICS and any of the pipelineStatistics indicate compute operations, the VkCommandPool that commandBuffer was allocated from **must** support compute operations

- VUID-vkCmdBeginQuery-commandBuffer-01885
  commandBuffer **must** not be a protected command buffer

- VUID-vkCmdBeginQuery-query-00808
  If called within a render pass instance, the sum of query and the number of bits set in the current subpass’s view mask **must** be less than or equal to the number of queries in queryPool

- VUID-vkCmdBeginQuery-queryType-07126
  If the queryType used to create queryPool was VK_QUERY_TYPE_RESULT_STATUS_ONLY_KHR, then the VkCommandPool that commandBuffer was allocated from **must** have been created with a queue family index that supports result status queries, as indicated by VkQueueFamilyQueryResultStatusPropertiesKHR::queryResultStatusSupport

- VUID-vkCmdBeginQuery-None-07127
  If there is a bound video session, then there **must** be no active queries

- VUID-vkCmdBeginQuery-queryType-07128
  If the queryType used to create queryPool was VK_QUERY_TYPE_RESULT_STATUS_ONLY_KHR and there is a bound video session, then queryPool **must** have been created with a VkVideoProfileInfoKHR structure included in the pNext chain of VkQueryPoolCreateInfo identical to the one specified in VkVideoSessionCreateInfoKHR::pVideoProfile the bound video session was created with

- VUID-vkCmdBeginQuery-queryType-04862
  If the queryType used to create queryPool was VK_QUERY_TYPE_VIDEO_ENCODE_FEEDBACK_KHR, then the VkCommandPool that commandBuffer was allocated from **must** support video encode operations

- VUID-vkCmdBeginQuery-queryType-07129
  If the queryType used to create queryPool was VK_QUERY_TYPE_VIDEO_ENCODE_FEEDBACK_KHR, then there **must** be a bound video session

- VUID-vkCmdBeginQuery-queryType-07130
  If the queryType used to create queryPool was VK_QUERY_TYPE_VIDEO_ENCODE_FEEDBACK_KHR and there is a bound video session, then queryPool **must** have been created with a VkVideoProfileInfoKHR structure included in the pNext chain of VkQueryPoolCreateInfo identical to the one specified in VkVideoSessionCreateInfoKHR::pVideoProfile the bound video session was created with

- VUID-vkCmdBeginQuery-queryType-07131
  If the queryType used to create queryPool was not VK_QUERY_TYPE_RESULT_STATUS_ONLY_KHR or VK_QUERY_TYPE_VIDEO_ENCODE_FEEDBACK_KHR, then there **must** be no bound video session

- VUID-vkCmdBeginQuery-queryPool-01922
  queryPool **must** have been created with a queryType that differs from that of any queries that are active within commandBuffer
• VUID-vkCmdBeginQuery-queryType-07070
If the queryType used to create queryPool was VK_QUERY_TYPE_MESH_PRIMITIVES_GENERATED_EXT the VkCommandPool that commandBuffer was allocated from must support graphics operations

• VUID-vkCmdBeginQuery-queryType-02327
If the queryType used to create queryPool was VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT the VkCommandPool that commandBuffer was allocated from must support graphics operations

• VUID-vkCmdBeginQuery-queryType-02328
If the queryType used to create queryPool was VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT then VkPhysicalDeviceTransformFeedbackPropertiesEXT::transformFeedbackQueries must be supported

• VUID-vkCmdBeginQuery-queryPool-07289
If queryPool was created with a queryType of VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR, then the VkQueryPoolPerformanceCreateInfoKHR::queueFamilyIndex queryPool was created with must equal the queue family index of the VkCommandPool that commandBuffer was allocated from

• VUID-vkCmdBeginQuery-queryPool-03223
If queryPool was created with a queryType of VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR, the profiling lock must have been held before vkBeginCommandBuffer was called on commandBuffer

• VUID-vkCmdBeginQuery-queryPool-03224
If queryPool was created with a queryType of VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR and one of the counters used to create queryPool was VK_PERFORMANCE_COUNTER_SCOPE_COMMAND_BUFFER_KHR, the query begin must be the first recorded command in commandBuffer

• VUID-vkCmdBeginQuery-queryPool-03225
If queryPool was created with a queryType of VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR and another query pool with a queryType VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR has been used within commandBuffer, its parent primary command buffer or secondary command buffer recorded within the same parent primary command buffer as commandBuffer, the performanceCounterMultipleQueryPools feature must be enabled
If `queryPool` was created with a `queryType` of `VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR`, this command must not be recorded in a command buffer that, either directly or through secondary command buffers, also contains a `vkCmdResetQueryPool` command affecting the same query.

### Valid Usage (Implicit)

- **VUID-vkCmdBeginQuery-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- **VUID-vkCmdBeginQuery-queryPool-parameter**
  `queryPool` must be a valid `VkQueryPool` handle.

- **VUID-vkCmdBeginQuery-flags-parameter**
  `flags` must be a valid combination of `VkQueryControlFlagBits` values.

- **VUID-vkCmdBeginQuery-commandBuffer-recording**
  `commandBuffer` must be in the recording state.

- **VUID-vkCmdBeginQuery-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, compute, decode, or encode operations.

- **VUID-vkCmdBeginQuery-commonparent**
  Both of `commandBuffer`, and `queryPool` must have been created, allocated, or retrieved from the same `VkDevice`.

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

### Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
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<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Secondary</td>
<td>Both</td>
<td>Both</td>
<td>Graphics Compute Decode Encode</td>
<td>Action State</td>
</tr>
</tbody>
</table>

To begin an indexed query, call:
// Provided by VK_EXT_transform_feedback

```c
void vkCmdBeginQueryIndexedEXT(
    VkCommandBuffer commandBuffer,
    VkQueryPool queryPool,
    uint32_t query,
    VkQueryControlFlags flags,
    uint32_t index);
```

- **commandBuffer** is the command buffer into which this command will be recorded.
- **queryPool** is the query pool that will manage the results of the query.
- **query** is the query index within the query pool that will contain the results.
- **flags** is a bitmask of `VkQueryControlFlagBits` specifying constraints on the types of queries that can be performed.
- **index** is the query type specific index. When the query type is `VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT` or `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT`, the index represents the vertex stream.

The `vkCmdBeginQueryIndexedEXT` command operates the same as the `vkCmdBeginQuery` command, except that it also accepts a query type specific `index` parameter.

This command defines an execution dependency between other query commands that reference the same query index.

The first **synchronization scope** includes all commands which reference the queries in `queryPool` indicated by `query` and `index` that occur earlier in submission order.

The second **synchronization scope** includes all commands which reference the queries in `queryPool` indicated by `query` and `index` that occur later in submission order.

The operation of this command happens after the first scope and happens before the second scope.

---

**Valid Usage**

- **VUID-vkCmdBeginQueryIndexedEXT-None-00807**
  All queries used by the command must be unavailable

- **VUID-vkCmdBeginQueryIndexedEXT-queryType-02804**
  The `queryType` used to create `queryPool` must not be `VK_QUERY_TYPE_TIMESTAMP`

- **VUID-vkCmdBeginQueryIndexedEXT-queryType-04728**
  The `queryType` used to create `queryPool` must not be `VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_KHR` or `VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIALIZATION_SIZE_KHR`

- **VUID-vkCmdBeginQueryIndexedEXT-queryType-06741**
  The `queryType` used to create `queryPool` must not be `VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SIZE_KHR` or `VK_QUERY_TYPE_ACCELERATION_STRUCTURE SERIALIALIZATION BOTTOM LEVEL POINTERS_KHR`
• VUID-vkCmdBeginQueryIndexedEXT-queryType-04729
The `queryType` used to create `queryPool` must not be `VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_NV`.

• VUID-vkCmdBeginQueryIndexedEXT-queryType-00800
If the `occlusionQueryPrecise` feature is not enabled, or the `queryType` used to create `queryPool` was not `VK_QUERY_TYPE_OCCLUSION`, flags must not contain `VK_QUERY_CONTROL_PRECISE_BIT`.

• VUID-vkCmdBeginQueryIndexedEXT-query-00802
`query` must be less than the number of queries in `queryPool`.

• VUID-vkCmdBeginQueryIndexedEXT-queryType-00803
If the `queryType` used to create `queryPool` was `VK_QUERY_TYPE_OCCLUSION`, the `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations.

• VUID-vkCmdBeginQueryIndexedEXT-queryType-00804
If the `queryType` used to create `queryPool` was `VK_QUERY_TYPE_PIPELINE_STATISTICS` and any of the `pipelineStatistics` indicate graphics operations, the `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations.

• VUID-vkCmdBeginQueryIndexedEXT-queryType-00805
If the `queryType` used to create `queryPool` was `VK_QUERY_TYPE_PIPELINE_STATISTICS` and any of the `pipelineStatistics` indicate compute operations, the `VkCommandPool` that `commandBuffer` was allocated from must support compute operations.

• VUID-vkCmdBeginQueryIndexedEXT-commandBuffer-01885
`commandBuffer` must not be a protected command buffer.

• VUID-vkCmdBeginQueryIndexedEXT-query-00808
If called within a render pass instance, the sum of `query` and the number of bits set in the current subpass's view mask must be less than or equal to the number of queries in `queryPool`.

• VUID-vkCmdBeginQueryIndexedEXT-queryType-07126
If the `queryType` used to create `queryPool` was `VK_QUERY_TYPE_RESULT_STATUS_ONLY_KHR`, then the `VkCommandPool` that `commandBuffer` was allocated from must have been created with a queue family index that supports result status queries, as indicated by `VkQueueFamilyQueryResultStatusPropertiesKHR::queryResultStatusSupport`.

• VUID-vkCmdBeginQueryIndexedEXT-None-07127
If there is a bound video session, then there must be no active queries.

• VUID-vkCmdBeginQueryIndexedEXT-queryType-07128
If the `queryType` used to create `queryPool` was `VK_QUERY_TYPE_RESULT_STATUS_ONLY_KHR` and there is a bound video session, then `queryPool` must have been created with a `VkVideoProfileInfoKHR` structure included in the `pNext` chain of `VkQueryPoolCreateInfo` identical to the one specified in `VkVideoSessionCreateInfoKHR::pVideoProfile` the bound video session was created with.

• VUID-vkCmdBeginQueryIndexedEXT-queryType-04862
If the `queryType` used to create `queryPool` was `VK_QUERY_TYPE_VIDEO_ENCODE_FEEDBACK_KHR`, then the `VkCommandPool` that `commandBuffer` was allocated from must support video encode operations.
If the queryType used to create queryPool was VK_QUERY_TYPE_VIDEO_ENCODE_FEEDBACK_KHR, then there must be a bound video session.

If the queryType used to create queryPool was VK_QUERY_TYPE_VIDEO_ENCODE_FEEDBACK_KHR and there is a bound video session, then queryPool must have been created with aVkVideoProfileInfoKHR structure included in the pNext chain of VkQueryPoolCreateInfo identical to the one specified in VkVideoSessionCreateInfoKHR::pVideoProfile the bound video session was created with.

If the queryType used to create queryPool was not VK_QUERY_TYPE_RESULT_STATUS_ONLY_KHR or VK_QUERY_TYPE_VIDEO_ENCODE_FEEDBACK_KHR, then there must be no bound video session.

If the queryPool was created with the same queryType as that of another active query within commandBuffer, then index must not match the index used for the active query.

If the queryType used to create queryPool was VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT the VkCommandPool that commandBuffer was allocated from must support graphics operations.

If the queryType used to create queryPool was VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT the index parameter must be less than VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackStreams.

If the queryType used to create queryPool was VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT the VkCommandPool that commandBuffer was allocated from must support graphics operations.

If the queryType used to create queryPool was VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT the index parameter must be less than VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackStreams.

If the queryType used to create queryPool was VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT and the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled, the index parameter must be zero.

If the queryType used to create queryPool was not VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT and not VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT, the index must be zero.

If the queryType used to create queryPool was VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT then primitivesGeneratedQuery must be enabled.

If the queryType used to create queryPool was VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT
then VkPhysicalDeviceTransformFeedbackPropertiesEXT::transformFeedbackQueries must be supported

- VUID-vkCmdBeginQueryIndexedEXT-queryType-07071
  The queryType used to create queryPool must not be VK_QUERY_TYPE_MESH_PRIMITIVES_GENERATED_EXT

- VUID-vkCmdBeginQueryIndexedEXT-queryPool-07289
  If queryPool was created with a queryType of VKQUERYTYPE_PERFORMANCE_QUERY_KHR, then the
  VkQueryPoolPerformanceCreateInfoKHR::queueFamilyIndex queryPool was created with
  must equal the queue family index of the VkCommandPool that commandBuffer was allocated from

- VUID-vkCmdBeginQueryIndexedEXT-queryPool-03223
  If queryPool was created with a queryType of VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR, the
  profiling lock must have been held before vkBeginCommandBuffer was called on commandBuffer

- VUID-vkCmdBeginQueryIndexedEXT-queryPool-03224
  If queryPool was created with a queryType of VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR and one
  of the counters used to create queryPool was
  VK_PERFORMANCE_COUNTER_SCOPE_COMMAND_BUFFER_KHR, the query begin must be the first
  recorded command in commandBuffer

- VUID-vkCmdBeginQueryIndexedEXT-queryPool-03225
  If queryPool was created with a queryType of VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR and one
  of the counters used to create queryPool was
  VK_PERFORMANCE_COUNTER_SCOPE_RENDER_PASS_KHR, the begin command must not be recorded
  within a render pass instance

- VUID-vkCmdBeginQueryIndexedEXT-queryPool-03226
  If queryPool was created with a queryType of VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR and another query pool with a queryType VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR has been used
  within commandBuffer, its parent primary command buffer or secondary command buffer recorded within the same parent primary command buffer as commandBuffer, the
  performanceCounterMultipleQueryPools feature must be enabled

- VUID-vkCmdBeginQueryIndexedEXT-None-02863
  If queryPool was created with a queryType of VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR, this
  command must not be recorded in a command buffer that, either directly or through
  secondary command buffers, also contains a vkCmdResetQueryPool command affecting the
  same query

---

**Valid Usage (Implicit)**

- VUID-vkCmdBeginQueryIndexedEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdBeginQueryIndexedEXT-queryPool-parameter
  queryPool must be a valid VkQueryPool handle

- VUID-vkCmdBeginQueryIndexedEXT-flags-parameter
flags must be a valid combination of VkQueryControlFlagBits values

- VUID-vkCmdBeginQueryIndexedEXT-commandBuffer-recording
  commandBuffer must be in the recording state
- VUID-vkCmdBeginQueryIndexedEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics, compute, decode, or encode operations
- VUID-vkCmdBeginQueryIndexedEXT-videocoding
  This command must only be called outside of a video coding scope
- VUID-vkCmdBeginQueryIndexedEXT-commonparent
  Both of commandBuffer, and queryPool must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
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<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics</td>
<td>Action State</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td>Compute</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Decode</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Encode</td>
<td></td>
</tr>
</tbody>
</table>

Bits which can be set in vkCmdBeginQuery::flags, specifying constraints on the types of queries that can be performed, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkQueryControlFlagBits {
    VK_QUERY_CONTROL_PRECISE_BIT = 0x00000001,
} VkQueryControlFlagBits;
```

- VK_QUERY_CONTROL_PRECISE_BIT specifies the precision of occlusion queries.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkQueryControlFlags;
```

VkQueryControlFlags is a bitmask type for setting a mask of zero or more VkQueryControlFlagBits.
To end a query after the set of desired drawing or dispatching commands is executed, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdEndQuery(
    VkCommandBuffer commandBuffer,
    VkQueryPool queryPool,
    uint32_t query);
```

- `commandBuffer` is the command buffer into which this command will be recorded.
- `queryPool` is the query pool that is managing the results of the query.
- `query` is the query index within the query pool where the result is stored.

The command completes the query in `queryPool` identified by `query`, and marks it as available.

This command defines an execution dependency between other query commands that reference the same query.

The first synchronization scope includes all commands which reference the queries in `queryPool` indicated by `query` that occur earlier in submission order.

The second synchronization scope includes only the operation of this command.

Calling `vkCmdEndQuery` is equivalent to calling `vkCmdEndQueryIndexedEXT` with the `index` parameter set to zero.

### Valid Usage

- VUID-vkCmdEndQuery-None-01923
  All queries used by the command must be active

- VUID-vkCmdEndQuery-query-00810
  query must be less than the number of queries in `queryPool`

- VUID-vkCmdEndQuery-commandBuffer-01886
  commandBuffer must not be a protected command buffer

- VUID-vkCmdEndQuery-query-00812
  If `vkCmdEndQuery` is called within a render pass instance, the sum of `query` and the number of bits set in the current subpass's view mask must be less than or equal to the number of queries in `queryPool`

- VUID-vkCmdEndQuery-queryPool-03227
  If `queryPool` was created with a `queryType` of `VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR` and one or more of the counters used to create `queryPool` was `VK_PERFORMANCE_COUNTER_SCOPE_COMMAND_BUFFER_KHR`, the `vkCmdEndQuery` must be the last recorded command in `commandBuffer`

- VUID-vkCmdEndQuery-queryPool-03228
  If `queryPool` was created with a `queryType` of `VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR` and one or more of the counters used to create `queryPool` was
The `vkCmdEndQuery` must not be recorded within a render pass instance.

- **VUID-vkCmdEndQuery-None-07007**
  If called within a subpass of a render pass instance, the corresponding `vkCmdBeginQuery` command must have been called previously within the same subpass.

- **VUID-vkCmdEndQuery-None-07008**
  If called outside of a render pass instance, the corresponding `vkCmdBeginQuery` command must have been called outside of a render pass instance.

### Valid Usage (Implicit)

- VUID-vkCmdEndQuery-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- VUID-vkCmdEndQuery-queryPool-parameter
  `queryPool` must be a valid `VkQueryPool` handle.

- VUID-vkCmdEndQuery-commandBuffer-recording
  `commandBuffer` must be in the recording state.

- VUID-vkCmdEndQuery-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, compute, decode, or encode operations.

- VUID-vkCmdEndQuery-commonparent
  Both of `commandBuffer`, and `queryPool` must have been created, allocated, or retrieved from the same `VkDevice`.

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

### Command Properties

<table>
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<td>Both</td>
<td>Both</td>
<td>Graphics Compute Decode Encode</td>
<td>Action State</td>
</tr>
</tbody>
</table>

To end an indexed query after the set of desired drawing or dispatching commands is recorded,
The command completes the query in `queryPool` identified by `query` and `index`, and marks it as available.

The `vkCmdEndQueryIndexedEXT` command operates the same as the `vkCmdEndQuery` command, except that it also accepts a query type specific `index` parameter.

This command defines an execution dependency between other query commands that reference the same query index.

The first synchronization scope includes all commands which reference the queries in `queryPool` indicated by `query` that occur earlier in submission order.

The second synchronization scope includes only the operation of this command.

### Valid Usage

- **VUID-vkCmdEndQueryIndexedEXT-None-02342**
  All queries used by the command must be active

- **VUID-vkCmdEndQueryIndexedEXT-query-02343**
  `query` must be less than the number of queries in `queryPool`

- **VUID-vkCmdEndQueryIndexedEXT-commandBuffer-02344**
  `commandBuffer` must not be a protected command buffer

- **VUID-vkCmdEndQueryIndexedEXT-query-02345**
  If `vkCmdEndQueryIndexedEXT` is called within a render pass instance, the sum of `query` and the number of bits set in the current subpass's view mask must be less than or equal to the number of queries in `queryPool`

- **VUID-vkCmdEndQueryIndexedEXT-queryType-06694**
  If the `queryType` used to create `queryPool` was `VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT` or `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT`, the `index` parameter must be less than `VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackStreams`

- **VUID-vkCmdEndQueryIndexedEXT-queryType-06695**

```c
// Provided by VK_EXT_transform_feedback
void vkCmdEndQueryIndexedEXT(
    VkCommandBuffer commandBuffer,
    VkQueryPool queryPool,
    uint32_t query,
    uint32_t index);
```
If the `queryType` used to create `queryPool` was not `VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT` and not `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT`, the index must be zero

- VUID-vkCmdEndQueryIndexedEXT-queryType-06696
  If the `queryType` used to create `queryPool` was `VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT` or `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT`, index must equal the index used to begin the query

- VUID-vkCmdEndQueryIndexedEXT-None-07007
  If called within a subpass of a render pass instance, the corresponding `vkCmdBeginQuery*` command must have been called previously within the same subpass

- VUID-vkCmdEndQueryIndexedEXT-None-07008
  If called outside of a render pass instance, the corresponding `vkCmdBeginQuery*` command must have been called outside of a render pass instance

**Valid Usage (Implicit)**

- VUID-vkCmdEndQueryIndexedEXT-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdEndQueryIndexedEXT-queryPool-parameter
  `queryPool` must be a valid `VkQueryPool` handle

- VUID-vkCmdEndQueryIndexedEXT-commandBuffer-recording
  `commandBuffer` must be in the recording state

- VUID-vkCmdEndQueryIndexedEXT-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, compute, decode, or encode operations

- VUID-vkCmdEndQueryIndexedEXT-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdEndQueryIndexedEXT-commonparent
  Both of `commandBuffer`, and `queryPool` must have been created, allocated, or retrieved from the same `VkDevice`

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized
An application can retrieve results either by requesting they be written into application-provided memory, or by requesting they be copied into a `VkBuffer`. In either case, the layout in memory is defined as follows:

- The first query's result is written starting at the first byte requested by the command, and each subsequent query's result begins `stride` bytes later.

- Occlusion queries, pipeline statistics queries, transform feedback queries, primitives generated queries, mesh shader queries, video encode feedback queries, and timestamp queries store results in a tightly packed array of unsigned integers, either 32- or 64-bits as requested by the command, storing the numerical results and, if requested, the availability status.

- Performance queries store results in a tightly packed array whose type is determined by the `unit` member of the corresponding `VkPerformanceCounterKHR`.

- If `VK_QUERY_RESULT_WITH_AVAILABILITY_BIT` is used, the final element of each query's result is an integer indicating whether the query's result is available, with any non-zero value indicating that it is available.

- If `VK_QUERY_RESULT_WITH_STATUS_BIT_KHR` is used, the final element of each query's result is an integer value indicating that status of the query result. Positive values indicate success, negative values indicate failure, and 0 indicates that the result is not yet available. Specific error codes are encoded in the `VkQueryResultStatusKHR` enumeration.

- Occlusion queries write one integer value - the number of samples passed. Pipeline statistics queries write one integer value for each bit that is enabled in the `pipelineStatistics` when the pool is created, and the statistics values are written in bit order starting from the least significant bit. Timestamp queries write one integer value. Performance queries write one `VkPerformanceCounterResultKHR` value for each `VkPerformanceCounterKHR` in the query. Transform feedback queries write two integers; the first integer is the number of primitives successfully written to the corresponding transform feedback buffer and the second is the number of primitives output to the vertex stream, regardless of whether they were successfully captured or not. In other words, if the transform feedback buffer was sized too small for the number of primitives output by the vertex stream, the first integer represents the number of primitives actually written and the second is the number that would have been written if all the transform feedback buffers associated with that vertex stream were large enough. Primitives generated queries write the number of primitives output to the vertex stream, regardless of whether transform feedback is active or not, or whether they were successfully captured by transform feedback or not. This is identical to the second integer of the transform feedback queries if transform feedback is active. Mesh shader queries write a single integer. Video
encode feedback queries write one or more integer values for each bit that is enabled in
\texttt{VkQueryPoolVideoEncodeFeedbackCreateInfoKHR::encodeFeedbackFlags} when the pool is
created, and the feedback values are written in bit order starting from the least significant bit,
as described here.

- If more than one query is retrieved and \texttt{stride} is not at least as large as the size of the array of
values corresponding to a single query, the values written to memory are undefined.

To retrieve status and results for a set of queries, call:

\begin{verbatim}
// Provided by VK_VERSION_1_0
VkResult vkGetQueryPoolResults(
    VkDevice device, // Logical device that owns the query pool.
    VkQueryPool queryPool, // Query pool managing the queries containing the desired results.
    uint32_t firstQuery, // Initial query index.
    uint32_t queryCount, // Number of queries to read.
    size_t dataSize, // Size in bytes of the buffer pointed to by pData.
    void* pData, // Pointer to a user-allocated buffer where the results will be written.
    VkDeviceSize stride, // Stride in bytes between results for individual queries within pData.
    VkQueryResultFlags flags // Bitmap of VkQueryResultFlagBits specifying how and when results are returned.
);
\end{verbatim}

- \texttt{device} is the logical device that owns the query pool.
- \texttt{queryPool} is the query pool managing the queries containing the desired results.
- \texttt{firstQuery} is the initial query index.
- \texttt{queryCount} is the number of queries to read.
- \texttt{dataSize} is the size in bytes of the buffer pointed to by \texttt{pData}.
- \texttt{pData} is a pointer to a user-allocated buffer where the results will be written.
- \texttt{stride} is the stride in bytes between results for individual queries within \texttt{pData}.
- \texttt{flags} is a bitmask of \texttt{VkQueryResultFlagBits} specifying how and when results are returned.

Any results written for a query are written according to a layout dependent on the query type.

If no bits are set in \texttt{flags}, and all requested queries are in the available state, results are written as
an array of 32-bit unsigned integer values. Behavior when not all queries are available is described
below.

If \texttt{VK_QUERY_RESULT_WITH_AVAILABILITY_BIT} is set, results for all queries in \texttt{queryPool} identified by
\texttt{firstQuery} and \texttt{queryCount} are copied to \texttt{pData}, along with an extra availability or status value
written directly after the results of each query and interpreted as an unsigned integer. A value of
zero indicates that the results are not yet available, otherwise the query is complete and results are
available. The size of the availability or status values is 64 bits if \texttt{VK_QUERY_RESULT_64_BIT} is set in
\texttt{flags}. Otherwise, it is 32 bits.

If \texttt{VK_QUERY_RESULT_WITH_STATUS_BIT_KHR} is set, results for all queries in \texttt{queryPool} identified by
\texttt{firstQuery} and \texttt{queryCount} are copied to \texttt{pData}, along with an extra status value written directly after
the results of each query and interpreted as a signed integer. A value of zero indicates that the
results are not yet available. Positive values indicate that the operations within the query completed successfully, and the query results are valid. Negative values indicate that the operations within the query completed unsuccessfully.

_vkQueryResultStatusKHR_ defines specific meaning for values returned here, though implementations are free to return other values.

### Note

If `VK_QUERY_RESULT_WITH_AVAILABILITY_BIT` or `VK_QUERY_RESULT_WITH_STATUS_BIT_KHR` is set, the layout of data in the buffer is a `(result,availability)` or `(result,status)` pair for each query returned, and `stride` is the stride between each pair.

Results for any available query written by this command are final and represent the final result of the query. If `VK_QUERY_RESULT_PARTIAL_BIT` is set, then for any query that is unavailable, an intermediate result between zero and the final result value is written for that query. Otherwise, any result written by this command is undefined.

If `VK_QUERY_RESULT_64_BIT` is set, results and, if returned, availability or status values for all queries are written as an array of 64-bit values. If the `queryPool` was created with `VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR`, results for each query are written as an array of the type indicated by `VkPerformanceCounterKHR::storage` for the counter being queried. Otherwise, results and availability or status values are written as an array of 32-bit values. If an unsigned integer query's value overflows the result type, the value **may** either wrap or saturate. If a signed integer query's value overflows the result type, the value is undefined. If a floating point query's value is not representable as the result type, the value is undefined.

If `VK_QUERY_RESULT_WAIT_BIT` is set, this command defines an execution dependency with any earlier commands that writes one of the identified queries. The first synchronization scope includes all instances of `vkCmdEndQuery`, `vkCmdEndQueryIndexedEXT`, `vkCmdWriteTimestamp2`, and `vkCmdWriteTimestamp` that reference any query in `queryPool` indicated by `firstQuery` and `queryCount`. The second synchronization scope includes the host operations of this command.

If `VK_QUERY_RESULT_WAIT_BIT` is not set, `vkGetQueryPoolResults` may return `VK_NOT_READY` if there are queries in the unavailable state.

### Note

Applications **must** take care to ensure that use of the `VK_QUERY_RESULT_WAIT_BIT` bit has the desired effect.

For example, if a query has been used previously and a command buffer records the commands `vkCmdResetQueryPool`, `vkCmdBeginQuery`, and `vkCmdEndQuery` for that query, then the query will remain in the available state until `vkResetQueryPool` is called or the `vkCmdResetQueryPool` command executes on a queue. Applications **can** use fences or events to ensure that a query has already been reset before checking for its results or availability status. Otherwise, a stale value could be returned from a previous use of the query.

The above also applies when `VK_QUERY_RESULT_WAIT_BIT` is used in combination with `VK_QUERY_RESULT_WITH_AVAILABILITY_BIT`. In this case, the returned availability
status may reflect the result of a previous use of the query unless \texttt{vkResetQueryPool} is called or the \texttt{vkCmdResetQueryPool} command has been executed since the last use of the query.

A similar situation can arise with the \texttt{VK_QUERY_RESULT_WITH_STATUS_BIT_KHR} flag.

\textit{Note}

Applications can double-buffer query pool usage, with a pool per frame, and reset queries at the end of the frame in which they are read.

\begin{itemize}
\item \textbf{VUID-vkGetQueryPoolResults-firstQuery-00813}  
  \textit{firstQuery} must be less than the number of queries in \textit{queryPool}.

\item \textbf{VUID-vkGetQueryPoolResults-flags-02828}  
  If \textit{VK_QUERY_RESULT_64_BIT} is not set in \textit{flags} and the \textit{queryType} used to create \textit{queryPool} was not \textit{VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR}, then \textit{pData} and \textit{stride} must be multiples of 4.

\item \textbf{VUID-vkGetQueryPoolResults-flags-00815}  
  If \textit{VK_QUERY_RESULT_64_BIT} is set in \textit{flags} then \textit{pData} and \textit{stride} must be multiples of 8.

\item \textbf{VUID-vkGetQueryPoolResults-stride-08993}  
  If \textit{VK_QUERY_RESULT_WITH_AVAILABILITY_BIT} is set, \textit{stride} must be large enough to contain the unsigned integer representing availability or status in addition to the query result.

\item \textbf{VUID-vkGetQueryPoolResults-queryType-03229}  
  If the \textit{queryType} used to create \textit{queryPool} was \textit{VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR}, then \textit{pData} and \textit{stride} must be multiples of the size of \texttt{VkPerformanceCounterResultKHR}.

\item \textbf{VUID-vkGetQueryPoolResults-queryType-04519}  
  If the \textit{queryType} used to create \textit{queryPool} was \textit{VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR}, then \textit{stride} must be large enough to contain the \texttt{VkQueryPoolPerformanceCreateInfoKHR} ::\texttt{counterIndexCount} used to create \textit{queryPool} times the size of \texttt{VkPerformanceCounterResultKHR}.

\item \textbf{VUID-vkGetQueryPoolResults-firstQuery-00816}  
  The sum of \textit{firstQuery} and \textit{queryCount} must be less than or equal to the number of queries in \textit{queryPool}.

\item \textbf{VUID-vkGetQueryPoolResults-dataSize-00817}  
  \textit{dataSize} must be large enough to contain the result of each query, as described here.

\item \textbf{VUID-vkGetQueryPoolResults-queryType-00818}  
  If the \textit{queryType} used to create \textit{queryPool} was \textit{VK_QUERY_TYPE_TIMESTAMP}, \textit{flags} must not contain \textit{VK_QUERY_RESULT_PARTIAL_BIT}.

\item \textbf{VUID-vkGetQueryPoolResults-queryType-03230}  
  If the \textit{queryType} used to create \textit{queryPool} was \textit{VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR}, \textit{flags} must not contain \textit{VK_QUERY_RESULT_WITH_AVAILABILITY_BIT}, \textit{VK_QUERY_RESULT_WITH_STATUS_BIT_KHR}, \textit{VK_QUERY_RESULT_PARTIAL_BIT}, or \textit{VK_QUERY_RESULT_64_BIT}.
\end{itemize}
If the `queryType` used to create `queryPool` was `VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR`, the `queryPool` must have been recorded once for each pass as retrieved via a call to `vkGetPhysicalDeviceQueueFamilyPerformanceQueryPassesKHR`.

If the `queryType` used to create `queryPool` was `VK_QUERY_TYPE_RESULT_STATUS_ONLY_KHR`, then `flags` must include `VK_QUERY_RESULT_WITH_STATUS_BIT_KHR`.

If `flags` includes `VK_QUERY_RESULT_WITH_STATUS_BIT_KHR`, then it must not include `VK_QUERY_RESULT_WITH_AVAILABILITY_BIT`.

**Valid Usage (Implicit)**

- `device` must be a valid `VkDevice` handle
- `queryPool` must be a valid `VkQueryPool` handle
- `pData` must be a valid pointer to an array of `dataSize` bytes
- `flags` must be a valid combination of `VkQueryResultFlagBits` values
- `dataSize` must be greater than 0
- `queryPool` must have been created, allocated, or retrieved from `device`

**Return Codes**

**Success**

- `VK_SUCCESS`
- `VK_NOT_READY`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_DEVICE_LOST`

Bits which can be set in `vkGetQueryPoolResults::flags` and `vkCmdCopyQueryPoolResults::flags`, specifying how and when results are returned, are:

```cpp
// Provided by VK_VERSION_1_0
```
typedef enum VkQueryResultFlagBits {
    VK_QUERY_RESULT_64_BIT = 0x00000001,
    VK_QUERY_RESULT_WAIT_BIT = 0x00000002,
    VK_QUERY_RESULT_WITH_AVAILABILITY_BIT = 0x00000004,
    VK_QUERY_RESULT_PARTIAL_BIT = 0x00000008,
    // Provided by VK_KHR_video_queue
    VK_QUERY_RESULT_WITH_STATUS_BIT_KHR = 0x00000010,
} VkQueryResultFlagBits;

- **VK_QUERY_RESULT_64_BIT** specifies the results will be written as an array of 64-bit unsigned integer values. If this bit is not set, the results will be written as an array of 32-bit unsigned integer values.

- **VK_QUERY_RESULT_WAIT_BIT** specifies that Vulkan will wait for each query’s status to become available before retrieving its results.

- **VK_QUERY_RESULT_WITH_AVAILABILITY_BIT** specifies that the availability status accompanies the results.

- **VK_QUERY_RESULT_PARTIAL_BIT** specifies that returning partial results is acceptable.

- **VK_QUERY_RESULT_WITH_STATUS_BIT_KHR** specifies that the last value returned in the query is a VkQueryResultStatusKHR value. See result status query for information on how an application can determine whether the use of this flag bit is supported.

// Provided by VK_VERSION_1_0
typedef VkFlags VkQueryResultFlags;

**VkQueryResultFlags** is a bitmask type for setting a mask of zero or more **VkQueryResultFlagBits**.

Specific status codes that can be returned from a query are:

// Provided by VK_KHR_video_queue
typedef enum VkQueryResultStatusKHR {
    VK_QUERY_RESULT_STATUS_ERROR_KHR = -1,
    VK_QUERY_RESULT_STATUS_NOT_READY_KHR = 0,
    VK_QUERY_RESULT_STATUS_COMPLETE_KHR = 1,
    // Provided by VK_KHR_video_encode_queue
    VK_QUERY_RESULT_STATUS_INSUFFICIENT_BITSTREAM_BUFFER_RANGE_KHR = -1000299000,
} VkQueryResultStatusKHR;

- **VK_QUERY_RESULT_STATUS_NOT_READY_KHR** specifies that the query result is not yet available.

- **VK_QUERY_RESULT_STATUS_ERROR_KHR** specifies that operations did not complete successfully.

- **VK_QUERY_RESULT_STATUS_COMPLETE_KHR** specifies that operations completed successfully and the query result is available.

- **VK_QUERY_RESULT_STATUS_INSUFFICIENT_BITSTREAM_BUFFER_RANGE_KHR** indicates that a video encode operation did not complete successfully due to the destination video bitstream buffer range not being sufficiently large to fit the encoded bitstream data.
To copy query statuses and numerical results directly to buffer memory, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdCopyQueryPoolResults(
    VkCommandBuffer commandBuffer,
    VkQueryPool queryPool,
    uint32_t firstQuery,
    uint32_t queryCount,
    VkBuffer dstBuffer,
    VkDeviceSize dstOffset,
    VkDeviceSize stride,
    VkQueryResultFlags flags);
```

- `commandBuffer` is the command buffer into which this command will be recorded.
- `queryPool` is the query pool managing the queries containing the desired results.
- `firstQuery` is the initial query index.
- `queryCount` is the number of queries. `firstQuery` and `queryCount` together define a range of queries.
- `dstBuffer` is a `VkBuffer` object that will receive the results of the copy command.
- `dstOffset` is an offset into `dstBuffer`.
- `stride` is the stride in bytes between results for individual queries within `dstBuffer`. The required size of the backing memory for `dstBuffer` is determined as described above for `vkGetQueryPoolResults`.
- `flags` is a bitmask of `VkQueryResultFlagBits` specifying how and when results are returned.

Any results written for a query are written according to a layout dependent on the query type.

Results for any query in `queryPool` identified by `firstQuery` and `queryCount` that is available are copied to `dstBuffer`.

If `VK_QUERY_RESULT_WITH_AVAILABILITY_BIT` is set, results for all queries in `queryPool` identified by `firstQuery` and `queryCount` are copied to `dstBuffer`, along with an extra availability value written directly after the results of each query and interpreted as an unsigned integer. A value of zero indicates that the results are not yet available, otherwise the query is complete and results are available.

If `VK_QUERY_RESULT_WITH_STATUS_BIT_KHR` is set, results for all queries in `queryPool` identified by `firstQuery` and `queryCount` are copied to `dstBuffer`, along with an extra status value written directly after the results of each query and interpreted as a signed integer. A value of zero indicates that the results are not yet available. Positive values indicate that the operations within the query completed successfully, and the query results are valid. Negative values indicate that the operations within the query completed unsuccessfully.

`VkQueryResultStatusKHR` defines specific meaning for values returned here, though implementations are free to return other values.
Results for any available query written by this command are final and represent the final result of the query. If `VK_QUERY_RESULT_PARTIAL_BIT` is set, then for any query that is unavailable, an intermediate result between zero and the final result value is written for that query. Otherwise, any result written by this command is undefined.

If `VK_QUERY_RESULT_64_BIT` is set, results and availability or status values for all queries are written as an array of 64-bit values. If the `queryPool` was created with `VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR`, results for each query are written as an array of the type indicated by `VkPerformanceCounterKHR::storage` for the counter being queried. Otherwise, results and availability or status values are written as an array of 32-bit values. If an unsigned integer query’s value overflows the result type, the value may either wrap or saturate. If a signed integer query’s value overflows the result type, the value is undefined. If a floating point query’s value is not representable as the result type, the value is undefined.

This command defines an execution dependency between other query commands that reference the same query.

The first synchronization scope includes all commands which reference the queries in `queryPool` indicated by `query` that occur earlier in submission order. If `flags` does not include `VK_QUERY_RESULT_WAIT_BIT`, `vkCmdEndQueryIndexedEXT`, `vkCmdWriteTimestamp2`, `vkCmdEndQuery`, and `vkCmdWriteTimestamp` are excluded from this scope.

The second synchronization scope includes all commands which reference the queries in `queryPool` indicated by `query` that occur later in submission order.

The operation of this command happens after the first scope and happens before the second scope.

`vkCmdCopyQueryPoolResults` is considered to be a transfer operation, and its writes to buffer memory must be synchronized using `VK_PIPELINE_STAGE_TRANSFER_BIT` and `VK_ACCESS_TRANSFER_WRITE_BIT` before using the results.

### Valid Usage

- **VUID-vkCmdCopyQueryPoolResults-dstOffset-00819**
  
  `dstOffset` must be less than the size of `dstBuffer`

- **VUID-vkCmdCopyQueryPoolResults-firstQuery-00820**
  
  `firstQuery` must be less than the number of queries in `queryPool`

- **VUID-vkCmdCopyQueryPoolResults-firstQuery-00821**
  
  The sum of `firstQuery` and `queryCount` must be less than or equal to the number of queries in `queryPool`

- **VUID-vkCmdCopyQueryPoolResults-flags-00822**
  
  If `VK_QUERY_RESULT_64_BIT` is not set in `flags` then `dstOffset` and `stride` must be multiples of 4

- **VUID-vkCmdCopyQueryPoolResults-flags-00823**
  
  If `VK_QUERY_RESULT_64_BIT` is set in `flags` then `dstOffset` and `stride` must be multiples of 8

- **VUID-vkCmdCopyQueryPoolResults-dstBuffer-00824**
  
  `dstBuffer` must have enough storage, from `dstOffset`, to contain the result of each query,
as described here

- VUID-vkCmdCopyQueryPoolResults-dstBuffer-00825
dstBuffer must have been created with VK_BUFFER_USAGE_TRANSFER_DST_BIT usage flag

- VUID-vkCmdCopyQueryPoolResults-dstBuffer-00826
If dstBuffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdCopyQueryPoolResults-queryType-00827
If the queryType used to create queryPool was VK_QUERY_TYPE_TIMESTAMP, flags must not contain VK_QUERY_RESULT_PARTIAL_BIT

- VUID-vkCmdCopyQueryPoolResults-queryType-03232
If the queryType used to create queryPool was VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR, VkPhysicalDevicePerformanceQueryPropertiesKHR::allowCommandBufferQueryCopies must be VK_TRUE

- VUID-vkCmdCopyQueryPoolResults-queryType-03233
If the queryType used to create queryPool was VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR, flags must not contain VK_QUERY_RESULT_WITH_AVAILABILITY_BIT, VK_QUERY_RESULT_WITH_STATUS_BIT_KHR, VK_QUERY_RESULT_PARTIAL_BIT, or VK_QUERY_RESULT_64_BIT

- VUID-vkCmdCopyQueryPoolResults-queryType-03234
If the queryType used to create queryPool was VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR, the queryPool must have been submitted once for each pass as retrieved via a call to vkGetPhysicalDeviceQueueFamilyPerformanceQueryPassesKHR

- VUID-vkCmdCopyQueryPoolResults-queryType-02734
vkCmdCopyQueryPoolResults must not be called if the queryType used to create queryPool was VK_QUERY_TYPE_PERFORMANCE_QUERY_INTEL

- VUID-vkCmdCopyQueryPoolResults-queryType-06901
If the queryType used to create queryPool was VK_QUERY_TYPE_RESULT_STATUS_ONLY_KHR, then flags must include VK_QUERY_RESULT_WITH_STATUS_BIT_KHR

- VUID-vkCmdCopyQueryPoolResults-flags-06902
If flags includes VK_QUERY_RESULT_WITH_STATUS_BIT_KHR, then it must not include VK_QUERY_RESULT_WITH_AVAILABILITY_BIT

- VUID-vkCmdCopyQueryPoolResults-None-07429
All queries used by the command must not be active

- VUID-vkCmdCopyQueryPoolResults-None-08752
All queries used by the command must have been made available by prior executed commands

**Valid Usage (Implicit)**

- VUID-vkCmdCopyQueryPoolResults-commandBuffer-parameter
commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdCopyQueryPoolResults-queryPool-parameter
**queryPool** must be a valid `VkQueryPool` handle

- VUID-vkCmdCopyQueryPoolResults-dstBuffer-parameter
dstBuffer must be a valid `VkBuffer` handle

- VUID-vkCmdCopyQueryPoolResults-flags-parameter
flags must be a valid combination of `VkQueryResultFlagBits` values

- VUID-vkCmdCopyQueryPoolResults-commandBuffer-recording
commandBuffer must be in the recording state

- VUID-vkCmdCopyQueryPoolResults-commandBuffer-cmdpool
The `VkCommandPool` that commandBuffer was allocated from must support graphics, or compute operations

- VUID-vkCmdCopyQueryPoolResults-renderpass
This command must only be called outside of a render pass instance

- VUID-vkCmdCopyQueryPoolResults-videocoding
This command must only be called outside of a video coding scope

- VUID-vkCmdCopyQueryPoolResults-commonparent
Each of commandBuffer, dstBuffer, and queryPool must have been created, allocated, or retrieved from the same `VkDevice`

---

**Host Synchronization**

- Host access to commandBuffer must be externally synchronized
- Host access to the `VkCommandPool` that commandBuffer was allocated from must be externally synchronized

---

**Command Properties**

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Rendering operations such as clears, MSAA resolves, attachment load/store operations, and blits may count towards the results of queries. This behavior is implementation-dependent and may vary depending on the path used within an implementation. For example, some implementations have several types of clears, some of which may include vertices and some not.

### 18.3. Occlusion Queries

Occlusion queries track the number of samples that pass the per-fragment tests for a set of drawing commands. As such, occlusion queries are only available on queue families supporting graphics operations. The application can then use these results to inform future rendering decisions.
occlusion query is begun and ended by calling `vkCmdBeginQuery` and `vkCmdEndQuery`, respectively. When an occlusion query begins, the count of passing samples always starts at zero. For each drawing command, the count is incremented as described in Sample Counting. If `flags` does not contain `VK_QUERY_CONTROL_PRECISE_BIT` an implementation may generate any non-zero result value for the query if the count of passing samples is non-zero.

**Note**

Not setting `VK_QUERY_CONTROL_PRECISE_BIT` mode may be more efficient on some implementations, and should be used where it is sufficient to know a boolean result on whether any samples passed the per-fragment tests. In this case, some implementations may only return zero or one, indifferent to the actual number of samples passing the per-fragment tests.

Setting `VK_QUERY_CONTROL_PRECISE_BIT` does not guarantee that different implementations return the same number of samples in an occlusion query. Some implementations may kill fragments in the pre-rasterization shader stage, and these killed fragments do not contribute to the final result of the query. It is possible that some implementations generate a zero result value for the query, while others generate a non-zero value.

When an occlusion query finishes, the result for that query is marked as available. The application can then either copy the result to a buffer (via `vkCmdCopyQueryPoolResults`) or request it be put into host memory (via `vkGetQueryPoolResults`).

**Note**

If occluding geometry is not drawn first, samples can pass the depth test, but still not be visible in a final image.

18.4. Pipeline Statistics Queries

Pipeline statistics queries allow the application to sample a specified set of `VkPipeline` counters. These counters are accumulated by Vulkan for a set of either drawing or dispatching commands while a pipeline statistics query is active. As such, pipeline statistics queries are available on queue families supporting either graphics or compute operations. The availability of pipeline statistics queries is indicated by the `pipelineStatisticsQuery` member of the `VkPhysicalDeviceFeatures` object (see `vkGetPhysicalDeviceFeatures` and `vkCreateDevice` for detecting and requesting this query type on a `VkDevice`).

A pipeline statistics query is begun and ended by calling `vkCmdBeginQuery` and `vkCmdEndQuery`, respectively. When a pipeline statistics query begins, all statistics counters are set to zero. While the query is active, the pipeline type determines which set of statistics are available, but these must be configured on the query pool when it is created. If a statistic counter is issued on a command buffer that does not support the corresponding operation, the value of that counter is undefined after the query has been made available. At least one statistic counter relevant to the operations supported on the recording command buffer must be enabled.

Bits which can be set in `VkQueryPoolCreateInfo::pipelineStatistics` for query pools and in
VkCommandBufferInheritanceInfo::pipelineStatistics for secondary command buffers, individually enabling pipeline statistics counters, are:

```cpp
// Provided by VK_VERSION_1_0
typedef enum VkQueryPipelineStatisticFlagBits {
    VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_VERTICES_BIT = 0x00000001,
    VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_PRIMITIVES_BIT = 0x00000002,
    VK_QUERY_PIPELINE_STATISTIC_VERTEX_SHADER_INVOCATIONS_BIT = 0x00000004,
    VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_INVOCATIONS_BIT = 0x00000008,
    VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_PRIMITIVES_BIT = 0x00000010,
    VK_QUERY_PIPELINE_STATISTIC_CLIPPING_INVOCATIONS_BIT = 0x00000020,
    VK_QUERY_PIPELINE_STATISTIC_CLIPPING_PRIMITIVES_BIT = 0x00000040,
    VK_QUERY_PIPELINE_STATISTIC_FRAGMENT_SHADER_INVOCATIONS_BIT = 0x00000080,
    VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_CONTROL_SHADER_PATCHES_BIT = 0x00000100,
    VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_EVALUATION_SHADER_INVOCATIONS_BIT = 0x00000200,
    VKQUERY_PIPELINE_STATISTIC_COMPUTE_SHADER_INVOCATIONS_BIT = 0x00000400,
    // Provided by VK_EXT_mesh_shader
    VK_QUERY_PIPELINE_STATISTIC_TASK_SHADER_INVOCATIONS_BIT_EXT = 0x00000800,
    // Provided by VK_EXT_mesh_shader
    VK_QUERY_PIPELINE_STATISTIC_MESH_SHADER_INVOCATIONS_BIT_EXT = 0x00001000,
    // Provided by VK_HUAWEI_cluster_culling_shader
    VK_QUERY_PIPELINE_STATISTIC_CLUSTER_CULLING_SHADER_INVOCATIONS_BIT_HUAWEI = 0x00002000,
} VkQueryPipelineStatisticFlagBits;
```

- **VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_VERTICES_BIT** specifies that queries managed by the pool will count the number of vertices processed by the **input assembly** stage. Vertices corresponding to incomplete primitives **may** contribute to the count.

- **VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_PRIMITIVES_BIT** specifies that queries managed by the pool will count the number of primitives processed by the **input assembly** stage. If primitive restart is enabled, restarting the primitive topology has no effect on the count. Incomplete primitives **may** be counted.

- **VK_QUERY_PIPELINE_STATISTIC_VERTEX_SHADER_INVOCATIONS_BIT** specifies that queries managed by the pool will count the number of vertex shader invocations. This counter’s value is incremented each time a vertex shader is **invoked**.

- **VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_INVOCATIONS_BIT** specifies that queries managed by the pool will count the number of geometry shader invocations. This counter’s value is incremented each time a geometry shader is **invoked**. In the case of **instanced geometry shaders**, the geometry shader invocations count is incremented for each separate instanced invocation.

- **VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_PRIMITIVES_BIT** specifies that queries managed by the pool will count the number of primitives generated by geometry shader invocations. The counter’s value is incremented each time the geometry shader emits a primitive. Restarting primitive topology using the SPIR-V instructions **OpEndPrimitive** or **OpEndStreamPrimitive** has no effect on the geometry shader output primitives count.
• **VK_QUERY_PIPELINE_STATISTIC_CLIPPING_INVOCATIONS_BIT** specifies that queries managed by the pool will count the number of primitives processed by the Primitive Clipping stage of the pipeline. The counter’s value is incremented each time a primitive reaches the primitive clipping stage.

• **VK_QUERY_PIPELINE_STATISTIC_CLIPPING_PRIMITIVES_BIT** specifies that queries managed by the pool will count the number of primitives output by the Primitive Clipping stage of the pipeline. The counter’s value is incremented each time a primitive passes the primitive clipping stage. The actual number of primitives output by the primitive clipping stage for a particular input primitive is implementation-dependent but **must** satisfy the following conditions:
  ◦ If at least one vertex of the input primitive lies inside the clipping volume, the counter is incremented by one or more.
  ◦ Otherwise, the counter is incremented by zero or more.

• **VK_QUERY_PIPELINE_STATISTIC_FRAGMENT_SHADER_INVOCATIONS_BIT** specifies that queries managed by the pool will count the number of fragment shader invocations. The counter’s value is incremented each time the fragment shader is **invoked**.

• **VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_CONTROL_SHADER_PATCHES_BIT** specifies that queries managed by the pool will count the number of patches processed by the tessellation control shader. The counter’s value is incremented once for each patch for which a tessellation control shader is **invoked**.

• **VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_EVALUATION_SHADER_INVOCATIONS_BIT** specifies that queries managed by the pool will count the number of invocations of the tessellation evaluation shader. The counter’s value is incremented each time the tessellation evaluation shader is **invoked**.

• **VK_QUERY_PIPELINE_STATISTIC_COMPUTE_SHADER_INVOCATIONS_BIT** specifies that queries managed by the pool will count the number of compute shader invocations. The counter’s value is incremented every time the compute shader is invoked. Implementations **may** skip the execution of certain compute shader invocations or execute additional compute shader invocations for implementation-dependent reasons as long as the results of rendering otherwise remain unchanged.

• **VK_QUERY_PIPELINE_STATISTIC_TASK_SHADER_INVOCATIONS_BIT_EXT** specifies that queries managed by the pool will count the number of task shader invocations. The counter’s value is incremented every time the task shader is invoked.

• **VK_QUERY_PIPELINE_STATISTIC_MESH_SHADER_INVOCATIONS_BIT_EXT** specifies that queries managed by the pool will count the number of mesh shader invocations. The counter’s value is incremented every time the mesh shader is invoked.

These values are intended to measure relative statistics on one implementation. Various device architectures will count these values differently. Any or all counters **may** be affected by the issues described in **Query Operation**.

This counting difference is especially true if the pipeline contains mesh or task shaders, which may affect several of the counters in unexpected ways.
For example, tile-based rendering devices may need to replay the scene multiple times, affecting some of the counts.

If a pipeline has rasterizerDiscardEnable enabled, implementations may discard primitives after the final pre-rasterization shader stage. As a result, if rasterizerDiscardEnable is enabled, the clipping input and output primitives counters may not be incremented.

When a pipeline statistics query finishes, the result for that query is marked as available. The application can copy the result to a buffer (via vkCmdCopyQueryPoolResults), or request it be put into host memory (via vkGetQueryPoolResults).

```
// Provided by VK_VERSION_1_0
typedef VkFlags VkQueryPipelineStatisticFlags;
```

VkQueryPipelineStatisticFlags is a bitmask type for setting a mask of zero or more VkQueryPipelineStatisticFlagBits.

### 18.5. Timestamp Queries

Timestamps provide applications with a mechanism for timing the execution of commands. A timestamp is an integer value generated by the VkPhysicalDevice. Unlike other queries, timestamps do not operate over a range, and so do not use vkCmdBeginQuery or vkCmdEndQuery. The mechanism is built around a set of commands that allow the application to tell the VkPhysicalDevice to write timestamp values to a query pool and then either read timestamp values on the host (using vkGetQueryPoolResults) or copy timestamp values to a VkBuffer (using vkCmdCopyQueryPoolResults). The application can then compute differences between timestamps to determine execution time.

The number of valid bits in a timestamp value is determined by the VkQueueFamilyProperties::timestampValidBits property of the queue on which the timestamp is written. Timestamps are supported on any queue which reports a non-zero value for timestampValidBits via vkGetPhysicalDeviceQueueFamilyProperties. If the timestampComputeAndGraphics limit is VK_TRUE, timestamps are supported by every queue family that supports either graphics or compute operations (see VkQueueFamilyProperties).

The number of nanoseconds it takes for a timestamp value to be incremented by 1 can be obtained from VkPhysicalDeviceLimits::timestampPeriod after a call to vkGetPhysicalDeviceProperties.

To request a timestamp and write the value to memory, call:

```
// Provided by VK_VERSION_1_3
void vkCmdWriteTimestamp2(
    VkCommandBuffer
    commandBuffer,
    VkPipelineStageFlags2
    stage,
    VkQueryPool
    queryPool,
    uint32_t
    query);
```
or the equivalent command

```c
void vkCmdWriteTimestamp2KHR(
    VkCommandBuffer commandBuffer,
    VkPipelineStageFlags2 stage,
    VkQueryPool queryPool,
    uint32_t query);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `stage` specifies a stage of the pipeline.
- `queryPool` is the query pool that will manage the timestamp.
- `query` is the query within the query pool that will contain the timestamp.

When `vkCmdWriteTimestamp2KHR` is submitted to a queue, it defines an execution dependency on commands that were submitted before it, and writes a timestamp to a query pool.

The first **synchronization scope** includes all commands that occur earlier in **submission order**. The synchronization scope is limited to operations on the pipeline stage specified by `stage`.

The second **synchronization scope** includes only the timestamp write operation.

**Note**

Implementations may write the timestamp at any stage that is **logically later** than `stage`.

Any timestamp write that **happens-after** another timestamp write in the same submission **must** not have a lower value unless its value overflows the maximum supported integer bit width of the query. If `VK_EXT_calibrated_timestamps` is enabled, this extends to timestamp writes across all submissions on the same logical device: any timestamp write that **happens-after** another **must** not have a lower value unless its value overflows the maximum supported integer bit width of the query. Timestamps written by this command **must** be in the [VK_TIME_DOMAIN_DEVICE_EXT](https://www.khronos.org/registry/vulkan/specs/1.3-extensions/man/html/vkCmdWriteTimestamp2KHR.html) time domain. If an overflow occurs, the timestamp value **must** wrap back to zero.

**Note**

Comparisons between timestamps should be done between timestamps where they are guaranteed to not decrease. For example, subtracting an older timestamp from a newer one to determine the execution time of a sequence of commands is only a reliable measurement if the two timestamp writes were performed in the same submission, or if the writes were performed on the same logical device and `VK_EXT_calibrated_timestamps` is enabled.

If `vkCmdWriteTimestamp2KHR` is called while executing a render pass instance that has multiview enabled, the timestamp uses \( N \) consecutive query indices in the query pool (starting at `query`) where \( N \) is the number of bits set in the view mask of the subpass the command is executed in. The resulting query values are determined by an implementation-dependent choice of one of the following behaviors:
• The first query is a timestamp value and (if more than one bit is set in the view mask) zero is written to the remaining queries. If two timestamps are written in the same subpass, the sum of the execution time of all views between those commands is the difference between the first query written by each command.

• All N queries are timestamp values. If two timestamps are written in the same subpass, the sum of the execution time of all views between those commands is the sum of the difference between corresponding queries written by each command. The difference between corresponding queries may be the execution time of a single view.

In either case, the application can sum the differences between all N queries to determine the total execution time.

### Valid Usage

- **VUID-vkCmdWriteTimestamp2-stage-03929**
  If the geometryShader feature is not enabled, stage must not contain 
  `VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT`

- **VUID-vkCmdWriteTimestamp2-stage-03930**
  If the tessellationShader feature is not enabled, stage must not contain 
  `VK_PIPELINE_STAGE_2_TESSellation_CONTROL_SHADER_BIT` or 
  `VK_PIPELINE_STAGE_2_TESSellation_EVALUATION_SHADER_BIT`

- **VUID-vkCmdWriteTimestamp2-stage-03931**
  If the conditionalRendering feature is not enabled, stage must not contain 
  `VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT`

- **VUID-vkCmdWriteTimestamp2-stage-03932**
  If the fragmentDensityMap feature is not enabled, stage must not contain 
  `VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT`

- **VUID-vkCmdWriteTimestamp2-stage-03933**
  If the transformFeedback feature is not enabled, stage must not contain 
  `VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT`

- **VUID-vkCmdWriteTimestamp2-stage-03934**
  If the meshShader feature is not enabled, stage must not contain 
  `VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT`

- **VUID-vkCmdWriteTimestamp2-stage-03935**
  If the taskShader feature is not enabled, stage must not contain 
  `VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT`

- **VUID-vkCmdWriteTimestamp2-stage-07316**
  If neither the shadingRateImage or attachmentFragmentShadingRate are enabled, stage must not contain 
  `VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`

- **VUID-vkCmdWriteTimestamp2-stage-04957**
  If the subpassShading feature is not enabled, stage must not contain 
  `VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI`

- **VUID-vkCmdWriteTimestamp2-stage-04995**
  If the invocationMask feature is not enabled, stage must not contain
If neither the VK_NV_ray_tracing extension or rayTracingPipeline feature are enabled, stage must not contain VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR.

The synchronization2 feature must be enabled.

stage must only include a single pipeline stage.

stage must only include stages valid for the queue family that was used to create the command pool that commandBuffer was allocated from.

queryPool must have been created with a queryType of VK_QUERY_TYPE_TIMESTAMP.

The command pool's queue family must support a non-zero timestampValidBits.

query must be less than the number of queries in queryPool.

All queries used by the command must be unavailable.

If vkCmdWriteTimestamp2 is called within a render pass instance, the sum of query and the number of bits set in the current subpass's view mask must be less than or equal to the number of queries in queryPool.

Valid Usage (Implicit)

commandBuffer must be a valid VkCommandBuffer handle.

stage must be a valid combination of VkPipelineStageFlagBits2 values.

queryPool must be a valid VkQueryPool handle.

commandBuffer must be in the recording state.

The VkCommandPool that commandBuffer was allocated from must support transfer, graphics, compute, decode, or encode operations.

Both of commandBuffer, and queryPool must have been created, allocated, or retrieved from the same VkDevice.
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Both</td>
<td>Both</td>
<td>Transfer, Graphics, Compute, Decode, Encode</td>
<td>Action</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To request a timestamp and write the value to memory, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdWriteTimestamp(
    VkCommandBuffer commandBuffer,
    VkPipelineStageFlagBits pipelineStage,
    VkQueryPool queryPool,
    uint32_t query);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `pipelineStage` is a `VkPipelineStageFlagBits` value, specifying a stage of the pipeline.
- `queryPool` is the query pool that will manage the timestamp.
- `query` is the query within the query pool that will contain the timestamp.

When `vkCmdWriteTimestamp` is submitted to a queue, it defines an execution dependency on commands that were submitted before it, and writes a timestamp to a query pool.

The first synchronization scope includes all commands that occur earlier in submission order. The synchronization scope is limited to operations on the pipeline stage specified by `pipelineStage`.

The second synchronization scope includes only the timestamp write operation.

**Note**
Implementations may write the timestamp at any stage that is logically later than stage.

Any timestamp write that happens-after another timestamp write in the same submission must not
have a lower value unless its value overflows the maximum supported integer bit width of the query. If `VK_EXT_calibrated_timestamps` is enabled, this extends to timestamp writes across all submissions on the same logical device: any timestamp write that happens-after another must not have a lower value unless its value overflows the maximum supported integer bit width of the query. Timestamps written by this command must be in the `VK_TIME_DOMAIN_DEVICE_EXT` time domain. If an overflow occurs, the timestamp value must wrap back to zero.

**Note**
Comparisons between timestamps should be done between timestamps where they are guaranteed to not decrease. For example, subtracting an older timestamp from a newer one to determine the execution time of a sequence of commands is only a reliable measurement if the two timestamp writes were performed in the same submission, or if the writes were performed on the same logical device and `VK_EXT_calibrated_timestamps` is enabled.

If `vkCmdWriteTimestamp` is called while executing a render pass instance that has multiview enabled, the timestamp uses N consecutive query indices in the query pool (starting at `query`) where N is the number of bits set in the view mask of the subpass the command is executed in. The resulting query values are determined by an implementation-dependent choice of one of the following behaviors:

- The first query is a timestamp value and (if more than one bit is set in the view mask) zero is written to the remaining queries. If two timestamps are written in the same subpass, the sum of the execution time of all views between those commands is the difference between the first query written by each command.

- All N queries are timestamp values. If two timestamps are written in the same subpass, the sum of the execution time of all views between those commands is the sum of the difference between corresponding queries written by each command. The difference between corresponding queries may be the execution time of a single view.

In either case, the application can sum the differences between all N queries to determine the total execution time.

**Valid Usage**

- VUID-vkCmdWriteTimestamp-pipelineStage-04074
  `pipelineStage` must be a valid stage for the queue family that was used to create the command pool that `commandBuffer` was allocated from

- VUID-vkCmdWriteTimestamp-pipelineStage-04075
  If the `geometryShader` feature is not enabled, `pipelineStage` must not be `VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT`

- VUID-vkCmdWriteTimestamp-pipelineStage-04076
  If the `tessellationShader` feature is not enabled, `pipelineStage` must not be `VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT` or `VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT`

- VUID-vkCmdWriteTimestamp-pipelineStage-04077
  If the `conditionalRendering` feature is not enabled, `pipelineStage` must not be
VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT

- VUID-vkCmdWriteTimestamp-pipelineStage-04078
  If the fragmentDensityMap feature is not enabled, pipelineStage must not be VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT

- VUID-vkCmdWriteTimestamp-pipelineStage-04079
  If the transformFeedback feature is not enabled, pipelineStage must not be VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT

- VUID-vkCmdWriteTimestamp-pipelineStage-04080
  If the meshShader feature is not enabled, pipelineStage must not be VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT

- VUID-vkCmdWriteTimestamp-pipelineStage-07077
  If the taskShader feature is not enabled, pipelineStage must not be VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT

- VUID-vkCmdWriteTimestamp-shadingRateImage-07314
  If neither the shadingRateImage or attachmentFragmentShadingRate are enabled, pipelineStage must not be VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

- VUID-vkCmdWriteTimestamp-synchronization2-06489
  If the synchronization2 feature is not enabled, pipelineStage must not be VK_PIPELINE_STAGE_NONE

- VUID-vkCmdWriteTimestamp-rayTracingPipeline-07943
  If neither the VK_NV_ray_tracing extension or rayTracingPipeline feature are enabled, pipelineStage must not be VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR

- VUID-vkCmdWriteTimestamp-queryPool-01416
  queryPool must have been created with a queryType of VK_QUERY_TYPE_TIMESTAMP

- VUID-vkCmdWriteTimestamp-timestampValidBits-00829
  The command pool's queue family must support a non-zero timestampValidBits

- VUID-vkCmdWriteTimestamp-query-04904
  query must be less than the number of queries in queryPool

- VUID-vkCmdWriteTimestamp-None-00830
  All queries used by the command must be unavailable

- VUID-vkCmdWriteTimestamp-query-00831
  If vkCmdWriteTimestamp is called within a render pass instance, the sum of query and the number of bits set in the current subpass's view mask must be less than or equal to the number of queries in queryPool

Valid Usage (Implicit)

- VUID-vkCmdWriteTimestamp-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdWriteTimestamp-pipelineStage-parameter
  pipelineStage must be a valid VkPipelineStageFlagBits value
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

Command Properties

<table>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

18.6. Performance Queries

Performance queries provide applications with a mechanism for getting performance counter information about the execution of command buffers, render passes, and commands.

Each queue family advertises the performance counters that can be queried on a queue of that family via a call to `vkEnumeratePhysicalDeviceQueueFamilyPerformanceQueryCountersKHR`. Implementations may limit access to performance counters based on platform requirements or only to specialized drivers for development purposes.

Note

This may include no performance counters being enumerated, or a reduced set. Please refer to platform-specific documentation for guidance on any such restrictions.
Performance queries use the existing vkCmdBeginQuery and vkCmdEndQuery to control what command buffers, render passes, or commands to get performance information for.

Implementations may require multiple passes where the command buffer, render passes, or commands being recorded are the same and are executed on the same queue to record performance counter data. This is achieved by submitting the same batch and providing a VkPerformanceQuerySubmitInfoKHR structure containing a counter pass index. The number of passes required for a given performance query pool can be queried via a call to vkGetPhysicalDeviceQueueFamilyPerformanceQueryPassesKHR.

Note
Command buffers created with VK_COMMAND_BUFFER_USAGE_ONE_TIME_SUBMIT_BIT must not be re-submitted. Changing command buffer usage bits may affect performance. To avoid this, the application should re-record any command buffers with the VK_COMMAND_BUFFER_USAGE_ONE_TIME_SUBMIT_BIT when multiple counter passes are required.

Performance counter results from a performance query pool can be obtained with the command vkGetQueryPoolResults.

The VkPerformanceCounterResultKHR union is defined as:

```c
// Provided by VK_KHR_performance_query
typedef union VkPerformanceCounterResultKHR {
    int32_t     int32;
    int64_t     int64;
    uint32_t    uint32;
    uint64_t    uint64;
    float       float32;
    double      float64;
} VkPerformanceCounterResultKHR;
```

- int32 is a 32-bit signed integer value.
- int64 is a 64-bit signed integer value.
- uint32 is a 32-bit unsigned integer value.
- uint64 is a 64-bit unsigned integer value.
- float32 is a 32-bit floating-point value.
- float64 is a 64-bit floating-point value.

Performance query results are returned in an array of VkPerformanceCounterResultKHR unions containing the data associated with each counter in the query, stored in the same order as the counters supplied in pCounterIndices when creating the performance query. VkPerformanceCounterKHR::storage specifies how to parse the counter data.
18.6.1. Profiling Lock

To record and submit a command buffer containing a performance query pool the profiling lock must be held. The profiling lock must be acquired prior to any call to `vkBeginCommandBuffer` that will be using a performance query pool. The profiling lock must be held while any command buffer containing a performance query pool is in the recording, executable, or pending state. To acquire the profiling lock, call:

```c
// Provided by VK_KHR_performance_query
VkResult vkAcquireProfilingLockKHR(
    VkDevice device,
    const VkAcquireProfilingLockInfoKHR* pInfo);
```

- `device` is the logical device to profile.
- `pInfo` is a pointer to a `VkAcquireProfilingLockInfoKHR` structure containing information about how the profiling is to be acquired.

Implementations may allow multiple actors to hold the profiling lock concurrently.

**Valid Usage (Implicit)**

- VUID-vkAcquireProfilingLockKHR-device-parameter `device` must be a valid `VkDevice` handle
- VUID-vkAcquireProfilingLockKHR-pInfo-parameter `pInfo` must be a valid pointer to a valid `VkAcquireProfilingLockInfoKHR` structure

**Return Codes**

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_TIMEOUT`

The `VkAcquireProfilingLockInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_performance_query
typedef struct VkAcquireProfilingLockInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkAcquireProfilingLockFlagsKHR flags;
    uint64_t timeout;
} VkAcquireProfilingLockInfoKHR;
```
• **sType** is a *VkStructureType* value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **flags** is reserved for future use.

• **timeout** indicates how long the function waits, in nanoseconds, if the profiling lock is not available.

### Valid Usage (Implicit)

- VUID-VkAcquireProfilingLockInfoKHR-sType-sType
  - **sType** must be `VK_STRUCTURE_TYPE_ACQUIRE_PROFILING_LOCK_INFO_KHR`
- VUID-VkAcquireProfilingLockInfoKHR-pNext-pNext
  - **pNext** must be **NULL**
- VUID-VkAcquireProfilingLockInfoKHR-flags-zerobitmask
  - **flags** must be **0**

If **timeout** is **0**, **vkAcquireProfilingLockKHR** will not block while attempting to acquire the profiling lock. If **timeout** is **UINT64_MAX**, the function will not return until the profiling lock was acquired.

```c
// Provided by VK_KHR_performance_query
typedef enum VkAcquireProfilingLockFlagBitsKHR {
} VkAcquireProfilingLockFlagBitsKHR;
```

```c
// Provided by VK_KHR_performance_query
typedef VkFlags VkAcquireProfilingLockFlagsKHR;
```

**VkAcquireProfilingLockFlagsKHR** is a bitmask type for setting a mask, but is currently reserved for future use.

To release the profiling lock, call:

```c
// Provided by VK_KHR_performance_query
void vkReleaseProfilingLockKHR(
    VkDevice device);
```

• **device** is the logical device to cease profiling on.

### Valid Usage

- VUID-vkReleaseProfilingLockKHR-device-03235
  - The profiling lock of **device** must have been held via a previous successful call to **vkAcquireProfilingLockKHR**
Valid Usage (Implicit)

- VUID-vkReleaseProfilingLockKHR-device-parameter
device must be a valid VkDevice handle

18.7. Transform Feedback Queries

Transform feedback queries track the number of primitives attempted to be written and actually written, by the vertex stream being captured, to a transform feedback buffer. This query is updated during drawing commands while transform feedback is active. The number of primitives actually written will be less than the number attempted to be written if the bound transform feedback buffer size was too small for the number of primitives actually drawn. Primitives are not written beyond the bound range of the transform feedback buffer. A transform feedback query is begun and ended by calling `vkCmdBeginQuery` and `vkCmdEndQuery`, respectively to query for vertex stream zero. `vkCmdBeginQueryIndexedEXT` and `vkCmdEndQueryIndexedEXT` can be used to begin and end transform feedback queries for any supported vertex stream. When a transform feedback query begins, the count of primitives written and primitives needed starts from zero. For each drawing command, the count is incremented as vertex attribute outputs are captured to the transform feedback buffers while transform feedback is active.

When a transform feedback query finishes, the result for that query is marked as available. The application can then either copy the result to a buffer (via `vkCmdCopyQueryPoolResults`) or request it be put into host memory (via `vkGetQueryPoolResults`).

18.8. Primitives Generated Queries

When a generated primitive query for a vertex stream is active, the primitives-generated count is incremented every time a primitive emitted to that stream reaches the transform feedback stage, whether or not transform feedback is active. A primitives generated query is begun and ended by calling `vkCmdBeginQuery` and `vkCmdEndQuery`, respectively to query for vertex stream zero. `vkCmdBeginQueryIndexedEXT` and `vkCmdEndQueryIndexedEXT` can be used to begin and end primitives generated queries for any supported vertex stream. When a primitives generated query begins, the count of primitives generated starts from zero.

When a primitives generated query finishes, the result for that query is marked as available. The application can then either copy the result to a buffer (via `vkCmdCopyQueryPoolResults`) or request it be put into host memory (via `vkGetQueryPoolResults`).

Note

The result of this query is typically identical to `VK_QUERY_PIPELINE_STATISTIC_CLIPPING_INVOCATIONS_BIT`, but the primitives generated query is deterministic, i.e. it must be identical to the number of primitives processed. `VK_QUERY_PIPELINE_STATISTIC_CLIPPING_INVOCATIONS_BIT` may vary for implementation-dependent reasons, e.g. the same primitive may be processed multiple times for purposes of clipping.
18.9. Mesh Shader Queries

When a generated mesh primitives query is active, the mesh-primitives-generated count is incremented every time a primitive emitted from the mesh shader stage reaches the fragment shader stage. When a generated mesh primitives query begins, the mesh-primitives-generated count starts from zero.

Mesh and task shader pipeline statistics queries function the same way that invocation queries work for other shader stages, counting the number of times the respective shader stage has been run. When the statistics query begins, the invocation counters start from zero.

18.10. Intel performance queries

Intel performance queries allow an application to capture performance data for a set of commands. Performance queries are used in a similar way than other types of queries. A main difference with existing queries is that the resulting data should be handed over to a library capable to produce human readable results rather than being read directly by an application.

Prior to creating a performance query pool, initialize the device for performance queries with the call:

```c
// Provided by VK_INTEL_performance_query
VkResult vkInitializePerformanceApiINTEL(
    VkDevice device,
    const VkInitializePerformanceApiInfoINTEL* pInitializeInfo);
```

- `device` is the logical device used for the queries.
- `pInitializeInfo` is a pointer to a `VkInitializePerformanceApiInfoINTEL` structure specifying initialization parameters.

**Valid Usage (Implicit)**

- VUID-vkInitializePerformanceApiINTEL-device-parameter
  - `device` must be a valid `VkDevice` handle
- VUID-vkInitializePerformanceApiINTEL-pInitializeInfo-parameter
  - `pInitializeInfo` must be a valid pointer to a valid `VkInitializePerformanceApiInfoINTEL` structure

**Return Codes**

- **Success**
  - `VK_SUCCESS`
- **Failure**
  - `VK_ERROR_TOO_MANY_OBJECTS`
The `VkInitializePerformanceApiInfoINTEL` structure is defined as:

```c
// Provided by VK_INTEL_performance_query
typedef struct VkInitializePerformanceApiInfoINTEL {
    VkStructureType sType;
    const void* pNext;
    void* pUserData;
} VkInitializePerformanceApiInfoINTEL;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `pUserData` is a pointer for application data.

### Valid Usage (Implicit)

- VUID-VkInitializePerformanceApiInfoINTEL-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_INITIALIZE_PERFORMANCE_API_INFO_INTEL`
- VUID-VkInitializePerformanceApiInfoINTEL-pNext-pNext
  - `pNext` must be `NULL`

Once performance query operations have completed, uninitialize the device for performance queries with the call:

```c
// Provided by VK_INTEL_performance_query
void vkUninitializePerformanceApiINTEL(
    VkDevice device);
```

- `device` is the logical device used for the queries.

### Valid Usage (Implicit)

- VUID-vkUninitializePerformanceApiINTEL-device-parameter
  - `device` must be a valid `VkDevice` handle

Some performance query features of a device can be discovered with the call:

```c
// Provided by VK_INTEL_performance_query
VkResult vkGetPerformanceParameterINTEL(
    VkDevice device,
    VkPerformanceParameterTypeINTEL parameter,
);```
VkPerformanceValueINTEL* pValue);

- **device** is the logical device to query.
- **parameter** is the parameter to query.
- **pValue** is a pointer to a VkPerformanceValueINTEL structure in which the type and value of the parameter are returned.

### Valid Usage (Implicit)

- VUID-vkGetPerformanceParameterINTEL-device-parameter
  - **device must** be a valid VkDevice handle
- VUID-vkGetPerformanceParameterINTEL-parameter-parameter
  - **parameter must** be a valid VkPerformanceParameterTypeINTEL value
- VUID-vkGetPerformanceParameterINTEL-pValue-parameter
  - **pValue must** be a valid pointer to a VkPerformanceValueINTEL structure

### Return Codes

#### Success
- **VK_SUCCESS**

#### Failure
- **VK_ERROR_TOO_MANY_OBJECTS**
- **VK_ERROR_OUT_OF_HOST_MEMORY**

Possible values of vkGetPerformanceParameterINTEL::parameter, specifying a performance query feature, are:

```c
// Provided by VK_INTEL_performance_query
typedef enum VkPerformanceParameterTypeINTEL {
    VK_PERFORMANCE_PARAMETER_TYPE_HW_COUNTERS_SUPPORTED_INTEL = 0,
    VK_PERFORMANCE_PARAMETER_TYPE_STREAM_MARKER_VALID_BITS_INTEL = 1,
} VkPerformanceParameterTypeINTEL;
```

- **VK_PERFORMANCE_PARAMETER_TYPE_HW_COUNTERS_SUPPORTED_INTEL** has a boolean result which tells whether hardware counters can be captured.
- **VK_PERFORMANCE_PARAMETER_TYPE_STREAM_MARKER_VALID_BITS_INTEL** has a 32 bits integer result which tells how many bits can be written into the VkPerformanceValueINTEL value.

The VkPerformanceValueINTEL structure is defined as:

```c
// Provided by VK_INTEL_performance_query
typedef struct VkPerformanceValueINTEL {
```
• **type** is a `VkPerformanceValueTypeINTEL` value specifying the type of the returned data.

• **data** is a `VkPerformanceValueDataINTEL` union specifying the value of the returned data.

### Valid Usage (Implicit)

- VUID-VkPerformanceValueINTEL-type-parameter
  ```
  type must be a valid `VkPerformanceValueTypeINTEL` value
  ```

- VUID-VkPerformanceValueINTEL-valueString-parameter
  If **type** is `VK_PERFORMANCE_VALUE_TYPE_STRING_INTEL`, the `valueString` member of **data** must be a null-terminated UTF-8 string.

Possible values of `VkPerformanceValueINTEL::type`, specifying the type of the data returned in `VkPerformanceValueINTEL::data`, are:

- `VK_PERFORMANCE_VALUE_TYPE_UINT32_INTEL` specifies that unsigned 32-bit integer data is returned in `data.value32`.

- `VK_PERFORMANCE_VALUE_TYPE_UINT64_INTEL` specifies that unsigned 64-bit integer data is returned in `data.value64`.

- `VK_PERFORMANCE_VALUE_TYPE_FLOAT_INTEL` specifies that floating-point data is returned in `data.valueFloat`.

- `VK_PERFORMANCE_VALUE_TYPE_BOOL_INTEL` specifies that `VkBool32` data is returned in `data.valueBool`.

- `VK_PERFORMANCE_VALUE_TYPE_STRING_INTEL` specifies that a pointer to a null-terminated UTF-8 string is returned in `data.valueString`. The pointer is valid for the lifetime of the `device` parameter passed to `vkGetPerformanceParameterINTEL`.

```c
// Provided by VK_INTEL_performance_query
typedef enum VkPerformanceValueTypeINTEL {
    VK_PERFORMANCE_VALUE_TYPE_UINT32_INTEL = 0,
    VK_PERFORMANCE_VALUE_TYPE_UINT64_INTEL = 1,
    VK_PERFORMANCE_VALUE_TYPE_FLOAT_INTEL = 2,
    VK_PERFORMANCE_VALUE_TYPE_BOOL_INTEL = 3,
    VK_PERFORMANCE_VALUE_TYPE_STRING_INTEL = 4,
} VkPerformanceValueTypeINTEL;
```

The `VkPerformanceValueDataINTEL` union is defined as:

```c
// Provided by VK_INTEL_performance_query
typedef union VkPerformanceValueDataINTEL {
    uint32_t value32;
```
uint64_t value64;
float valueFloat;
VkBool32 valueBool;
const char* valueString;
} VkPerformanceValueDataINTEL;

• data.value32 represents 32-bit integer data.
• data.value64 represents 64-bit integer data.
• data.valueFloat represents floating-point data.
• data.valueBool represents VkBool32 data.
• data.valueString represents a pointer to a null-terminated UTF-8 string.

The correct member of the union is determined by the associated VkPerformanceValueTypeINTEL value.

The VkQueryPoolPerformanceQueryCreateInfoINTEL structure is defined as:

```c
// Provided by VK_INTEL_performance_query
typedef struct VkQueryPoolPerformanceQueryCreateInfoINTEL {
    VkStructureType sType;
    const void* pNext;
    VkQueryPoolSamplingModeINTEL performanceCountersSampling;
} VkQueryPoolPerformanceQueryCreateInfoINTEL;
```

To create a pool for Intel performance queries, set VkQueryPoolCreateInfo::queryType to VK_QUERY_TYPE_PERFORMANCE_QUERY_INTEL and add a VkQueryPoolPerformanceQueryCreateInfoINTEL structure to thepNext chain of the VkQueryPoolCreateInfo structure.

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• performanceCountersSampling describe how performance queries should be captured.

Valid Usage (Implicit)

• VUID-VkQueryPoolPerformanceQueryCreateInfoINTEL-sType-sType sType must be VK_STRUCTURE_TYPE_QUERY_POOL_PERFORMANCE_QUERY_CREATE_INFO_INTEL
• VUID-VkQueryPoolPerformanceQueryCreateInfoINTEL-performanceCountersSampling-parameter performanceCountersSampling must be a valid VkQueryPoolSamplingModeINTEL value
Possible values of `VkQueryPoolPerformanceQueryCreateInfoINTEL::performanceCountersSampling` are:

```c
typedef enum VkQueryPoolSamplingModeINTEL {
    VK_QUERY_POOL_SAMPLING_MODE_MANUAL_INTEL = 0,
} VkQueryPoolSamplingModeINTEL;
```

- `VK_QUERY_POOL_SAMPLING_MODE_MANUAL_INTEL` is the default mode in which the application calls `vkCmdBeginQuery` and `vkCmdEndQuery` to record performance data.

To help associate query results with a particular point at which an application emitted commands, markers can be set into the command buffers with the call:

```c
VkResult vkCmdSetPerformanceMarkerINTEL(VkCommandBuffer commandBuffer, const VkPerformanceMarkerInfoINTEL* pMarkerInfo);
```

The last marker set onto a command buffer before the end of a query will be part of the query result.

**Valid Usage (Implicit)**

- VUID-vkCmdSetPerformanceMarkerINTEL-commandBuffer-parameter
  - `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetPerformanceMarkerINTEL-pMarkerInfo-parameter
  - `pMarkerInfo` must be a valid pointer to a valid `VkPerformanceMarkerInfoINTEL` structure
- VUID-vkCmdSetPerformanceMarkerINTEL-commandBuffer-recording
  - `commandBuffer` must be in the recording state
- VUID-vkCmdSetPerformanceMarkerINTEL-commandBuffer-cmdpool
  - The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, compute, or transfer operations
- VUID-vkCmdSetPerformanceMarkerINTEL-videocoding
  - This command must only be called outside of a video coding scope

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized
Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics</td>
<td>Action</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td>Compute</td>
<td>State</td>
</tr>
<tr>
<td>Both</td>
<td></td>
<td></td>
<td>Transfer</td>
<td></td>
</tr>
</tbody>
</table>

Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_TOO_MANY_OBJECTS
- VK_ERROR_OUT_OF_HOST_MEMORY

The `VkPerformanceMarkerInfoINTEL` structure is defined as:

```c
// Provided by VK_INTEL_performance_query
typedef struct VkPerformanceMarkerInfoINTEL {
    VkStructureType sType;
    const void* pNext;
    uint64_t marker;
} VkPerformanceMarkerInfoINTEL;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `marker` is the marker value that will be recorded into the opaque query results.

Valid Usage (Implicit)

- VUID-VkPerformanceMarkerInfoINTEL-sType-sType
  `sType` **must** be `VK_STRUCTURE_TYPE_PERFORMANCE_MARKER_INFO_INTEL`
- VUID-VkPerformanceMarkerInfoINTEL-pNext-pNext
  `pNext` **must** be `NULL`

When monitoring the behavior of an application within the dataset generated by the entire set of applications running on the system, it is useful to identify draw calls within a potentially huge amount of performance data. To do so, application can generate stream markers that will be used to trace back a particular draw call with a particular performance data item.
/// Provided by VK_INTEL_performance_query

VkResult vkCmdSetPerformanceStreamMarkerINTEL(
    VkCommandBuffer commandBuffer,
    const VkPerformanceStreamMarkerInfoINTEL* pMarkerInfo);

Valid Usage (Implicit)

- **VUID-vkCmdSetPerformanceStreamMarkerINTEL-commandBuffer-parameter**
  parameter `commandBuffer` must be a valid `VkCommandBuffer` handle

- **VUID-vkCmdSetPerformanceStreamMarkerINTEL-pMarkerInfo-parameter**
  parameter `pMarkerInfo` must be a valid pointer to a valid `VkPerformanceStreamMarkerInfoINTEL` structure

- **VUID-vkCmdSetPerformanceStreamMarkerINTEL-commandBuffer-recording**
  parameter `commandBuffer` must be in the recording state

- **VUID-vkCmdSetPerformanceStreamMarkerINTEL-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, compute, or transfer operations

- **VUID-vkCmdSetPerformanceStreamMarkerINTEL-videocoding**
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

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</tr>
</thead>
<tbody>
<tr>
<td>Primary Secondary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics, Compute, Transfer</td>
<td>Action State</td>
</tr>
</tbody>
</table>

Return Codes

- **Success**
  - `VK_SUCCESS`
Failure

- VK_ERROR_TOO_MANY_OBJECTS
- VK_ERROR_OUT_OF_HOST_MEMORY

The `VkPerformanceStreamMarkerInfoINTEL` structure is defined as:

```c
// Provided by VK_INTEL_performance_query
typedef struct VkPerformanceStreamMarkerInfoINTEL {
    VkStructureType sType;
    const void* pNext;
    uint32_t marker;
} VkPerformanceStreamMarkerInfoINTEL;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `marker` is the marker value that will be recorded into the reports consumed by an external application.

Valid Usage

- VUID-VkPerformanceStreamMarkerInfoINTEL-marker-02735
  The value written by the application into `marker` must only used the valid bits as reported by `vkGetPerformanceParameterINTEL` with the `VK_PERFORMANCE_PARAMETER_TYPE_STREAM_MARKER_VALID_BITS_INTEL`

Valid Usage (Implicit)

- VUID-VkPerformanceStreamMarkerInfoINTEL-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_PERFORMANCE_STREAM_MARKER_INFO_INTEL`
- VUID-VkPerformanceStreamMarkerInfoINTEL-pNext-pNext
  `pNext` must be `NULL`

Some applications might want measure the effect of a set of commands with a different settings. It is possible to override a particular settings using:

```c
// Provided by VK_INTEL_performance_query
VkResult vkCmdSetPerformanceOverrideINTEL(
    VkCommandBuffer commandBuffer,
    const VkPerformanceOverrideInfoINTEL* pOverrideInfo);
```

- `commandBuffer` is the command buffer where the override takes place.
- `pOverrideInfo` is a pointer to a `VkPerformanceOverrideInfoINTEL` structure selecting the
parameter to override.

**Valid Usage**

- VUID-vkCmdSetPerformanceOverrideINTEL-pOverrideInfo-02736
  - `pOverrideInfo` must not be used with a `VkPerformanceOverrideTypeINTEL` that is not reported available by `vkGetPerformanceParameterINTEL`

**Valid Usage (Implicit)**

- VUID-vkCmdSetPerformanceOverrideINTEL-commandBuffer-parameter
  - `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetPerformanceOverrideINTEL-pOverrideInfo-parameter
  - `pOverrideInfo` must be a valid pointer to a valid `VkPerformanceOverrideInfoINTEL` structure
- VUID-vkCmdSetPerformanceOverrideINTEL-commandBuffer-recording
  - `commandBuffer` must be in the `recording` state
- VUID-vkCmdSetPerformanceOverrideINTEL-commandBuffer-cmdpool
  - The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, compute, or transfer operations
- VUID-vkCmdSetPerformanceOverrideINTEL-videocoding
  - This command must only be called outside of a video coding scope

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

**Command Properties**

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
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<td></td>
<td></td>
<td>Compute</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Transfer</td>
<td></td>
</tr>
</tbody>
</table>
## Return Codes

**Success**

- VK_SUCCESS

**Failure**

- VK_ERROR_TOO_MANY_OBJECTS
- VK_ERROR_OUT_OF_HOST_MEMORY

The *VkPerformanceOverrideInfoINTEL* structure is defined as:

```c
// Provided by VK_INTEL_performance_query
typedef struct VkPerformanceOverrideInfoINTEL {
    VkStructureType  sType;
    const void*     pNext;
    VkPerformanceOverrideTypeINTEL type;
    VkBool32        enable;
    uint64_t        parameter;
} VkPerformanceOverrideInfoINTEL;
```

- **type** is the particular *VkPerformanceOverrideTypeINTEL* to set.
- **enable** defines whether the override is enabled.
- **parameter** is a potential required parameter for the override.

### Valid Usage (Implicit)

- VUID-VkPerformanceOverrideInfoINTEL-sType-sType
  *sType* must be *VK_STRUCTURE_TYPE_PERFORMANCE_OVERRIDE_INFO_INTEL*

- VUID-VkPerformanceOverrideInfoINTEL-pNext-pNext
  *pNext* must be NULL

- VUID-VkPerformanceOverrideInfoINTEL-type-parameter
  *type* must be a valid *VkPerformanceOverrideTypeINTEL* value

Possible values of *VkPerformanceOverrideInfoINTEL::type*, specifying performance override types, are:

```c
// Provided by VK_INTEL_performance_query
typedef enum VkPerformanceOverrideTypeINTEL {
    VK_PERFORMANCE_OVERRIDE_TYPE_NULL_HARDWARE_INTEL = 0,
    VK_PERFORMANCE_OVERRIDE_TYPE_FLUSH_GPU_CACHES_INTEL = 1,
} VkPerformanceOverrideTypeINTEL;
```

- **VK_PERFORMANCE_OVERRIDE_TYPE_NULL_HARDWARE_INTEL** turns all rendering operations into noop.
VK_PERFORMANCE_OVERRIDE_TYPE_FLUSH_GPU_CACHES_INTEL stalls the stream of commands until all previously emitted commands have completed and all caches been flushed and invalidated.

Before submitting command buffers containing performance queries commands to a device queue, the application must acquire and set a performance query configuration. The configuration can be released once all command buffers containing performance query commands are not in a pending state.

```c
// Provided by VK_INTEL_performance_query
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkPerformanceConfigurationINTEL)
```

To acquire a device performance configuration, call:

```c
// Provided by VK_INTEL_performance_query
VkResult vkAcquirePerformanceConfigurationINTEL(
    VkDevice device,
    const VkPerformanceConfigurationAcquireInfoINTEL* pAcquireInfo,
    VkPerformanceConfigurationINTEL* pConfiguration);
```

- device is the logical device that the performance query commands will be submitted to.
- pAcquireInfo is a pointer to a VkPerformanceConfigurationAcquireInfoINTEL structure, specifying the performance configuration to acquire.
- pConfiguration is a pointer to a VkPerformanceConfigurationINTEL handle in which the resulting configuration object is returned.

**Valid Usage (Implicit)**

- VUID-vkAcquirePerformanceConfigurationINTEL-device-parameter device must be a valid VkDevice handle
- VUID-vkAcquirePerformanceConfigurationINTEL-pAcquireInfo-parameter pAcquireInfo must be a valid pointer to a valid VkPerformanceConfigurationAcquireInfoINTEL structure
- VUID-vkAcquirePerformanceConfigurationINTEL-pConfiguration-parameter pConfiguration must be a valid pointer to a VkPerformanceConfigurationINTEL handle

**Return Codes**

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_TOO_MANY_OBJECTS
- VK_ERROR_OUT_OF_HOST_MEMORY
The `VkPerformanceConfigurationAcquireInfoINTEL` structure is defined as:

```c
// Provided by VK_INTEL_performance_query
typedef struct VkPerformanceConfigurationAcquireInfoINTEL {
    VkStructureType sType;
    const void* pNext;
    VkPerformanceConfigurationTypeINTEL type;
} VkPerformanceConfigurationAcquireInfoINTEL;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `type` is one of the `VkPerformanceConfigurationTypeINTEL` type of performance configuration that will be acquired.

### Valid Usage (Implicit)

- `VUID-VkPerformanceConfigurationAcquireInfoINTEL-sType-sType
  sType must be VK_STRUCTURE_TYPE_PERFORMANCE_CONFIGURATION_ACQUIRE_INFO_INTEL`
- `VUID-VkPerformanceConfigurationAcquireInfoINTEL-pNext-pNext
  pNext must be NULL`
- `VUID-VkPerformanceConfigurationAcquireInfoINTEL-type-parameter
  type must be a valid VkPerformanceConfigurationTypeINTEL value`

Possible values of `VkPerformanceConfigurationAcquireInfoINTEL::type`, specifying performance configuration types, are:

```c
// Provided by VK_INTEL_performance_query
typedef enum VkPerformanceConfigurationTypeINTEL {
    VK_PERFORMANCE_CONFIGURATION_TYPE_COMMAND_QUEUE_METRICS_DISCOVERY_ACTIVATED_INTEL = 0,
} VkPerformanceConfigurationTypeINTEL;
```

To set a performance configuration, call:

```c
// Provided by VK_INTEL_performance_query
VkResult vkQueueSetPerformanceConfigurationINTEL(
    VkQueue queue,
    VkPerformanceConfigurationINTEL configuration);
```

- `queue` is the queue on which the configuration will be used.
- `configuration` is the configuration to use.
Valid Usage (Implicit)

- VUID-vkQueueSetPerformanceConfigurationINTEL-queue-parameter 
  queue must be a valid VkQueue handle

- VUID-vkQueueSetPerformanceConfigurationINTEL-configuration-parameter 
  configuration must be a valid VkPerformanceConfigurationINTEL handle

- VUID-vkQueueSetPerformanceConfigurationINTEL-commonparent 
  Both of configuration, and queue must have been created, allocated, or retrieved from the same VkDevice

Command Properties

<table>
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Any</td>
<td>-</td>
</tr>
</tbody>
</table>

Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_TOO_MANY_OBJECTS
- VK_ERROR_OUT_OF_HOST_MEMORY

To release a device performance configuration, call:

```c
// Provided by VK_INTEL_performance_query
VkResult vkReleasePerformanceConfigurationINTEL(VkDevice device, VkPerformanceConfigurationINTEL configuration);
```

- device is the device associated to the configuration object to release.
- configuration is the configuration object to release.

Valid Usage

- VUID-vkReleasePerformanceConfigurationINTEL-configuration-02737 
  configuration must not be released before all command buffers submitted while the configuration was set are in pending state
### Valid Usage (Implicit)

- **VUID-vkReleasePerformanceConfigurationINTEL-device-parameter**  
  *device* must be a valid VkDevice handle

- **VUID-vkReleasePerformanceConfigurationINTEL-configuration-parameter**  
  If *configuration* is not VK_NULL_HANDLE, *configuration* must be a valid VkPerformanceConfigurationINTEL handle

- **VUID-vkReleasePerformanceConfigurationINTEL-configuration-parent**  
  If *configuration* is a valid handle, it must have been created, allocated, or retrieved from *device*

### Host Synchronization

- Host access to *configuration* must be externally synchronized

### Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_TOO_MANY_OBJECTS
- VK_ERROR_OUT_OF_HOST_MEMORY

### 18.11. Result Status Queries

Result status queries serve a single purpose: allowing the application to determine whether a set of operations have completed successfully or not, as indicated by the VkQueryResultStatusKHR value written when retrieving the result of a query using the VK_QUERY_RESULT_WITH_STATUS_BIT_KHR flag.

Unlike other query types, result status queries do not track or maintain any other data beyond the completion status, thus no other data is written when retrieving their results.

Support for result status queries is indicated by VkQueueFamilyQueryResultStatusPropertiesKHR::queryResultStatusSupport, as returned by vkGetPhysicalDeviceQueueFamilyProperties2 for the queue family in question.

### 18.12. Video Encode Feedback Queries

Video encode feedback queries allow the application to capture feedback values generated by video encode operations. As such, video encode feedback queries are available on queue families supporting video encode operations. The availability of individual video encode feedback values is indicated by the bits of VkVideoEncodeCapabilitiesKHR::supportedEncodeFeedbackFlags, as returned...
by `vkGetPhysicalDeviceVideoCapabilitiesKHR` for the video profile the queries are intended to be used with.

The set of enabled video encode feedback values must be configured on the query pool when it is created using the `encodeFeedbackFlags` member of the `VkQueryPoolVideoEncodeFeedbackCreateInfoKHR` included in the `pNext` chain of `VkQueryPoolCreateInfo`.

The `VkQueryPoolVideoEncodeFeedbackCreateInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_video_encode_queue
typedef struct VkQueryPoolVideoEncodeFeedbackCreateInfoKHR {
    VkStructureType          sType;
    const void*             pNext;
    VkVideoEncodeFeedbackFlagsKHR encodeFeedbackFlags;
} VkQueryPoolVideoEncodeFeedbackCreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `encodeFeedbackFlags` is a bitmask of `VkVideoEncodeFeedbackFlagBitsKHR` values specifying the set of enabled video encode feedback values captured by queries of the new pool.

Valid Usage (Implicit)

- VUID-VkQueryPoolVideoEncodeFeedbackCreateInfoKHR-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_QUERY_POOL_VIDEO_ENCODE_FEEDBACK_CREATE_INFO_KHR`

- VUID-VkQueryPoolVideoEncodeFeedbackCreateInfoKHR-encodeFeedbackFlags-parameter
  `encodeFeedbackFlags` must be a valid combination of `VkVideoEncodeFeedbackFlagBitsKHR` values

- VUID-VkQueryPoolVideoEncodeFeedbackCreateInfoKHR-encodeFeedbackFlags-requiredbitmask
  `encodeFeedbackFlags` must not be 0

Bits which can be set in `VkQueryPoolVideoEncodeFeedbackCreateInfoKHR::encodeFeedbackFlags` for video encode feedback query pools are:

```c
// Provided by VK_KHR_video_encode_queue
typedef enum VkVideoEncodeFeedbackFlagBitsKHR {
    VK_VIDEO_ENCODE_FEEDBACK_BITSTREAM_BUFFER_OFFSET_BIT_KHR = 0x00000001,
    VK_VIDEO_ENCODE_FEEDBACK_BITSTREAM_BYTES_WRITTEN_BIT_KHR = 0x00000002,
    VK_VIDEO_ENCODE_FEEDBACK_BITSTREAM_HAS_OVERRIDES_BIT_KHR = 0x00000004,
} VkVideoEncodeFeedbackFlagBitsKHR;
```

- `VK_VIDEO_ENCODE_FEEDBACK_BITSTREAM_BUFFER_OFFSET_BIT_KHR` specifies that queries managed by the pool will capture the byte offset of the bitstream data written by the video encode operation
to the bitstream buffer specified in `VkVideoEncodeInfoKHR::dstBuffer` relative to the offset specified in `VkVideoEncodeInfoKHR::dstBufferOffset`.

- `VK_VIDEO_ENCODE_FEEDBACK_BITSTREAM_BYTES_WRITTEN_BIT_KHR` specifies that queries managed by the pool will capture the number of bytes written by the video encode operation to the bitstream buffer specified in `VkVideoEncodeInfoKHR::dstBuffer`.

- `VK_VIDEO_ENCODE_FEEDBACK_BITSTREAM_HAS_OVERRIDES_BIT_KHR` specifies that queries managed by the pool will capture a boolean value indicating that the data written to the bitstream buffer specified in `VkVideoEncodeInfoKHR::dstBuffer` contains overridden parameters.

When retrieving the results of video encode feedback queries, the values corresponding to each enabled video encode feedback are written in the order of the bits defined above, followed by an optional value indicating availability or result status if `VK_QUERY_RESULT_WITH_AVAILABILITY_BIT` or `VK_QUERY_RESULT_WITH_STATUS_BIT_KHR` is specified, respectively.

```c
// Provided by VK_KHR_video_encode_queue
typedef VkFlags VkVideoEncodeFeedbackFlagsKHR;
```

`VkVideoEncodeFeedbackFlagsKHR` is a bitmask type for setting a mask of zero or more `VkVideoEncodeFeedbackFlagBitsKHR`. 
Chapter 19. Clear Commands

19.1. Clearing Images Outside A Render Pass Instance

Color and depth/stencil images can be cleared outside a render pass instance using `vkCmdClearColorImage` or `vkCmdClearDepthStencilImage`, respectively. These commands are only allowed outside of a render pass instance.

To clear one or more subranges of a color image, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdClearColorImage(
    VkCommandBuffer commandBuffer,
    VkImage image,
    VkImageLayout imageLayout,
    const VkClearColorValue* pColor,
    uint32_t rangeCount,
    const VkImageSubresourceRange* pRanges);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `image` is the image to be cleared.
- `imageLayout` specifies the current layout of the image subresource ranges to be cleared, and must be `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR`, `VK_IMAGE_LAYOUT_GENERAL` or `VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL`.
- `pColor` is a pointer to a `VkClearColorValue` structure containing the values that the image subresource ranges will be cleared to (see Clear Values below).
- `rangeCount` is the number of image subresource range structures in `pRanges`.
- `pRanges` is a pointer to an array of `VkImageSubresourceRange` structures describing a range of mipmap levels, array layers, and aspects to be cleared, as described in Image Views.

Each specified range in `pRanges` is cleared to the value specified by `pColor`.

Valid Usage

- VUID-vkCmdClearColorImage-image-01993
  The *format features* of `image` *must* contain `VK_FORMAT_FEATURE_TRANSFER_DST_BIT`

- VUID-vkCmdClearColorImage-image-00002
  `image` *must* have been created with `VK_IMAGE_USAGE_TRANSFER_DST_BIT` usage flag

- VUID-vkCmdClearColorImage-image-01545
  `image` *must* not use any of the *formats that require a sampler Y’C’bC’r conversion*

- VUID-vkCmdClearColorImage-image-00003
  If `image` is non-sparse then it *must* be bound completely and contiguously to a single `VkDeviceMemory` object
imageLayout must specify the layout of the image subresource ranges of image specified in pRanges at the time this command is executed on a VkDevice.

imageLayout must be VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR, VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL or VK_IMAGE_LAYOUT_GENERAL.

The VkImageSubresourceRange::aspectMask members of the elements of the pRanges array must each only include VK_IMAGE_ASPECT_COLOR_BIT.

The VkImageSubresourceRange::baseMipLevel members of the elements of the pRanges array must each be less than the mipLevels specified in VkImageCreateInfo when image was created.

For each VkImageSubresourceRange element of pRanges, if the levelCount member is not VK_REMAINING_MIP_LEVELS, then baseMipLevel + levelCount must be less than or equal to the mipLevels specified in VkImageCreateInfo when image was created.

The VkImageSubresourceRange::baseArrayLayer members of the elements of the pRanges array must each be less than the arrayLayers specified in VkImageCreateInfo when image was created.

For each VkImageSubresourceRange element of pRanges, if the layerCount member is not VK_REMAINING_ARRAY_LAYERS, then baseArrayLayer + layerCount must be less than or equal to the arrayLayers specified in VkImageCreateInfo when image was created.

image must not have a compressed or depth/stencil format.

pColor must be a valid pointer to a VkClearColorValue union.

If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, image must not be a protected image.

If commandBuffer is a protected command buffer and protectedNoFault is not supported, must not be an unprotected image.

Valid Usage (Implicit)

commandBuffer must be a valid VkCommandBuffer handle.

image must be a valid VkImage handle.
Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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<td></td>
<td>Compute</td>
<td></td>
</tr>
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</table>

To clear one or more subranges of a depth/stencil image, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdClearColorImage(imageLayout must be a valid VkImageLayout value
imageLayout must be a valid pointer to an array of rangeCount valid VkImageSubresourceRange structures
commandBuffer must be in the recording state
The VkCommandPool that commandBuffer was allocated from must support graphics, or compute operations
This command must only be called outside of a render pass instance
This command must only be called outside of a video coding scope
rangeCount must be greater than 0
Both of commandBuffer, and image must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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</table>

To clear one or more subranges of a depth/stencil image, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdClearDepthStencilImage(
    VkCommandBuffer commandBuffer,    
    VkImage image,                    
    VkImageLayout imageLayout,        
    const VkClearColorDepthStencilValue* pDepthStencil,
) 
```
• `commandBuffer` is the command buffer into which the command will be recorded.
• `image` is the image to be cleared.
• `imageLayout` specifies the current layout of the image subresource ranges to be cleared, and
  must be `VK_IMAGE_LAYOUT_GENERAL` or `VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL`.
• `pDepthStencil` is a pointer to a `VkClearDepthStencilValue` structure containing the values that
  the depth and stencil image subresource ranges will be cleared to (see Clear Values below).
• `rangeCount` is the number of image subresource range structures in `pRanges`.
• `pRanges` is a pointer to an array of `VkImageSubresourceRange` structures describing a range of
  mipmap levels, array layers, and aspects to be cleared, as described in Image Views.

Valid Usage

• VUID-vkCmdClearDepthStencilImage-image-01994
  The format features of `image` must contain `VK_FORMAT_FEATURE_TRANSFER_DST_BIT`

• VUID-vkCmdClearDepthStencilImage-pRanges-02658
  If the aspect member of any element of `pRanges` includes `VK_IMAGE_ASPECT_STENCIL_BIT`, and
  `image` was created with separate stencil usage, `VK_IMAGE_USAGE_TRANSFER_DST_BIT` must have
  been included in the `VkImageStencilUsageCreateInfo::stencilUsage` used to create `image`

• VUID-vkCmdClearDepthStencilImage-pRanges-02659
  If the aspect member of any element of `pRanges` includes `VK_IMAGE_ASPECT_STENCIL_BIT`, and
  `image` was not created with separate stencil usage, `VK_IMAGE_USAGE_TRANSFER_DST_BIT` must
  have been included in the `VkImageCreateInfo::usage` used to create `image`

• VUID-vkCmdClearDepthStencilImage-pRanges-02660
  If the aspect member of any element of `pRanges` includes `VK_IMAGE_ASPECT_DEPTH_BIT`,
  `VK_IMAGE_USAGE_TRANSFER_DST_BIT` must have been included in the `VkImageCreateInfo ::usage` used to create `image`

• VUID-vkCmdClearDepthStencilImage-image-00010
  If `image` is non-sparse then it must be bound completely and contiguously to a single
  `VkDeviceMemory` object

• VUID-vkCmdClearDepthStencilImage-imageLayout-00011
  The layout must specify the layout of the image subresource ranges of `image` specified in
  `pRanges` at the time this command is executed on a `VkDevice`

• VUID-vkCmdClearDepthStencilImage-imageLayout-00012
  The `imageLayout` must be either of `VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL` or
  `VK_IMAGE_LAYOUT_GENERAL`

• VUID-vkCmdClearDepthStencilImage-aspectMask-02824
  The `VkImageSubresourceRange::aspectMask` member of each element of the `pRanges` array
  must not include bits other than `VK_IMAGE_ASPECT_DEPTH_BIT` or `VK_IMAGE_ASPECT_STENCIL_BIT`
If the image's format does not have a stencil component, then the `VkImageSubresourceRange::aspectMask` member of each element of the `pRanges` array must not include the `VK_IMAGE_ASPECT_STENCIL_BIT` bit.

If the image's format does not have a depth component, then the `VkImageSubresourceRange::aspectMask` member of each element of the `pRanges` array must not include the `VK_IMAGE_ASPECT_DEPTH_BIT` bit.

The `VkImageSubresourceRange::baseMipLevel` members of the elements of the `pRanges` array must each be less than the `mipLevels` specified in `VkImageCreateInfo` when image was created.

For each `VkImageSubresourceRange` element of `pRanges`, if the `levelCount` member is not `VK_REMAINING_MIP_LEVELS`, then `baseMipLevel + levelCount` must be less than or equal to the `mipLevels` specified in `VkImageCreateInfo` when image was created.

The `VkImageSubresourceRange::baseArrayLayer` members of the elements of the `pRanges` array must each be less than the `arrayLayers` specified in `VkImageCreateInfo` when image was created.

For each `VkImageSubresourceRange` element of `pRanges`, if the `layerCount` member is not `VK_REMAINING_ARRAY_LAYERS`, then `baseArrayLayer + layerCount` must be less than or equal to the `arrayLayers` specified in `VkImageCreateInfo` when image was created.

image must have a depth/stencil format.

If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, image must not be a protected image.

If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, image must not be an unprotected image.

Valid Usage (Implicit)

commandBuffer must be a valid `VkCommandBuffer` handle

image must be a valid `VkImage` handle

imageLayout must be a valid `VkImageLayout` value

pDepthStencil-parameter
pDepthStencil must be a valid pointer to a valid VkClearDepthStencilValue structure

- VUID-vkCmdClearDepthStencilImage-pRanges-parameter
  pRanges must be a valid pointer to an array of rangeCount valid VkImageSubresourceRange structures

- VUID-vkCmdClearDepthStencilImage-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdClearDepthStencilImage-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdClearDepthStencilImage-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdClearDepthStencilImage-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdClearDepthStencilImage-rangeCount-arraylength
  rangeCount must be greater than 0

- VUID-vkCmdClearDepthStencilImage-commonparent
  Both of commandBuffer, and image must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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Clears outside render pass instances are treated as transfer operations for the purposes of memory barriers.

19.2. Clearing Images Inside A Render Pass Instance

To clear one or more regions of color and depth/stencil attachments inside a render pass instance, call:
void vkCmdClearAttachments(
    VkCommandBuffer commandBuffer,
    uint32_t attachmentCount,
    const VkClearAttachment* pAttachments,
    uint32_t rectCount,
    const VkClearRect* pRects);

- `commandBuffer` is the command buffer into which the command will be recorded.
- `attachmentCount` is the number of entries in the `pAttachments` array.
- `pAttachments` is a pointer to an array of `VkClearAttachment` structures defining the attachments to clear and the clear values to use.
- `rectCount` is the number of entries in the `pRects` array.
- `pRects` is a pointer to an array of `VkClearRect` structures defining regions within each selected attachment to clear.

If the render pass has a fragment density map attachment, clears follow the operations of fragment density maps as if each clear region was a primitive which generates fragments. The clear color is applied to all pixels inside each fragment's area regardless if the pixels lie outside of the clear region. Clears may have a different set of supported fragment areas than draws.

Unlike other clear commands, `vkCmdClearAttachments` is not a transfer command. It performs its operations in rasterization order. For color attachments, the operations are executed as color attachment writes, by the `VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT` stage. For depth/stencil attachments, the operations are executed as depth writes and stencil writes by the `VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT` and `VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT` stages.

`vkCmdClearAttachments` is not affected by the bound pipeline state.

**Note**

It is generally preferable to clear attachments by using the `VK_ATTACHMENT_LOAD_OP_CLEAR` load operation at the start of rendering, as it is more efficient on some implementations.

If any attachment's `aspectMask` to be cleared is not backed by an image view, the clear has no effect on that aspect.

If an attachment being cleared refers to an image view created with an `aspectMask` equal to one of `VK_IMAGE_ASPECT_PLANE_0_BIT`, `VK_IMAGE_ASPECT_PLANE_1_BIT` or `VK_IMAGE_ASPECT_PLANE_2_BIT`, it is considered to be `VK_IMAGE_ASPECT_COLOR_BIT` for purposes of this command, and must be cleared with the `VK_IMAGE_ASPECT_COLOR_BIT` aspect as specified by image view creation.

**Valid Usage**

- VUID-vkCmdClearAttachments-aspectMask-07884
  If the current render pass instance does not use dynamic rendering, and the `aspectMask`
member of any element of pAttachments contains VK_IMAGE_ASPECT_DEPTH_BIT, the current subpass instance’s depth-stencil attachment must be either VK_ATTACHMENT_UNUSED or the attachment format must contain a depth component

• VUID-vkCmdClearAttachments-aspectMask-07885
If the current render pass instance does not use dynamic rendering, and the aspectMask member of any element of pAttachments contains VK_IMAGE_ASPECT_STENCIL_BIT, the current subpass instance’s depth-stencil attachment must be either VK_ATTACHMENT_UNUSED or the attachment format must contain a stencil component

• VUID-vkCmdClearAttachments-aspectMask-07271
If the aspectMask member of any element of pAttachments contains VK_IMAGE_ASPECT_COLOR_BIT, the colorAttachment must be a valid color attachment index in the current render pass instance

• VUID-vkCmdClearAttachments-rect-02682
The rect member of each element of pRects must have an extent.width greater than 0

• VUID-vkCmdClearAttachments-rect-02683
The rect member of each element of pRects must have an extent.height greater than 0

• VUID-vkCmdClearAttachments-pRects-00016
The rectangular region specified by each element of pRects must be contained within the render area of the current render pass instance

• VUID-vkCmdClearAttachments-pRects-06937
The layers specified by each element of pRects must be contained within every attachment that pAttachments refers to, i.e. for each element of pRects, VkClearRect::baseArrayLayer + VkClearRect::layerCount must be less than or equal to the number of layers rendered to in the current render pass instance

• VUID-vkCmdClearAttachments-layerCount-01934
The layerCount member of each element of pRects must not be 0

• VUID-vkCmdClearAttachments-commandBuffer-02504
If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, each attachment to be cleared must not be a protected image

• VUID-vkCmdClearAttachments-commandBuffer-02505
If commandBuffer is a protected command buffer and protectedNoFault is not supported, each attachment to be cleared must not be an unprotected image

• VUID-vkCmdClearAttachments-baseArrayLayer-00018
If the render pass instance this is recorded in uses multiview, then baseArrayLayer must be zero and layerCount must be one

Valid Usage (Implicit)

• VUID-vkCmdClearAttachments-commandBuffer-parameter
commandBuffer must be a valid VkCommandBuffer handle

• VUID-vkCmdClearAttachments-pAttachments-parameter
pAttachments must be a valid pointer to an array of attachmentCount valid
**VkClearAttachment** structures

- **VUID-vkCmdClearAttachments-pRects-parameter**
  
  *pRects must* be a valid pointer to an array of *rectCount VkClearRect* structures

- **VUID-vkCmdClearAttachments-commandBuffer-recording**
  
  *commandBuffer must* be in the *recording state*

- **VUID-vkCmdClearAttachments-commandBuffer-cmdpool**
  
  The *VkCommandPool* that *commandBuffer* was allocated from *must* support graphics operations

- **VUID-vkCmdClearAttachments-renderpass**
  
  This command *must* only be called inside of a render pass instance

- **VUID-vkCmdClearAttachments-videocoding**
  
  This command *must* only be called outside of a video coding scope

- **VUID-vkCmdClearAttachments-attachmentCount-arraylength**
  
  *attachmentCount must* be greater than 0

- **VUID-vkCmdClearAttachments-rectCount-arraylength**
  
  *rectCount must* be greater than 0

**Host Synchronization**

- Host access to *commandBuffer* *must* be externally synchronized

- Host access to the *VkCommandPool* that *commandBuffer* was allocated from *must* be externally synchronized

**Command Properties**

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</table>

The *VkClearRect* structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkClearRect {
    VkRect2D rect;
    uint32_t baseArrayLayer;
    uint32_t layerCount;
} VkClearRect;
```

- *rect* is the two-dimensional region to be cleared.
• **baseArrayLayer** is the first layer to be cleared.
• **layerCount** is the number of layers to clear.

The layers \([\text{baseArrayLayer}, \text{baseArrayLayer} + \text{layerCount}]\) counting from the base layer of the attachment image view are cleared.

The **VkClearAttachment** structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkClearAttachment {
    VkImageAspectFlags aspectMask;
    uint32_t colorAttachment;
    VkClearValue clearValue;
} VkClearAttachment;
```

• **aspectMask** is a mask selecting the color, depth and/or stencil aspects of the attachment to be cleared.

• **colorAttachment** is only meaningful if **VK_IMAGE_ASPECT_COLOR_BIT** is set in **aspectMask**, in which case it is an index into the currently bound color attachments.

• **clearValue** is the color or depth/stencil value to clear the attachment to, as described in **Clear Values** below.

### Valid Usage

• VUID-VkClearAttachment-aspectMask-00019
  If **aspectMask** includes **VK_IMAGE_ASPECT_COLOR_BIT**, it must not include **VK_IMAGE_ASPECT_DEPTH_BIT** or **VK_IMAGE_ASPECT_STENCIL_BIT**

• VUID-VkClearAttachment-aspectMask-00020
  **aspectMask** must not include **VK_IMAGE_ASPECT_METADATA_BIT**

• VUID-VkClearAttachment-aspectMask-02246
  **aspectMask** must not include **VK_IMAGE_ASPECT_MEMORY_PLANE_i_BIT_EXT** for any index \(i\)

• VUID-VkClearAttachment-clearValue-00021
  **clearValue** must be a valid **VkClearValue** union

### Valid Usage (Implicit)

• VUID-VkClearAttachment-aspectMask-parameter
  **aspectMask** must be a valid combination of **VkImageAspectFlagBits** values

• VUID-VkClearAttachment-aspectMask-requiredbitmask
  **aspectMask** must not be \(0\)
19.3. Clear Values

The `VkClearColorValue` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef union VkClearColorValue {
    float   float32[4];
    int32_t  int32[4];
    uint32_t uint32[4];
} VkClearColorValue;
```

- `float32` are the color clear values when the format of the image or attachment is one of the numeric formats with a numeric type that is floating-point. Floating point values are automatically converted to the format of the image, with the clear value being treated as linear if the image is sRGB.

- `int32` are the color clear values when the format of the image or attachment has a numeric type that is signed integer (`SINT`). Signed integer values are converted to the format of the image by casting to the smaller type (with negative 32-bit values mapping to negative values in the smaller type). If the integer clear value is not representable in the target type (e.g. would overflow in conversion to that type), the clear value is undefined.

- `uint32` are the color clear values when the format of the image or attachment has a numeric type that is unsigned integer (`UINT`). Unsigned integer values are converted to the format of the image by casting to the integer type with fewer bits.

The four array elements of the clear color map to R, G, B, and A components of image formats, in order.

If the image has more than one sample, the same value is written to all samples for any pixels being cleared.

The `VkClearDepthStencilValue` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkClearDepthStencilValue {
    float   depth;
    uint32_t stencil;
} VkClearDepthStencilValue;
```

- `depth` is the clear value for the depth aspect of the depth/stencil attachment. It is a floating-point value which is automatically converted to the attachment’s format.

- `stencil` is the clear value for the stencil aspect of the depth/stencil attachment. It is a 32-bit integer value which is converted to the attachment’s format by taking the appropriate number of LSBs.
Valid Usage

• VUID-VkClearDepthStencilValue-depth-00022
  Unless the VK_EXT_depth_range_unrestricted extension is enabled depth must be between 0.0 and 1.0, inclusive

The VkClearValue union is defined as:

```cpp
// Provided by VK_VERSION_1_0
typedef union VkClearValue {
  VkClearColorValue color;
  VkClearDepthStencilValue depthStencil;
} VkClearValue;
```

• color specifies the color image clear values to use when clearing a color image or attachment.
• depthStencil specifies the depth and stencil clear values to use when clearing a depth/stencil image or attachment.

This union is used where part of the API requires either color or depth/stencil clear values, depending on the attachment, and defines the initial clear values in the VkRenderPassBeginInfo structure.

19.4. Filling Buffers

To clear buffer data, call:

```cpp
// Provided by VK_VERSION_1_0
void vkCmdFillBuffer(
  VkCommandBuffer commandBuffer,
  VkBuffer dstBuffer,
  VkDeviceSize dstOffset,
  VkDeviceSize size,
  uint32_t data);
```

• commandBuffer is the command buffer into which the command will be recorded.
• dstBuffer is the buffer to be filled.
• dstOffset is the byte offset into the buffer at which to start filling, and must be a multiple of 4.
• size is the number of bytes to fill, and must be either a multiple of 4, or VK_WHOLE_SIZE to fill the range from offset to the end of the buffer. If VK_WHOLE_SIZE is used and the remaining size of the buffer is not a multiple of 4, then the nearest smaller multiple is used.
• data is the 4-byte word written repeatedly to the buffer to fill size bytes of data. The data word is written to memory according to the host endianness.

vkCmdFillBuffer is treated as a “transfer” operation for the purposes of synchronization barriers.
The **VK_BUFFER_USAGE_TRANSFER_DST_BIT** must be specified in *usage* of `VkBufferCreateInfo` in order for the buffer to be compatible with `vkCmdFillBuffer`.

### Valid Usage

- **VUID-vkCmdFillBuffer-dstOffset-00024**
  
  `dstOffset` **must** be less than the size of `dstBuffer`

- **VUID-vkCmdFillBuffer-dstOffset-00025**
  
  `dstOffset` **must** be a multiple of 4

- **VUID-vkCmdFillBuffer-size-00026**
  
  If `size` is not equal to `VK_WHOLE_SIZE`, `size` **must** be greater than 0

- **VUID-vkCmdFillBuffer-size-00027**
  
  If `size` is not equal to `VK_WHOLE_SIZE`, `size` **must** be less than or equal to the size of `dstBuffer` minus `dstOffset`

- **VUID-vkCmdFillBuffer-size-00028**
  
  If `size` is not equal to `VK_WHOLE_SIZE`, `size` **must** be a multiple of 4

- **VUID-vkCmdFillBuffer-dstBuffer-00029**
  
  `dstBuffer` **must** have been created with `VK_BUFFER_USAGE_TRANSFER_DST_BIT` usage flag

- **VUID-vkCmdFillBuffer-apiVersion-07894**
  
  If the **VK_KHR_maintenance1** extension is not enabled and `VkPhysicalDeviceProperties::apiVersion` is less than Vulkan 1.1, the `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics or compute operations

- **VUID-vkCmdFillBuffer-dstBuffer-00031**
  
  If `dstBuffer` is non-sparse then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdFillBuffer-commandBuffer-01811**
  
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `dstBuffer` **must** not be a protected buffer

- **VUID-vkCmdFillBuffer-commandBuffer-01812**
  
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, `dstBuffer` **must** not be an unprotected buffer

### Valid Usage (Implicit)

- **VUID-vkCmdFillBuffer-commandBuffer-parameter**
  
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- **VUID-vkCmdFillBuffer-dstBuffer-parameter**
  
  `dstBuffer` **must** be a valid `VkBuffer` handle

- **VUID-vkCmdFillBuffer-commandBuffer-recording**
  
  `commandBuffer` **must** be in the recording state

- **VUID-vkCmdFillBuffer-commandBuffer-cmdpool**
  
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support transfer, graphics
or compute operations

- VUID-vkCmdFillBuffer-renderpass
  This command must only be called outside of a render pass instance
- VUID-vkCmdFillBuffer-videocoding
  This command must only be called outside of a video coding scope
- VUID-vkCmdFillBuffer-commonparent
  Both of commandBuffer, and dstBuffer must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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<td>Outside</td>
<td>Outside</td>
<td>Transfer Graphics</td>
<td>Action</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td>Compute</td>
<td></td>
</tr>
</tbody>
</table>

19.5. Updating Buffers

To update buffer data inline in a command buffer, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdUpdateBuffer(
  VkCommandBuffer commandBuffer,
  VkBuffer dstBuffer,
  VkDeviceSize dstOffset,
  VkDeviceSize dataSize,
  const void* pData);
```

- commandBuffer is the command buffer into which the command will be recorded.
- dstBuffer is a handle to the buffer to be updated.
- dstOffset is the byte offset into the buffer to start updating, and must be a multiple of 4.
- dataSize is the number of bytes to update, and must be a multiple of 4.
- pData is a pointer to the source data for the buffer update, and must be at least dataSize bytes in
size.

dataSize must be less than or equal to 65536 bytes. For larger updates, applications can use buffer to buffer copies.

**Note**

Buffer updates performed with vkCmdUpdateBuffer first copy the data into command buffer memory when the command is recorded (which requires additional storage and may incur an additional allocation), and then copy the data from the command buffer into dstBuffer when the command is executed on a device.

The additional cost of this functionality compared to buffer to buffer copies means it is only recommended for very small amounts of data, and is why it is limited to only 65536 bytes.

Applications can work around this by issuing multiple vkCmdUpdateBuffer commands to different ranges of the same buffer, but it is strongly recommended that they should not.

The source data is copied from the user pointer to the command buffer when the command is called.

vkCmdUpdateBuffer is only allowed outside of a render pass. This command is treated as a “transfer” operation for the purposes of synchronization barriers. The VK_BUFFER_USAGE_TRANSFER_DST_BIT must be specified in usage of VkBufferCreateInfo in order for the buffer to be compatible with vkCmdUpdateBuffer.

**Valid Usage**

- VUID-vkCmdUpdateBuffer-dstOffset-00032
dstOffset must be less than the size of dstBuffer

- VUID-vkCmdUpdateBuffer-dataSize-00033
dataSize must be less than or equal to the size of dstBuffer minus dstOffset

- VUID-vkCmdUpdateBuffer-dstBuffer-00034
dstBuffer must have been created with VK_BUFFER_USAGE_TRANSFER_DST_BIT usage flag

- VUID-vkCmdUpdateBuffer-dstBuffer-00035
If dstBuffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdUpdateBuffer-dstOffset-00036
dstOffset must be a multiple of 4

- VUID-vkCmdUpdateBuffer-dataSize-00037
dataSize must be less than or equal to 65536

- VUID-vkCmdUpdateBuffer-dataSize-00038
dataSize must be a multiple of 4
• VUID-vkCmdUpdateBuffer-commandBuffer-01813
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, dstBuffer must not be a protected buffer

• VUID-vkCmdUpdateBuffer-commandBuffer-01814
  If commandBuffer is a protected command buffer and protectedNoFault is not supported, dstBuffer must not be an unprotected buffer

**Valid Usage (Implicit)**

• VUID-vkCmdUpdateBuffer-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

• VUID-vkCmdUpdateBuffer-dstBuffer-parameter
  dstBuffer must be a valid VkBuffer handle

• VUID-vkCmdUpdateBuffer-pData-parameter
  pData must be a valid pointer to an array of dataSize bytes

• VUID-vkCmdUpdateBuffer-commandBuffer-recording
  commandBuffer must be in the recording state

• VUID-vkCmdUpdateBuffer-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support transfer, graphics, or compute operations

• VUID-vkCmdUpdateBuffer-renderpass
  This command must only be called outside of a render pass instance

• VUID-vkCmdUpdateBuffer-videocoding
  This command must only be called outside of a video coding scope

• VUID-vkCmdUpdateBuffer-dataSize-arraylength
  dataSize must be greater than 0

• VUID-vkCmdUpdateBuffer-commonparent
  Both of commandBuffer, and dstBuffer must have been created, allocated, or retrieved from the same VkDevice

**Host Synchronization**

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
## Command Properties

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<td>Action</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td>Compute</td>
<td></td>
</tr>
</tbody>
</table>

### Note

The `pData` parameter was of type `uint32_t*` instead of `void*` prior to version 1.0.19 of the Specification and `VK_HEADER_VERSION` 19 of the Vulkan Header Files. This was a historical anomaly, as the source data may be of other types.
Chapter 20. Copy Commands

An application can copy buffer and image data using several methods described in this chapter, depending on the type of data transfer.

All copy commands are treated as “transfer” operations for the purposes of synchronization barriers.

All copy commands that have a source format with an X component in its format description read undefined values from those bits.

All copy commands that have a destination format with an X component in its format description write undefined values to those bits.

20.1. Copying Data Between Buffers

To copy data between buffer objects, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdCopyBuffer(
    VkCommandBuffer commandBuffer,
    VkBuffer srcBuffer,
    VkBuffer dstBuffer,
    uint32_t regionCount,
    const VkBufferCopy* pRegions);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `srcBuffer` is the source buffer.
- `dstBuffer` is the destination buffer.
- `regionCount` is the number of regions to copy.
- `pRegions` is a pointer to an array of `VkBufferCopy` structures specifying the regions to copy.

Each source region specified by `pRegions` is copied from the source buffer to the destination region of the destination buffer. If any of the specified regions in `srcBuffer` overlaps in memory with any of the specified regions in `dstBuffer`, values read from those overlapping regions are undefined.

Valid Usage

- VUID-vkCmdCopyBuffer-commandBuffer-01822
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `srcBuffer` must not be a protected buffer
- VUID-vkCmdCopyBuffer-commandBuffer-01823
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `dstBuffer` must not be a protected buffer
- VUID-vkCmdCopyBuffer-commandBuffer-01824
If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, `dstBuffer` must not be an unprotected buffer

- **VUID-vkCmdCopyBuffer-srcOffset-00113**
  The `srcOffset` member of each element of `pRegions` must be less than the size of `srcBuffer`.

- **VUID-vkCmdCopyBuffer-dstOffset-00114**
  The `dstOffset` member of each element of `pRegions` must be less than the size of `dstBuffer`.

- **VUID-vkCmdCopyBuffer-size-00115**
  The `size` member of each element of `pRegions` must be less than or equal to the size of `srcBuffer` minus `srcOffset`.

- **VUID-vkCmdCopyBuffer-size-00116**
  The `size` member of each element of `pRegions` must be less than or equal to the size of `dstBuffer` minus `dstOffset`.

- **VUID-vkCmdCopyBuffer-pRegions-00117**
  The union of the source regions, and the union of the destination regions, specified by the elements of `pRegions`, must not overlap in memory.

- **VUID-vkCmdCopyBuffer-srcBuffer-00118**
  `srcBuffer` must have been created with `VK_BUFFER_USAGE_TRANSFER_SRC_BIT` usage flag.

- **VUID-vkCmdCopyBuffer-srcBuffer-00119**
  If `srcBuffer` is non-sparse then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

- **VUID-vkCmdCopyBuffer-dstBuffer-00120**
  `dstBuffer` must have been created with `VK_BUFFER_USAGE_TRANSFER_DST_BIT` usage flag.

- **VUID-vkCmdCopyBuffer-dstBuffer-00121**
  If `dstBuffer` is non-sparse then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

### Valid Usage (Implicit)

- **VUID-vkCmdCopyBuffer-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- **VUID-vkCmdCopyBuffer-srcBuffer-parameter**
  `srcBuffer` must be a valid `VkBuffer` handle.

- **VUID-vkCmdCopyBuffer-dstBuffer-parameter**
  `dstBuffer` must be a valid `VkBuffer` handle.

- **VUID-vkCmdCopyBuffer-pRegions-parameter**
  `pRegions` must be a valid pointer to an array of `regionCount` valid `VkBufferCopy` structures.

- **VUID-vkCmdCopyBuffer-commandBuffer-recording**
  `commandBuffer` must be in the recording state.

- **VUID-vkCmdCopyBuffer-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support transfer, graphics, or compute operations.
- VUID-vkCmdCopyBuffer-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdCopyBuffer-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdCopyBuffer-regionCount-arraylength
  regionCount must be greater than 0

- VUID-vkCmdCopyBuffer-commonparent
  Each of commandBuffer, dstBuffer, and srcBuffer must have been created, allocated, or retrieved from the same VkDevice

**Host Synchronization**

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

**Command Properties**

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
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<tr>
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<td>Outside</td>
<td>Outside</td>
<td>Transfer Graphics Compute</td>
<td>Action</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The VkBufferCopy structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkBufferCopy {
    VkDeviceSize srcOffset;
    VkDeviceSize dstOffset;
    VkDeviceSize size;
} VkBufferCopy;
```

- `srcOffset` is the starting offset in bytes from the start of srcBuffer.
- `dstOffset` is the starting offset in bytes from the start of dstBuffer.
- `size` is the number of bytes to copy.

**Valid Usage**

- VUID-VkBufferCopy-size-01988
  The size must be greater than 0
A more extensible version of the copy buffer command is defined below.

To copy data between buffer objects, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdCopyBuffer2(
    VkCommandBuffer commandBuffer,
    const VkCopyBufferInfo2* pCopyBufferInfo);
```

or the equivalent command

```c
// Provided by VK_KHR_copy_commands2
void vkCmdCopyBuffer2KHR(
    VkCommandBuffer commandBuffer,
    const VkCopyBufferInfo2* pCopyBufferInfo);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `pCopyBufferInfo` is a pointer to a `VkCopyBufferInfo2` structure describing the copy parameters.

Each source region specified by `pCopyBufferInfo->pRegions` is copied from the source buffer to the destination region of the destination buffer. If any of the specified regions in `pCopyBufferInfo->srcBuffer` overlaps in memory with any of the specified regions in `pCopyBufferInfo->dstBuffer`, values read from those overlapping regions are undefined.

### Valid Usage

- **VUID-vkCmdCopyBuffer2-commandBuffer-01822**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `srcBuffer` **must** not be a protected buffer

- **VUID-vkCmdCopyBuffer2-commandBuffer-01823**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `dstBuffer` **must** not be a protected buffer

- **VUID-vkCmdCopyBuffer2-commandBuffer-01824**
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, `dstBuffer` **must** not be an unprotected buffer

### Valid Usage (Implicit)

- **VUID-vkCmdCopyBuffer2-commandBuffer-parameter**
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- **VUID-vkCmdCopyBuffer2-pCopyBufferInfo-parameter**
  `pCopyBufferInfo` **must** be a valid pointer to a valid `VkCopyBufferInfo2` structure

- **VUID-vkCmdCopyBuffer2-commandBuffer-recording**
commandBuffer must be in the recording state

- VUID-vkCmdCopyBuffer2-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support transfer, graphics, or compute operations

- VUID-vkCmdCopyBuffer2-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdCopyBuffer2-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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<tbody>
<tr>
<td>Primary</td>
<td>Secondary</td>
<td>Outside</td>
<td>Outside</td>
<td>Transfer Graphics Compute</td>
</tr>
</tbody>
</table>

The VkCopyBufferInfo2 structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkCopyBufferInfo2 {
  VkStructureType sType;
  const void* pNext;
  VkBuffer srcBuffer;
  VkBuffer dstBuffer;
  uint32_t regionCount;
  const VkBufferCopy2* pRegions;
} VkCopyBufferInfo2;
```

or the equivalent

```c
// Provided by VK_KHR_copy_commands2
typedef VkCopyBufferInfo2 VkCopyBufferInfo2KHR;
```

- `sType` is a VkStructureType value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.
• **srcBuffer** is the source buffer.
• **dstBuffer** is the destination buffer.
• **regionCount** is the number of regions to copy.
• **pRegions** is a pointer to an array of VkBufferCopy2 structures specifying the regions to copy.

### Valid Usage

- **VUID-VkCopyBufferInfo2-srcOffset-00113**
  The **srcOffset** member of each element of **pRegions** must be less than the size of **srcBuffer**

- **VUID-VkCopyBufferInfo2-dstOffset-00114**
  The **dstOffset** member of each element of **pRegions** must be less than the size of **dstBuffer**

- **VUID-VkCopyBufferInfo2-size-00115**
  The **size** member of each element of **pRegions** must be less than or equal to the size of **srcBuffer** minus **srcOffset**

- **VUID-VkCopyBufferInfo2-size-00116**
  The **size** member of each element of **pRegions** must be less than or equal to the size of **dstBuffer** minus **dstOffset**

- **VUID-VkCopyBufferInfo2-pRegions-00117**
  The union of the source regions, and the union of the destination regions, specified by the elements of **pRegions**, must not overlap in memory

- **VUID-VkCopyBufferInfo2-srcBuffer-00118**
  **srcBuffer** must have been created with **VK_BUFFER_USAGE_TRANSFER_SRC_BIT** usage flag

- **VUID-VkCopyBufferInfo2-srcBuffer-00119**
  If **srcBuffer** is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- **VUID-VkCopyBufferInfo2-dstBuffer-00120**
  **dstBuffer** must have been created with **VK_BUFFER_USAGE_TRANSFER_DST_BIT** usage flag

- **VUID-VkCopyBufferInfo2-dstBuffer-00121**
  If **dstBuffer** is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

### Valid Usage (Implicit)

- **VUID-VkCopyBufferInfo2-sType-sType**
  sType must be **VK_STRUCTURE_TYPE_COPY_BUFFER_INFO_2**

- **VUID-VkCopyBufferInfo2-pNext-pNext**
  pNext must be **NULL**

- **VUID-VkCopyBufferInfo2-srcBuffer-parameter**
  srcBuffer must be a valid VkBuffer handle
• VUID-VkCopyBufferInfo2-dstBuffer-parameter
dstBuffer must be a valid VkBuffer handle

• VUID-VkCopyBufferInfo2-pRegions-parameter
pRegions must be a valid pointer to an array of regionCount valid VkBufferCopy2 structures

• VUID-VkCopyBufferInfo2-regionCount-arraylength
regionCount must be greater than 0

• VUID-VkCopyBufferInfo2-commonparent
Both of dstBuffer, and srcBuffer must have been created, allocated, or retrieved from the same VkDevice

The VkBufferCopy2 structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkBufferCopy2 {
    VkStructureType sType;
    const void* pNext;
    VkDeviceSize srcOffset;
    VkDeviceSize dstOffset;
    VkDeviceSize size;
} VkBufferCopy2;
```

or the equivalent

```c
// Provided by VK_KHR_copy_commands2
typedef VkBufferCopy2 VkBufferCopy2KHR;
```

• sType is a VkStructureType value identifying this structure.

• pNext is NULL or a pointer to a structure extending this structure.

• srcOffset is the starting offset in bytes from the start of srcBuffer.

• dstOffset is the starting offset in bytes from the start of dstBuffer.

• size is the number of bytes to copy.

Valid Usage

• VUID-VkBufferCopy2-size-01988
The size must be greater than 0

Valid Usage (Implicit)

• VUID-VkBufferCopy2-sType-sType
sType must be VK_STRUCTURE_TYPE_BUFFER_COPY_2
20.2. Copying Data Between Images

To copy data between image objects, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdCopyImage(
    VkCommandBuffer commandBuffer,
    VkImage srcImage,
    VkImageLayout srcImageLayout,
    VkImage dstImage,
    VkImageLayout dstImageLayout,
    uint32_t regionCount,
    const VkImageCopy* pRegions);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `srcImage` is the source image.
- `srcImageLayout` is the current layout of the source image subresource.
- `dstImage` is the destination image.
- `dstImageLayout` is the current layout of the destination image subresource.
- `regionCount` is the number of regions to copy.
- `pRegions` is a pointer to an array of `VkImageCopy` structures specifying the regions to copy.

Each source region specified by `pRegions` is copied from the source image to the destination region of the destination image. If any of the specified regions in `srcImage` overlaps in memory with any of the specified regions in `dstImage`, values read from those overlapping regions are undefined.

**Multi-planar images** can only be copied on a per-plane basis, and the subresources used in each region when copying to or from such images **must** specify only one plane, though different regions **can** specify different planes. When copying planes of multi-planar images, the format considered is the compatible format for that plane, rather than the format of the multi-planar image.

If the format of the destination image has a different block extent than the source image (e.g. one is a compressed format), the offset and extent for each of the regions specified is **scaled according to the block extents of each format** to match in size. Copy regions for each image **must** be aligned to a multiple of the texel block extent in each dimension, except at the edges of the image, where region extents **must** match the edge of the image.

Image data **can** be copied between images with different image types. If one image is `VK_IMAGE_TYPE_3D` and the other image is `VK_IMAGE_TYPE_2D` with multiple layers, then each slice is copied to or from a different layer; **depth** slices in the 3D image correspond to `layerCount` layers in the 2D image, with an effective **depth** of 1 used for the 2D image. If **maintenance5** is enabled, all other combinations are allowed and function as if 1D images are 2D images with a height of 1. Otherwise,
other combinations of image types are disallowed.

**Valid Usage**

- **VUID-vkCmdCopyImage-commandBuffer-01825**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `srcImage` **must** not be a protected image.

- **VUID-vkCmdCopyImage-commandBuffer-01826**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `dstImage` **must** not be a protected image.

- **VUID-vkCmdCopyImage-commandBuffer-01827**
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, `dstImage` **must** not be an unprotected image.

- **VUID-vkCmdCopyImage-pRegions-00124**
  The union of all source regions, and the union of all destination regions, specified by the elements of `pRegions`, **must** not overlap in memory.

- **VUID-vkCmdCopyImage-srcImage-01995**
  The **format features** of `srcImage` **must** contain `VK_FORMAT_FEATURE_TRANSFER_SRC_BIT`.

- **VUID-vkCmdCopyImage-srcImageLayout-00128**
  `srcImageLayout` **must** specify the layout of the image subresources of `srcImage` specified in `pRegions` at the time this command is executed on a `VkDevice`.

- **VUID-vkCmdCopyImage-srcImageLayout-01917**
  `srcImageLayout` **must** be `VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL`, `VK_IMAGE_LAYOUT_GENERAL`, or `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR`.

- **VUID-vkCmdCopyImage-dstImage-01996**
  The **format features** of `dstImage` **must** contain `VK_FORMAT_FEATURE_TRANSFER_DST_BIT`.

- **VUID-vkCmdCopyImage-dstImageLayout-00133**
  `dstImageLayout` **must** specify the layout of the image subresources of `dstImage` specified in `pRegions` at the time this command is executed on a `VkDevice`.

- **VUID-vkCmdCopyImage-dstImageLayout-01395**
  `dstImageLayout` **must** be `VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL`, `VK_IMAGE_LAYOUT_GENERAL`, or `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR`.

- **VUID-vkCmdCopyImage-None-01549**
  In a copy to or from a plane of a multi-planar image, the **VkFormat** of the image and plane **must** be compatible according to the description of compatible planes for the plane being copied.

- **VUID-vkCmdCopyImage-srcImage-09247**
  If the **VkFormat** of each of `srcImage` and `dstImage` is a compressed image format, the formats **must** have the same texel block extent.
The sample count of `srcImage` and `dstImage` must match.

The `srcOffset` and `extent` members of each element of `pRegions` must respect the image transfer granularity requirements of `commandBuffer`'s command pool's queue family, as described in `VkQueueFamilyProperties`.

The `dstOffset` and `extent` members of each element of `pRegions` must respect the image transfer granularity requirements of `commandBuffer`'s command pool's queue family, as described in `VkQueueFamilyProperties`.

If neither `srcImage` nor `dstImage` has a multi-planar image format then for each element of `pRegions`, `srcSubresource.aspectMask` and `dstSubresource.aspectMask` must match.

If `srcImage` has a multi-planar image format, then for each element of `pRegions`, `srcSubresource.aspectMask` must be a single valid multi-planar aspect mask bit.

If `dstImage` has a multi-planar image format, then for each element of `pRegions`, `dstSubresource.aspectMask` must be a single valid multi-planar aspect mask bit.

If `srcImage` has a multi-planar image format and the `dstImage` does not have a multi-planar image format, then for each element of `pRegions`, `dstSubresource.aspectMask` must be `VK_IMAGE_ASPECT_COLOR_BIT`.

If `dstImage` has a multi-planar image format and the `srcImage` does not have a multi-planar image format, then for each element of `pRegions`, `srcSubresource.aspectMask` must be `VK_IMAGE_ASPECT_COLOR_BIT`.

For each element of `pRegions`, `srcSubresource.aspectMask` must specify aspects present in `srcImage`.

If the `VK_KHR_maintenance1` extension is not enabled, `VkPhysicalDeviceProperties::apiVersion` is less than Vulkan 1.1, and either `srcImage` or `dstImage` is of type `VK_IMAGE_TYPE_3D`, then for each element of `pRegions`, `srcSubresource.baseArrayLayer` and `dstSubresource.baseArrayLayer` must each be 0, and `srcSubresource.layerCount` and `dstSubresource.layerCount` must each be 1.

If `srcImage` is of type `VK_IMAGE_TYPE_3D`, then for each element of `pRegions`, `srcSubresource.baseArrayLayer` must be 0 and `srcSubresource.layerCount` must be 1.

If `dstImage` is of type `VK_IMAGE_TYPE_3D`, then for each element of `pRegions`, `dstSubresource.baseArrayLayer` must be 0 and `dstSubresource.layerCount` must be 1.

For each element of `pRegions`, `srcSubresource.aspectMask` must specify aspects present in `srcImage`.

For each element of `pRegions`, `srcSubresource.aspectMask` must specify aspects present in `srcImage`.

If `srcImage` is of type `VK_IMAGE_TYPE_3D`, then for each element of `pRegions`, `srcSubresource.baseArrayLayer` must be 0 and `srcSubresource.layerCount` must be 1.
For each element of \texttt{pRegions}, \texttt{dstSubresource.aspectMask} must specify aspects present in \texttt{dstImage}

- **VUID-vkCmdCopyImage-srcOffset-00144**
  For each element of \texttt{pRegions}, \texttt{srcOffset.x} and \((\text{extent.width} + \text{srcOffset.x})\) must both be greater than or equal to 0 and less than or equal to the width of the specified \texttt{srcSubresource} of \texttt{srcImage}

- **VUID-vkCmdCopyImage-srcOffset-00145**
  For each element of \texttt{pRegions}, \texttt{srcOffset.y} and \((\text{extent.height} + \text{srcOffset.y})\) must both be greater than or equal to 0 and less than or equal to the height of the specified \texttt{srcSubresource} of \texttt{srcImage}

- **VUID-vkCmdCopyImage-srcImage-00146**
  If \texttt{srcImage} is of type \texttt{VK_IMAGE_TYPE_1D}, then for each element of \texttt{pRegions}, \texttt{srcOffset.y} must be 0 and \texttt{extent.height} must be 1

- **VUID-vkCmdCopyImage-srcOffset-00147**
  If \texttt{srcImage} is of type \texttt{VK_IMAGE_TYPE_3D}, then for each element of \texttt{pRegions}, \texttt{srcOffset.z} and \((\text{extent.depth} + \text{srcOffset.z})\) must both be greater than or equal to 0 and less than or equal to the depth of the specified \texttt{srcSubresource} of \texttt{srcImage}

- **VUID-vkCmdCopyImage-srcImage-01785**
  If \texttt{srcImage} is of type \texttt{VK_IMAGE_TYPE_1D}, then for each element of \texttt{pRegions}, \texttt{srcOffset.z} must be 0 and \texttt{extent.depth} must be 1

- **VUID-vkCmdCopyImage-dstImage-01786**
  If \texttt{dstImage} is of type \texttt{VK_IMAGE_TYPE_1D}, then for each element of \texttt{pRegions}, \texttt{dstOffset.z} must be 0 and \texttt{extent.depth} must be 1

- **VUID-vkCmdCopyImage-apiVersion-07933**
  If the \texttt{VK_KHR_maintenance1} extension is not enabled, \texttt{VkPhysicalDeviceProperties::apiVersion} is less than Vulkan 1.1, \texttt{srcImage} and \texttt{dstImage} must have the same \texttt{VkImageType}

- **VUID-vkCmdCopyImage-apiVersion-08969**
  If the \texttt{VK_KHR_maintenance1} extension is not enabled, \texttt{VkPhysicalDeviceProperties::apiVersion} is less than Vulkan 1.1, and \texttt{srcImage} or \texttt{dstImage} is of type \texttt{VK_IMAGE_TYPE_2D}, then for each element of \texttt{pRegions}, \texttt{extent.depth} must be 1

- **VUID-vkCmdCopyImage-srcImage-07743**
  If \texttt{srcImage} and \texttt{dstImage} have a different \texttt{VkImageType}, and \texttt{maintenance5} is not enabled, one must be \texttt{VK_IMAGE_TYPE_3D} and the other must be \texttt{VK_IMAGE_TYPE_2D}

- **VUID-vkCmdCopyImage-maintenance5-08792**
  If the \texttt{maintenance5} feature is not enabled, the \texttt{layerCount} member of \texttt{srcSubresource} or \texttt{dstSubresource} must not be \texttt{VK_REMAINING_ARRAY_LAYERS}
• VUID-vkCmdCopyImage-srcImage-08793
  If srcImage and dstImage have the same VkImageType, and neither of the layerCount members of srcSubresource or dstSubresource are VK_REMAINING_ARRAY_LAYERS, the layerCount members must match

• VUID-vkCmdCopyImage-srcImage-08794
  If srcImage and dstImage have the same VkImageType, and one of the layerCount members of srcSubresource or dstSubresource is VK_REMAINING_ARRAY_LAYERS, the other member must be either VK_REMAINING_ARRAY_LAYERS or equal to the arrayLayers member of the VkImageCreateInfo used to create the image minus baseArrayLayer

• VUID-vkCmdCopyImage-srcImage-01790
  If srcImage and dstImage are both of type VK_IMAGE_TYPE_2D, then for each element of pRegions, extent.depth must be 1

• VUID-vkCmdCopyImage-srcImage-01791
  If srcImage is of type VK_IMAGE_TYPE_2D, and dstImage is of type VK_IMAGE_TYPE_3D, then for each element of pRegions, extent.depth must equal srcSubresource.layerCount

• VUID-vkCmdCopyImage-dstImage-01792
  If dstImage is of type VK_IMAGE_TYPE_2D, and srcImage is of type VK_IMAGE_TYPE_3D, then for each element of pRegions, extent.depth must equal dstSubresource.layerCount

• VUID-vkCmdCopyImage-dstOffset-00150
  For each element of pRegions, dstOffset.x and (extent.width + dstOffset.x) must both be greater than or equal to 0 and less than or equal to the width of the specified dstSubresource of dstImage

• VUID-vkCmdCopyImage-dstOffset-00151
  For each element of pRegions, dstOffset.y and (extent.height + dstOffset.y) must both be greater than or equal to 0 and less than or equal to the height of the specified dstSubresource of dstImage

• VUID-vkCmdCopyImage-dstImage-00152
  If dstImage is of type VK_IMAGE_TYPE_1D, then for each element of pRegions, dstOffset.y must be 0 and extent.height must be 1

• VUID-vkCmdCopyImage-dstOffset-00153
  If dstImage is of type VK_IMAGE_TYPE_3D, then for each element of pRegions, dstOffset.z and (extent.depth + dstOffset.z) must both be greater than or equal to 0 and less than or equal to the depth of the specified dstSubresource of dstImage

• VUID-vkCmdCopyImage-pRegions-07278
  For each element of pRegions, srcOffset.x must be a multiple of the texel block extent width of the VkFormat of srcImage

• VUID-vkCmdCopyImage-pRegions-07279
  For each element of pRegions, srcOffset.y must be a multiple of the texel block extent height of the VkFormat of srcImage

• VUID-vkCmdCopyImage-pRegions-07280
  For each element of pRegions, srcOffset.z must be a multiple of the texel block extent depth of the VkFormat of srcImage

• VUID-vkCmdCopyImage-pRegions-07281
For each element of \texttt{pRegions}, \texttt{dstOffset.x} must be a multiple of the texel block extent width of the \texttt{VkFormat} of \texttt{dstImage}

- VUID-vkCmdCopyImage-pRegions-07282
  For each element of \texttt{pRegions}, \texttt{dstOffset.y} must be a multiple of the texel block extent height of the \texttt{VkFormat} of \texttt{dstImage}

- VUID-vkCmdCopyImage-pRegions-07283
  For each element of \texttt{pRegions}, \texttt{dstOffset.z} must be a multiple of the texel block extent depth of the \texttt{VkFormat} of \texttt{dstImage}

- VUID-vkCmdCopyImage-srcImage-01728
  For each element of \texttt{pRegions}, if the sum of \texttt{srcOffset.x} and \texttt{extent.width} does not equal the width of the subresource specified by \texttt{srcSubresource}, \texttt{extent.width} must be a multiple of the texel block extent width of the \texttt{VkFormat} of \texttt{srcImage}

- VUID-vkCmdCopyImage-srcImage-01729
  For each element of \texttt{pRegions}, if the sum of \texttt{srcOffset.y} and \texttt{extent.height} does not equal the height of the subresource specified by \texttt{srcSubresource}, \texttt{extent.height} must be a multiple of the texel block extent height of the \texttt{VkFormat} of \texttt{srcImage}

- VUID-vkCmdCopyImage-srcImage-01730
  For each element of \texttt{pRegions}, if the sum of \texttt{srcOffset.z} and \texttt{extent.depth} does not equal the depth of the subresource specified by \texttt{srcSubresource}, \texttt{extent.depth} must be a multiple of the texel block extent depth of the \texttt{VkFormat} of \texttt{srcImage}

- VUID-vkCmdCopyImage-dstImage-01732
  For each element of \texttt{pRegions}, if the sum of \texttt{dstOffset.x} and \texttt{extent.width} does not equal the width of the subresource specified by \texttt{dstSubresource}, \texttt{extent.width} must be a multiple of the texel block extent width of the \texttt{VkFormat} of \texttt{dstImage}

- VUID-vkCmdCopyImage-dstImage-01733
  For each element of \texttt{pRegions}, if the sum of \texttt{dstOffset.y} and \texttt{extent.height} does not equal the height of the subresource specified by \texttt{dstSubresource}, \texttt{extent.height} must be a multiple of the texel block extent height of the \texttt{VkFormat} of \texttt{dstImage}

- VUID-vkCmdCopyImage-dstImage-01734
  For each element of \texttt{pRegions}, if the sum of \texttt{dstOffset.z} and \texttt{extent.depth} does not equal the depth of the subresource specified by \texttt{dstSubresource}, \texttt{extent.depth} must be a multiple of the texel block extent depth of the \texttt{VkFormat} of \texttt{dstImage}

- VUID-vkCmdCopyImage-aspect-06662
  If the aspect member of any element of \texttt{pRegions} includes any flag other than \texttt{VK_IMAGE_ASPECT_STENCIL_BIT} or \texttt{srcImage} was not created with separate stencil usage, \texttt{VK_IMAGE_USAGE_TRANSFER_SRC_BIT} must have been included in the \texttt{VkImageCreateInfo} ::usage used to create \texttt{srcImage}

- VUID-vkCmdCopyImage-aspect-06663
  If the aspect member of any element of \texttt{pRegions} includes any flag other than \texttt{VK_IMAGE_ASPECT_STENCIL_BIT} or \texttt{dstImage} was not created with separate stencil usage, \texttt{VK_IMAGE_USAGE_TRANSFER_DST_BIT} must have been included in the \texttt{VkImageCreateInfo} ::usage used to create \texttt{dstImage}

- VUID-vkCmdCopyImage-aspect-06664
If the `aspect` member of any element of `pRegions` includes `VK_IMAGE_ASPECT_STENCIL_BIT`, and `srcImage` was created with separate stencil usage, `VK_IMAGE_USAGE_TRANSFER_SRC_BIT` must have been included in the `VkImageStencilUsageCreateInfo::stencilUsage` used to create `srcImage`.

- **VUID-vkCmdCopyImage-aspect-06665**
  If the `aspect` member of any element of `pRegions` includes `VK_IMAGE_ASPECT_STENCIL_BIT`, and `dstImage` was created with separate stencil usage, `VK_IMAGE_USAGE_TRANSFER_DST_BIT` must have been included in the `VkImageStencilUsageCreateInfo::stencilUsage` used to create `dstImage`.

- **VUID-vkCmdCopyImage-srcImage-07966**
  If `srcImage` is non-sparse then the image or the specified disjoint plane must be bound completely and contiguously to a single `VkDeviceMemory` object.

- **VUID-vkCmdCopyImage-srcSubresource-07967**
  The `srcSubresource.mipLevel` member of each element of `pRegions` must be less than the `mipLevels` specified in `VkImageCreateInfo` when `srcImage` was created.

- **VUID-vkCmdCopyImage-srcSubresource-07968**
  The `srcSubresource.baseArrayLayer + srcSubresource.layerCount` of each element of `pRegions`, if `srcSubresource.layerCount` is not `VK_REMAINING_ARRAY_LAYERS` and `maintenance5` is not enabled, must be less than or equal to the `arrayLayers` specified in `VkImageCreateInfo` when `srcImage` was created.

- **VUID-vkCmdCopyImage-srcImage-07969**
  `srcImage` must not have been created with flags containing `VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT`.

- **VUID-vkCmdCopyImage-dstImage-07966**
  If `dstImage` is non-sparse then the image or the specified disjoint plane must be bound completely and contiguously to a single `VkDeviceMemory` object.

- **VUID-vkCmdCopyImage-dstSubresource-07967**
  The `dstSubresource.mipLevel` member of each element of `pRegions` must be less than the `mipLevels` specified in `VkImageCreateInfo` when `dstImage` was created.

- **VUID-vkCmdCopyImage-dstSubresource-07968**
  The `dstSubresource.baseArrayLayer + dstSubresource.layerCount` of each element of `pRegions`, if `dstSubresource.layerCount` is not `VK_REMAINING_ARRAY_LAYERS` and `maintenance5` is not enabled, must be less than or equal to the `arrayLayers` specified in `VkImageCreateInfo` when `dstImage` was created.

- **VUID-vkCmdCopyImage-dstImage-07969**
  `dstImage` must not have been created with flags containing `VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT`.

---

**Valid Usage (Implicit)**

- **VUID-vkCmdCopyImage-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle.
VUID-vkCmdCopyImage-srcImage-parameter
srcImage must be a valid VkImage handle

VUID-vkCmdCopyImage-srcImageLayout-parameter
srcImageLayout must be a valid VkImageLayout value

VUID-vkCmdCopyImage-dstImage-parameter
dstImage must be a valid VkImage handle

VUID-vkCmdCopyImage-dstImageLayout-parameter
dstImageLayout must be a valid VkImageLayout value

VUID-vkCmdCopyImage-pRegions-parameter
pRegions must be a valid pointer to an array of regionCount valid VkImageCopy structures

VUID-vkCmdCopyImage-commandBuffer-recording
commandBuffer must be in the recording state

VUID-vkCmdCopyImage-commandBuffer-cmdpool
The VkCommandPool that commandBuffer was allocated from must support transfer, graphics, or compute operations

VUID-vkCmdCopyImage-renderpass
This command must only be called outside of a render pass instance

VUID-vkCmdCopyImage-videocoding
This command must only be called outside of a video coding scope

VUID-vkCmdCopyImage-regionCount-arraylength
regionCount must be greater than 0

VUID-vkCmdCopyImage-commonparent
Each of commandBuffer, dstImage, and srcImage must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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The VkImageCopy structure is defined as:
typedef struct VkImageCopy {
    VkImageSubresourceLayers srcSubresource;
    VkOffset3D srcOffset;
    VkImageSubresourceLayers dstSubresource;
    VkOffset3D dstOffset;
    VkExtent3D extent;
} VkImageCopy;

- `srcSubresource` and `dstSubresource` are `VkImageSubresourceLayers` structures specifying the image subresources of the images used for the source and destination image data, respectively.
- `srcOffset` and `dstOffset` select the initial \(x\), \(y\), and \(z\) offsets in texels of the sub-regions of the source and destination image data.
- `extent` is the size in texels of the image to copy in width, height and depth.

Valid Usage

- VUID-VkImageCopy-apiVersion-07940
  If the `VK_KHR_sampler_ycbcr_conversion` extension is not enabled and `VkPhysicalDeviceProperties::apiVersion` is less than Vulkan 1.1, the `aspectMask` member of `srcSubresource` and `dstSubresource` must match

- VUID-VkImageCopy-apiVersion-07941
  If the `VK_KHR_maintenance1` extension is not enabled and `VkPhysicalDeviceProperties::apiVersion` is less than Vulkan 1.1, the `layerCount` member of `srcSubresource` and `dstSubresource` must match

- VUID-VkImageCopy-extent-06668
  `extent.width` must not be 0

- VUID-VkImageCopy-extent-06669
  `extent.height` must not be 0

- VUID-VkImageCopy-extent-06670
  `extent.depth` must not be 0

Valid Usage (Implicit)

- VUID-VkImageCopy-srcSubresource-parameter
  `srcSubresource` must be a valid `VkImageSubresourceLayers` structure

- VUID-VkImageCopy-dstSubresource-parameter
  `dstSubresource` must be a valid `VkImageSubresourceLayers` structure

The `VkImageSubresourceLayers` structure is defined as:

// Provided by VK_VERSION_1_0
typedef struct VkImageSubresourceLayers {
    VkImageAspectFlags aspectMask;
    uint32_t mipLevel;
    uint32_t baseArrayLayer;
    uint32_t layerCount;
} VkImageSubresourceLayers;

• aspectMask is a combination of VkImageAspectFlagBits, selecting the color, depth and/or stencil aspects to be copied.
• mipLevel is the mipmap level to copy
• baseArrayLayer and layerCount are the starting layer and number of layers to copy.

### Valid Usage

- VUID-VkImageSubresourceLayers-aspectMask-00167
  If aspectMask contains VK_IMAGE_ASPECT_COLOR_BIT, it must not contain either of
  VK_IMAGE_ASPECT_DEPTH_BIT or VK_IMAGE_ASPECT_STENCIL_BIT

- VUID-VkImageSubresourceLayers-aspectMask-00168
  aspectMask must not contain VK_IMAGE_ASPECT_METADATA_BIT

- VUID-VkImageSubresourceLayers-aspectMask-02247
  aspectMask must not include VK_IMAGE_ASPECT_MEMORY_PLANE_i_BIT_EXT for any index i

- VUID-VkImageSubresourceLayers-layerCount-09243
  If the maintenance5 feature is not enabled, layerCount must not be
  VK_REMAINING_ARRAY_LAYERS

- VUID-VkImageSubresourceLayers-layerCount-01700
  If layerCount is not VK_REMAINING_ARRAY_LAYERS, it must be greater than 0

### Valid Usage (Implicit)

- VUID-VkImageSubresourceLayers-aspectMask-parameter
  aspectMask must be a valid combination of VkImageAspectFlagBits values

- VUID-VkImageSubresourceLayers-aspectMask-requiredbitmask
  aspectMask must not be 0

A more extensible version of the copy image command is defined below.

To copy data between image objects, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdCopyImage2(
    VkCommandBuffer commandBuffer, const VkCopyImageInfo2* pCopyImageInfo);
```
or the equivalent command

```c
// Provided by VK_KHR_copy_commands2
void vkCmdCopyImage2KHR(
    VkCommandBuffer commandBuffer,
    const VkCopyImageInfo2* pCopyImageInfo);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `pCopyImageInfo` is a pointer to a `VkCopyImageInfo2` structure describing the copy parameters.

This command is functionally identical to `vkCmdCopyImage`, but includes extensible sub-structures that include `sType` and `pNext` parameters, allowing them to be more easily extended.

### Valid Usage

- **VUID-vkCmdCopyImage2-commandBuffer-01825**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `srcImage` must not be a protected image.

- **VUID-vkCmdCopyImage2-commandBuffer-01826**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `dstImage` must not be a protected image.

- **VUID-vkCmdCopyImage2-commandBuffer-01827**
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, `dstImage` must not be an unprotected image.

### Valid Usage (Implicit)

- **VUID-vkCmdCopyImage2-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- **VUID-vkCmdCopyImage2-pCopyImageInfo-parameter**
  `pCopyImageInfo` must be a valid pointer to a valid `VkCopyImageInfo2` structure.

- **VUID-vkCmdCopyImage2-commandBuffer-recording**
  `commandBuffer` must be in the recording state.

- **VUID-vkCmdCopyImage2-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support transfer, graphics, or compute operations.

- **VUID-vkCmdCopyImage2-renderpass**
  This command must only be called outside of a render pass instance.

- **VUID-vkCmdCopyImage2-videocoding**
  This command must only be called outside of a video coding scope.
Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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</table>

The VkCopyImageInfo2 structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkCopyImageInfo2 {
    VkStructureType sType;
    const void* pNext;
    VkImage srcImage;
    VkImageLayout srcImageLayout;
    VkImage dstImage;
    VkImageLayout dstImageLayout;
    uint32_t regionCount;
    const VkImageCopy2* pRegions;
} VkCopyImageInfo2;
```

or the equivalent

```c
// Provided by VK_KHR_copy_commands2
typedef VkCopyImageInfo2 VkCopyImageInfo2KHR;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `srcImage` is the source image.
- `srcImageLayout` is the current layout of the source image subresource.
- `dstImage` is the destination image.
- `dstImageLayout` is the current layout of the destination image subresource.
- `regionCount` is the number of regions to copy.
- `pRegions` is a pointer to an array of VkImageCopy2 structures specifying the regions to copy.
Valid Usage

- **VUID-VkCopyImageInfo2-pRegions-00124**
  The union of all source regions, and the union of all destination regions, specified by the elements of `pRegions`, **must** not overlap in memory.

- **VUID-VkCopyImageInfo2-srcImage-01995**
  The *format features* of `srcImage` **must** contain `VK_FORMAT_FEATURE_TRANSFER_SRC_BIT`.

- **VUID-VkCopyImageInfo2-srcImageLayout-00128**
  `srcImageLayout` **must** specify the layout of the image subresources of `srcImage` specified in `pRegions` at the time this command is executed on a `VkDevice`.

- **VUID-VkCopyImageInfo2-srcImageLayout-01917**
  `srcImageLayout` **must** be `VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL`, `VK_IMAGE_LAYOUT_GENERAL`, or `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR`.

- **VUID-VkCopyImageInfo2-dstImage-01996**
  The *format features* of `dstImage` **must** contain `VK_FORMAT_FEATURE_TRANSFER_DST_BIT`.

- **VUID-VkCopyImageInfo2-dstImageLayout-00133**
  `dstImageLayout` **must** specify the layout of the image subresources of `dstImage` specified in `pRegions` at the time this command is executed on a `VkDevice`.

- **VUID-VkCopyImageInfo2-dstImageLayout-01395**
  `dstImageLayout` **must** be `VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL`, `VK_IMAGE_LAYOUT_GENERAL`, or `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR`.

- **VUID-VkCopyImageInfo2-srcImage-01548**
  If the `VkFormat` of each of `srcImage` and `dstImage` is not a multi-planar format, the `VkFormat` of each of `srcImage` and `dstImage` **must** be size-compatible.

- **VUID-VkCopyImageInfo2-None-01549**
  In a copy to or from a plane of a multi-planar image, the `VkFormat` of the image and plane **must** be compatible according to the description of compatible planes for the plane being copied.

- **VUID-VkCopyImageInfo2-srcImage-09247**
  If the `VkFormat` of each of `srcImage` and `dstImage` is a compressed image format, the formats **must** have the same texel block extent.

- **VUID-VkCopyImageInfo2-srcImage-00136**
  The sample count of `srcImage` and `dstImage` **must** match.

- **VUID-VkCopyImageInfo2-srcOffset-01783**
  The `srcOffset` and `extent` members of each element of `pRegions` **must** respect the image transfer granularity requirements of `commandBuffer`’s command pool’s queue family, as described in `VkQueueFamilyProperties`.

- **VUID-VkCopyImageInfo2-dstOffset-01784**
  The `dstOffset` and `extent` members of each element of `pRegions` **must** respect the image transfer granularity requirements of `commandBuffer`’s command pool’s queue family, as described in `VkQueueFamilyProperties`.

- **VUID-VkCopyImageInfo2-srcImage-01551**
  1554
If neither srcImage nor dstImage has a multi-planar image format then for each element of pRegions, srcSubresource.aspectMask and dstSubresource.aspectMask must match

- VUID-VkCopyImageInfo2-srcImage-08713
  If srcImage has a multi-planar image format, then for each element of pRegions, srcSubresource.aspectMask must be a single valid multi-planar aspect mask bit

- VUID-VkCopyImageInfo2-dstImage-08714
  If dstImage has a multi-planar image format, then for each element of pRegions, dstSubresource.aspectMask must be a single valid multi-planar aspect mask bit

- VUID-VkCopyImageInfo2-srcImage-01556
  If srcImage has a multi-planar image format and the dstImage does not have a multi-planar image format, then for each element of pRegions, dstSubresource.aspectMask must be VK_IMAGE_ASPECT_COLOR_BIT

- VUID-VkCopyImageInfo2-dstImage-01557
  If dstImage has a multi-planar image format and the srcImage does not have a multi-planar image format, then for each element of pRegions, srcSubresource.aspectMask must be VK_IMAGE_ASPECT_COLOR_BIT

- VUID-VkCopyImageInfo2-apiVersion-07932
  If the VK_KHR_maintenance1 extension is not enabled, VkPhysicalDeviceProperties::apiVersion is less than Vulkan 1.1, and either srcImage or dstImage is of type VK_IMAGE_TYPE_3D, then for each element of pRegions, srcSubresource.baseArrayLayer and dstSubresource.baseArrayLayer must each be 0, and srcSubresource.layerCount and dstSubresource.layerCount must each be 1

- VUID-VkCopyImageInfo2-srcImage-04443
  If srcImage is of type VK_IMAGE_TYPE_3D, then for each element of pRegions, srcSubresource.baseArrayLayer must be 0 and srcSubresource.layerCount must be 1

- VUID-VkCopyImageInfo2-dstImage-04444
  If dstImage is of type VK_IMAGE_TYPE_3D, then for each element of pRegions, dstSubresource.baseArrayLayer must be 0 and dstSubresource.layerCount must be 1

- VUID-VkCopyImageInfo2-aspectMask-00142
  For each element of pRegions, srcSubresource.aspectMask must specify aspects present in srcImage

- VUID-VkCopyImageInfo2-aspectMask-00143
  For each element of pRegions, dstSubresource.aspectMask must specify aspects present in dstImage

- VUID-VkCopyImageInfo2-srcOffset-00144
  For each element of pRegions, srcOffset.x and (extent.width + srcOffset.x) must both be greater than or equal to 0 and less than or equal to the width of the specified srcSubresource of srcImage

- VUID-VkCopyImageInfo2-srcOffset-00145
  For each element of pRegions, srcOffset.y and (extent.height + srcOffset.y) must both be greater than or equal to 0 and less than or equal to the height of the specified srcSubresource of srcImage

- VUID-VkCopyImageInfo2-srcImage-00146
If `srcImage` is of type `VK_IMAGE_TYPE_1D`, then for each element of `pRegions`, `srcOffset.y` must be 0 and `extent.height` must be 1.

- **VUID-VkCopyImageInfo2-srcOffset-00147**
  If `srcImage` is of type `VK_IMAGE_TYPE_3D`, then for each element of `pRegions`, `srcOffset.z` and `(extent.depth + srcOffset.z)` must both be greater than or equal to 0 and less than or equal to the depth of the specified `srcSubresource` of `srcImage`.

- **VUID-VkCopyImageInfo2-srcImage-01785**
  If `srcImage` is of type `VK_IMAGE_TYPE_1D`, then for each element of `pRegions`, `srcOffset.z` must be 0 and `extent.depth` must be 1.

- **VUID-VkCopyImageInfo2-dstImage-01786**
  If `dstImage` is of type `VK_IMAGE_TYPE_1D`, then for each element of `pRegions`, `dstOffset.z` must be 0 and `extent.depth` must be 1.

- **VUID-VkCopyImageInfo2-apiVersion-07933**
  If the `VK_KHR_maintenance1` extension is not enabled, `VkPhysicalDeviceProperties::apiVersion` is less than Vulkan 1.1, `srcImage` and `dstImage` must have the same `VkImageType`.

- **VUID-VkCopyImageInfo2-apiVersion-08969**
  If the `VK_KHR_maintenance1` extension is not enabled, `VkPhysicalDeviceProperties::apiVersion` is less than Vulkan 1.1, and `srcImage` or `dstImage` is of type `VK_IMAGE_TYPE_2D`, then for each element of `pRegions`, `extent.depth` must be 1.

- **VUID-VkCopyImageInfo2-srcImage-07743**
  If `srcImage` and `dstImage` have a different `VkImageType`, and `maintenance5` is not enabled, one must be `VK_IMAGE_TYPE_3D` and the other must be `VK_IMAGE_TYPE_2D`.

- **VUID-VkCopyImageInfo2-maintenance5-08792**
  If the `maintenance5` feature is not enabled, the `layerCount` member of `srcSubresource` or `dstSubresource` must not be `VK_REMAINING_ARRAY_LAYERS`.

- **VUID-VkCopyImageInfo2-srcImage-08793**
  If `srcImage` and `dstImage` have the same `VkImageType`, and neither of the `layerCount` members of `srcSubresource` or `dstSubresource` are `VK_REMAINING_ARRAY_LAYERS`, the `layerCount` members must match.

- **VUID-VkCopyImageInfo2-srcImage-08794**
  If `srcImage` and `dstImage` have the same `VkImageType`, and one of the `layerCount` members of `srcSubresource` or `dstSubresource` is `VK_REMAINING_ARRAY_LAYERS`, the other member must be either `VK_REMAINING_ARRAY_LAYERS` or equal to the `arrayLayers` member of the `VkImageCreateInfo` used to create the image minus `baseArrayLayer`.

- **VUID-VkCopyImageInfo2-srcImage-01790**
  If `srcImage` and `dstImage` are both of type `VK_IMAGE_TYPE_2D`, then for each element of...
pRegions, extent.depth must be 1

- VUID-VkCopyImageInfo2-srcImage-01791
  If srcImage is of type VK_IMAGE_TYPE_2D, and dstImage is of type VK_IMAGE_TYPE_3D, then for each element of pRegions, extent.depth must equal srcSubresource.layerCount

- VUID-VkCopyImageInfo2-dstImage-01792
  If dstImage is of type VK_IMAGE_TYPE_2D, and srcImage is of type VK_IMAGE_TYPE_3D, then for each element of pRegions, extent.depth must equal dstSubresource.layerCount

- VUID-VkCopyImageInfo2-dstOffset-00150
  For each element of pRegions, dstOffset.x and (extent.width + dstOffset.x) must both be greater than or equal to 0 and less than or equal to the width of the specified dstSubresource of dstImage

- VUID-VkCopyImageInfo2-dstOffset-00151
  For each element of pRegions, dstOffset.y and (extent.height + dstOffset.y) must both be greater than or equal to 0 and less than or equal to the height of the specified dstSubresource of dstImage

- VUID-VkCopyImageInfo2-dstImage-00152
  If dstImage is of type VK_IMAGE_TYPE_1D, then for each element of pRegions, dstOffset.y must be 0 and extent.height must be 1

- VUID-VkCopyImageInfo2-dstOffset-00153
  If dstImage is of type VK_IMAGE_TYPE_3D, then for each element of pRegions, dstOffset.z and (extent.depth + dstOffset.z) must both be greater than or equal to 0 and less than or equal to the depth of the specified dstSubresource of dstImage

- VUID-VkCopyImageInfo2-pRegions-07278
  For each element of pRegions, srcOffset.x must be a multiple of the texel block extent width of the VkFormat of srcImage

- VUID-VkCopyImageInfo2-pRegions-07279
  For each element of pRegions, srcOffset.y must be a multiple of the texel block extent height of the VkFormat of srcImage

- VUID-VkCopyImageInfo2-pRegions-07280
  For each element of pRegions, srcOffset.z must be a multiple of the texel block extent depth of the VkFormat of srcImage

- VUID-VkCopyImageInfo2-pRegions-07281
  For each element of pRegions, dstOffset.x must be a multiple of the texel block extent width of the VkFormat of dstImage

- VUID-VkCopyImageInfo2-pRegions-07282
  For each element of pRegions, dstOffset.y must be a multiple of the texel block extent height of the VkFormat of dstImage

- VUID-VkCopyImageInfo2-pRegions-07283
  For each element of pRegions, dstOffset.z must be a multiple of the texel block extent depth of the VkFormat of dstImage

- VUID-VkCopyImageInfo2-srcImage-01728
  For each element of pRegions, if the sum of srcOffset.x and extent.width does not equal the width of the subresource specified by srcSubresource, extent.width must be a multiple
of the texel block extent width of the VkFormat of srcImage

• VUID-VkCopyImageInfo2-srcImage-01729
  For each element of pRegions, if the sum of srcOffset.y and extent.height does not equal the height of the subresource specified by srcSubresource, extent.height must be a multiple of the texel block extent height of the VkFormat of srcImage

• VUID-VkCopyImageInfo2-srcImage-01730
  For each element of pRegions, if the sum of srcOffset.z and extent.depth does not equal the depth of the subresource specified by srcSubresource, extent.depth must be a multiple of the texel block extent depth of the VkFormat of srcImage

• VUID-VkCopyImageInfo2-dstImage-01732
  For each element of pRegions, if the sum of dstOffset.x and extent.width does not equal the width of the subresource specified by dstSubresource, extent.width must be a multiple of the texel block extent width of the VkFormat of dstImage

• VUID-VkCopyImageInfo2-dstImage-01733
  For each element of pRegions, if the sum of dstOffset.y and extent.height does not equal the height of the subresource specified by dstSubresource, extent.height must be a multiple of the texel block extent height of the VkFormat of dstImage

• VUID-VkCopyImageInfo2-dstImage-01734
  For each element of pRegions, if the sum of dstOffset.z and extent.depth does not equal the depth of the subresource specified by dstSubresource, extent.depth must be a multiple of the texel block extent depth of the VkFormat of dstImage

• VUID-VkCopyImageInfo2-aspect-06662
  If the aspect member of any element of pRegions includes any flag other than VK_IMAGE_ASPECT_STENCIL_BIT or srcImage was not created with separate stencil usage, VK_IMAGE_USAGE_TRANSFER_SRC_BIT must have been included in the VkImageCreateInfo::usage used to create srcImage

• VUID-VkCopyImageInfo2-aspect-06663
  If the aspect member of any element of pRegions includes any flag other than VK_IMAGE_ASPECT_STENCIL_BIT or dstImage was not created with separate stencil usage, VK_IMAGE_USAGE_TRANSFER_DST_BIT must have been included in the VkImageCreateInfo::usage used to create dstImage

• VUID-VkCopyImageInfo2-aspect-06664
  If the aspect member of any element of pRegions includes VK_IMAGE_ASPECT_STENCIL_BIT, and srcImage was created with separate stencil usage, VK_IMAGE_USAGE_TRANSFER_SRC_BIT must have been included in the VkImageStencilUsageCreateInfo::stencilUsage used to create srcImage

• VUID-VkCopyImageInfo2-aspect-06665
  If the aspect member of any element of pRegions includes VK_IMAGE_ASPECT_STENCIL_BIT, and dstImage was created with separate stencil usage, VK_IMAGE_USAGE_TRANSFER_DST_BIT must have been included in the VkImageStencilUsageCreateInfo::stencilUsage used to create dstImage

• VUID-VkCopyImageInfo2-srcImage-07966
  If srcImage is non-sparse then the image or the specified disjoint plane must be bound
completely and contiguously to a single VkDeviceMemory object

• VUID-VkCopyImageInfo2-srcSubresource-07967
  The srcSubresource.mipLevel member of each element of pRegions must be less than the mipLevels specified in VkImageCreateInfo when srcImage was created

• VUID-VkCopyImageInfo2-srcSubresource-07968
  The srcSubresource.baseArrayLayer + srcSubresource.layerCount of each element of pRegions, if srcSubresource.layerCount is not VK_REMAINING_ARRAY_LAYERS and maintenance5 is not enabled, must be less than or equal to the arrayLayers specified in VkImageCreateInfo when srcImage was created

• VUID-VkCopyImageInfo2-srcImage-07969
  srcImage must not have been created with flags containing VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT

• VUID-VkCopyImageInfo2-dstImage-07966
  If dstImage is non-sparse then the image or the specified disjoint plane must be bound completely and contiguously to a single VkDeviceMemory object

• VUID-VkCopyImageInfo2-dstSubresource-07967
  The dstSubresource.mipLevel member of each element of pRegions must be less than the mipLevels specified in VkImageCreateInfo when dstImage was created

• VUID-VkCopyImageInfo2-dstSubresource-07968
  The dstSubresource.baseArrayLayer + dstSubresource.layerCount of each element of pRegions, if dstSubresource.layerCount is not VK_REMAINING_ARRAY_LAYERS and maintenance5 is not enabled, must be less than or equal to the arrayLayers specified in VkImageCreateInfo when dstImage was created

• VUID-VkCopyImageInfo2-dstImage-07969
  dstImage must not have been created with flags containing VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT

Valid Usage (Implicit)

• VUID-VkCopyImageInfo2-sType-sType
  sType must be VK_STRUCTURE_TYPE_COPY_IMAGE_INFO_2

• VUID-VkCopyImageInfo2-pNext-pNext
  pNext must be NULL

• VUID-VkCopyImageInfo2-srcImage-parameter
  srcImage must be a valid VkImage handle

• VUID-VkCopyImageInfo2-srcImageLayout-parameter
  srcImageLayout must be a valid VkImageLayout value

• VUID-VkCopyImageInfo2-dstImage-parameter
  dstImage must be a valid VkImage handle

• VUID-VkCopyImageInfo2-dstImageLayout-parameter
  dstImageLayout must be a valid VkImageLayout value
VUID-VkCopyImageInfo2-pRegions-parameter

*pRegions must be a valid pointer to an array of regionCount valid VkImageCopy2 structures*

VUID-VkCopyImageInfo2-regionCount-arraylength

*regionCount must be greater than 0*

VUID-VkCopyImageInfo2-commonparent

Both of dstImage, and srcImage must have been created, allocated, or retrieved from the same VkDevice

The VkImageCopy2 structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkImageCopy2 {
    VkStructureType sType;
    const void* pNext;
    VkImageSubresourceLayers srcSubresource;
    VkOffset3D srcOffset;
    VkImageSubresourceLayers dstSubresource;
    VkOffset3D dstOffset;
    VkExtent3D extent;
} VkImageCopy2;
```

or the equivalent

```c
// Provided by VK_KHR_copy_commands2
typedef VkImageCopy2 VkImageCopy2KHR;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **srcSubresource** and **dstSubresource** are VkImageSubresourceLayers structures specifying the image subresources of the images used for the source and destination image data, respectively.
- **srcOffset** and **dstOffset** select the initial \( x, y, \) and \( z \) offsets in texels of the sub-regions of the source and destination image data.
- **extent** is the size in texels of the image to copy in width, height and depth.

**Valid Usage**

- **VUID-VkImageCopy2-apiVersion-07940**
  If the VK_KHR_sampler_ycbcr_conversion extension is not enabled and VkPhysicalDeviceProperties::apiVersion is less than Vulkan 1.1, the aspectMask member of srcSubresource and dstSubresource must match
- **VUID-VkImageCopy2-apiVersion-07941**
  If the VK_KHR_maintenance1 extension is not enabled and VkPhysicalDeviceProperties
::apiVersion is less than Vulkan 1.1, the layerCount member of srcSubresource and dstSubresource must match

- VUID-VkImageCopy2-extent-06668 extent.width must not be 0
- VUID-VkImageCopy2-extent-06669 extent.height must not be 0
- VUID-VkImageCopy2-extent-06670 extent.depth must not be 0

Valid Usage (Implicit)

- VUID-VkImageCopy2-sType-sType sType must be VK_STRUCTURE_TYPE_IMAGE_COPY_2
- VUID-VkImageCopy2-pNext-pNext pNext must be NULL
- VUID-VkImageCopy2-srcSubresource-parameter srcSubresource must be a valid VkImageSubresourceLayers structure
- VUID-VkImageCopy2-dstSubresource-parameter dstSubresource must be a valid VkImageSubresourceLayers structure

20.3. Copying Data Between Buffers and Images

Data can be copied between buffers and images, enabling applications to load and store data between images and user defined offsets in buffer memory.

When copying between a buffer and an image, whole texel blocks are always copied; each texel block in the specified extent in the image to be copied will be written to a region in the buffer, specified according to the position of the texel block, and the texel block extent and size of the format being copied.

For a set of coordinates (x,y,z,layer), where:

x is in the range \([\text{imageOffset.x} / \text{blockWidth}, \left\lceil (\text{imageOffset.x} + \text{imageExtent.width}) / \text{blockWidth}\right\rceil]\),

y is in the range \([\text{imageOffset.y} / \text{blockHeight}, \left\lceil (\text{imageOffset.y} + \text{imageExtent.height}) / \text{blockHeight}\right\rceil]\),

z is in the range \([\text{imageOffset.z} / \text{blockDepth}, \left\lceil (\text{imageOffset.z} + \text{imageExtent.depth}) / \text{blockDepth}\right\rceil]\),
layer is in the range \([imageSubresource.baseArrayLayer, imageSubresource.baseArrayLayer + imageSubresource.layerCount]\),

and where blockWidth, blockHeight, and blockDepth are the dimensions of the texel block extent of the image’s format.

For each \((x,y,z,\text{layer})\) coordinate, texels in the image layer selected by layer are accessed in the following ranges:

\[
[x \times \text{blockWidth}, \max( (x \times \text{blockWidth}) + \text{blockWidth}, \text{imageWidth}) )
\]

\[
[y \times \text{blockHeight}, \max( (y \times \text{blockHeight}) + \text{blockHeight}, \text{imageHeight}) )
\]

\[
[z \times \text{blockDepth}, \max( (z \times \text{blockDepth}) + \text{blockDepth}, \text{imageDepth}) )
\]

where imageWidth, imageHeight, and imageDepth are the dimensions of the image subresource.

For each \((x,y,z,\text{layer})\) coordinate, bytes in the buffer are accessed at offsets in the range \([\text{texelOffset}, \text{texelOffset} + \text{blockSize}]\), where:

\[
\text{texelOffset} = \text{bufferOffset} + (x \times \text{blockSize}) + (y \times \text{rowExtent}) + (z \times \text{sliceExtent}) + (\text{layer} \times \text{layerExtent})
\]

\(\text{blockSize}\) is the size of the block in bytes for the format

\[
\text{rowExtent} = \max(\text{bufferRowLength}, \lceil \frac{\text{imageExtent.width}}{\text{blockWidth}} \rceil \times \text{blockSize})
\]

\[
\text{sliceExtent} = \max(\text{bufferImageHeight}, \text{imageExtent.height} \times \text{rowExtent})
\]

\[
\text{layerExtent} = \text{imageExtent.depth} \times \text{sliceExtent}
\]

If a rotation is specified by \textbf{VkCopyCommandTransformInfoQCOM}, the 2D region of the image being addressed is rotated around the offset, modifying the range of \(x\) and \(y\) coordinates for the image address according to the specified \textbf{VkSurfaceTransformFlagBitsKHR}:

- If \textbf{VK_SURFACE_TRANSFORM_IDENTITY_BIT_KHR} is specified, no rotation is performed:

  \(x'\) is in the same range as \(x\)
y' is in the same range as \( y \)

\[
\text{blockWidth}' = \text{blockWidth}
\]

\[
\text{blockHeight}' = \text{blockHeight}
\]

\[
\text{imageWidth}' = \text{imageWidth}
\]

\[
\text{imageHeight}' = \text{imageHeight}
\]

- If \texttt{VK_SURFACE_TRANSFORM_ROTATE_90_BIT_KHR} is specified

\[
x' \text{ is in the range } \left \lfloor \frac{\text{imageOffset.x} - \text{imageExtent.height}}{\text{blockHeight}} \right \rfloor, \left \lceil \frac{\text{imageOffset.x} - \text{imageOffset.x} - \text{image}/\text{blockHeight}}{\text{blockHeight}} \right \rceil
\]

\[
y' \text{ is in the range } \left \lfloor \frac{\text{imageOffset.y}}{\text{blockWidth}} \right \rfloor, \left \lceil \frac{\text{imageOffset.y} + \text{imageExtent.width}}{\text{blockWidth}} \right \rceil
\]

\[
\text{blockWidth}' = \text{blockHeight}
\]

\[
\text{blockHeight}' = \text{blockWidth}
\]

\[
\text{imageWidth}' = \text{imageHeight}
\]

\[
\text{imageHeight}' = \text{imageWidth}
\]

- If \texttt{VK_SURFACE_TRANSFORM_ROTATE_180_BIT_KHR} is specified:

\[
x' \text{ is in the range } \left \lceil \frac{\text{imageOffset.x} - \text{imageExtent.width}}{\text{blockWidth}} \right \rceil, \frac{\text{imageOffset.x}}{\text{blockWidth}}\]

\[
y' \text{ is in the range } \left \lfloor \frac{\text{imageOffset.x} + \text{imageExtent.height}}{\text{blockHeight}} \right \rfloor, \left \lceil \frac{\text{imageOffset.x} + \text{imageOffset.x} + \text{image}/\text{blockHeight}}{\text{blockHeight}} \right \rceil
\]
If `VK_SURFACE_TRANSFORM_ROTATE_270_BIT_KHR` is specified:

\[
x \text{ is in the range } \left[ \frac{\text{imageOffset.x}}{\text{blockHeight}}, \left\lceil \frac{\text{imageOffset.x} + \text{imageExtent.height}}{\text{blockHeight}} \right\rceil \right)
\]

\[
y \text{ is in the range } \left[ \left\lceil \frac{\text{imageOffset.y} - \text{imageExtent.width}}{\text{blockWidth}} \right\rceil, \frac{\text{imageOffset.y}}{\text{blockWidth}} \right).
\]

\[
\text{blockWidth'} = \text{blockHeight}
\]

\[
\text{blockHeight'} = \text{blockWidth}
\]

\[
\text{imageWidth'} = \text{imageHeight}
\]

\[
\text{imageHeight'} = \text{imageWidth}
\]

When rotation is performed, for each \((x,y,z,\text{layer})\) coordinate, texels in the image layer selected by \(\text{layer}\) are instead accessed in the following ranges:

\[
[x' \times \text{blockWidth'}, \max( (x' \times \text{blockWidth'}) + \text{blockWidth'}, \text{imageWidth'})]
\]

\[
[y' \times \text{blockHeight'}, \max( (y' \times \text{blockHeight'}) + \text{blockHeight'}, \text{imageHeight'})]
\]

\[
[z' \times \text{blockDepth'}, \max( (z' \times \text{blockDepth'}) + \text{blockDepth'}, \text{imageDepth'})]
\]

Buffer addressing calculations are unaffected by this rotation.

When copying between a buffer and the depth or stencil aspect of an image, data in the buffer is
assumed to be laid out as separate planes rather than interleaved. Addressing calculations are thus performed for a different format than the base image, according to the aspect, as described in the following table:

Table 30. Depth/Stencil Aspect Copy Table

<table>
<thead>
<tr>
<th>Base Format</th>
<th>Depth Aspect Format</th>
<th>Stencil Aspect Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_FORMAT_D16_UNORM</td>
<td>VK_FORMAT_D16_UNORM</td>
<td>-</td>
</tr>
<tr>
<td>VK_FORMAT_X8_D24_UNORM_PACK32</td>
<td>VK_FORMAT_X8_D24_UNORM_PACK32</td>
<td>-</td>
</tr>
<tr>
<td>VK_FORMAT_D32_SFLOAT</td>
<td>VK_FORMAT_D32_SFLOAT</td>
<td>-</td>
</tr>
<tr>
<td>VK_FORMAT_S8_UINT</td>
<td>-</td>
<td>VK_FORMAT_S8_UINT</td>
</tr>
<tr>
<td>VK_FORMAT_D16_UNORM_S8_UINT</td>
<td>VK_FORMAT_D16_UNORM</td>
<td>VK_FORMAT_S8_UINT</td>
</tr>
<tr>
<td>VK_FORMAT_D24_UNORM_S8_UINT</td>
<td>VK_FORMAT_X8_D24_UNORM_PACK32</td>
<td>VK_FORMAT_S8_UINT</td>
</tr>
<tr>
<td>VK_FORMAT_D32_SFLOAT_S8_UINT</td>
<td>VK_FORMAT_D32_SFLOAT</td>
<td>VK_FORMAT_S8_UINT</td>
</tr>
</tbody>
</table>

When copying between a buffer and any plane of a multi-planar image, addressing calculations are performed using the compatible format for that plane, rather than the format of the multi-planar image.

Each texel block is copied from one resource to the other according to the above addressing equations.

To copy data from a buffer object to an image object, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdCopyBufferToImage(
    VkCommandBuffer commandBuffer,
    VkBuffer srcBuffer,
    VkImage dstImage,
    VkImageLayout dstImageLayout,
    uint32_t regionCount,
    const VkBufferImageCopy* pRegions);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `srcBuffer` is the source buffer.
- `dstImage` is the destination image.
- `dstImageLayout` is the layout of the destination image subresources for the copy.
- `regionCount` is the number of regions to copy.
- `pRegions` is a pointer to an array of `VkBufferImageCopy` structures specifying the regions to copy.

Each source region specified by `pRegions` is copied from the source buffer to the destination region of the destination image according to the addressing calculations for each resource. If any of the specified regions in `srcBuffer` overlaps in memory with any of the specified regions in `dstImage`, values read from those overlapping regions are undefined. If any region accesses a depth aspect in `dstImage` and the `VK_EXT_depth_range_unrestricted` extension is not enabled, values copied from
srcBuffer outside of the range [0,1] will be written as undefined values to the destination image.

Copy regions for the image must be aligned to a multiple of the texel block extent in each dimension, except at the edges of the image, where region extents must match the edge of the image.

Valid Usage

- VUID-vkCmdCopyBufferToImage-dstImage-07966
  If dstImage is non-sparse then the image or the specified disjoint plane must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdCopyBufferToImage-imageSubresource-07967
  The imageSubresource.mipLevel member of each element of pRegions must be less than the mipLevels specified in VkImageCreateInfo when dstImage was created

- VUID-vkCmdCopyBufferToImage-imageSubresource-07968
  The imageSubresource.baseArrayLayer + imageSubresource.layerCount of each element of pRegions, if imageSubresource.layerCount is not VK_REMAINING_ARRAY_LAYERS and maintenance5 is not enabled, must be less than or equal to the arrayLayers specified in VkImageCreateInfo when dstImage was created

- VUID-vkCmdCopyBufferToImage-dstImage-07969
  dstImage must not have been created with flags containing VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT

- VUID-vkCmdCopyBufferToImage-imageSubresource-07970
  The image region specified by each element of pRegions must be contained within the specified imageSubresource of dstImage

- VUID-vkCmdCopyBufferToImage-imageSubresource-07971
  For each element of pRegions, imageOffset.x and (imageExtent.width + imageOffset.x) must both be greater than or equal to 0 and less than or equal to the width of the specified imageSubresource of dstImage

- VUID-vkCmdCopyBufferToImage-imageSubresource-07972
  For each element of pRegions, imageOffset.y and (imageExtent.height + imageOffset.y) must both be greater than or equal to 0 and less than or equal to the height of the specified imageSubresource of dstImage

- VUID-vkCmdCopyBufferToImage-dstImage-07973
  dstImage must have a sample count equal to VK_SAMPLE_COUNT_1_BIT

- VUID-vkCmdCopyBufferToImage-commandBuffer-01828
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, srcBuffer must not be a protected buffer

- VUID-vkCmdCopyBufferToImage-commandBuffer-01829
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, dstImage must not be a protected image

- VUID-vkCmdCopyBufferToImage-commandBuffer-01830
  If commandBuffer is a protected command buffer and protectedNoFault is not supported,
**dstImage** must not be an unprotected image

- **VUID-vkCmdCopyBufferToImage-commandBuffer-07737**
  If the queue family used to create the *VkCommandPool* which *commandBuffer* was allocated from does not support VK_QUEUE_GRAPHICS_BIT or VK_QUEUE.Compute_BIT, the *bufferOffset* member of any element of *pRegions* must be a multiple of 4

- **VUID-vkCmdCopyBufferToImage-commandBuffer-imageOffset-00178**
  The *imageOffset* and *imageExtent* members of each element of *pRegions* must respect the image transfer granularity requirements of *commandBuffer*’s command pool’s queue family, as described in *VkQueueFamilyProperties*

- **VUID-vkCmdCopyBufferToImage-commandBuffer-07739**
  If the queue family used to create the *VkCommandPool* which *commandBuffer* was allocated from does not support VK_QUEUE_GRAPHICS_BIT, for each element of *pRegions*, the *aspectMask* member of *imageSubresource* must not be VK_IMAGE_ASPECT_DEPTH_BIT or VK_IMAGE_ASPECT_STENCIL_BIT

- **VUID-vkCmdCopyBufferToImage-pRegions-00171**
  *srcBuffer* must be large enough to contain all buffer locations that are accessed according to *Buffer and Image Addressing*, for each element of *pRegions*

- **VUID-vkCmdCopyBufferToImage-pRegions-00173**
  The union of all source regions, and the union of all destination regions, specified by the elements of *pRegions*, must not overlap in memory

- **VUID-vkCmdCopyBufferToImage-srcBuffer-00174**
  *srcBuffer* must have been created with VK_BUFFER_USAGE_TRANSFER_SRC_BIT usage flag

- **VUID-vkCmdCopyBufferToImage-dstImage-01997**
  The *format features* of *dstImage* must contain VK_FORMAT_FEATURE_TRANSFER_DST_BIT

- **VUID-vkCmdCopyBufferToImage-dstImage-00177**
  *dstImage* must have been created with VK_IMAGE_USAGE_TRANSFER_DST_BIT usage flag

- **VUID-vkCmdCopyBufferToImage-dstImageLayout-00180**
  *dstImageLayout* must specify the layout of the image subresources of *dstImage* specified in *pRegions* at the time this command is executed on a *VkDevice*

- **VUID-vkCmdCopyBufferToImage-dstImageLayout-01396**
  *dstImageLayout* must be VK_IMAGE_LAYOUTTRANSFER_DST_OPTIMAL, VK_IMAGE_LAYOUT_GENERAL, or VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR

- **VUID-vkCmdCopyBufferToImage-pRegions-07931**
  If VK_EXT_depth_range_unrestricted is not enabled, for each element of *pRegions* whose *imageSubresource* contains a depth aspect, the data in *srcBuffer* must be in the range [0,1]

- **VUID-vkCmdCopyBufferToImage-dstImage-07979**
  If *dstImage* is of type VK_IMAGE_TYPE_1D, then for each element of *pRegions*, *imageOffset.y* must be 0 and *imageExtent.height* must be 1
For each element of `pRegions`, `imageOffset.z` and `(imageExtent.depth + imageOffset.z)` must both be greater than or equal to 0 and less than or equal to the depth of the specified `imageSubresource` of `dstImage`.

If `dstImage` is of type `VK_IMAGE_TYPE_1D` or `VK_IMAGE_TYPE_2D`, then for each element of `pRegions`, `imageOffset.z` must be 0 and `imageExtent.depth` must be 1.

For each element of `pRegions`, `imageOffset.x` must be a multiple of the texel block extent width of the `VkFormat` of `dstImage`.

For each element of `pRegions`, `imageOffset.y` must be a multiple of the texel block extent height of the `VkFormat` of `dstImage`.

For each element of `pRegions`, `imageOffset.z` must be a multiple of the texel block extent depth of the `VkFormat` of `dstImage`.

For each element of `pRegions`, if the sum of `imageOffset.x` and `extent.width` does not equal the width of the subresource specified by `srcSubresource`, `extent.width` must be a multiple of the texel block extent width of the `VkFormat` of `dstImage`.

For each element of `pRegions`, if the sum of `imageOffset.y` and `extent.height` does not equal the height of the subresource specified by `srcSubresource`, `extent.height` must be a multiple of the texel block extent height of the `VkFormat` of `dstImage`.

For each element of `pRegions`, if the sum of `imageOffset.z` and `extent.depth` does not equal the depth of the subresource specified by `srcSubresource`, `extent.depth` must be a multiple of the texel block extent depth of the `VkFormat` of `dstImage`.

For each element of `pRegions`, `imageSubresource.aspectMask` must specify aspects present in `dstImage`.

If `dstImage` has a multi-planar image format, then for each element of `pRegions`, `imageSubresource.aspectMask` must be a single valid multi-planar aspect mask bit.

If `dstImage` is of type `VK_IMAGE_TYPE_3D`, for each element of `pRegions`, `imageSubresource.baseArrayLayer` must be 0 and `imageSubresource.layerCount` must be 1.

For each element of `pRegions`, `bufferRowLength` must be a multiple of the texel block extent width of the `VkFormat` of `dstImage`.

For each element of `pRegions`, `bufferImageHeight` must be a multiple of the texel block extent height of the `VkFormat` of `dstImage`.
For each element of \( pRegions \), \( \text{bufferRowLength} \) divided by the \( \text{texel block extent width} \) and then multiplied by the \( \text{texel block size of dstImage} \) must be less than or equal to \( 2^{31} - 1 \).

If \( dstImage \) does not have either a depth/stencil or a multi-planar format, then for each element of \( pRegions \), \( \text{bufferOffset} \) must be a multiple of the \( \text{texel block size} \).

If \( dstImage \) has a multi-planar format, then for each element of \( pRegions \), \( \text{bufferOffset} \) must be a multiple of the element size of the compatible format for the format and the \( \text{aspectMask} \) of the \( \text{imageSubresource} \) as defined in Compatible formats of planes of multi-planar formats.

If \( dstImage \) has a depth/stencil format, the \( \text{bufferOffset} \) member of any element of \( pRegions \) must be a multiple of 4.

**Valid Usage (Implicit)**

- \( \text{commandBuffer} \) must be a valid \( \text{VkCommandBuffer} \) handle
- \( \text{srcBuffer} \) must be a valid \( \text{VkBuffer} \) handle
- \( \text{dstImage} \) must be a valid \( \text{VkImage} \) handle
- \( \text{dstImageLayout} \) must be a valid \( \text{VkImageLayout} \) value
- \( pRegions \) must be a valid pointer to an array of \( \text{regionCount} \) valid \( \text{VkBufferImageCopy} \) structures
- \( \text{commandBuffer} \) must be in the \( \text{recording state} \)
- The \( \text{VkCommandPool} \) that \( \text{commandBuffer} \) was allocated from must support transfer, graphics, or compute operations
- This command must only be called outside of a render pass instance
- This command must only be called outside of a video coding scope
- \( \text{regionCount} \) must be greater than 0
- Each of \( \text{commandBuffer} \), \( \text{dstImage} \), and \( \text{srcBuffer} \) must have been created, allocated, or
retrieved from the same VkDevice

**Host Synchronization**

- Host access to `commandBuffer` **must** be externally synchronized
- Host access to the VkCommandPool that `commandBuffer` was allocated from **must** be externally synchronized

**Command Properties**

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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To copy data from an image object to a buffer object, call:

```c
// Provided by VK_VERSION_1_0

void vkCmdCopyImageToBuffer(
    VkCommandBuffer commandBuffer,  // Provided by VK_VERSION_1_0
    VkImage srcImage,              // Provided by VK_VERSION_1_0
    VkImageLayout srcImageLayout,  // Provided by VK_VERSION_1_0
    VkBuffer dstBuffer,            // Provided by VK_VERSION_1_0
    uint32_t regionCount,          // Provided by VK_VERSION_1_0
    const VkBufferImageCopy* pRegions); // Provided by VK_VERSION_1_0
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `srcImage` is the source image.
- `srcImageLayout` is the layout of the source image subresources for the copy.
- `dstBuffer` is the destination buffer.
- `regionCount` is the number of regions to copy.
- `pRegions` is a pointer to an array of VkBufferImageCopy structures specifying the regions to copy.

Each source region specified by `pRegions` is copied from the source image to the destination region of the destination buffer according to the addressing calculations for each resource. If any of the specified regions in `srcImage` overlaps in memory with any of the specified regions in `dstBuffer`, values read from those overlapping regions are undefined.

Copy regions for the image **must** be aligned to a multiple of the texel block extent in each dimension, except at the edges of the image, where region extents **must** match the edge of the image.
Valid Usage

- VUID-vkCmdCopyImageToBuffer-srcImage-07966
  If `srcImage` is non-sparse then the image or the specified disjoint plane must be bound completely and contiguously to a single `VkDeviceMemory` object.

- VUID-vkCmdCopyImageToBuffer-imageSubresource-07967
  The `imageSubresource.mipLevel` member of each element of `pRegions` must be less than the `mipLevels` specified in `VkImageCreateInfo` when `srcImage` was created.

- VUID-vkCmdCopyImageToBuffer-imageSubresource-07968
  The `imageSubresource.baseArrayLayer + imageSubresource.layerCount` of each element of `pRegions`, if `imageSubresource.layerCount` is not `VK_REMAINING_ARRAY_LAYERS` and `maintenance5` is not enabled, must be less than or equal to the `arrayLayers` specified in `VkImageCreateInfo` when `srcImage` was created.

- VUID-vkCmdCopyImageToBuffer-srcImage-07969
  `srcImage` must not have been created with flags containing `VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT`.

- VUID-vkCmdCopyImageToBuffer-imageSubresource-07970
  The image region specified by each element of `pRegions` must be contained within the specified `imageSubresource` of `srcImage`.

- VUID-vkCmdCopyImageToBuffer-imageSubresource-07971
  For each element of `pRegions`, `imageOffset.x` and `(imageExtent.width + imageOffset.x)` must both be greater than or equal to 0 and less than or equal to the width of the specified `imageSubresource` of `srcImage`.

- VUID-vkCmdCopyImageToBuffer-imageSubresource-07972
  For each element of `pRegions`, `imageOffset.y` and `(imageExtent.height + imageOffset.y)` must both be greater than or equal to 0 and less than or equal to the height of the specified `imageSubresource` of `srcImage`.

- VUID-vkCmdCopyImageToBuffer-srcImage-07973
  `srcImage` must have a sample count equal to `VK_SAMPLE_COUNT_1_BIT`.

- VUID-vkCmdCopyImageToBuffer-commandBuffer-01831
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `srcImage` must not be a protected image.

- VUID-vkCmdCopyImageToBuffer-commandBuffer-01832
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `dstBuffer` must not be a protected buffer.

- VUID-vkCmdCopyImageToBuffer-commandBuffer-01833
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, `dstBuffer` must not be an unprotected buffer.

- VUID-vkCmdCopyImageToBuffer-commandBuffer-07746
  If the queue family used to create the `VkCommandPool` which `commandBuffer` was allocated from does not support `VK_QUEUE_GRAPHICS_BIT` or `VK_QUEUE_COMPUTE_BIT`, the `bufferOffset` member of any element of `pRegions` must be a multiple of 4.
The `imageOffset` and `imageExtent` members of each element of `pRegions` must respect the image transfer granularity requirements of `commandBuffer`'s command pool's queue family, as described in `VkQueueFamilyProperties`.

**dstBuffer** must be large enough to contain all buffer locations that are accessed according to `Buffer and Image Addressing`, for each element of `pRegions`.

The union of all source regions, and the union of all destination regions, specified by the elements of `pRegions`, must not overlap in memory.

`srcImage` must have been created with `VK_IMAGE_USAGE_TRANSFER_SRC_BIT` usage flag.

The `format features` of `srcImage` must contain `VK_FORMAT_FEATURE_TRANSFER_SRC_BIT`.

**dstBuffer** must have been created with `VK_BUFFER_USAGE_TRANSFER_DST_BIT` usage flag.

If `dstBuffer` is non-sparse then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

`srcImageLayout` must specify the layout of the image subresources of `srcImage` specified in `pRegions` at the time this command is executed on a `VkDevice`.

`srcImageLayout` must be `VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL`, `VK_IMAGE_LAYOUT_GENERAL`, or `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR`.

If `srcImage` is of type `VK_IMAGE_TYPE_1D`, then for each element of `pRegions`, `imageOffset.y` must be 0 and `imageExtent.height` must be 1.

For each element of `pRegions`, `imageOffset.z` and `(imageExtent.depth + imageOffset.z)` must both be greater than or equal to 0 and less than or equal to the depth of the specified `imageSubresource` of `srcImage`.

If `srcImage` is of type `VK_IMAGE_TYPE_1D` or `VK_IMAGE_TYPE_2D`, then for each element of `pRegions`, `imageOffset.z` must be 0 and `imageExtent.depth` must be 1.

For each element of `pRegions`, `imageOffset.x` must be a multiple of the `texel block extent width` of the `VkFormat` of `srcImage`.

For each element of `pRegions`, `imageOffset.y` must be a multiple of the `texel block extent height` of the `VkFormat` of `srcImage`.
For each element of `pRegions`, `imageOffset.z` must be a multiple of the texel block extent depth of the `VkFormat` of `srcImage`.

For each element of `pRegions`, if the sum of `imageOffset.x` and `extent.width` does not equal the width of the subresource specified by `srcSubresource`, `extent.width` must be a multiple of the texel block extent width of the `VkFormat` of `srcImage`.

For each element of `pRegions`, if the sum of `imageOffset.y` and `extent.height` does not equal the height of the subresource specified by `srcSubresource`, `extent.height` must be a multiple of the texel block extent height of the `VkFormat` of `srcImage`.

For each element of `pRegions`, if the sum of `imageOffset.z` and `extent.depth` does not equal the depth of the subresource specified by `srcSubresource`, `extent.depth` must be a multiple of the texel block extent depth of the `VkFormat` of `srcImage`.

For each element of `pRegions`, `imageSubresource.aspectMask` must specify aspects present in `srcImage`.

If `srcImage` has a multi-planar image format, then for each element of `pRegions`, `imageSubresource.aspectMask` must be a single valid multi-planar aspect mask bit.

If `srcImage` is of type `VK_IMAGE_TYPE_3D`, for each element of `pRegions`, `imageSubresource.baseArrayLayer` must be 0 and `imageSubresource.layerCount` must be 1.

For each element of `pRegions`, `bufferRowLength` must be a multiple of the texel block extent width of the `VkFormat` of `srcImage`.

For each element of `pRegions`, `bufferImageHeight` must be a multiple of the texel block extent height of the `VkFormat` of `srcImage`.

For each element of `pRegions`, `bufferRowLength` divided by the texel block size of `srcImage` must be less than or equal to 2^{31}-1.

If `srcImage` does not have either a depth/stencil or a multi-planar format, then for each element of `pRegions`, `bufferOffset` must be a multiple of the texel block size.

If `srcImage` has a multi-planar format, then for each element of `pRegions`, `bufferOffset` must be a multiple of the element size of the compatible format for the format and the `aspectMask` of the `imageSubresource` as defined in Compatible formats of planes of multi-planar formats.

If `srcImage` does not have either a depth/stencil or a multi-planar format, then for each element of `pRegions`, `bufferOffset` must be a multiple of the texel block size.
If `srcImage` has a depth/stencil format, the `bufferOffset` member of any element of `pRegions` must be a multiple of 4

### Valid Usage (Implicit)

- **VUID-vkCmdCopyImageToBuffer-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- **VUID-vkCmdCopyImageToBuffer-srcImage-parameter**
  `srcImage` must be a valid `VkImage` handle

- **VUID-vkCmdCopyImageToBuffer-srcImageLayout-parameter**
  `srcImageLayout` must be a valid `VkImageLayout` value

- **VUID-vkCmdCopyImageToBuffer-dstBuffer-parameter**
  `dstBuffer` must be a valid `VkBuffer` handle

- **VUID-vkCmdCopyImageToBuffer-pRegions-parameter**
  `pRegions` must be a valid pointer to an array of `regionCount` valid `VkBufferImageCopy` structures

- **VUID-vkCmdCopyImageToBuffer-commandBuffer-recording**
  `commandBuffer` must be in the `recording` state

- **VUID-vkCmdCopyImageToBuffer-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support transfer, graphics, or compute operations

- **VUID-vkCmdCopyImageToBuffer-renderpass**
  This command must only be called outside of a render pass instance

- **VUID-vkCmdCopyImageToBuffer-videocoding**
  This command must only be called outside of a video coding scope

- **VUID-vkCmdCopyImageToBuffer-regionCount-arraylength**
  `regionCount` must be greater than 0

- **VUID-vkCmdCopyImageToBuffer-commonparent**
  Each of `commandBuffer`, `dstBuffer`, and `srcImage` must have been created, allocated, or retrieved from the same `VkDevice`

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized
Command Properties

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</tr>
<tr>
<td>Secondary</td>
<td></td>
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</table>

For both `vkCmdCopyBufferToImage` and `vkCmdCopyImageToBuffer`, each element of `pRegions` is a structure defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkBufferImageCopy {
    VkDeviceSize bufferOffset;
    uint32_t bufferRowLength;
    uint32_t bufferImageHeight;
    VkImageSubresourceLayers imageSubresource;
    VkOffset3D imageOffset;
    VkExtent3D imageExtent;
} VkBufferImageCopy;
```

- `bufferOffset` is the offset in bytes from the start of the buffer object where the image data is copied from or to.
- `bufferRowLength` and `bufferImageHeight` specify in texels a subregion of a larger two- or three-dimensional image in buffer memory, and control the addressing calculations. If either of these values is zero, that aspect of the buffer memory is considered to be tightly packed according to the `imageExtent`.
- `imageSubresource` is a `VkImageSubresourceLayers` used to specify the specific image subresources of the image used for the source or destination image data.
- `imageOffset` selects the initial x, y, z offsets in texels of the sub-region of the source or destination image data.
- `imageExtent` is the size in texels of the image to copy in width, height and depth.

Valid Usage

- VUID-VkBufferImageCopy-bufferRowLength-09101
  `bufferRowLength` must be 0, or greater than or equal to the width member of `imageExtent`
- VUID-VkBufferImageCopy-bufferImageHeight-09102
  `bufferImageHeight` must be 0, or greater than or equal to the height member of `imageExtent`
- VUID-VkBufferImageCopy-aspectMask-09103
  The `aspectMask` member of `imageSubresource` must only have a single bit set
- VUID-VkBufferImageCopy-imageExtent-06659
imageExtent.width must not be 0
- VUID-VkBufferImageCopy-imageExtent-06660
imageExtent.height must not be 0
- VUID-VkBufferImageCopy-imageExtent-06661
imageExtent.depth must not be 0

Valid Usage (Implicit)
- VUID-VkBufferImageCopy-imageSubresource-parameter
imageSubresource must be a valid VkImageSubresourceLayers structure

More extensible versions of the commands to copy between buffers and images are defined below.

To copy data from a buffer object to an image object, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdCopyBufferToImage2(
    VkCommandBuffer commandBuffer,
    const VkCopyBufferToImageInfo2* pCopyBufferToImageInfo);
```
or the equivalent command

```c
// Provided by VK_KHR_copy_commands2
void vkCmdCopyBufferToImage2KHR(
    VkCommandBuffer commandBuffer,
    const VkCopyBufferToImageInfo2* pCopyBufferToImageInfo);
```

- commandBuffer is the command buffer into which the command will be recorded.
- pCopyBufferToImageInfo is a pointer to a VkCopyBufferToImageInfo2 structure describing the copy parameters.

This command is functionally identical to vkCmdCopyBufferToImage, but includes extensible substructures that include sType and pNext parameters, allowing them to be more easily extended.

Valid Usage
- VUID-vkCmdCopyBufferToImage2-commandBuffer-01828
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, srcBuffer must not be a protected buffer
- VUID-vkCmdCopyBufferToImage2-commandBuffer-01829
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, dstImage must not be a protected image
- VUID-vkCmdCopyBufferToImage2-commandBuffer-01830

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If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, `dstImage` must not be an unprotected image.

- **VUID-vkCmdCopyBufferToImage2-commandBuffer-07737**
  If the queue family used to create the `VkCommandPool` which `commandBuffer` was allocated from does not support `VK_QUEUE_GRAPHICS_BIT` or `VK_QUEUE_COMPUTE_BIT`, the `bufferOffset` member of any element of `pCopyBufferToImageInfo->pRegions` must be a multiple of 4.

- **VUID-vkCmdCopyBufferToImage2-imageOffset-07738**
  The `imageOffset` and `imageExtent` members of each element of `pCopyBufferToImageInfo->pRegions` must respect the image transfer granularity requirements of `commandBuffer`'s command pool's queue family, as described in `VkQueueFamilyProperties`.

- **VUID-vkCmdCopyBufferToImage2-commandBuffer-07739**
  If the queue family used to create the `VkCommandPool` which `commandBuffer` was allocated from does not support `VK_QUEUE_GRAPHICS_BIT`, for each element of `pCopyBufferToImageInfo->pRegions`, the `aspectMask` member of `imageSubresource` must not be `VK_IMAGE_ASPECT_DEPTH_BIT` or `VK_IMAGE_ASPECT_STENCIL_BIT`.

---

**Valid Usage (Implicit)**

- **VUID-vkCmdCopyBufferToImage2-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- **VUID-vkCmdCopyBufferToImage2-pCopyBufferToImageInfo-parameter**
  `pCopyBufferToImageInfo` must be a valid pointer to a valid `VkCopyBufferToImageInfo2` structure.

- **VUID-vkCmdCopyBufferToImage2-commandBuffer-recording**
  `commandBuffer` must be in the recording state.

- **VUID-vkCmdCopyBufferToImage2-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support transfer, graphics, or compute operations.

- **VUID-vkCmdCopyBufferToImage2-renderpass**
  This command must only be called outside of a render pass instance.

- **VUID-vkCmdCopyBufferToImage2-videocoding**
  This command must only be called outside of a video coding scope.

---

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized.

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.
Command Properties

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The `VkCopyBufferToImageInfo2` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkCopyBufferToImageInfo2 {
    VkStructureType sType;
    const void* pNext;
    VkBuffer srcBuffer;
    VkImage dstImage;
    VkImageLayout dstImageLayout;
    uint32_t regionCount;
    const VkBufferImageCopy2* pRegions;
} VkCopyBufferToImageInfo2;
```

or the equivalent

```c
// Provided by VK_KHR_copy_commands2
typedef VkCopyBufferToImageInfo2 VkCopyBufferToImageInfo2KHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `srcBuffer` is the source buffer.
- `dstImage` is the destination image.
- `dstImageLayout` is the layout of the destination image subresources for the copy.
- `regionCount` is the number of regions to copy.
- `pRegions` is a pointer to an array of `VkBufferImageCopy2` structures specifying the regions to copy.

**Valid Usage**

- VUID-VkCopyBufferToImageInfo2-pRegions-04565
  The image region specified by each element of `pRegions` that does not contain `VkCopyCommandTransformInfoQCOM` in its `pNext` chain must be contained within the specified `imageSubresource` of `dstImage`
If the image region specified by each element of \texttt{pRegions} contains \texttt{VkCopyCommandTransformInfoQCOM} in its \texttt{pNext} chain, the rotated destination region as described in \texttt{[copies-buffers-images-rotation-addressing]} must be contained within \texttt{dstImage}

- **VUID-VkCopyBufferToImageInfo2KHR-pRegions-04555**
  If any element of \texttt{pRegions} contains \texttt{VkCopyCommandTransformInfoQCOM} in its \texttt{pNext} chain, then \texttt{dstImage} must have a 1x1x1 texel block extent

- **VUID-VkCopyBufferToImageInfo2KHR-pRegions-06203**
  If any element of \texttt{pRegions} contains \texttt{VkCopyCommandTransformInfoQCOM} in its \texttt{pNext} chain, then \texttt{dstImage} must be of type \texttt{VK_IMAGE_TYPE_2D}

- **VUID-VkCopyBufferToImageInfo2KHR-pRegions-06204**
  If any element of \texttt{pRegions} contains \texttt{VkCopyCommandTransformInfoQCOM} in its \texttt{pNext} chain, then \texttt{dstImage} must not have a multi-planar format

- **VUID-VkCopyBufferToImageInfo2-pRegions-00171**
  \texttt{srcBuffer} must be large enough to contain all buffer locations that are accessed according to \texttt{Buffer and Image Addressing}, for each element of \texttt{pRegions}

- **VUID-VkCopyBufferToImageInfo2-pRegions-00173**
  The union of all source regions, and the union of all destination regions, specified by the elements of \texttt{pRegions}, must not overlap in memory

- **VUID-VkCopyBufferToImageInfo2-srcBuffer-00174**
  \texttt{srcBuffer} must have been created with \texttt{VK_BUFFER_USAGE_TRANSFER_SRC_BIT} usage flag

- **VUID-VkCopyBufferToImageInfo2-dstImage-01997**
  The format features of \texttt{dstImage} must contain \texttt{VK_FORMAT_FEATURE_TRANSFER_DST_BIT}

- **VUID-VkCopyBufferToImageInfo2-srcBuffer-00176**
  If \texttt{srcBuffer} is non-sparse then it must be bound completely and contiguously to a single \texttt{VkDeviceMemory} object

- **VUID-VkCopyBufferToImageInfo2-dstImage-00177**
  \texttt{dstImage} must have been created with \texttt{VK_IMAGE_USAGE_TRANSFER_DST_BIT} usage flag

- **VUID-VkCopyBufferToImageInfo2-dstImageLayout-00180**
  \texttt{dstImageLayout} must specify the layout of the image subresources of \texttt{dstImage} specified in \texttt{pRegions} at the time this command is executed on a \texttt{VkDevice}

- **VUID-VkCopyBufferToImageInfo2-dstImageLayout-01396**
  \texttt{dstImageLayout} must be \texttt{VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL}, \texttt{VK_IMAGE_LAYOUT_GENERAL}, or \texttt{VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR}

- **VUID-VkCopyBufferToImageInfo2-pRegions-07931**
  If \texttt{VK_EXT_depth_range_unrestricted} is not enabled, for each element of \texttt{pRegions} whose \texttt{imageSubresource} contains a depth aspect, the data in \texttt{srcBuffer} must be in the range \([0,1]\)

- **VUID-VkCopyBufferToImageInfo2-dstImage-07966**
  If \texttt{dstImage} is non-sparse then the image or the specified \texttt{disjoint} plane must be bound completely and contiguously to a single \texttt{VkDeviceMemory} object

- **VUID-VkCopyBufferToImageInfo2-imageSubresource-07967**
The `imageSubresource.mipLevel` member of each element of `pRegions` must be less than the `mipLevels` specified in `VkImageCreateInfo` when `dstImage` was created.

- VUID-VkCopyBufferToImageInfo2-imageSubresource-07968
  The `imageSubresource.baseArrayLayer + imageSubresource.layerCount` of each element of `pRegions`, if `imageSubresource.layerCount` is not `VK_REMAINING_ARRAY_LAYERS` and `maintenance5` is not enabled, must be less than or equal to the `arrayLayers` specified in `VkImageCreateInfo` when `dstImage` was created.

- VUID-VkCopyBufferToImageInfo2-dstImage-07969
  `dstImage` must not have been created with `flags` containing `VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT`.

- VUID-VkCopyBufferToImageInfo2-dstImage-07973
  `dstImage` must have a sample count equal to `VK_SAMPLE_COUNT_1_BIT`.

- VUID-VkCopyBufferToImageInfo2-dstImage-07979
  If `dstImage` is of type `VK_IMAGE_TYPE_1D`, then for each element of `pRegions`, `imageOffset.y` must be 0 and `imageExtent.height` must be 1.

- VUID-VkCopyBufferToImageInfo2-imageOffset-09104
  For each element of `pRegions`, `imageOffset.z` and `(imageExtent.depth + imageOffset.z)` must both be greater than or equal to 0 and less than or equal to the depth of the specified `imageSubresource` of `dstImage`.

- VUID-VkCopyBufferToImageInfo2-dstImage-07980
  If `dstImage` is of type `VK_IMAGE_TYPE_1D` or `VK_IMAGE_TYPE_2D`, then for each element of `pRegions`, `imageOffset.z` must be 0 and `imageExtent.depth` must be 1.

- VUID-VkCopyBufferToImageInfo2-dstImage-07274
  For each element of `pRegions`, `imageOffset.x` must be a multiple of the `texel block extent width` of the `VkFormat` of `dstImage`.

- VUID-VkCopyBufferToImageInfo2-dstImage-07275
  For each element of `pRegions`, `imageOffset.y` must be a multiple of the `texel block extent height` of the `VkFormat` of `dstImage`.

- VUID-VkCopyBufferToImageInfo2-dstImage-07276
  For each element of `pRegions`, `imageOffset.z` must be a multiple of the `texel block extent depth` of the `VkFormat` of `dstImage`.

- VUID-VkCopyBufferToImageInfo2-dstImage-00207
  For each element of `pRegions`, if the sum of `imageOffset.x` and `extent.width` does not equal the width of the subresource specified by `srcSubresource`, `extent.width` must be a multiple of the `texel block extent width` of the `VkFormat` of `dstImage`.

- VUID-VkCopyBufferToImageInfo2-dstImage-00208
  For each element of `pRegions`, if the sum of `imageOffset.y` and `extent.height` does not equal the height of the subresource specified by `srcSubresource`, `extent.height` must be a multiple of the `texel block extent height` of the `VkFormat` of `dstImage`.

- VUID-VkCopyBufferToImageInfo2-dstImage-00209
  For each element of `pRegions`, if the sum of `imageOffset.z` and `extent.depth` does not equal the depth of the subresource specified by `srcSubresource`, `extent.depth` must be a multiple
of the texel block extent depth of the VkFormat of dstImage

- VUID-VkCopyBufferToImageInfo2-imageSubresource-09105
  For each element of pRegions, imageSubresource.aspectMask must specify aspects present in dstImage

- VUID-VkCopyBufferToImageInfo2-dstImage-07981
  If dstImage has a multi-planar image format, then for each element of pRegions, imageSubresource.aspectMask must be a single valid multi-planar aspect mask bit

- VUID-VkCopyBufferToImageInfo2-dstImage-07983
  If dstImage is of type VK_IMAGE_TYPE_3D, for each element of pRegions, imageSubresource.baseArrayLayer must be 0 and imageSubresource.layerCount must be 1

- VUID-VkCopyBufferToImageInfo2-bufferRowLength-09106
  For each element of pRegions, bufferRowLength must be a multiple of the texel block extent width of the VkFormat of dstImage

- VUID-VkCopyBufferToImageInfo2-bufferImageHeight-09107
  For each element of pRegions, bufferImageHeight must be a multiple of the texel block extent height of the VkFormat of dstImage

- VUID-VkCopyBufferToImageInfo2-bufferRowLength-09108
  For each element of pRegions, bufferRowLength divided by the texel block extent width and then multiplied by the texel block size of dstImage must be less than or equal to 2^31-1

- VUID-VkCopyBufferToImageInfo2-dstImage-07975
  If dstImage does not have either a depth/stencil or a multi-planar format, then for each element of pRegions, bufferOffset must be a multiple of the texel block size

- VUID-VkCopyBufferToImageInfo2-dstImage-07976
  If dstImage has a multi-planar format, then for each element of pRegions, bufferOffset must be a multiple of the element size of the compatible format for the format and the aspectMask of the imageSubresource as defined in Compatible formats of planes of multi-planar formats

- VUID-VkCopyBufferToImageInfo2-dstImage-07978
  If dstImage has a depth/stencil format, the bufferOffset member of any element of pRegions must be a multiple of 4

- VUID-VkCopyBufferToImageInfo2-pRegions-06223
  For each element of pRegions not containing VkCopyCommandTransformInfoQCOM in its pNext chain, imageOffset.x and (imageExtent.width + imageOffset.x) must both be greater than or equal to 0 and less than or equal to the width of the specified imageSubresource of dstImage

- VUID-VkCopyBufferToImageInfo2-pRegions-06224
  For each element of pRegions not containing VkCopyCommandTransformInfoQCOM in its pNext chain, imageOffset.y and (imageExtent.height + imageOffset.y) must both be greater than or equal to 0 and less than or equal to the height of the specified imageSubresource of dstImage
Valid Usage (Implicit)

- **VUID-VkCopyBufferToImageInfo2-sType-sType**
  sType must be `VK_STRUCTURE_TYPE_COPY_BUFFER_TO_IMAGE_INFO_2`

- **VUID-VkCopyBufferToImageInfo2-pNext-pNext**
  pNext must be `NULL`

- **VUID-VkCopyBufferToImageInfo2-srcBuffer-parameter**
  srcBuffer must be a valid `VkBuffer` handle

- **VUID-VkCopyBufferToImageInfo2-dstImage-parameter**
  dstImage must be a valid `VkImage` handle

- **VUID-VkCopyBufferToImageInfo2-dstImageLayout-parameter**
  dstImageLayout must be a valid `VkImageLayout` value

- **VUID-VkCopyBufferToImageInfo2-pRegions-parameter**
  pRegions must be a valid pointer to an array of `regionCount` valid `VkBufferImageCopy2` structures

- **VUID-VkCopyBufferToImageInfo2-regionCount-arraylength**
  regionCount must be greater than 0

- **VUID-VkCopyBufferToImageInfo2-commonparent**
  Both of dstImage, and srcBuffer must have been created, allocated, or retrieved from the same `VkDevice`

To copy data from an image object to a buffer object, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdCopyImageToBuffer2(
    VkCommandBuffer commandBuffer,
    const VkCopyImageToBufferInfo2* pCopyImageToBufferInfo);
```

or the equivalent command

```c
// Provided by VK_KHR_copy_commands2
void vkCmdCopyImageToBuffer2KHR(
    VkCommandBuffer commandBuffer,
    const VkCopyImageToBufferInfo2* pCopyImageToBufferInfo);
```

- **commandBuffer** is the command buffer into which the command will be recorded.
- **pCopyImageToBufferInfo** is a pointer to a `VkCopyImageToBufferInfo2` structure describing the copy parameters.

This command is functionally identical to `vkCmdCopyImageToBuffer`, but includes extensible sub-structures that include `sType` and `pNext` parameters, allowing them to be more easily extended.
Valid Usage

- VUID-vkCmdCopyImageToBuffer2-commandBuffer-01831
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `srcImage` must not be a protected image.

- VUID-vkCmdCopyImageToBuffer2-commandBuffer-01832
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `dstBuffer` must not be a protected buffer.

- VUID-vkCmdCopyImageToBuffer2-commandBuffer-01833
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, `dstBuffer` must not be an unprotected buffer.

- VUID-vkCmdCopyImageToBuffer2-commandBuffer-07746
  If the queue family used to create the `VkCommandPool` which `commandBuffer` was allocated from does not support `VK_QUEUE_GRAPHICS_BIT` or `VK_QUEUE_COMPUTE_BIT`, the `bufferOffset` member of any element of `pCopyImageToBufferInfo->pRegions` must be a multiple of 4.

- VUID-vkCmdCopyImageToBuffer2-imageOffset-07747
  The `imageOffset` and `imageExtent` members of each element of `pCopyImageToBufferInfo->pRegions` must respect the image transfer granularity requirements of `commandBuffer`'s command pool’s queue family, as described in `VkQueueFamilyProperties`.

Valid Usage (Implicit)

- VUID-vkCmdCopyImageToBuffer2-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- VUID-vkCmdCopyImageToBuffer2-pCopyImageToBufferInfo-parameter
  `pCopyImageToBufferInfo` must be a valid pointer to a valid `VkCopyImageToBufferInfo2` structure.

- VUID-vkCmdCopyImageToBuffer2-commandBuffer-recording
  `commandBuffer` must be in the `recording state`.

- VUID-vkCmdCopyImageToBuffer2-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support transfer, graphics, or compute operations.

- VUID-vkCmdCopyImageToBuffer2-renderpass
  This command must only be called outside of a render pass instance.

- VUID-vkCmdCopyImageToBuffer2-videocoding
  This command must only be called outside of a video coding scope.

Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally...
The `VkCopyImageToBufferInfo2` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkCopyImageToBufferInfo2 {
    VkStructureType sType;
    const void* pNext;
    VkImage srcImage;
    VkImageLayout srcImageLayout;
    VkBuffer dstBuffer;
    uint32_t regionCount;
    const VkBufferImageCopy2* pRegions;
} VkCopyImageToBufferInfo2;
```

or the equivalent

```c
// Provided by VK_KHR_copy_commands2
typedef VkCopyImageToBufferInfo2 VkCopyImageToBufferInfo2KHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `srcImage` is the source image.
- `srcImageLayout` is the layout of the source image subresources for the copy.
- `dstBuffer` is the destination buffer.
- `regionCount` is the number of regions to copy.
- `pRegions` is a pointer to an array of `VkBufferImageCopy2` structures specifying the regions to copy.

**Valid Usage**

- VUID-VkCopyImageToBufferInfo2-pRegions-04566
  The image region specified by each element of `pRegions` that does not contain `VkCopyCommandTransformInfoQCOM` in its `pNext` chain **must** be contained within the
If the image region specified by each element of \( p\text{Regions} \) contains \( \text{VkCopyCommandTransformInfoQCOM} \) in its \( p\text{Next} \) chain, the rotated source region as described in [copies-buffers-images-rotation-addressing] must be contained within \( \text{srcImage} \).

If any element of \( p\text{Regions} \) contains \( \text{VkCopyCommandTransformInfoQCOM} \) in its \( p\text{Next} \) chain, then \( \text{srcImage} \) must have a 1x1x1 texel block extent.

If any element of \( p\text{Regions} \) contains \( \text{VkCopyCommandTransformInfoQCOM} \) in its \( p\text{Next} \) chain, then \( \text{srcImage} \) must be of type \( \text{VK\_IMAGE\_TYPE\_2D} \).

If any element of \( p\text{Regions} \) contains \( \text{VkCopyCommandTransformInfoQCOM} \) in its \( p\text{Next} \) chain, then \( \text{srcImage} \) must not have a multi-planar format.

\( \text{dstBuffer} \) must be large enough to contain all buffer locations that are accessed according to Buffer and Image Addressing, for each element of \( p\text{Regions} \).

The union of all source regions, and the union of all destination regions, specified by the elements of \( p\text{Regions} \), must not overlap in memory.

\( \text{srcImage} \) must have been created with \( \text{VK\_IMAGE\_USAGE\_TRANSFER\_SRC\_BIT} \) usage flag.

The format features of \( \text{srcImage} \) must contain \( \text{VK\_FORMAT\_FEATURE\_TRANSFER\_SRC\_BIT} \).

\( \text{dstBuffer} \) must have been created with \( \text{VK\_BUFFER\_USAGE\_TRANSFER\_DST\_BIT} \) usage flag.

If \( \text{dstBuffer} \) is non-sparse then it must be bound completely and contiguously to a single \( \text{VkDeviceMemory} \) object.

\( \text{srcImageLayout} \) must specify the layout of the image subresources of \( \text{srcImage} \) specified in \( p\text{Regions} \) at the time this command is executed on a \( \text{VkDevice} \).

\( \text{srcImageLayout} \) must be \( \text{VK\_IMAGE\_LAYOUT\_TRANSFER\_SRC\_OPTIMAL} \), \( \text{VK\_IMAGE\_LAYOUT\_GENERAL} \), or \( \text{VK\_IMAGE\_LAYOUT\_SHARED\_PRESENT\_KHR} \).

If \( \text{srcImage} \) is non-sparse then the image or the specified disjoint plane must be bound completely and contiguously to a single \( \text{VkDeviceMemory} \) object.

The \( \text{imageSubresource.mipLevel} \) member of each element of \( p\text{Regions} \) must be less than the
mipLevels specified in VkImageCreateInfo when srcImage was created

• VUID-VkCopyImageToBufferInfo2-imageSubresource-07968
  The imageSubresource.baseArrayLayer + imageSubresource.layerCount of each element of pRegions, if imageSubresource.layerCount is not VK_REMAINING_ARRAY_LAYERS and maintenance5 is not enabled, must be less than or equal to the arrayLayers specified in VkImageCreateInfo when srcImage was created

• VUID-VkCopyImageToBufferInfo2-srcImage-07969
  srcImage must not have been created with flags containing VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT

• VUID-VkCopyImageToBufferInfo2-srcImage-07973
  srcImage must have a sample count equal to VK_SAMPLE_COUNT_1_BIT

• VUID-VkCopyImageToBufferInfo2-srcImage-07979
  If srcImage is of type VK_IMAGE_TYPE_1D, then for each element of pRegions, imageOffset.y must be 0 and imageExtent.height must be 1

• VUID-VkCopyImageToBufferInfo2-imageOffset-09104
  For each element of pRegions, imageOffset.z and (imageExtent.depth + imageOffset.z) must both be greater than or equal to 0 and less than or equal to the depth of the specified imageSubresource of srcImage

• VUID-VkCopyImageToBufferInfo2-srcImage-07980
  If srcImage is of type VK_IMAGE_TYPE_1D or VK_IMAGE_TYPE_2D, then for each element of pRegions, imageOffset.z must be 0 and imageExtent.depth must be 1

• VUID-VkCopyImageToBufferInfo2-srcImage-07274
  For each element of pRegions, imageOffset.x must be a multiple of the texel block extent width of the VkFormat of srcImage

• VUID-VkCopyImageToBufferInfo2-srcImage-07275
  For each element of pRegions, imageOffset.y must be a multiple of the texel block extent height of the VkFormat of srcImage

• VUID-VkCopyImageToBufferInfo2-srcImage-07276
  For each element of pRegions, imageOffset.z must be a multiple of the texel block extent depth of the VkFormat of srcImage

• VUID-VkCopyImageToBufferInfo2-srcImage-00207
  For each element of pRegions, if the sum of imageOffset.x and extent.width does not equal the width of the subresource specified by srcSubresource, extent.width must be a multiple of the texel block extent width of the VkFormat of srcImage

• VUID-VkCopyImageToBufferInfo2-srcImage-00208
  For each element of pRegions, if the sum of imageOffset.y and extent.height does not equal the height of the subresource specified by srcSubresource, extent.height must be a multiple of the texel block extent height of the VkFormat of srcImage

• VUID-VkCopyImageToBufferInfo2-srcImage-00209
  For each element of pRegions, if the sum of imageOffset.z and extent.depth does not equal the depth of the subresource specified by srcSubresource, extent.depth must be a multiple of the texel block extent depth of the VkFormat of srcImage
For each element of pRegions, imageSubresource.aspectMask must specify aspects present in srcImage.

If srcImage has a multi-planar image format, then for each element of pRegions, imageSubresource.aspectMask must be a single valid multi-planar aspect mask bit.

If srcImage is of type VK_IMAGE_TYPE_3D, for each element of pRegions, imageSubresource.baseArrayLayer must be 0 and imageSubresource.layerCount must be 1.

For each element of pRegions, bufferRowLength must be a multiple of the texel block extent width of the VkFormat of srcImage.

For each element of pRegions, bufferImageHeight must be a multiple of the texel block extent height of the VkFormat of srcImage.

For each element of pRegions, bufferRowLength divided by the texel block extent width and then multiplied by the texel block size of srcImage must be less than or equal to $2^{31} - 1$.

If srcImage does not have either a depth/stencil or a multi-planar format, then for each element of pRegions, bufferOffset must be a multiple of the texel block size.

If srcImage has a multi-planar format, then for each element of pRegions, bufferOffset must be a multiple of the element size of the compatible format for the format and the aspectMask of the imageSubresource as defined in Compatible formats of planes of multi-planar formats.

If srcImage has a depth/stencil format, the bufferOffset member of any element of pRegions must be a multiple of 4.

For each element of pRegions not containing VkCopyCommandTransformInfoQCOM in its pNext chain, imageOffset.x and (imageExtent.width + imageOffset.x) must both be greater than or equal to 0 and less than or equal to the width of the specified imageSubresource of srcImage.

For each element of pRegions not containing VkCopyCommandTransformInfoQCOM in its pNext chain, imageOffset.y and (imageExtent.height + imageOffset.y) must both be greater than or equal to 0 and less than or equal to the height of the specified imageSubresource of srcImage.

Valid Usage (Implicit)

- VUID-VkCopyImageToBufferInfo2-sType-sType
sType **must** be **VK_STRUCTURE_TYPE_COPY_IMAGE_TO_BUFFER_INFO_2**

- **VUID-VkCopyImageToBufferInfo2-pNext-pNext**
  pNext **must** be **NULL**

- **VUID-VkCopyImageToBufferInfo2-srcImage-parameter**
  srcImage **must** be a valid **VkImage** handle

- **VUID-VkCopyImageToBufferInfo2-srcImageLayout-parameter**
  srcImageLayout **must** be a valid **VkImageLayout** value

- **VUID-VkCopyImageToBufferInfo2-dstBuffer-parameter**
  dstBuffer **must** be a valid **VkBuffer** handle

- **VUID-VkCopyImageToBufferInfo2-pRegions-parameter**
  pRegions **must** be a valid pointer to an array of regionCount valid **VkBufferImageCopy2** structures

- **VUID-VkCopyImageToBufferInfo2-regionCount-arraylength**
  regionCount **must** be greater than 0

- **VUID-VkCopyImageToBufferInfo2-commonparent**
  Both of dstBuffer, and srcImage **must** have been created, allocated, or retrieved from the same **VkDevice**

For both **vkCmdCopyBufferToImage2** and **vkCmdCopyImageToBuffer2**, each element of pRegions is a structure defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkBufferImageCopy2 {
    VkStructureType sType;
    const void* pNext;
    VkDeviceSize bufferOffset;
    uint32_t bufferRowLength;
    uint32_t bufferImageHeight;
    VkImageSubresourceLayers imageSubresource;
    VkOffset3D imageOffset;
    VkExtent3D imageExtent;
} VkBufferImageCopy2;
```

or the equivalent

```c
// Provided by VK_KHR_copy_commands2
typedef VkBufferImageCopy2 VkBufferImageCopy2KHR;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **bufferOffset** is the offset in bytes from the start of the buffer object where the image data is copied from or to.
• `bufferRowLength` and `bufferImageHeight` specify in texels a subregion of a larger two- or three-dimensional image in buffer memory, and control the addressing calculations. If either of these values is zero, that aspect of the buffer memory is considered to be tightly packed according to the `imageExtent`.

• `imageSubresource` is a `VkImageSubresourceLayers` used to specify the specific image subresources of the image used for the source or destination image data.

• `imageOffset` selects the initial $x$, $y$, $z$ offsets in texels of the sub-region of the source or destination image data.

• `imageExtent` is the size in texels of the image to copy in `width`, `height` and `depth`.

This structure is functionally identical to `VkBufferImageCopy`, but adds `sType` and `pNext` parameters, allowing it to be more easily extended.

### Valid Usage

- VUID-VkBufferImageCopy2-bufferRowLength-09101  
  `bufferRowLength` must be 0, or greater than or equal to the `width` member of `imageExtent`  
- VUID-VkBufferImageCopy2-bufferImageHeight-09102  
  `bufferImageHeight` must be 0, or greater than or equal to the `height` member of `imageExtent`  
- VUID-VkBufferImageCopy2-aspectMask-09103  
  The `aspectMask` member of `imageSubresource` must only have a single bit set  
- VUID-VkBufferImageCopy2-imageExtent-06659  
  `imageExtent.width` must not be 0  
- VUID-VkBufferImageCopy2-imageExtent-06660  
  `imageExtent.height` must not be 0  
- VUID-VkBufferImageCopy2-imageExtent-06661  
  `imageExtent.depth` must not be 0

### Valid Usage (Implicit)

- VUID-VkBufferImageCopy2-sType-sType  
  `sType` must be `VK_STRUCTURE_TYPE_BUFFER_IMAGE_COPY_2`  
- VUID-VkBufferImageCopy2-pNext-pNext  
  `pNext` must be `NULL` or a pointer to a valid instance of `VkCopyCommandTransformInfoQCOM`  
- VUID-VkBufferImageCopy2-sType-unique  
  The `sType` value of each struct in the `pNext` chain must be unique  
- VUID-VkBufferImageCopy2-imageSubresource-parameter  
  `imageSubresource` must be a valid `VkImageSubresourceLayers` structure

The `VkCopyCommandTransformInfoQCOM` structure is defined as:
typedef struct VkCopyCommandTransformInfoQCOM {
    VkStructureType sType;
    const void* pNext;
    VkSurfaceTransformFlagBitsKHR transform;
} VkCopyCommandTransformInfoQCOM;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• transform is a VkSurfaceTransformFlagBitsKHR value describing the transform to be applied.

Including this structure in the pNext chain of VkBufferImageCopy2 defines a rotation to be performed when copying between an image and a buffer. Including this structure in the pNext chain of VkBlitImageInfo2 defines a rotation to be performed when blitting between two images. If this structure is not specified in either case, the implementation behaves as if it was specified with a transform equal to VK_SURFACE_TRANSFORM_IDENTITY_BIT_KHR.

Specifying a transform for a copy between an image and a buffer rotates the region accessed in the image around the offset. Specifying a transform for a blit performs a similar transform as described in Image Blits with Scaling and Rotation.

Rotations other than VK_SURFACE_TRANSFORM_IDENTITY_BIT_KHR can only be specified for single-plane 2D images with a 1x1x1 texel block extent.

Valid Usage

• VUID-VkCopyCommandTransformInfoQCOM-transform-04560
  transform must be VK_SURFACE_TRANSFORM_IDENTITY_BIT_KHR,
  VK_SURFACE_TRANSFORM_ROTATE_90_BIT_KHR, VK_SURFACE_TRANSFORM_ROTATE_180_BIT_KHR, or
  VK_SURFACE_TRANSFORM_ROTATE_270_BIT_KHR

Valid Usage (Implicit)

• VUID-VkCopyCommandTransformInfoQCOM-sType-sType
  sType must be VK_STRUCTURE_TYPE_COPY_COMMAND_TRANSFORM_INFO_QCOM

The following commands can be used to copy between host memory and images.

To copy data from host memory to an image object, call:

// Provided by VK_EXT_host_image_copy
VkResult vkCopyMemoryToImageEXT(
    VkDevice device,
    const VkCopyMemoryToImageInfoEXT* pCopyMemoryToImageInfo);
• `device` is the device which owns `pCopyMemoryToImageInfo->dstImage`.
• `pCopyMemoryToImageInfo` is a pointer to a `VkCopyMemoryToImageInfoEXT` structure describing the copy parameters.

This command is functionally similar to `vkCmdCopyBufferToImage2`, except it is executed on the host and reads from host memory instead of a buffer.

**Valid Usage**

- VUID-vkCopyMemoryToImageEXT-hostImageCopy-09058
  The `hostImageCopy` feature **must** be enabled

**Valid Usage (Implicit)**

- VUID-vkCopyMemoryToImageEXT-device-parameter
  `device` **must** be a valid `VkDevice` handle
- VUID-vkCopyMemoryToImageEXT-pCopyMemoryToImageInfo-parameter
  `pCopyMemoryToImageInfo` **must** be a valid pointer to a valid `VkCopyMemoryToImageInfoEXT` structure

**Return Codes**

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_INITIALIZATION_FAILED`
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_MEMORY_MAP_FAILED`

The `VkCopyMemoryToImageInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_host_image_copy
typedef struct VkCopyMemoryToImageInfoEXT {
    VkStructureType     sType;
    const void*        pNext;
    VkHostImageCopyFlagsEXT      flags;
    VkImage
    VkImageLayout
    uint32_t
    const VkMemoryToImageCopyEXT* pRegions;
} VkCopyMemoryToImageInfoEXT;
```
• **sType** is a VkStructureType value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.
• **flags** is a bitmask of VkHostImageCopyFlagBitsEXT values describing additional copy parameters.
• **dstImage** is the destination image.
• **dstImageLayout** is the layout of the destination image subresources for the copy.
• **regionCount** is the number of regions to copy.
• **pRegions** is a pointer to an array of VkMemoryToImageCopyEXT structures specifying the regions to copy.

vkCopyMemoryToImageEXT does not check whether the device memory associated with dstImage is currently in use before performing the copy. The application must guarantee that any previously submitted command that reads from or writes to the copy regions has completed before the host performs the copy.

Copy regions for the image must be aligned to a multiple of the texel block extent in each dimension, except at the edges of the image, where region extents must match the edge of the image.

### Valid Usage

- **VUID-VkCopyMemoryToImageInfoEXT-dstImage-09109**
  If dstImage is sparse then all memory ranges accessed by the copy command must be bound as described in Binding Resource Memory

- **VUID-VkCopyMemoryToImageInfoEXT-dstImage-09111**
  If the stencil aspect of dstImage is accessed, and dstImage was not created with separate stencil usage, the image must have been created with VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT set in VkImageCreateInfo::usage

- **VUID-VkCopyMemoryToImageInfoEXT-dstImage-09112**
  If the stencil aspect of dstImage is accessed, and dstImage was created with separate stencil usage, the image must have been created with VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT set in VkImageStencilUsageCreateInfo::stencilUsage

- **VUID-VkCopyMemoryToImageInfoEXT-dstImage-09113**
  If non-stencil aspects of dstImage are accessed, the image must have been created with VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT set in VkImageCreateInfo::usage

- **VUID-VkCopyMemoryToImageInfoEXT-imageOffset-09114**
  If flags contains VK_HOST_IMAGE_COPY_MEMCPY_EXT, the x, y, and z members of the imageOffset member of each element of pRegions must be 0

- **VUID-VkCopyMemoryToImageInfoEXT-dstImage-09115**
  If flags contains VK_HOST_IMAGE_COPY_MEMCPY_EXT, the imageExtent member of each element of pRegions must equal the extents of dstImage identified by imageSubresource

- **VUID-VkCopyMemoryToImageInfoEXT-dstImage-07966**
  If dstImage is non-sparse then the image or the specified disjoint plane must be bound
completely and contiguously to a single `VkDeviceMemory` object

- **VUID-VkCopyMemoryToImageInfoEXT-imageSubresource-07967**
  The `imageSubresource.mipLevel` member of each element of `pRegions` must be less than the `mipLevels` specified in `VkImageCreateInfo` when `dstImage` was created

- **VUID-VkCopyMemoryToImageInfoEXT-imageSubresource-07968**
  The `imageSubresource.baseArrayLayer + imageSubresource.layerCount` of each element of `pRegions`, if `imageSubresource.layerCount` is not `VK_REMAINING_ARRAY_LAYERS` and `maintenance5` is not enabled, must be less than or equal to the `arrayLayers` specified in `VkImageCreateInfo` when `dstImage` was created

- **VUID-VkCopyMemoryToImageInfoEXT-dstImage-07969**
  `dstImage` must not have been created with flags containing `VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT`

- **VUID-VkCopyMemoryToImageInfoEXT-imageSubresource-07970**
  The image region specified by each element of `pRegions` must be contained within the specified `imageSubresource` of `dstImage`

- **VUID-VkCopyMemoryToImageInfoEXT-imageSubresource-07971**
  For each element of `pRegions`, `imageOffset.x` and `(imageExtent.width + imageOffset.x)` must both be greater than or equal to 0 and less than or equal to the width of the specified `imageSubresource` of `dstImage`

- **VUID-VkCopyMemoryToImageInfoEXT-imageSubresource-07972**
  For each element of `pRegions`, `imageOffset.y` and `(imageExtent.height + imageOffset.y)` must both be greater than or equal to 0 and less than or equal to the height of the specified `imageSubresource` of `dstImage`

- **VUID-VkCopyMemoryToImageInfoEXT-dstImage-07973**
  `dstImage` must have a sample count equal to `VK_SAMPLE_COUNT_1_BIT`

- **VUID-VkCopyMemoryToImageInfoEXT-dstImage-07979**
  If `dstImage` is of type `VK_IMAGE_TYPE_1D`, then for each element of `pRegions`, `imageOffset.y` must be 0 and `imageExtent.height` must be 1

- **VUID-VkCopyMemoryToImageInfoEXT-imageOffset-09104**
  For each element of `pRegions`, `imageOffset.z` and `(imageExtent.depth + imageOffset.z)` must both be greater than or equal to 0 and less than or equal to the depth of the specified `imageSubresource` of `dstImage`

- **VUID-VkCopyMemoryToImageInfoEXT-dstImage-07980**
  If `dstImage` is of type `VK_IMAGE_TYPE_1D` or `VK_IMAGE_TYPE_2D`, then for each element of `pRegions`, `imageOffset.z` must be 0 and `imageExtent.depth` must be 1

- **VUID-VkCopyMemoryToImageInfoEXT-dstImage-07274**
  For each element of `pRegions`, `imageOffset.x` must be a multiple of the texel block extent width of the `VkFormat` of `dstImage`

- **VUID-VkCopyMemoryToImageInfoEXT-dstImage-07275**
  For each element of `pRegions`, `imageOffset.y` must be a multiple of the texel block extent height of the `VkFormat` of `dstImage"
For each element of `pRegions`, `imageOffset.z` must be a multiple of the texel block extent depth of the `VkFormat` of `dstImage`.

For each element of `pRegions`, if the sum of `image Offset.x` and `extent.width` does not equal the width of the subresource specified by `srcSubresource`, `extent.width` must be a multiple of the texel block extent width of the `VkFormat` of `dstImage`.

For each element of `pRegions`, if the sum of `imageOffset.y` and `extent.height` does not equal the height of the subresource specified by `srcSubresource`, `extent.height` must be a multiple of the texel block extent height of the `VkFormat` of `dstImage`.

For each element of `pRegions`, if the sum of `imageOffset.z` and `extent.depth` does not equal the depth of the subresource specified by `srcSubresource`, `extent.depth` must be a multiple of the texel block extent depth of the `VkFormat` of `dstImage`.

For each element of `pRegions`, `imageSubresource.aspectMask` must specify aspects present in `dstImage`.

If `dstImage` has a multi-planar image format, then for each element of `pRegions`, `imageSubresource.aspectMask` must be a single valid multi-planar aspect mask bit.

If `dstImage` is of type `VK_IMAGE_TYPE_3D`, for each element of `pRegions`, `imageSubresource.baseArrayLayer` must be 0 and `imageSubresource.layerCount` must be 1.

For each element of `pRegions`, `memoryRowLength` must be a multiple of the texel block extent width of the `VkFormat` of `dstImage`.

For each element of `pRegions`, `memoryImageHeight` must be a multiple of the texel block extent height of the `VkFormat` of `dstImage`.

For each element of `pRegions`, `memoryRowLength` divided by the texel block extent width and then multiplied by the texel block size of `dstImage` must be less than or equal to $2^{31} - 1$.

`dstImageLayout` must specify the current layout of the image subresources of `dstImage` specified in `pRegions`.

`dstImageLayout` must be one of the image layouts returned in `VkPhysicalDeviceHostImageCopyPropertiesEXT::pCopyDstLayouts`.
Valid Usage (Implicit)

- **VUID-VkCopyMemoryToImageInfoEXT-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_COPY_MEMORY_TO_IMAGE_INFO_EXT`

- **VUID-VkCopyMemoryToImageInfoEXT-pNext-pNext**
  `pNext` must be `NULL`

- **VUID-VkCopyMemoryToImageInfoEXT-flags-parameter**
  `flags` must be a valid combination of `VkHostImageCopyFlagBitsEXT` values

- **VUID-VkCopyMemoryToImageInfoEXT-dstImage-parameter**
  `dstImage` must be a valid `VkImage` handle

- **VUID-VkCopyMemoryToImageInfoEXT-dstImageLayout-parameter**
  `dstImageLayout` must be a valid `VkImageLayout` value

- **VUID-VkCopyMemoryToImageInfoEXT-pRegions-parameter**
  `pRegions` must be a valid pointer to an array of `regionCount` valid `VkMemoryToImageCopyEXT` structures

- **VUID-VkCopyMemoryToImageInfoEXT-regionCount-arraylength**
  `regionCount` must be greater than 0

Each element of `VkCopyMemoryToImageInfoEXT::pRegions` is a structure defined as:

```c
typedef struct VkMemoryToImageCopyEXT {
    VkStructureType         sType;
    const void*             pNext;
    const void*             pHostPointer;
    uint32_t                memoryRowLength;
    uint32_t                memoryImageHeight;
    VkImageSubresourceLayers imageSubresource;
    VkOffset3D              imageOffset;
    VkExtent3D              imageExtent;
} VkMemoryToImageCopyEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **pHostPointer** is the host memory address which is the source of the copy.
- **memoryRowLength** and **memoryImageHeight** specify in texels a subregion of a larger two- or three-dimensional image in host memory, and control the addressing calculations. If either of these values is zero, that aspect of the host memory is considered to be tightly packed according to the `imageExtent`.
- **imageSubresource** is a `VkImageSubresourceLayers` used to specify the specific image subresources of the image used for the source or destination image data.
- **imageOffset** selects the initial x, y, z offsets in texels of the sub-region of the destination image
• **imageExtent** is the size in texels of the image to copy in **width**, **height** and **depth**.

This structure is functionally similar to **VkBufferImageCopy2**, except it defines host memory as the source of copy instead of a buffer. In particular, the same data packing rules and restrictions as that structure apply here as well.

---

### Valid Usage

- **VUID-VkMemoryToImageCopyEXT-pHostPointer-09061**
  
  *pHostPointer* **must** point to memory that is large enough to contain all memory locations that are accessed according to **Buffer and Image Addressing**, for each element of *pRegions*

- **VUID-VkMemoryToImageCopyEXT-pRegions-09062**
  
  The union of all source regions, and the union of all destination regions, specified by the elements of *pRegions*, **must** not overlap in memory

- **VUID-VkMemoryToImageCopyEXT-memoryRowLength-09101**
  
  *memoryRowLength* **must** be 0, or greater than or equal to the **width** member of *imageExtent*

- **VUID-VkMemoryToImageCopyEXT-memoryImageHeight-09102**
  
  *memoryImageHeight* **must** be 0, or greater than or equal to the **height** member of *imageExtent*

- **VUID-VkMemoryToImageCopyEXT-aspectMask-09103**
  
  The **aspectMask** member of *imageSubresource** **must** only have a single bit set

- **VUID-VkMemoryToImageCopyEXT-imageExtent-06659**
  
  *imageExtent.width* **must** not be 0

- **VUID-VkMemoryToImageCopyEXT-imageExtent-06660**
  
  *imageExtent.height* **must** not be 0

- **VUID-VkMemoryToImageCopyEXT-imageExtent-06661**
  
  *imageExtent.depth* **must** not be 0

---

### Valid Usage (Implicit)

- **VUID-VkMemoryToImageCopyEXT-sType-sType**
  
  *sType* **must** be **VK_STRUCTURE_TYPE_MEMORY_TO_IMAGE_COPY_EXT**

- **VUID-VkMemoryToImageCopyEXT-pNext-pNext**
  
  *pNext* **must** be **NULL**

- **VUID-VkMemoryToImageCopyEXT-pHostPointer-parameter**
  
  *pHostPointer* **must** be a pointer value

- **VUID-VkMemoryToImageCopyEXT-imageSubresource-parameter**
  
  *imageSubresource* **must** be a valid **VkImageSubresourceLayers** structure

---

To copy data from an image object to host memory, call:
VkResult vkCopyImageToMemoryEXT(VkDevice device, const VkCopyImageToMemoryInfoEXT* pCopyImageToMemoryInfo);

- `device` is the device which owns `pCopyImageToMemoryInfo->srcImage`.
- `pCopyImageToMemoryInfo` is a pointer to a `VkCopyImageToMemoryInfoEXT` structure describing the copy parameters.

This command is functionally similar to `vkCmdCopyImageToBuffer2`, except it is executed on the host and writes to host memory instead of a buffer.

### Valid Usage

- VUID-vkCopyImageToMemoryEXT-hostImageCopy-09063
  The `hostImageCopy` feature **must** be enabled

### Valid Usage (Implicit)

- VUID-vkCopyImageToMemoryEXT-device-parameter
  `device` **must** be a valid `VkDevice` handle
- VUID-vkCopyImageToMemoryEXT-pCopyImageToMemoryInfo-parameter
  `pCopyImageToMemoryInfo` **must** be a valid pointer to a valid `VkCopyImageToMemoryInfoEXT` structure

### Return Codes

#### Success

- `VK_SUCCESS`

#### Failure

- `VK_ERROR_INITIALIZATION_FAILED`
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_MEMORY_MAP_FAILED`

The `VkCopyImageToMemoryInfoEXT` structure is defined as:

```c
typedef struct VkCopyImageToMemoryInfoEXT {
    VkStructureType sType;
    const void* pNext;
} VkCopyImageToMemoryInfoEXT;
```
VkHostImageCopyFlagsEXT flags;
VkImage srcImage;
VkImageLayout srcImageLayout;
uint32_t regionCount;
const VkImageToMemoryCopyEXT* pRegions;
} VkCopyImageToMemoryInfoEXT;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkHostImageCopyFlagBitsEXT` values describing additional copy parameters.
- `srcImage` is the source image.
- `srcImageLayout` is the layout of the source image subresources for the copy.
- `regionCount` is the number of regions to copy.
- `pRegions` is a pointer to an array of `VkImageToMemoryCopyEXT` structures specifying the regions to copy.

`vkCopyImageToMemoryEXT` does not check whether the device memory associated with `srcImage` is currently in use before performing the copy. The application **must** guarantee that any previously submitted command that writes to the copy regions has completed before the host performs the copy.

Copy regions for the image **must** be aligned to a multiple of the texel block extent in each dimension, except at the edges of the image, where region extents **must** match the edge of the image.

### Valid Usage

- **VUID-VkCopyImageToMemoryInfoEXT-srcImage-09109**
  If `srcImage` is sparse then all memory ranges accessed by the copy command **must** be bound as described in `Binding Resource Memory`

- **VUID-VkCopyImageToMemoryInfoEXT-srcImage-09111**
  If the stencil aspect of `srcImage` is accessed, and `srcImage` was not created with separate stencil usage, the image **must** have been created with `VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT` set in `VkImageCreateInfo::usage`

- **VUID-VkCopyImageToMemoryInfoEXT-srcImage-09112**
  If the stencil aspect of `srcImage` is accessed, and `srcImage` was created with separate stencil usage, the image **must** have been created with `VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT` set in `VkImageStencilUsageCreateInfo::stencilUsage`

- **VUID-VkCopyImageToMemoryInfoEXT-srcImage-09113**
  If non-stencil aspects of `srcImage` are accessed, the image **must** have been created with `VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT` set in `VkImageCreateInfo::usage`

- **VUID-VkCopyImageToMemoryInfoEXT-imageOffset-09114**
  If `flags` contains `VK_HOST_IMAGE_COPY_MEMCPY_EXT`, the `x`, `y`, and `z` members of the
imageOffset member of each element of pRegions must be 0

- VUID-VkCopyImageToMemoryInfoEXT-srcImage-09115
  If flags contains VK_HOST_IMAGE_COPY_MEMCPY_EXT, the imageExtent member of each element of pRegions must equal the extents of srcImage identified by imageSubresource

- VUID-VkCopyImageToMemoryInfoEXT-srcImage-07966
  If srcImage is non-sparse then the image or the specified disjoint plane must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-VkCopyImageToMemoryInfoEXT-imageSubresource-07967
  The imageSubresource.mipLevel member of each element of pRegions must be less than the mipLevels specified in VkImageCreateInfo when srcImage was created

- VUID-VkCopyImageToMemoryInfoEXT-imageSubresource-07968
  The imageSubresource.baseArrayLayer + imageSubresource.layerCount of each element of pRegions, if imageSubresource.layerCount is not VK_REMAINING_ARRAY_LAYERS and maintenance5 is not enabled, must be less than or equal to the arrayLayers specified in VkImageCreateInfo when srcImage was created

- VUID-VkCopyImageToMemoryInfoEXT-srcImage-07969
  srcImage must not have been created with flags containing VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT

- VUID-VkCopyImageToMemoryInfoEXT-imageSubresource-07970
  The image region specified by each element of pRegions must be contained within the specified imageSubresource of srcImage

- VUID-VkCopyImageToMemoryInfoEXT-imageSubresource-07971
  For each element of pRegions, imageOffset.x and (imageExtent.width + imageOffset.x) must both be greater than or equal to 0 and less than or equal to the width of the specified imageSubresource of srcImage

- VUID-VkCopyImageToMemoryInfoEXT-imageSubresource-07972
  For each element of pRegions, imageOffset.y and (imageExtent.height + imageOffset.y) must both be greater than or equal to 0 and less than or equal to the height of the specified imageSubresource of srcImage

- VUID-VkCopyImageToMemoryInfoEXT-srcImage-07973
  srcImage must have a sample count equal to VK_SAMPLE_COUNT_1_BIT

- VUID-VkCopyImageToMemoryInfoEXT-srcImage-07979
  If srcImage is of type VK_IMAGE_TYPE_1D, then for each element of pRegions, imageOffset.y must be 0 and imageExtent.height must be 1

- VUID-VkCopyImageToMemoryInfoEXT-imageOffset-09104
  For each element of pRegions, imageOffset.z and (imageExtent.depth + imageOffset.z) must both be greater than or equal to 0 and less than or equal to the depth of the specified imageSubresource of srcImage

- VUID-VkCopyImageToMemoryInfoEXT-srcImage-07980
  If srcImage is of type VK_IMAGE_TYPE_1D or VK_IMAGE_TYPE_2D, then for each element of pRegions, imageOffset.z must be 0 and imageExtent.depth must be 1
VUID-VkCopyImageToMemoryInfoEXT-srcImage-07274
For each element of \texttt{pRegions}, \texttt{imageOffset.x} must be a multiple of the texel block extent width of the \texttt{VkFormat} of \texttt{srcImage}

VUID-VkCopyImageToMemoryInfoEXT-srcImage-07275
For each element of \texttt{pRegions}, \texttt{imageOffset.y} must be a multiple of the texel block extent height of the \texttt{VkFormat} of \texttt{srcImage}

VUID-VkCopyImageToMemoryInfoEXT-srcImage-07276
For each element of \texttt{pRegions}, \texttt{imageOffset.z} must be a multiple of the texel block extent depth of the \texttt{VkFormat} of \texttt{srcImage}

VUID-VkCopyImageToMemoryInfoEXT-srcImage-00207
For each element of \texttt{pRegions}, if the sum of \texttt{imageOffset.x} and \texttt{extent.width} does not equal the width of the subresource specified by \texttt{srcSubresource}, \texttt{extent.width} must be a multiple of the texel block extent width of the \texttt{VkFormat} of \texttt{srcImage}

VUID-VkCopyImageToMemoryInfoEXT-srcImage-00208
For each element of \texttt{pRegions}, if the sum of \texttt{imageOffset.y} and \texttt{extent.height} does not equal the height of the subresource specified by \texttt{srcSubresource}, \texttt{extent.height} must be a multiple of the texel block extent height of the \texttt{VkFormat} of \texttt{srcImage}

VUID-VkCopyImageToMemoryInfoEXT-srcImage-00209
For each element of \texttt{pRegions}, if the sum of \texttt{imageOffset.z} and \texttt{extent.depth} does not equal the depth of the subresource specified by \texttt{srcSubresource}, \texttt{extent.depth} must be a multiple of the texel block extent depth of the \texttt{VkFormat} of \texttt{srcImage}

VUID-VkCopyImageToMemoryInfoEXT-imageSubresource-09105
For each element of \texttt{pRegions}, \texttt{imageSubresource.aspectMask} must specify aspects present in \texttt{srcImage}

VUID-VkCopyImageToMemoryInfoEXT-srcImage-07981
If \texttt{srcImage} has a multi-planar image format, then for each element of \texttt{pRegions}, \texttt{imageSubresource.aspectMask} must be a single valid multi-planar aspect mask bit

VUID-VkCopyImageToMemoryInfoEXT-srcImage-07983
If \texttt{srcImage} is of type \texttt{VK_IMAGE_TYPE_3D}, for each element of \texttt{pRegions}, \texttt{imageSubresource.baseArrayLayer} must be 0 and \texttt{imageSubresource.layerCount} must be 1

VUID-VkCopyImageToMemoryInfoEXT-memoryRowLength-09106
For each element of \texttt{pRegions}, \texttt{memoryRowLength} must be a multiple of the texel block extent width of the \texttt{VkFormat} of \texttt{srcImage}

VUID-VkCopyImageToMemoryInfoEXT-memoryImageHeight-09107
For each element of \texttt{pRegions}, \texttt{memoryImageHeight} must be a multiple of the texel block extent height of the \texttt{VkFormat} of \texttt{srcImage}

VUID-VkCopyImageToMemoryInfoEXT-memoryRowLength-09108
For each element of \texttt{pRegions}, \texttt{memoryRowLength} divided by the texel block extent width and then multiplied by the texel block size of \texttt{srcImage} must be less than or equal to $2^{31} - 1$

VUID-VkCopyImageToMemoryInfoEXT-srcImageLayout-09064
\texttt{srcImageLayout} must specify the current layout of the image subresources of \texttt{srcImage} specified in \texttt{pRegions}
• VUID-VkCopyImageToMemoryInfoEXT-srcImageLayout-09065
  srcImageLayout must be one of the image layouts returned in
  VkPhysicalDeviceHostImageCopyPropertiesEXT::pCopySrcLayouts

Valid Usage (Implicit)

• VUID-VkCopyImageToMemoryInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_COPY_IMAGE_TO_MEMORY_INFO_EXT

• VUID-VkCopyImageToMemoryInfoEXT-pNext-pNext
  pNext must be NULL

• VUID-VkCopyImageToMemoryInfoEXT-flags-parameter
  flags must be a valid combination of VkHostImageCopyFlagBitsEXT values

• VUID-VkCopyImageToMemoryInfoEXT-srcImage-parameter
  srcImage must be a valid VkImage handle

• VUID-VkCopyImageToMemoryInfoEXT-srcImageLayout-parameter
  srcImageLayout must be a valid VkImageLayout value

• VUID-VkCopyImageToMemoryInfoEXT-pRegions-parameter
  pRegions must be a valid pointer to an array of regionCount valid
  VkImageToMemoryCopyEXT structures

• VUID-VkCopyImageToMemoryInfoEXT-regionCount-arraylength
  regionCount must be greater than 0

Each element of VkCopyImageToMemoryInfoEXT::pRegions is a structure defined as:

```c
// Provided by VK_EXT_host_image_copy
typedef struct VkImageToMemoryCopyEXT {
  VkStructureType sType;
  const void* pNext;
  void* pHostPointer;
  uint32_t memoryRowLength;
  uint32_t memoryImageHeight;
  VkImageSubresourceLayers imageSubresource;
  VkOffset3D imageOffset;
  VkExtent3D imageExtent;
} VkImageToMemoryCopyEXT;
```

• sType is a VkStructureType value identifying this structure.

• pNext is NULL or a pointer to a structure extending this structure.

• pHostPointer is the host memory address which is the destination of the copy.

• memoryRowLength and memoryImageHeight specify in texels a subregion of a larger two- or three-
  dimensional image in host memory, and control the addressing calculations. If either of these
  values is zero, that aspect of the host memory is considered to be tightly packed according to the
imageExtent.

- **imageSubresource** is a VkImageSubresourceLayers used to specify the specific image subresources of the image used for the source or destination image data.
- **imageOffset** selects the initial x, y, z offsets in texels of the sub-region of the source image data.
- **imageExtent** is the size in texels of the image to copy in width, height and depth.

This structure is functionally similar to VkBufferImageCopy2, except it defines host memory as the target of copy instead of a buffer. In particular, the same data packing rules and restrictions as that structure apply here as well.

### Valid Usage

- **VUID-VkImageToMemoryCopyEXT-pHostPointer-09066**
  pHostPointer **must** point to memory that is large enough to contain all memory locations that are accessed according to Buffer and Image Addressing, for each element of pRegions

- **VUID-VkImageToMemoryCopyEXT-pRegions-09067**
  The union of all source regions, and the union of all destination regions, specified by the elements of pRegions, **must** not overlap in memory

- **VUID-VkImageToMemoryCopyEXT-memoryRowLength-09101**
  memoryRowLength **must** be 0, or greater than or equal to the width member of imageExtent

- **VUID-VkImageToMemoryCopyEXT-memoryImageHeight-09102**
  memoryImageHeight **must** be 0, or greater than or equal to the height member of imageExtent

- **VUID-VkImageToMemoryCopyEXT-aspectMask-09103**
  The aspectMask member of imageSubresource **must** only have a single bit set

- **VUID-VkImageToMemoryCopyEXT-imageExtent-06659**
  imageExtent.width **must** not be 0

- **VUID-VkImageToMemoryCopyEXT-imageExtent-06660**
  imageExtent.height **must** not be 0

- **VUID-VkImageToMemoryCopyEXT-imageExtent-06661**
  imageExtent.depth **must** not be 0

### Valid Usage (Implicit)

- **VUID-VkImageToMemoryCopyEXT-sType-sType**
  sType **must** be VK_STRUCTURE_TYPE_IMAGE_TO_MEMORY_COPY_EXT

- **VUID-VkImageToMemoryCopyEXT-pNext-pNext**
  pNext **must** be NULL

- **VUID-VkImageToMemoryCopyEXT-pHostPointer-parameter**
  pHostPointer **must** be a pointer value

- **VUID-VkImageToMemoryCopyEXT-imageSubresource-parameter**
  imageSubresource **must** be a valid VkImageSubresourceLayers structure
Bits which can be set in VkCopyMemoryToImageInfoEXT::flags, VkCopyImageToMemoryInfoEXT::flags, and VkCopyImageToImageInfoEXT::flags, specifying additional copy parameters are:

```
// Provided by VK_EXT_host_image_copy
typedef enum VkHostImageCopyFlagBitsEXT {
    VK_HOST_IMAGE_COPY_MEMCPY_EXT = 0x00000001,
} VkHostImageCopyFlagBitsEXT;
```

- **VK_HOST_IMAGE_COPY_MEMCPY_EXT** specifies that no memory layout swizzling is to be applied during data copy. For copies between memory and images, this flag indicates that image data in host memory is swizzled in exactly the same way as the image data on the device. Using this flag indicates that the implementations may use a simple memory copy to transfer the data between the host memory and the device memory. The format of the swizzled data in host memory is platform dependent and is not defined in this specification.

```
// Provided by VK_EXT_host_image_copy
typedef VkFlags VkHostImageCopyFlagsEXT;
```

VkHostImageCopyFlagsEXT is a bitmask type for setting a mask of zero or more VkHostImageCopyFlagBitsEXT.

To copy data from an image object to another image object using the host, call:

```
// Provided by VK_EXT_host_image_copy
VkResult vkCopyImageToImageEXT(
    VkDevice device,
    const VkCopyImageToImageInfoEXT* pCopyImageToImageInfo);
```

- **device** is the device which owns pCopyImageToMemoryInfo->srcImage.
- **pCopyImageToImageInfo** is a pointer to a VkCopyImageToImageInfoEXT structure describing the copy parameters.

This command is functionally similar to vkCmdCopyImage2, except it is executed on the host.

**Valid Usage**

- VUID-vkCopyImageToImageEXT-hostImageCopy-09068
  The hostImageCopy feature must be enabled

**Valid Usage (Implicit)**

- VUID-vkCopyImageToImageEXT-device-parameter
  device must be a valid VkDevice handle
- VUID-vkCopyImageToImageEXT-pCopyImageToImageInfo-parameter
The `VkCopyImageToImageInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_host_image_copy
typedef struct VkCopyImageToImageInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkHostImageCopyFlagsEXT flags;
    VkImage srcImage;
    VkImageLayout srcImageLayout;
    VkImage dstImage;
    VkImageLayout dstImageLayout;
    uint32_t regionCount;
    const VkImageCopy2* pRegions;
} VkCopyImageToImageInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkHostImageCopyFlagBitsEXT` values describing additional copy parameters.
- `srcImage` is the source image.
- `srcImageLayout` is the layout of the source image subresources for the copy.
- `dstImage` is the destination image.
- `dstImageLayout` is the layout of the destination image subresources for the copy.
- `regionCount` is the number of regions to copy.
- `pRegions` is a pointer to an array of `VkImageCopy2` structures specifying the regions to copy.

`vkCopyImageToImageInfoEXT` does not check whether the device memory associated with `srcImage` or `dstImage` is currently in use before performing the copy. The application must guarantee that any
previously submitted command that writes to the copy regions has completed before the host performs the copy.

Valid Usage

- VUID-VkCopyImageToImageInfoEXT-srcImage-09069
  *srcImage* and *dstImage* must have been created with identical image creation parameters.

- VUID-VkCopyImageToImageInfoEXT-srcImage-09109
  If *srcImage* is sparse then all memory ranges accessed by the copy command must be bound as described in Binding Resource Memory.

- VUID-VkCopyImageToImageInfoEXT-srcImage-09111
  If the stencil aspect of *srcImage* is accessed, and *srcImage* was not created with separate stencil usage, the image must have been created with VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT set in VkImageCreateInfo::usage.

- VUID-VkCopyImageToImageInfoEXT-srcImage-09112
  If the stencil aspect of *srcImage* is accessed, and *srcImage* was created with separate stencil usage, the image must have been created with VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT set in VkImageStencilUsageCreateInfo::stencilUsage.

- VUID-VkCopyImageToImageInfoEXT-srcImage-09113
  If non-stencil aspects of *srcImage* are accessed, the image must have been created with VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT set in VkImageCreateInfo::usage.

- VUID-VkCopyImageToImageInfoEXT-srcOffset-09114
  If *flags* contains VK_HOST_IMAGE_COPY_MEMCPY_EXT, the x, y, and z members of the *srcOffset* member of each element of *pRegions* must be 0.

- VUID-VkCopyImageToImageInfoEXT-srcImage-09115
  If *flags* contains VK_HOST_IMAGE_COPY_MEMCPY_EXT, the extent member of each element of *pRegions* must equal the extents of *srcImage* identified by *srcSubresource*.

- VUID-VkCopyImageToImageInfoEXT-srcImage-07966
  If *srcImage* is non-sparse then the image or the specified disjoint plane must be bound completely and contiguously to a single VkDeviceMemory object.

- VUID-VkCopyImageToImageInfoEXT-srcSubresource-07967
  The *srcSubresource*.mipLevel member of each element of *pRegions* must be less than the *mipLevels* specified in VkImageCreateInfo when *srcImage* was created.

- VUID-VkCopyImageToImageInfoEXT-srcSubresource-07968
  The *srcSubresource*.baseArrayLayer + *srcSubresource*.layerCount of each element of *pRegions*, if *srcSubresource*.layerCount is not VK_REMAINING_ARRAY_LAYERS and maintenance5 is not enabled, must be less than or equal to the *arrayLayers* specified in VkImageCreateInfo when *srcImage* was created.

- VUID-VkCopyImageToImageInfoEXT-srcImage-07969
  *srcImage* must not have been created with *flags* containing VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT.

- VUID-VkCopyImageToImageInfoEXT-srcSubresource-07970
The image region specified by each element of \( p\text{Regions} \) must be contained within the specified \( src\text{Subresource} \) of \( src\text{Image} \)

- VUID-VkCopyImageToImageInfoEXT-srcSubresource-07971
  For each element of \( p\text{Regions} \), \( src\text{Offset}.x \) and \((\text{extent.width} + src\text{Offset}.x)\) must both be greater than or equal to 0 and less than or equal to the width of the specified \( src\text{Subresource} \) of \( src\text{Image} \)

- VUID-VkCopyImageToImageInfoEXT-srcSubresource-07972
  For each element of \( p\text{Regions} \), \( src\text{Offset}.y \) and \((\text{extent.height} + src\text{Offset}.y)\) must both be greater than or equal to 0 and less than or equal to the height of the specified \( src\text{Subresource} \) of \( src\text{Image} \)

- VUID-VkCopyImageToImageInfoEXT-srcImage-07979
  If \( src\text{Image} \) is of type \( VK\_IMAGE\_TYPE\_1D \), then for each element of \( p\text{Regions} \), \( src\text{Offset}.y \) must be 0 and \( \text{extent.height} \) must be 1

- VUID-VkCopyImageToImageInfoEXT-srcImage-07980
  If \( src\text{Image} \) is of type \( VK\_IMAGE\_TYPE\_1D \) or \( VK\_IMAGE\_TYPE\_2D \), then for each element of \( p\text{Regions} \), \( src\text{Offset}.z \) must be 0 and \( \text{extent.depth} \) must be 1

- VUID-VkCopyImageToImageInfoEXT-srcImage-07274
  For each element of \( p\text{Regions} \), \( src\text{Offset}.x \) must be a multiple of the texel block extent width of the \( Vk\text{Format} \) of \( src\text{Image} \)

- VUID-VkCopyImageToImageInfoEXT-srcImage-07275
  For each element of \( p\text{Regions} \), \( src\text{Offset}.y \) must be a multiple of the texel block extent height of the \( Vk\text{Format} \) of \( src\text{Image} \)

- VUID-VkCopyImageToImageInfoEXT-srcImage-07276
  For each element of \( p\text{Regions} \), \( src\text{Offset}.z \) must be a multiple of the texel block extent depth of the \( Vk\text{Format} \) of \( src\text{Image} \)

- VUID-VkCopyImageToImageInfoEXT-srcImage-00207
  For each element of \( p\text{Regions} \), if the sum of \( src\text{Offset}.x \) and \( \text{extent.width} \) does not equal the width of the subresource specified by \( src\text{Subresource} \), \( \text{extent.width} \) must be a multiple of the texel block extent width of the \( Vk\text{Format} \) of \( src\text{Image} \)

- VUID-VkCopyImageToImageInfoEXT-srcImage-00208
  For each element of \( p\text{Regions} \), if the sum of \( src\text{Offset}.y \) and \( \text{extent.height} \) does not equal the height of the subresource specified by \( src\text{Subresource} \), \( \text{extent.height} \) must be a multiple of the texel block extent height of the \( Vk\text{Format} \) of \( src\text{Image} \)

- VUID-VkCopyImageToImageInfoEXT-srcImage-00209
  For each element of \( p\text{Regions} \), if the sum of \( src\text{Offset}.z \) and \( \text{extent.depth} \) does not equal the depth of the subresource specified by \( src\text{Subresource} \), \( \text{extent.depth} \) must be a multiple of the texel block extent depth of the \( Vk\text{Format} \) of \( src\text{Image} \)

- VUID-VkCopyImageToImageInfoEXT-srcSubresource-09105
  For each element of \( p\text{Regions} \), \( src\text{Subresource}.\text{aspectMask} \) must specify aspects present in
srcImage

- VUID-VkCopyImageToImageInfoEXT-srcImage-07981
  If srcImage has a multi-planar image format, then for each element of pRegions, srcSubresource.aspectMask must be a single valid multi-planar aspect mask bit

- VUID-VkCopyImageToImageInfoEXT-srcImage-07983
  If srcImage is of type VK_IMAGE_TYPE_3D, for each element of pRegions, srcSubresource.baseArrayLayer must be 0 and srcSubresource.layerCount must be 1

- VUID-VkCopyImageToImageInfoEXT-dstImage-09109
  If dstImage is sparse then all memory ranges accessed by the copy command must be bound as described in Binding Resource Memory

- VUID-VkCopyImageToImageInfoEXT-dstImage-09111
  If the stencil aspect of dstImage is accessed, and dstImage was not created with separate stencil usage, the image must have been created with VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT set in VkImageCreateInfo::usage

- VUID-VkCopyImageToImageInfoEXT-dstImage-09112
  If the stencil aspect of dstImage is accessed, and dstImage was created with separate stencil usage, the image must have been created with VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT set in VkImageStencilUsageCreateInfo::stencilUsage

- VUID-VkCopyImageToImageInfoEXT-dstImage-09113
  If non-stencil aspects of dstImage are accessed, the image must have been created with VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT set in VkImageCreateInfo::usage

- VUID-VkCopyImageToImageInfoEXT-dstOffset-09114
  If flags contains VK_HOST_IMAGE_COPY_MEMCPY_EXT, the x, y, and z members of the dstOffset member of each element of pRegions must be 0

- VUID-VkCopyImageToImageInfoEXT-dstImage-09115
  If flags contains VK_HOST_IMAGE_COPY_MEMCPY_EXT, the extent member of each element of pRegions must equal the extents of dstImage identified by dstSubresource

- VUID-VkCopyImageToImageInfoEXT-dstImage-07966
  If dstImage is non-sparse then the image or the specified disjoint plane must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-VkCopyImageToImageInfoEXT-dstSubresource-07967
  The dstSubresource.mipLevel member of each element of pRegions must be less than the mipLevels specified in VkImageCreateInfo when dstImage was created

- VUID-VkCopyImageToImageInfoEXT-dstSubresource-07968
  The dstSubresource.baseArrayLayer + dstSubresource.layerCount of each element of pRegions, if dstSubresource.layerCount is not VK_REMAINING_ARRAY_LAYERS and maintenance5 is not enabled, must be less than or equal to the arrayLayers specified in VkImageCreateInfo when dstImage was created

- VUID-VkCopyImageToImageInfoEXT-dstImage-07969
  dstImage must not have been created with flags containing VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT
The image region specified by each element of \( p\text{Regions} \) must be contained within the specified \( \text{dstSubresource} \) of \( \text{dstImage} \).

For each element of \( p\text{Regions}, \text{dstOffset}.x \) and \((\text{extent}.\text{width} + \text{dstOffset}.x)\) must both be greater than or equal to 0 and less than or equal to the width of the specified \( \text{dstSubresource} \) of \( \text{dstImage} \).

For each element of \( p\text{Regions}, \text{dstOffset}.y \) and \((\text{extent}.\text{height} + \text{dstOffset}.y)\) must both be greater than or equal to 0 and less than or equal to the height of the specified \( \text{dstSubresource} \) of \( \text{dstImage} \).

If \( \text{dstImage} \) is of type \( \text{VK_IMAGE_TYPE_1D} \), then for each element of \( p\text{Regions}, \text{dstOffset}.y \) must be 0 and \( \text{extent}.\text{height} \) must be 1.

For each element of \( p\text{Regions}, \text{dstOffset}.z \) and \((\text{extent}.\text{depth} + \text{dstOffset}.z)\) must both be greater than or equal to 0 and less than or equal to the depth of the specified \( \text{dstSubresource} \) of \( \text{dstImage} \).

If \( \text{dstImage} \) is of type \( \text{VK_IMAGE_TYPE_1D} \) or \( \text{VK_IMAGE_TYPE_2D} \), then for each element of \( p\text{Regions}, \text{dstOffset}.z \) must be 0 and \( \text{extent}.\text{depth} \) must be 1.

For each element of \( p\text{Regions}, \text{dstOffset}.x \) must be a multiple of the texel block extent width of the \( \text{VkFormat} \) of \( \text{dstImage} \).

For each element of \( p\text{Regions}, \text{dstOffset}.y \) must be a multiple of the texel block extent height of the \( \text{VkFormat} \) of \( \text{dstImage} \).

For each element of \( p\text{Regions}, \text{dstOffset}.z \) must be a multiple of the texel block extent depth of the \( \text{VkFormat} \) of \( \text{dstImage} \).

For each element of \( p\text{Regions}, \text{if the sum of} \ \text{dstOffset}.x \text{ and} \ \text{extent}.\text{width} \text{ does not equal the width of the subresource specified by} \ \text{srcSubresource}, \ \text{extent}.\text{width} \text{ must be a multiple of the} \ \text{texel block extent width} \text{ of the} \ \text{VkFormat} \text{ of} \ \text{dstImage} \).

For each element of \( p\text{Regions}, \text{if the sum of} \ \text{dstOffset}.y \text{ and} \ \text{extent}.\text{height} \text{ does not equal the height of the subresource specified by} \ \text{srcSubresource}, \ \text{extent}.\text{height} \text{ must be a multiple of the} \ \text{texel block extent height} \text{ of the} \ \text{VkFormat} \text{ of} \ \text{dstImage} \).

For each element of \( p\text{Regions}, \text{if the sum of} \ \text{dstOffset}.z \text{ and} \ \text{extent}.\text{depth} \text{ does not equal the depth of the subresource specified by} \ \text{srcSubresource}, \ \text{extent}.\text{depth} \text{ must be a multiple of the} \ \text{texel block extent depth} \text{ of the} \ \text{VkFormat} \text{ of} \ \text{dstImage} \).

• VUID-VkCopyImageToImageInfoEXT-dstImage-07274
  • VUID-VkCopyImageToImageInfoEXT-dstImage-07275
  • VUID-VkCopyImageToImageInfoEXT-dstImage-07276
  • VUID-VkCopyImageToImageInfoEXT-dstImage-00207
  • VUID-VkCopyImageToImageInfoEXT-dstImage-00208
  • VUID-VkCopyImageToImageInfoEXT-dstImage-00209
For each element of \( \text{pRegions} \), \( \text{dstSubresource.aspectMask} \) must specify aspects present in \( \text{dstImage} \):

- **VUID-VkCopyImageToImageInfoEXT-dstImage-07981**
  If \( \text{dstImage} \) has a **multi-planar image format**, then for each element of \( \text{pRegions} \), \( \text{dstSubresource.aspectMask} \) must be a single valid **multi-planar aspect mask** bit.

- **VUID-VkCopyImageToImageInfoEXT-dstImage-07983**
  If \( \text{dstImage} \) is of type **VK_IMAGE_TYPE_3D**, for each element of \( \text{pRegions} \), \( \text{dstSubresource.baseArrayLayer} \) must be 0 and \( \text{dstSubresource.layerCount} \) must be 1.

- **VUID-VkCopyImageToImageInfoEXT-srcImageLayout-09070**
  \( \text{srcImageLayout} \) must specify the current layout of the image subresources of \( \text{srcImage} \) specified in \( \text{pRegions} \).

- **VUID-VkCopyImageToImageInfoEXT-dstImageLayout-09071**
  \( \text{dstImageLayout} \) must specify the current layout of the image subresources of \( \text{dstImage} \) specified in \( \text{pRegions} \).

- **VUID-VkCopyImageToImageInfoEXT-srcImageLayout-09072**
  \( \text{srcImageLayout} \) must be one of the image layouts returned in \( \text{VkPhysicalDeviceHostImageCopyPropertiesEXT::pCopySrcLayouts} \).

- **VUID-VkCopyImageToImageInfoEXT-dstImageLayout-09073**
  \( \text{dstImageLayout} \) must be one of the image layouts returned in \( \text{VkPhysicalDeviceHostImageCopyPropertiesEXT::pCopyDstLayouts} \).

**Valid Usage (Implicit)**

- **VUID-VkCopyImageToImageInfoEXT-sType-sType**
  \( \text{sType} \) must be **VK_STRUCTURE_TYPE_COPY_IMAGE_TO_IMAGE_INFO_EXT**.

- **VUID-VkCopyImageToImageInfoEXT-pNext-pNext**
  \( \text{pNext} \) must be **NULL**.

- **VUID-VkCopyImageToImageInfoEXT-flags-parameter**
  \( \text{flags} \) must be a valid combination of **VkHostImageCopyFlagBitsEXT** values.

- **VUID-VkCopyImageToImageInfoEXT-srcImage-parameter**
  \( \text{srcImage} \) must be a valid **VkImage** handle.

- **VUID-VkCopyImageToImageInfoEXT-srcImageLayout-parameter**
  \( \text{srcImageLayout} \) must be a valid **VkImageLayout** value.

- **VUID-VkCopyImageToImageInfoEXT-dstImage-parameter**
  \( \text{dstImage} \) must be a valid **VkImage** handle.

- **VUID-VkCopyImageToImageInfoEXT-dstImageLayout-parameter**
  \( \text{dstImageLayout} \) must be a valid **VkImageLayout** value.

- **VUID-VkCopyImageToImageInfoEXT-pRegions-parameter**
  \( \text{pRegions} \) must be a valid pointer to an array of **regionCount** valid **VkImageCopy2** structures.

- **VUID-VkCopyImageToImageInfoEXT-regionCount-arraylength**
  **regionCount** must be an arraylength.
regionCount must be greater than 0

• VUID-VkCopyImageToImageInfoEXT-commonparent
  Both of dstImage, and srcImage must have been created, allocated, or retrieved from the sameVkDevice

20.4. Indirect Copies

An application can use indirect copies when the copy parameters are not known during the command buffer creation time.

To copy data between two memory regions by specifying copy parameters indirectly in a buffer, call:

```c
// Provided by VK_NV_copy_memory_indirect
void vkCmdCopyMemoryIndirectNV(
  VkCommandBuffer commandBuffer,
  VkDeviceAddress copyBufferAddress,
  uint32_t copyCount,
  uint32_t stride);
```

• commandBuffer is the command buffer into which the command will be recorded.

• copyBufferAddress is the buffer address specifying the copy parameters. This buffer is laid out in memory as an array of VkCopyMemoryIndirectCommandNV structures.

• copyCount is the number of copies to execute, and can be zero.

• stride is the stride in bytes between successive sets of copy parameters.

Each region read from copyBufferAddress is copied from the source region to the specified destination region. The results are undefined if any of the source and destination regions overlap in memory.

Valid Usage

• VUID-vkCmdCopyMemoryIndirectNV-None-07653
  The indirectCopy feature must be enabled

• VUID-vkCmdCopyMemoryIndirectNV-copyBufferAddress-07654
  copyBufferAddress must be 4 byte aligned

• VUID-vkCmdCopyMemoryIndirectNV-stride-07655
  stride must be a multiple of 4 and must be greater than or equal to sizeof(VkCopyMemoryIndirectCommandNV)

• VUID-vkCmdCopyMemoryIndirectNV-commandBuffer-07656
  The VkCommandPool that commandBuffer was allocated from must support at least one of the VkPhysicalDeviceCopyMemoryIndirectPropertiesNV::supportedQueues
Valid Usage (Implicit)

- VUID-vkCmdCopyMemoryIndirectNV-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdCopyMemoryIndirectNV-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdCopyMemoryIndirectNV-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support transfer, graphics, or compute operations

- VUID-vkCmdCopyMemoryIndirectNV-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdCopyMemoryIndirectNV-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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</table>

The structure describing source and destination memory regions, VkCopyMemoryIndirectCommandNV is defined as:

```c
// Provided by VK_NV_copy_memory_indirect
typedef struct VkCopyMemoryIndirectCommandNV {
    VkDeviceAddress srcAddress;
    VkDeviceAddress dstAddress;
    VkDeviceSize size;
} VkCopyMemoryIndirectCommandNV;
```

- `srcAddress` is the starting address of the source host or device memory to copy from.
- `dstAddress` is the starting address of the destination host or device memory to copy to.
• *size* is the size of the copy in bytes.

### Valid Usage

- VUID-VkCopyMemoryIndirectCommandNV-srcAddress-07657
  The *srcAddress* **must** be 4 byte aligned
- VUID-VkCopyMemoryIndirectCommandNV-dstAddress-07658
  The *dstAddress* **must** be 4 byte aligned
- VUID-VkCopyMemoryIndirectCommandNV-size-07659
  The *size* **must** be 4 byte aligned

To copy data from a memory region to an image object by specifying copy parameters in a buffer, call:

```c
// Provided by VK_NV_copy_memory_indirect
void vkCmdCopyMemoryToImageIndirectNV(
    VkCommandBuffer commandBuffer,  // Provided by VK_NV_copy_memory_indirect
    VkDeviceAddress copyBufferAddress,
    uint32_t copyCount,
    uint32_t stride,
    VkImage dstImage,
    VkImageLayout dstImageLayout,
    const VkImageSubresourceLayers* pImageSubresources);
```

- *commandBuffer* is the command buffer into which the command will be recorded.
- *copyBufferAddress* is the buffer address specifying the copy parameters. This buffer is laid out in memory as an array of *VkCopyMemoryToImageIndirectCommandNV* structures.
- *copyCount* is the number of copies to execute, and can be zero.
- *stride* is the byte stride between successive sets of copy parameters.
- *dstImage* is the destination image.
- *dstImageLayout* is the layout of the destination image subresources for the copy.
- *pImageSubresources* is a pointer to an array of size *copyCount* of *VkImageSubresourceLayers* used to specify the specific image subresource of the destination image data for that copy.

Each region in *copyBufferAddress* is copied from the source memory region to an image region in the destination image. If the destination image is of type *VK_IMAGE_TYPE_3D*, the starting slice and number of slices to copy are specified in *pImageSubresources::baseArrayLayer* and *pImageSubresources::layerCount* respectively. The copy **must** be performed on a queue that supports indirect copy operations, see *VkPhysicalDeviceCopyMemoryIndirectPropertiesNV*.
The indirectCopy feature must be enabled

- VUID-vkCmdCopyMemoryToImageIndirectNV-dstImage-07661
  dstImage must not be a protected image

- VUID-vkCmdCopyMemoryToImageIndirectNV-aspectMask-07662
  The aspectMask member for every subresource in pImageSubresources must only have a single bit set

- VUID-vkCmdCopyMemoryToImageIndirectNV-dstImage-07663
  The image region specified by each element in copyBufferAddress must be a region that is contained within dstImage

- VUID-vkCmdCopyMemoryToImageIndirectNV-dstImage-07664
  dstImage must have been created with VK_IMAGE_USAGE_TRANSFER_DST_BIT usage flag

- VUID-vkCmdCopyMemoryToImageIndirectNV-dstImage-07665
  If dstImage is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdCopyMemoryToImageIndirectNV-dstImage-07973
  dstImage must have a sample count equal to VK_SAMPLE_COUNT_1_BIT

- VUID-vkCmdCopyMemoryToImageIndirectNV-dstImageLayout-07667
  dstImageLayout must specify the layout of the image subresources of dstImage at the time this command is executed on a VkDevice

- VUID-vkCmdCopyMemoryToImageIndirectNV-dstImageLayout-07669
  dstImageLayout must be VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL, VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR, or VK_IMAGE_LAYOUT_GENERAL

- VUID-vkCmdCopyMemoryToImageIndirectNV-mipLevel-07670
  The specified mipLevel of each region must be less than the mipLevels specified in VkImageCreateInfo when dstImage was created

- VUID-vkCmdCopyMemoryToImageIndirectNV-layerCount-09244
  If the maintenance5 feature is not enabled, layerCount must not be VK_REMAINING_ARRAY_LAYERS

- VUID-vkCmdCopyMemoryToImageIndirectNV-layerCount-08764
  If layerCount is not VK_REMAINING_ARRAY_LAYERS, the specified baseArrayLayer + layerCount of each region must be less than or equal to the arrayLayers specified in VkImageCreateInfo when dstImage was created

- VUID-vkCmdCopyMemoryToImageIndirectNV-imageOffset-07672
  The imageOffset and imageExtent members of each region must respect the image transfer granularity requirements of commandBuffer’s command pool’s queue family, as described in VkQueueFamilyProperties

- VUID-vkCmdCopyMemoryToImageIndirectNV-dstImage-07673
  dstImage must not have been created with flags containing VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT

- VUID-vkCmdCopyMemoryToImageIndirectNV-commandBuffer-07674
  If the queue family used to create the VkCommandPool which commandBuffer was allocated from does not support VK_QUEUE_GRAPHICS_BIT, for each region, the aspectMask member of...
**pImageSubresources** must not be `VK_IMAGE_ASPECT_DEPTH_BIT` or `VK_IMAGE_ASPECT_STENCIL_BIT`

- **VUID-vkCmdCopyMemoryToImageIndirectNV-imageOffset-07675**
  For each region in `copyBufferAddress`, `imageOffset.y` and `(imageExtent.height + imageOffset.y)` must both be greater than or equal to 0 and less than or equal to the height of the specified subresource

- **VUID-vkCmdCopyMemoryToImageIndirectNV-offset-07676**
  `offset` must be 4 byte aligned

- **VUID-vkCmdCopyMemoryToImageIndirectNV-stride-07677**
  `stride` must be a multiple of 4 and must be greater than or equal to `sizeof(VkCopyMemoryToImageIndirectCommandNV)`

### Valid Usage (Implicit)

- **VUID-vkCmdCopyMemoryToImageIndirectNV-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- **VUID-vkCmdCopyMemoryToImageIndirectNV-dstImage-parameter**
  `dstImage` must be a valid `VkImage` handle

- **VUID-vkCmdCopyMemoryToImageIndirectNV-dstImageLayout-parameter**
  `dstImageLayout` must be a valid `VkImageLayout` value

- **VUID-vkCmdCopyMemoryToImageIndirectNV-pImageSubresources-parameter**
  `pImageSubresources` must be a valid pointer to an array of `copyCount` valid `VkImageSubresourceLayers` structures

- **VUID-vkCmdCopyMemoryToImageIndirectNV-commandBuffer-recording**
  `commandBuffer` must be in the recording state

- **VUID-vkCmdCopyMemoryToImageIndirectNV-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support transfer, graphics, or compute operations

- **VUID-vkCmdCopyMemoryToImageIndirectNV-renderpass**
  This command must only be called outside of a render pass instance

- **VUID-vkCmdCopyMemoryToImageIndirectNV-videocoding**
  This command must only be called outside of a video coding scope

- **VUID-vkCmdCopyMemoryToImageIndirectNV-copyCount-arraylength**
  `copyCount` must be greater than 0

- **VUID-vkCmdCopyMemoryToImageIndirectNV-commonparent**
  Both of `commandBuffer`, and `dstImage` must have been created, allocated, or retrieved from the same `VkDevice`

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized.

Command Properties

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The VkCopyMemoryToImageIndirectCommandNV is defined as:

```c
// Provided by VK_NV_copy_memory_indirect
typedef struct VkCopyMemoryToImageIndirectCommandNV {
    VkDeviceAddress srcAddress;
    uint32_t bufferRowLength;
    uint32_t bufferImageHeight;
    VkImageSubresourceLayers imageSubresource;
    VkOffset3D imageOffset;
    VkExtent3D imageExtent;
} VkCopyMemoryToImageIndirectCommandNV;
```

- **srcAddress** is the starting address of the source host or device memory to copy from.
- **bufferRowLength** and **bufferImageHeight** specify in texels a subregion of a larger two- or three-dimensional image in buffer memory, and control the addressing calculations. If either of these values is zero, that aspect of the buffer memory is considered to be tightly packed according to the **imageExtent**.
- **imageSubresource** is a VkImageSubresourceLayers used to specify the specific image subresources of the image used for the destination image data, which must match the values specified in pImageSubresources parameter of vkCmdCopyMemoryToImageIndirectNV during command recording.
- **imageOffset** selects the initial x, y, z offsets in texels of the sub-region of the destination image data.
- **imageExtent** is the size in texels of the destination image in width, height and depth.

Valid Usage

- **VUID-VkCopyMemoryToImageIndirectCommandNV-srcAddress-07678**
  The srcAddress must be 4 byte aligned

- **VUID-VkCopyMemoryToImageIndirectCommandNV-bufferRowLength-07679**
  bufferRowLength must be 0, or greater than or equal to the width member of imageExtent
• VUID-VkCopyMemoryToImageIndirectCommandNV-bufferImageHeight-07680
  bufferImageHeight must be 0, or greater than or equal to the height member of imageExtent

• VUID-VkCopyMemoryToImageIndirectCommandNV-imageOffset-07681
  imageOffset must specify a valid offset in the destination image

• VUID-VkCopyMemoryToImageIndirectCommandNV-imageExtent-07682
  imageExtent must specify a valid region in the destination image and can be 0

Valid Usage (Implicit)

• VUID-VkCopyMemoryToImageIndirectCommandNV-imageSubresource-parameter
  imageSubresource must be a valid VkImageSubresourceLayers structure

20.5. Image Copies with Scaling

To copy regions of a source image into a destination image, potentially performing format conversion, arbitrary scaling, and filtering, call:

```
// Provided by VK_VERSION_1_0
void vkCmdBlitImage(
  VkCommandBuffer commandBuffer,
  VkImage srcImage,
  VkImageLayout srcImageLayout,
  VkImage dstImage,
  VkImageLayout dstImageLayout,
  uint32_t regionCount,
  const VkImageBlit* pRegions,
  VkFilter filter);
```

• `commandBuffer` is the command buffer into which the command will be recorded.
• `srcImage` is the source image.
• `srcImageLayout` is the layout of the source image subresources for the blit.
• `dstImage` is the destination image.
• `dstImageLayout` is the layout of the destination image subresources for the blit.
• `regionCount` is the number of regions to blit.
• `pRegions` is a pointer to an array of `VkImageBlit` structures specifying the regions to blit.
• `filter` is a `VkFilter` specifying the filter to apply if the blits require scaling.

`vkCmdBlitImage` must not be used for multisampled source or destination images. Use `vkCmdResolveImage` for this purpose.

As the sizes of the source and destination extents can differ in any dimension, texels in the source extent are scaled and filtered to the destination extent. Scaling occurs via the following operations:
• For each destination texel, the integer coordinate of that texel is converted to an unnormalized texture coordinate, using the effective inverse of the equations described in *unnormalized to integer conversion*:

\[
\begin{align*}
    u_{\text{base}} &= i + \frac{1}{2} \\
    v_{\text{base}} &= j + \frac{1}{2} \\
    w_{\text{base}} &= k + \frac{1}{2}
\end{align*}
\]

• These base coordinates are then offset by the first destination offset:

\[
\begin{align*}
    u_{\text{offset}} &= u_{\text{base}} - x_{\text{dst0}} \\
    v_{\text{offset}} &= v_{\text{base}} - y_{\text{dst0}} \\
    w_{\text{offset}} &= w_{\text{base}} - z_{\text{dst0}} \\
    a_{\text{offset}} &= a - \text{baseArrayCount}_{\text{dst}}
\end{align*}
\]

• The scale is determined from the source and destination regions, and applied to the offset coordinates:

\[
\begin{align*}
    \text{scale}_u &= (x_{\text{src1}} - x_{\text{src0}}) / (x_{\text{dst1}} - x_{\text{dst0}}) \\
    \text{scale}_v &= (y_{\text{src1}} - y_{\text{src0}}) / (y_{\text{dst1}} - y_{\text{dst0}}) \\
    \text{scale}_w &= (z_{\text{src1}} - z_{\text{src0}}) / (z_{\text{dst1}} - z_{\text{dst0}})
\end{align*}
\]

\[
\begin{align*}
    u_{\text{scaled}} &= u_{\text{offset}} \times \text{scale}_u \\
    v_{\text{scaled}} &= v_{\text{offset}} \times \text{scale}_v \\
    w_{\text{scaled}} &= w_{\text{offset}} \times \text{scale}_w
\end{align*}
\]

• Finally the source offset is added to the scaled coordinates, to determine the final unnormalized coordinates:
coordinates used to sample from \textit{srcImage}:

\[
    u = u_{\text{scaled}} + x_{\text{src0}}
\]

\[
    v = v_{\text{scaled}} + y_{\text{src0}}
\]

\[
    w = w_{\text{scaled}} + z_{\text{src0}}
\]

\[
    q = \text{mipLevel}
\]

\[
    a = a_{\text{offset}} + \text{baseArrayCount}_{\text{src}}
\]

These coordinates are used to sample from the source image, as described in \textit{Image Operations chapter}, with the filter mode equal to that of \textit{filter}, a mipmap mode of \textit{VK_SAMPLER_MIPMAP_MODE_NEAREST} and an address mode of \textit{VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE}. Implementations \textbf{must} clamp at the edge of the source image, and \textbf{may} additionally clamp to the edge of the source region.

\begin{quote}
\textbf{Note}

Due to allowable rounding errors in the generation of the source texture coordinates, it is not always possible to guarantee exactly which source texels will be sampled for a given blit. As rounding errors are implementation-dependent, the exact results of a blitting operation are also implementation-dependent.
\end{quote}

Blits are done layer by layer starting with the \textit{baseArrayLayer} member of \textit{srcSubresource} for the source and \textit{dstSubresource} for the destination. \textit{layerCount} layers are blitted to the destination image.

When blitting 3D textures, slices in the destination region bounded by \textit{dstOffsets[0].z} and \textit{dstOffsets[1].z} are sampled from slices in the source region bounded by \textit{srcOffsets[0].z} and \textit{srcOffsets[1].z}. If the \textit{filter} parameter is \textit{VK_FILTER_LINEAR} then the value sampled from the source image is taken by doing linear filtering using the interpolated \textit{z} coordinate represented by \textit{w} in the previous equations. If the \textit{filter} parameter is \textit{VK_FILTER_NEAREST} then the value sampled from the source image is taken from the single nearest slice, with an implementation-dependent arithmetic rounding mode.

The following filtering and conversion rules apply:

\begin{itemize}
    \item Integer formats \textbf{can} only be converted to other integer formats with the same signedness.
    \item No format conversion is supported between depth/stencil images. The formats \textbf{must} match.
    \item Format conversions on unorm, snorm, scaled and packed float formats of the copied aspect of the image are performed by first converting the pixels to float values.
    \item For sRGB source formats, nonlinear RGB values are converted to linear representation prior to
filtering.

- After filtering, the float values are first clamped and then cast to the destination image format. In case of sRGB destination format, linear RGB values are converted to nonlinear representation before writing the pixel to the image.

Signed and unsigned integers are converted by first clamping to the representable range of the destination format, then casting the value.

**Valid Usage**

- VUID-vkCmdBlitImage-commandBuffer-01834
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `srcImage` must not be a protected image.

- VUID-vkCmdBlitImage-commandBuffer-01835
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `dstImage` must not be a protected image.

- VUID-vkCmdBlitImage-commandBuffer-01836
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, `dstImage` must not be an unprotected image.

- VUID-vkCmdBlitImage-pRegions-00215
  The source region specified by each element of `pRegions` must be a region that is contained within `srcImage`.

- VUID-vkCmdBlitImage-pRegions-00216
  The destination region specified by each element of `pRegions` must be a region that is contained within `dstImage`.

- VUID-vkCmdBlitImage-pRegions-00217
  The union of all destination regions, specified by the elements of `pRegions`, must not overlap in memory with any texel that may be sampled during the blit operation.

- VUID-vkCmdBlitImage-srcImage-01999
  The format features of `srcImage` must contain `VK_FORMAT_FEATURE_BLIT_SRC_BIT`.

- VUID-vkCmdBlitImage-srcImage-06421
  `srcImage` must not use a format that requires a sampler YCbCr conversion.

- VUID-vkCmdBlitImage-srcImage-00219
  `srcImage` must have been created with `VK_IMAGE_USAGE_TRANSFER_SRC_BIT` usage flag.

- VUID-vkCmdBlitImage-srcImage-00220
  If `srcImage` is non-sparse then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

- VUID-vkCmdBlitImage-srcImageLayout-00221
  `srcImageLayout` must specify the layout of the image subresources of `srcImage` specified in `pRegions` at the time this command is executed on a `VkDevice`.

- VUID-vkCmdBlitImage-srcImageLayout-01398
  `srcImageLayout` must be `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR`, `VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL` or `VK_IMAGE_LAYOUT_GENERAL`. 

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The **format features** of **dstImage** must contain **VK_FORMAT_FEATURE_BLIT_DST_BIT**.

**dstImage** must not use a format that requires a sampler Y’CbCr conversion.

**dstImage** must have been created with **VK_IMAGE_USAGE_TRANSFER_DST_BIT** usage flag.

If **dstImage** is non-sparse then it must be bound completely and contiguously to a single **VkDeviceMemory** object.

**dstImageLayout** must specify the layout of the image subresources of **dstImage** specified in **pRegions** at the time this command is executed on a **VkDevice**.

**dstImageLayout** must be **VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR**, **VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL** or **VK_IMAGE_LAYOUT_GENERAL**.

If either of **srcImage** or **dstImage** was created with a signed integer **VkFormat**, the other must also have been created with a signed integer **VkFormat**.

If either of **srcImage** or **dstImage** was created with an unsigned integer **VkFormat**, the other must also have been created with an unsigned integer **VkFormat**.

If either of **srcImage** or **dstImage** was created with a depth/stencil format, the other must have exactly the same format.

If **srcImage** was created with a depth/stencil format, **filter** must be **VK_FILTER_NEAREST**.

**srcImage** must have been created with a **samples** value of **VK_SAMPLE_COUNT_1_BIT**.

**dstImage** must have been created with a **samples** value of **VK_SAMPLE_COUNT_1_BIT**.

If **filter** is **VK_FILTER_LINEAR**, then the **format features** of **srcImage** must contain **VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT**.

If **filter** is **VK_FILTER_CUBIC_EXT**, then the **format features** of **srcImage** must contain **VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT**.

If **filter** is **VK_FILTER_CUBIC_EXT**, **srcImage** must be of type **VK_IMAGE_TYPE_2D**.

The **srcSubresource.mipLevel** member of each element of **pRegions** must be less than the **mipLevels** specified in **VkImageCreateInfo** when **srcImage** was created.
• VUID-vkCmdBlitImage-dstSubresource-01706
  The dstSubresource.mipLevel member of each element of pRegions must be less than the mipLevels specified in VkImageCreateInfo when dstImage was created

• VUID-vkCmdBlitImage-srcSubresource-01707
  The srcSubresource.baseArrayLayer + srcSubresource.layerCount of each element of pRegions, if srcSubresource.layerCount is not VK_REMAINING_ARRAY_LAYERS and maintenance5 is not enabled, must be less than or equal to the arrayLayers specified in VkImageCreateInfo when srcImage was created

• VUID-vkCmdBlitImage-dstSubresource-01708
  The dstSubresource.baseArrayLayer + dstSubresource.layerCount of each element of pRegions, if srcSubresource.layerCount is not VK_REMAINING_ARRAY_LAYERS and maintenance5 is not enabled, must be less than or equal to the arrayLayers specified in VkImageCreateInfo when dstImage was created

• VUID-vkCmdBlitImage-dstImage-02545
  dstImage and srcImage must not have been created with flags containing VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT

• VUID-vkCmdBlitImage-srcImage-00240
  If either srcImage or dstImage is of type VK_IMAGE_TYPE_3D, then for each element of pRegions, srcSubresource.baseArrayLayer and dstSubresource.baseArrayLayer must each be 0, and srcSubresource.layerCount and dstSubresource.layerCount must each be 1

• VUID-vkCmdBlitImage-aspectMask-00241
  For each element of pRegions, srcSubresource.aspectMask must specify aspects present in srcImage

• VUID-vkCmdBlitImage-aspectMask-00242
  For each element of pRegions, dstSubresource.aspectMask must specify aspects present in dstImage

• VUID-vkCmdBlitImage-srcOffset-00243
  For each element of pRegions, srcOffsets[0].x and srcOffsets[1].x must both be greater than or equal to 0 and less than or equal to the width of the specified srcSubresource of srcImage

• VUID-vkCmdBlitImage-srcOffset-00244
  For each element of pRegions, srcOffsets[0].y and srcOffsets[1].y must both be greater than or equal to 0 and less than or equal to the height of the specified srcSubresource of srcImage

• VUID-vkCmdBlitImage-srcImage-00245
  If srcImage is of type VK_IMAGE_TYPE_1D, then for each element of pRegions, srcOffsets[0].y must be 0 and srcOffsets[1].y must be 1

• VUID-vkCmdBlitImage-srcImage-00246
  For each element of pRegions, srcOffsets[0].z and srcOffsets[1].z must both be greater than or equal to 0 and less than or equal to the depth of the specified srcSubresource of srcImage

• VUID-vkCmdBlitImage-srcImage-00247
  If srcImage is of type VK_IMAGE_TYPE_1D or VK_IMAGE_TYPE_2D, then for each element of


- **pRegions, srcOffsets[0].z must be 0 and srcOffsets[1].z must be 1**

- **VUID-vkCmdBlitImage-dstOffset-00248**
  For each element of pRegions, dstOffsets[0].x and dstOffsets[1].x must both be greater than or equal to 0 and less than or equal to the width of the specified dstSubresource of dstImage.

- **VUID-vkCmdBlitImage-dstOffset-00249**
  For each element of pRegions, dstOffsets[0].y and dstOffsets[1].y must both be greater than or equal to 0 and less than or equal to the height of the specified dstSubresource of dstImage.

- **VUID-vkCmdBlitImage-dstImage-00250**
  If dstImage is of type VK_IMAGE_TYPE_1D, then for each element of pRegions, dstOffsets[0].y must be 0 and dstOffsets[1].y must be 1.

- **VUID-vkCmdBlitImage-dstOffset-00251**
  For each element of pRegions, dstOffsets[0].z and dstOffsets[1].z must both be greater than or equal to 0 and less than or equal to the depth of the specified dstSubresource of dstImage.

- **VUID-vkCmdBlitImage-dstImage-00252**
  If dstImage is of type VK_IMAGE_TYPE_1D or VK_IMAGE_TYPE_2D, then for each element of pRegions, dstOffsets[0].z must be 0 and dstOffsets[1].z must be 1.

### Valid Usage (Implicit)

- **VUID-vkCmdBlitImage-commandBuffer-parameter**
  commandBuffer must be a valid VkCommandBuffer handle.

- **VUID-vkCmdBlitImage-srcImage-parameter**
  srcImage must be a valid VkImage handle.

- **VUID-vkCmdBlitImage-srcImageLayout-parameter**
  srcImageLayout must be a valid VkImageLayout value.

- **VUID-vkCmdBlitImage-dstImage-parameter**
  dstImage must be a valid VkImage handle.

- **VUID-vkCmdBlitImage-dstImageLayout-parameter**
  dstImageLayout must be a valid VkImageLayout value.

- **VUID-vkCmdBlitImage-pRegions-parameter**
  pRegions must be a valid pointer to an array of regionCount valid VkImageBlit structures.

- **VUID-vkCmdBlitImage-filter-parameter**
  filter must be a valid VkFilter value.

- **VUID-vkCmdBlitImage-commandBuffer-recording**
  commandBuffer must be in the recording state.

- **VUID-vkCmdBlitImage-commandBuffer-cmdpool**
  The VkCommandPool that commandBuffer was allocated from must support graphics operations.
• VUID-vkCmdBlitImage-renderpass
  This command must only be called outside of a render pass instance

• VUID-vkCmdBlitImage-videocoding
  This command must only be called outside of a video coding scope

• VUID-vkCmdBlitImage-regionCount-arraylength
  regionCount must be greater than 0

• VUID-vkCmdBlitImage-commonparent
  Each of commandBuffer, dstImage, and srcImage must have been created, allocated, or retrieved from the same VkDevice

## Host Synchronization

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

## Command Properties

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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The VkImageBlit structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkImageBlit {
    VkImageSubresourceLayers srcSubresource;
    VkOffset3D srcOffsets[2];
    VkImageSubresourceLayers dstSubresource;
    VkOffset3D dstOffsets[2];
} VkImageBlit;
```

• `srcSubresource` is the subresource to blit from.

• `srcOffsets` is a pointer to an array of two VkOffset3D structures specifying the bounds of the source region within `srcSubresource`.

• `dstSubresource` is the subresource to blit into.

• `dstOffsets` is a pointer to an array of two VkOffset3D structures specifying the bounds of the destination region within `dstSubresource`.

For each element of the `pRegions` array, a blit operation is performed for the specified source and
A more extensible version of the blit image command is defined below.

To copy regions of a source image into a destination image, potentially performing format conversion, arbitrary scaling, and filtering, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdBlitImage2(
    VkCommandBuffer commandBuffer,
    const VkBlitImageInfo2* pBlitImageInfo);
```

or the equivalent command

```c
// Provided by VK_KHR_copy_commands2
void vkCmdBlitImage2KHR(
    VkCommandBuffer commandBuffer,
    const VkBlitImageInfo2* pBlitImageInfo);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
• `pBlitImageInfo` is a pointer to a `VkBlitImageInfo2` structure describing the blit parameters.

This command is functionally identical to `vkCmdBlitImage`, but includes extensible sub-structures that include `sType` and `pNext` parameters, allowing them to be more easily extended.

### Valid Usage

- **VUID-vkCmdBlitImage2-commandBuffer-01834**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `srcImage must not` be a protected image

- **VUID-vkCmdBlitImage2-commandBuffer-01835**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `dstImage must not` be a protected image

- **VUID-vkCmdBlitImage2-commandBuffer-01836**
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, `dstImage must not` be an unprotected image

### Valid Usage (Implicit)

- **VUID-vkCmdBlitImage2-commandBuffer-parameter**
  `commandBuffer must be` a valid `VkCommandBuffer` handle

- **VUID-vkCmdBlitImage2-pBlitImageInfo-parameter**
  `pBlitImageInfo must be` a valid pointer to a valid `VkBlitImageInfo2` structure

- **VUID-vkCmdBlitImage2-commandBuffer-recording**
  `commandBuffer must be` in the `recording state`

- **VUID-vkCmdBlitImage2-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from `must` support graphics operations

- **VUID-vkCmdBlitImage2-renderpass**
  This command `must only` be called outside of a render pass instance

- **VUID-vkCmdBlitImage2-videocoding**
  This command `must only` be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer must be` externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from `must be` externally synchronized
The *VkBlitImageInfo2* structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkBlitImageInfo2 {
    VkStructureType sType;
    const void* pNext;
    VkImage srcImage;
    VkImageLayout srcImageLayout;
    VkImage dstImage;
    VkImageLayout dstImageLayout;
    uint32_t regionCount;
    const VkImageBlit2* pRegions;
    VkFilter filter;
} VkBlitImageInfo2;
```

or the equivalent

```c
// Provided by VK_KHR_copy_commands2
typedef VkBlitImageInfo2 VkBlitImageInfo2KHR;
```

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **srcImage** is the source image.
- **srcImageLayout** is the layout of the source image subresources for the blit.
- **dstImage** is the destination image.
- **dstImageLayout** is the layout of the destination image subresources for the blit.
- **regionCount** is the number of regions to blit.
- **pRegions** is a pointer to an array of *VkImageBlit2* structures specifying the regions to blit.
- **filter** is a *VkFilter* specifying the filter to apply if the blits require scaling.

### Valid Usage

- **VUID-VkBlitImageInfo2-pRegions-00215**

  The source region specified by each element of *pRegions* must be a region that is
The destination region specified by each element of `pRegions` must be a region that is contained within `dstImage`.

The union of all destination regions, specified by the elements of `pRegions`, must not overlap in memory with any texel that may be sampled during the blit operation.

The format features of `srcImage` must contain `VK_FORMAT_FEATURE_BLIT_SRC_BIT`.

`srcImage` must not use a format that requires a sampler Y’C_bC_r conversion.

`srcImage` must have been created with `VK_IMAGE_USAGE_TRANSFER_SRC_BIT` usage flag.

If `srcImage` is non-sparse then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

`srcImageLayout` must specify the layout of the image subresources of `srcImage` specified in `pRegions` at the time this command is executed on a `VkDevice`.

`srcImageLayout` must be `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR`, `VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL` or `VK_IMAGE_LAYOUT_GENERAL`.

The format features of `dstImage` must contain `VK_FORMAT_FEATURE_BLIT_DST_BIT`.

`dstImage` must not use a format that requires a sampler Y’C_bC_r conversion.

`dstImage` must have been created with `VK_IMAGE_USAGE_TRANSFER_DST_BIT` usage flag.

If `dstImage` is non-sparse then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

`dstImageLayout` must specify the layout of the image subresources of `dstImage` specified in `pRegions` at the time this command is executed on a `VkDevice`.

`dstImageLayout` must be `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR`, `VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL` or `VK_IMAGE_LAYOUT_GENERAL`.

If either of `srcImage` or `dstImage` was created with a signed integer `VkFormat`, the other must also have been created with a signed integer `VkFormat`.

If either of `srcImage` or `dstImage` was created with a signed integer `VkFormat`, the other
If either of `srcImage` or `dstImage` was created with an unsigned integer `VkFormat`, the other must also have been created with an unsigned integer `VkFormat`

- VUID-VkBlitImageInfo2-srcImage-00231
  If either of `srcImage` or `dstImage` was created with a depth/stencil format, the other must have exactly the same format

- VUID-VkBlitImageInfo2-srcImage-00232
  If `srcImage` was created with a depth/stencil format, `filter` must be `VK_FILTER_NEAREST`

- VUID-VkBlitImageInfo2-srcImage-00233
  `srcImage` must have been created with a `samples` value of `VK_SAMPLE_COUNT_1_BIT`

- VUID-VkBlitImageInfo2-dstImage-00234
  `dstImage` must have been created with a `samples` value of `VK_SAMPLE_COUNT_1_BIT`

- VUID-VkBlitImageInfo2-filter-02001
  If `filter` is `VK_FILTER_LINEAR`, then the `format features` of `srcImage` must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- VUID-VkBlitImageInfo2-filter-02002
  If `filter` is `VK_FILTER_CUBIC_EXT`, then the `format features` of `srcImage` must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`

- VUID-VkBlitImageInfo2-filter-00237
  If `filter` is `VK_FILTER_CUBIC_EXT`, `srcImage` must be of type `VK_IMAGE_TYPE_2D`

- VUID-VkBlitImageInfo2-srcSubresource-01705
  The `srcSubresource.mipLevel` member of each element of `pRegions` must be less than the `mipLevels` specified in `VkImageCreateInfo` when `srcImage` was created

- VUID-VkBlitImageInfo2-dstSubresource-01706
  The `dstSubresource.mipLevel` member of each element of `pRegions` must be less than the `mipLevels` specified in `VkImageCreateInfo` when `dstImage` was created

- VUID-VkBlitImageInfo2-srcSubresource-01707
  The `srcSubresource.baseArrayLayer` + `srcSubresource.layerCount` of each element of `pRegions`, if `srcSubresource.layerCount` is not `VK_REMAINING_ARRAY_LAYERS` and `maintenance5` is not enabled, must be less than or equal to the `arrayLayers` specified in `VkImageCreateInfo` when `srcImage` was created

- VUID-VkBlitImageInfo2-dstSubresource-01708
  The `dstSubresource.baseArrayLayer` + `dstSubresource.layerCount` of each element of `pRegions`, if `dstSubresource.layerCount` is not `VK_REMAINING_ARRAY_LAYERS` and `maintenance5` is not enabled, must be less than or equal to the `arrayLayers` specified in `VkImageCreateInfo` when `dstImage` was created

- VUID-VkBlitImageInfo2-dstImage-02545
  `dstImage` and `srcImage` must not have been created with `flags` containing `VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT`

- VUID-VkBlitImageInfo2-srcImage-00240
  If either `srcImage` or `dstImage` is of type `VK_IMAGE_TYPE_3D`, then for each element of `pRegions`, `srcSubresource.baseArrayLayer` and `dstSubresource.baseArrayLayer` must each be 0, and `srcSubresource.layerCount` and `dstSubresource.layerCount` must each be 1
For each element of \( pRegions \), \( srcSubresource.aspectMask \) must specify aspects present in \( srcImage \) for all elements of \( pRegions \).

For each element of \( pRegions \), \( dstSubresource.aspectMask \) must specify aspects present in \( dstImage \) for all elements of \( pRegions \).

For each element of \( pRegions \), \( srcSubresource.srcOffsets[0].x \) and \( srcSubresource.srcOffsets[1].x \) must both be greater than or equal to 0 and less than or equal to the width of the specified \( srcSubresource \) of \( srcImage \) for all elements of \( pRegions \).

For each element of \( pRegions \), \( srcSubresource.srcOffsets[0].y \) and \( srcSubresource.srcOffsets[1].y \) must both be greater than or equal to 0 and less than or equal to the height of the specified \( srcSubresource \) of \( srcImage \) for all elements of \( pRegions \).

For each element of \( pRegions \), \( srcSubresource.srcOffsets[0].z \) and \( srcSubresource.srcOffsets[1].z \) must both be greater than or equal to 0 and less than or equal to the depth of the specified \( srcSubresource \) of \( srcImage \) for all elements of \( pRegions \).

If \( srcImage \) is of type \( VK_IMAGE_TYPE_1D \), then for each element of \( pRegions \), \( srcSubresource.srcOffsets[0].y \) must be 0 and \( srcSubresource.srcOffsets[1].y \) must be 1 for all elements of \( pRegions \).

For each element of \( pRegions \), \( dstSubresource.dstOffsets[0].x \) and \( dstSubresource.dstOffsets[1].x \) must both be greater than or equal to 0 and less than or equal to the width of the specified \( dstSubresource \) of \( dstImage \) for all elements of \( pRegions \).

For each element of \( pRegions \), \( dstSubresource.dstOffsets[0].y \) and \( dstSubresource.dstOffsets[1].y \) must both be greater than or equal to 0 and less than or equal to the height of the specified \( dstSubresource \) of \( dstImage \) for all elements of \( pRegions \).

For each element of \( pRegions \), \( dstSubresource.dstOffsets[0].z \) and \( dstSubresource.dstOffsets[1].z \) must both be greater than or equal to 0 and less than or equal to the depth of the specified \( dstSubresource \) of \( dstImage \) for all elements of \( pRegions \).

If \( dstImage \) is of type \( VK_IMAGE_TYPE_1D \), then for each element of \( pRegions \), \( dstSubresource.dstOffsets[0].y \) must be 0 and \( dstSubresource.dstOffsets[1].y \) must be 1 for all elements of \( pRegions \).

For each element of \( pRegions \), \( dstSubresource.dstOffsets[0].z \) and \( dstSubresource.dstOffsets[1].z \) must both be greater than or equal to 0 and less than or equal to the depth of the specified \( dstSubresource \) of \( dstImage \) for all elements of \( pRegions \).

If \( dstImage \) is of type \( VK_IMAGE_TYPE_1D \) or \( VK_IMAGE_TYPE_2D \), then for each element of \( pRegions \), \( dstSubresource.dstOffsets[0].z \) must be 0 and \( dstSubresource.dstOffsets[1].z \) must be 1 for all elements of \( pRegions \).
If any element of \( pRegions \) contains \( VkCopyCommandTransformInfoQCOM \) in its \( pNext \) chain, then \( srcImage \) and \( dstImage \) must not be block-compressed images

- **VUID-VkBlitImageInfo2KHR-pRegions-06207**
  If any element of \( pRegions \) contains \( VkCopyCommandTransformInfoQCOM \) in its \( pNext \) chain, then \( srcImage \) must be of type \( VK_IMAGE_TYPE_2D \)

- **VUID-VkBlitImageInfo2KHR-pRegions-06208**
  If any element of \( pRegions \) contains \( VkCopyCommandTransformInfoQCOM \) in its \( pNext \) chain, then \( srcImage \) must not have a multi-planar format

- **VUID-VkBlitImageInfo2-filter-09204**
  If \( filter \) is \( VK_FILTER_CUBIC_EXT \) and if the \( selectableCubicWeights \) feature is not enabled then the cubic weights must be \( VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM \)

### Valid Usage (Implicit)

- **VUID-VkBlitImageInfo2-sType-sType**
  \( sType \) must be \( VK_STRUCTURE_TYPE_BLIT_IMAGE_INFO_2 \)

- **VUID-VkBlitImageInfo2-pNext-pNext**
  \( pNext \) must be \( NULL \) or a pointer to a valid instance of \( VkBlitImageCubicWeightsInfoQCOM \)

- **VUID-VkBlitImageInfo2-sType-unique**
  The \( sType \) value of each struct in the \( pNext \) chain must be unique

- **VUID-VkBlitImageInfo2-srcImage-parameter**
  \( srcImage \) must be a valid \( VkImage \) handle

- **VUID-VkBlitImageInfo2-srcImageLayout-parameter**
  \( srcImageLayout \) must be a valid \( VkImageLayout \) value

- **VUID-VkBlitImageInfo2-dstImage-parameter**
  \( dstImage \) must be a valid \( VkImage \) handle

- **VUID-VkBlitImageInfo2-dstImageLayout-parameter**
  \( dstImageLayout \) must be a valid \( VkImageLayout \) value

- **VUID-VkBlitImageInfo2-pRegions-parameter**
  \( pRegions \) must be a valid pointer to an array of \( regionCount \) valid \( VkImageBlit2 \) structures

- **VUID-VkBlitImageInfo2-filter-parameter**
  \( filter \) must be a valid \( VkFilter \) value

- **VUID-VkBlitImageInfo2-regionCount-arraylength**
  \( regionCount \) must be greater than \( 0 \)

- **VUID-VkBlitImageInfo2-commonparent**
  Both of \( dstImage \), and \( srcImage \) must have been created, allocated, or retrieved from the same \( VkDevice \)

If \( filter \) is \( VK_FILTER_CUBIC_EXT \) and if the \( pNext \) chain of \( VkBlitImageInfo2 \) includes a \( VkBlitImageCubicWeightsInfoQCOM \) structure, then that structure specifies cubic weights are used in the blit. If that structure is not present, then cubic weights are considered to be
VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM.

The VkBlitImageCubicWeightsInfoQCOM structure is defined as:

```c
// Provided by VK_QCOM_filter_cubic_weights
typedef struct VkBlitImageCubicWeightsInfoQCOM {
    VkStructureType sType;
    const void* pNext;
    VkCubicFilterWeightsQCOM cubicWeights;
} VkBlitImageCubicWeightsInfoQCOM;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- cubicWeights is a VkCubicFilterWeightsQCOM value controlling cubic filter weights for the blit.

Valid Usage (Implicit)

- VUID-VkBlitImageCubicWeightsInfoQCOM-sType-sType sType must be VK_STRUCTURE_TYPE_BLIT_IMAGE_CUBIC_WEIGHTS_INFO_QCOM
- VUID-VkBlitImageCubicWeightsInfoQCOM-cubicWeights-parameter cubicWeights must be a valid VkCubicFilterWeightsQCOM value

The VkImageBlit2 structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkImageBlit2 {
    VkStructureType sType;
    const void* pNext;
    VkImageSubresourceLayers srcSubresource;
    VkOffset3D srcOffsets[2];
    VkImageSubresourceLayers dstSubresource;
    VkOffset3D dstOffsets[2];
} VkImageBlit2;
```

or the equivalent

```c
// Provided by VK_KHR_copy_commands2
typedef VkImageBlit2 VkImageBlit2KHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- srcSubresource is the subresource to blit from.
- srcOffsets is a pointer to an array of two VkOffset3D structures specifying the bounds of the
source region within `srcSubresource`.

- `dstSubresource` is the subresource to blit into.
- `dstOffsets` is a pointer to an array of two `VkOffset3D` structures specifying the bounds of the destination region within `dstSubresource`.

For each element of the `pRegions` array, a blit operation is performed for the specified source and destination regions.

Valid Usage

- VUID-VkImageBlit2-aspectMask-00238
  The `aspectMask` member of `srcSubresource` and `dstSubresource` must match

- VUID-VkImageBlit2-maintenance5-08799
  If the `maintenance5` feature is not enabled, the `layerCount` member of `srcSubresource` or `dstSubresource` must not be `VK_REMAINING_ARRAY_LAYERS`

- VUID-VkImageBlit2-layerCount-08800
  If neither of the `layerCount` members of `srcSubresource` or `dstSubresource` are `VK_REMAINING_ARRAY_LAYERS`, the `layerCount` members must match

- VUID-VkImageBlit2-layerCount-08801
  If one of the `layerCount` members of `srcSubresource` or `dstSubresource` is `VK_REMAINING_ARRAY_LAYERS`, the other member must be either `VK_REMAINING_ARRAY_LAYERS` or equal to the `arrayLayers` member of the `VkImageCreateInfo` used to create the image minus `baseArrayLayer`

Valid Usage (Implicit)

- VUID-VkImageBlit2-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_IMAGE_BLIT_2`

- VUID-VkImageBlit2-pNext-pNext
  `pNext` must be `NULL` or a pointer to a valid instance of `VkCopyCommandTransformInfoQCOM`

- VUID-VkImageBlit2-sType-unique
  The `sType` value of each struct in the `pNext` chain must be unique

- VUID-VkImageBlit2-srcSubresource-parameter
  `srcSubresource` must be a valid `VkImageSubresourceLayers` structure

- VUID-VkImageBlit2-dstSubresource-parameter
  `dstSubresource` must be a valid `VkImageSubresourceLayers` structure

For `vkCmdBlitImage2`, each region copied can include a rotation. To specify a rotated region, add `VkCopyCommandTransformInfoQCOM` to the `pNext` chain of `VkImageBlit2`. For each region with a rotation specified, Image Blits with Scaling and Rotation specifies how coordinates are rotated prior to sampling from the source image. When rotation is specified, the source and destination images
must each be 2D images, have a 1x1x1 texel block extent, and only one plane.

20.5.1. Image Blits with Scaling and Rotation

When `VkCopyCommandTransformInfoQCOM` is in the `pNext` chain of `VkImageBlit2`, the specified region is rotated during the blit. The following description of rotated addressing replaces the description in `vkCmdBlitImage`.

The following code computes rotation of normalized coordinates.

```c
// rotation of normalized coordinates
VkOffset2D RotateNormUV(VkOffset2D in, VkSurfaceTransformFlagBitsKHR flags)
{
    VkOffset2D output;
    switch (flags)
    {
        case VK_SURFACE_TRANSFORM_IDENTITY_BIT_KHR:
            out.x = in.x;
            out.y = in.y;
            break;
        case VK_SURFACE_TRANSFORM_ROTATE_90_BIT_KHR:
            out.x = in.y;
            out.y = 1.0 - in.x;
            break;
        case VK_SURFACE_TRANSFORM_ROTATE_180_BIT_KHR:
            out.x = 1.0 - in.x;
            out.y = 1.0 - in.y;
            break;
        case VK_SURFACE_TRANSFORM_ROTATE_270_BIT_KHR:
            out.x = 1.0 - in.y;
            out.y = in.x;
            break;
    }
    return out;
}
```

- For each destination texel, the integer coordinate of that texel is converted to an unnormalized texture coordinate, using the effective inverse of the equations described in unnormalized to integer conversion:

  \[
  u_{\text{base}} = i + \frac{1}{2} \\
  v_{\text{base}} = j + \frac{1}{2} \\
  w_{\text{base}} = k + \frac{1}{2}
  \]
• These base coordinates are then offset by the first destination offset:

\[
\begin{align*}
    u_{\text{offset}} & = u_{\text{base}} - x_{\text{dst0}} \\
    v_{\text{offset}} & = v_{\text{base}} - y_{\text{dst0}} \\
    w_{\text{offset}} & = w_{\text{base}} - z_{\text{dst0}} \\
    a_{\text{offset}} & = a - \text{baseArrayCount}_{\text{dst}}
\end{align*}
\]

• The UV destination coordinates are scaled by the destination region, rotated, and scaled by the source region.

\[
\begin{align*}
    u_{\text{dest_scaled}} & = u_{\text{offset}} / (x_{\text{dst1}} - x_{\text{dst0}}) \\
    v_{\text{dest_scaled}} & = v_{\text{offset}} / (y_{\text{dst1}} - y_{\text{dst0}}) \\
    (u_{\text{src_scaled}}, v_{\text{src_scaled}}) & = \text{RotateNormUV}(u_{\text{dest_scaled}}, v_{\text{dest_scaled}}, \text{transform}) \\
    u_{\text{scaled}} & = u_{\text{src_scaled}} \times (x_{\text{Src1}} - x_{\text{Src0}}) \\
    v_{\text{scaled}} & = v_{\text{src_scaled}} \times (y_{\text{Src1}} - y_{\text{Src0}})
\end{align*}
\]

• The W coordinate is unaffected by rotation. The scale is determined from the ratio of source and destination regions, and applied to the offset coordinate:

\[
\begin{align*}
    \text{scale}_w & = (z_{\text{Src1}} - z_{\text{Src0}}) / (z_{\text{dst1}} - z_{\text{dst0}}) \\
    w_{\text{scaled}} & = w_{\text{offset}} \times \text{scale}_w
\end{align*}
\]

• Finally the source offset is added to the scaled source coordinates, to determine the final unnormalized coordinates used to sample from srcImage:

\[
\begin{align*}
    u & = u_{\text{scaled}} + x_{\text{Src0}} \\
    v & = v_{\text{scaled}} + y_{\text{Src0}}
\end{align*}
\]
w = \( w_{\text{scaled}} + z_{\text{src0}} \)

\[ q = \text{mipLevel} \]

\[ a = a_{\text{offset}} + \text{baseArrayCount}_{\text{src}} \]

These coordinates are used to sample from the source image as described for Image Operations, with the filter mode equal to that of filter; a mipmap mode of \texttt{VK_SAMPLER_MIPMAP_MODE_NEAREST}; and an address mode of \texttt{VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE}. Implementations must clamp at the edge of the source image, and may additionally clamp to the edge of the source region.

## 20.6. Resolving Multisample Images

To resolve a multisample color image to a non-multisample color image, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdResolveImage(
    VkCommandBuffer commandBuffer,
    VkImage srcImage,
    VkImageLayout srcImageLayout,
    VkImage dstImage,
    VkImageLayout dstImageLayout,
    uint32_t regionCount,
    const VkImageResolve* pRegions);
```

- \texttt{commandBuffer} is the command buffer into which the command will be recorded.
- \texttt{srcImage} is the source image.
- \texttt{srcImageLayout} is the layout of the source image subresources for the resolve.
- \texttt{dstImage} is the destination image.
- \texttt{dstImageLayout} is the layout of the destination image subresources for the resolve.
- \texttt{regionCount} is the number of regions to resolve.
- \texttt{pRegions} is a pointer to an array of \texttt{VkImageResolve} structures specifying the regions to resolve.

During the resolve the samples corresponding to each pixel location in the source are converted to a single sample before being written to the destination. If the source formats are floating-point or normalized types, the sample values for each pixel are resolved in an implementation-dependent manner. If the source formats are integer types, a single sample’s value is selected for each pixel.

\texttt{srcOffset} and \texttt{dstOffset} select the initial \( x, y, \) and \( z \) offsets in texels of the sub-regions of the source and destination image data. \texttt{extent} is the size in texels of the source image to resolve in \texttt{width}, \texttt{height} and \texttt{depth}. Each element of \texttt{pRegions} must be a region that is contained within its corresponding image.
Resolves are done layer by layer starting with baseArrayLayer member of srcSubresource for the source and dstSubresource for the destination. layerCount layers are resolved to the destination image.

### Valid Usage

- **VUID-vkCmdResolveImage-commandBuffer-01837**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `srcImage` must not be a protected image

- **VUID-vkCmdResolveImage-commandBuffer-01838**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `dstImage` must not be a protected image

- **VUID-vkCmdResolveImage-commandBuffer-01839**
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, `dstImage` must not be an unprotected image

- **VUID-vkCmdResolveImage-pRegions-00255**
  The union of all source regions, and the union of all destination regions, specified by the elements of pRegions, must not overlap in memory

- **VUID-vkCmdResolveImage-srcImage-00256**
  If `srcImage` is non-sparse then it must be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdResolveImage-srcImage-00257**
  `srcImage` must have a sample count equal to any valid sample count value other than `VK_SAMPLE_COUNT_1_BIT`

- **VUID-vkCmdResolveImage-dstImage-00258**
  If `dstImage` is non-sparse then it must be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdResolveImage-dstImage-00259**
  `dstImage` must have a sample count equal to `VK_SAMPLE_COUNT_1_BIT`

- **VUID-vkCmdResolveImage-srcImageLayout-00260**
  `srcImageLayout` must specify the layout of the image subresources of `srcImage` specified in pRegions at the time this command is executed on a `VkDevice`

- **VUID-vkCmdResolveImage-srcImageLayout-01400**
  `srcImageLayout` must be `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR`, `VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL` or `VK_IMAGE_LAYOUT_GENERAL`

- **VUID-vkCmdResolveImage-dstImageLayout-00262**
  `dstImageLayout` must specify the layout of the image subresources of `dstImage` specified in pRegions at the time this command is executed on a `VkDevice`

- **VUID-vkCmdResolveImage-dstImageLayout-01401**
  `dstImageLayout` must be `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR`, `VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL` or `VK_IMAGE_LAYOUT_GENERAL`

- **VUID-vkCmdResolveImage-dstImage-02003**
The format features of dstImage must contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT

• VUID-vkCmdResolveImage-linearColorAttachment-06519
  If the linearColorAttachment feature is enabled and the image is created with VK_IMAGE_TILING_LINEAR, the format features of dstImage must contain VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV

• VUID-vkCmdResolveImage-srcImage-01386
  srcImage and dstImage must have been created with the same image format

• VUID-vkCmdResolveImage-srcSubresource-01709
  The srcSubresource.mipLevel member of each element of pRegions must be less than the mipLevels specified in VkImageCreateInfo when srcImage was created

• VUID-vkCmdResolveImage-dstSubresource-01710
  The dstSubresource.mipLevel member of each element of pRegions must be less than the mipLevels specified in VkImageCreateInfo when dstImage was created

• VUID-vkCmdResolveImage-srcSubresource-01711
  The srcSubresource.baseArrayLayer + srcSubresource.layerCount of each element of pRegions, if srcSubresource.layerCount is not VK_REMAINING_ARRAY_LAYERS and maintenance5 is not enabled, must be less than or equal to the arrayLayers specified in VkImageCreateInfo when srcImage was created

• VUID-vkCmdResolveImage-dstSubresource-01712
  The dstSubresource.baseArrayLayer + dstSubresource.layerCount of each element of pRegions, if dstSubresource.layerCount is not VK_REMAINING_ARRAY_LAYERS and maintenance5 is not enabled, must be less than or equal to the arrayLayers specified in VkImageCreateInfo when dstImage was created

• VUID-vkCmdResolveImage-dstImage-02546
  dstImage and srcImage must not have been created with flags containing VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT

• VUID-vkCmdResolveImage-srcImage-04446
  If dstImage is of type VK_IMAGE_TYPE_3D, then for each element of pRegions, srcSubresource.layerCount must be 1

• VUID-vkCmdResolveImage-srcImage-04447
  If dstImage is of type VK_IMAGE_TYPE_3D, then for each element of pRegions, dstSubresource.baseArrayLayer must be 0 and dstSubresource.layerCount must be 1

• VUID-vkCmdResolveImage-srcOffset-00269
  For each element of pRegions, srcOffset.x and (extent.width + srcOffset.x) must both be greater than or equal to 0 and less than or equal to the width of the specified srcSubresource of srcImage

• VUID-vkCmdResolveImage-srcOffset-00270
  For each element of pRegions, srcOffset.y and (extent.height + srcOffset.y) must both be greater than or equal to 0 and less than or equal to the height of the specified srcSubresource of srcImage

• VUID-vkCmdResolveImage-srcImage-00271
  If srcImage is of type VK_IMAGE_TYPE_1D, then for each element of pRegions, srcOffset.y must be 0 and extent.height must be 1
For each element of \textit{pRegions}, \textit{srcOffset.z} and \textit{(extent.depth + srcOffset.z)} must both be greater than or equal to 0 and less than or equal to the depth of the specified \textit{srcSubresource} of \textit{srcImage}

If \textit{srcImage} is of type \texttt{VK_IMAGE_TYPE_1D} or \texttt{VK_IMAGE_TYPE_2D}, then for each element of \textit{pRegions}, \textit{srcOffset.z} must be 0 and \textit{extent.depth} must be 1

For each element of \textit{pRegions}, \textit{dstOffset.x} and \textit{(extent.width + dstOffset.x)} must both be greater than or equal to 0 and less than or equal to the width of the specified \textit{dstSubresource} of \textit{dstImage}

For each element of \textit{pRegions}, \textit{dstOffset.y} and \textit{(extent.height + dstOffset.y)} must both be greater than or equal to 0 and less than or equal to the height of the specified \textit{dstSubresource} of \textit{dstImage}

If \textit{dstImage} is of type \texttt{VK_IMAGE_TYPE_1D}, then for each element of \textit{pRegions}, \textit{dstOffset.y} must be 0 and \textit{extent.height} must be 1

For each element of \textit{pRegions}, \textit{dstOffset.z} and \textit{(extent.depth + dstOffset.z)} must both be greater than or equal to 0 and less than or equal to the depth of the specified \textit{dstSubresource} of \textit{dstImage}

If \textit{dstImage} is of type \texttt{VK_IMAGE_TYPE_1D} or \texttt{VK_IMAGE_TYPE_2D}, then for each element of \textit{pRegions}, \textit{dstOffset.z} must be 0 and \textit{extent.depth} must be 1

\textit{srcImage} must have been created with \texttt{VK_IMAGE_USAGE_TRANSFER_SRC_BIT} usage flag

The format features of \textit{srcImage} must contain \texttt{VK_FORMAT_FEATURE_TRANSFER_SRC_BIT}

\textit{dstImage} must have been created with \texttt{VK_IMAGE_USAGE_TRANSFER_DST_BIT} usage flag

The format features of \textit{dstImage} must contain \texttt{VK_FORMAT_FEATURE_TRANSFER_DST_BIT}

Valid Usage (Implicit)

\textit{commandBuffer} must be a valid \texttt{VkCommandBuffer} handle

\textit{srcImage} must be a valid \texttt{VkImage} handle

\textit{srcImageLayout} must be a valid \texttt{VkImageLayout} value
• VUID-vkCmdResolveImage-dstImage-parameter
dstImage must be a valid VkImage handle

• VUID-vkCmdResolveImage-dstImageLayout-parameter
dstImageLayout must be a valid VkImageLayout value

• VUID-vkCmdResolveImage-pRegions-parameter
pRegions must be a valid pointer to an array of regionCount valid VkImageResolve structures

• VUID-vkCmdResolveImage-commandBuffer-recording
commandBuffer must be in the recording state

• VUID-vkCmdResolveImage-commandBuffer-cmdpool
The VkCommandPool that commandBuffer was allocated from must support graphics operations

• VUID-vkCmdResolveImage-renderpass
This command must only be called outside of a render pass instance

• VUID-vkCmdResolveImage-videocoding
This command must only be called outside of a video coding scope

• VUID-vkCmdResolveImage-regionCount-arraylength
regionCount must be greater than 0

• VUID-vkCmdResolveImage-commonparent
Each of commandBuffer, dstImage, and srcImage must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

<table>
<thead>
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<tr>
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<td>Outside</td>
<td>Outside</td>
<td>Graphics</td>
<td>Action</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The VkImageResolve structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkImageResolve {
    VkImageSubresourceLayers srcSubresource;
    VkOffset3D srcOffset;
} VkImageResolve;
```
• `srcSubresource` and `dstSubresource` are `VkImageSubresourceLayers` structures specifying the image subresources of the images used for the source and destination image data, respectively. Resolve of depth/stencil images is not supported.

• `srcOffset` and `dstOffset` select the initial x, y, and z offsets in texels of the sub-regions of the source and destination image data.

• `extent` is the size in texels of the source image to resolve in width, height and depth.

Valid Usage

• VUID-VkImageResolve-aspectMask-00266
  The `aspectMask` member of `srcSubresource` and `dstSubresource` must only contain `VK_IMAGE_ASPECT_COLOR_BIT`

• VUID-VkImageResolve-maintenance5-08802
  If the `maintenance5` feature is not enabled, the `layerCount` member of `srcSubresource` or `dstSubresource` must not be `VK_REMAINING_ARRAY_LAYERS`

• VUID-VkImageResolve-layerCount-08803
  If neither of the `layerCount` members of `srcSubresource` or `dstSubresource` are `VK_REMAINING_ARRAY_LAYERS`, the `layerCount` members must match

• VUID-VkImageResolve-layerCount-08804
  If one of the `layerCount` members of `srcSubresource` or `dstSubresource` is `VK_REMAINING_ARRAY_LAYERS`, the other member must be either `VK_REMAINING_ARRAY_LAYERS` or equal to the `arrayLayers` member of the `VkImageCreateInfo` used to create the image minus `baseArrayLayer`

Valid Usage (Implicit)

• VUID-VkImageResolve-srcSubresource-parameter
  `srcSubresource` must be a valid `VkImageSubresourceLayers` structure

• VUID-VkImageResolve-dstSubresource-parameter
  `dstSubresource` must be a valid `VkImageSubresourceLayers` structure

A more extensible version of the resolve image command is defined below.

To resolve a multisample image to a non-multisample image, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdResolveImage2(
  VkCommandBuffer commandBuffer,
  ...);
```
const VkResolveImageInfo2* pResolveImageInfo);

or the equivalent command

// Provided by VK_KHR_copy_commands2
void vkCmdResolveImage2KHR(
    VkCommandBuffer commandBuffer,
    const VkResolveImageInfo2* pResolveImageInfo);

- `commandBuffer` is the command buffer into which the command will be recorded.
- `pResolveImageInfo` is a pointer to a `VkResolveImageInfo2` structure describing the resolve parameters.

This command is functionally identical to `vkCmdResolveImage`, but includes extensible substructures that include `sType` and `pNext` parameters, allowing them to be more easily extended.

### Valid Usage

- VUID-vkCmdResolveImage2-commandBuffer-01837
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `srcImage` must not be a protected image

- VUID-vkCmdResolveImage2-commandBuffer-01838
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, `dstImage` must not be a protected image

- VUID-vkCmdResolveImage2-commandBuffer-01839
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, `dstImage` must not be an unprotected image

### Valid Usage (Implicit)

- VUID-vkCmdResolveImage2-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdResolveImage2-pResolveImageInfo-parameter
  `pResolveImageInfo` must be a valid pointer to a valid `VkResolveImageInfo2` structure

- VUID-vkCmdResolveImage2-commandBuffer-recording
  `commandBuffer` must be in the recording state

- VUID-vkCmdResolveImage2-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations

- VUID-vkCmdResolveImage2-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdResolveImage2-videocoding
This command **must** only be called outside of a video coding scope.

**Host Synchronization**

- Host access to `commandBuffer` **must** be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized.

**Command Properties**

<table>
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<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The `VkResolveImageInfo2` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkResolveImageInfo2 {
    VkStructureType sType;
    const void* pNext;
    VkImage srcImage;
    VkImageLayout srcImageLayout;
    VkImage dstImage;
    VkImageLayout dstImageLayout;
    uint32_t regionCount;
    const VkImageResolve2* pRegions;
} VkResolveImageInfo2;
```

or the equivalent

```c
// Provided by VK_KHR_copy_commands2
typedef VkResolveImageInfo2 VkResolveImageInfo2KHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **srcImage** is the source image.
- **srcImageLayout** is the layout of the source image subresources for the resolve.
- **dstImage** is the destination image.
- **dstImageLayout** is the layout of the destination image subresources for the resolve.
• `regionCount` is the number of regions to resolve.

• `pRegions` is a pointer to an array of `VkImageResolve2` structures specifying the regions to resolve.

---

## Valid Usage

- VUID-VkResolveImageInfo2-pRegions-00255
  The union of all source regions, and the union of all destination regions, specified by the elements of `pRegions`, **must** not overlap in memory

- VUID-VkResolveImageInfo2-srcImage-00256
  If `srcImage` is non-sparse then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object

- VUID-VkResolveImageInfo2-srcImage-00257
  `srcImage` **must** have a sample count equal to any valid sample count value other than `VK_SAMPLE_COUNT_1_BIT`

- VUID-VkResolveImageInfo2-dstImage-00258
  If `dstImage` is non-sparse then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object

- VUID-VkResolveImageInfo2-dstImage-00259
  `dstImage` **must** have a sample count equal to `VK_SAMPLE_COUNT_1_BIT`

- VUID-VkResolveImageInfo2-srcImageLayout-01400
  `srcImageLayout` **must** specify the layout of the image subresources of `srcImage` specified in `pRegions` at the time this command is executed on a `VkDevice`

- VUID-VkResolveImageInfo2-dstImageLayout-00260
  `dstImageLayout` **must** specify the layout of the image subresources of `dstImage` specified in `pRegions` at the time this command is executed on a `VkDevice`

- VUID-VkResolveImageInfo2-dstImage-02003
  The format features of `dstImage` **must** contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT`

- VUID-VkResolveImageInfo2-linearColorAttachment-06519
  If the `linearColorAttachment` feature is enabled and the image is created with `VK_IMAGE_TILING_LINEAR`, the format features of `dstImage` **must** contain `VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV`

- VUID-VkResolveImageInfo2-srcImage-01386
  `srcImage` and `dstImage` **must** have been created with the same image format

- VUID-VkResolveImageInfo2-srcSubresource-01709
  The `srcSubresource.mipLevel` member of each element of `pRegions` **must** be less than the
mipLevels specified in VkImageCreateInfo when srcImage was created

- VUID-VkResolveImageInfo2-dstSubresource-01710
  The dstSubresource.mipLevel member of each element of pRegions must be less than the mipLevels specified in VkImageCreateInfo when dstImage was created

- VUID-VkResolveImageInfo2-srcSubresource-01711
  The srcSubresource.baseArrayLayer + srcSubresource.layerCount of each element of pRegions, if srcSubresource.layerCount is not VK_REMAINING_ARRAY_LAYERS and maintenance5 is not enabled, must be less than or equal to the arrayLayers specified in VkImageCreateInfo when srcImage was created

- VUID-VkResolveImageInfo2-dstSubresource-01712
  The dstSubresource.baseArrayLayer + dstSubresource.layerCount of each element of pRegions, if dstSubresource.layerCount is not VK_REMAINING_ARRAY_LAYERS and maintenance5 is not enabled, must be less than or equal to the arrayLayers specified in VkImageCreateInfo when dstImage was created

- VUID-VkResolveImageInfo2-srcImage-00271
  If srcImage is of type VK_IMAGE_TYPE_1D, then for each element of pRegions, srcOffset.y must be 0 and extent.height must be 1

- VUID-VkResolveImageInfo2-srcOffset-00272
  For each element of pRegions, srcOffset.z and (extent.depth + srcOffset.z) must both be greater than or equal to 0 and less than or equal to the depth of the specified srcSubresource of srcImage

- VUID-VkResolveImageInfo2-srcImage-00273
  If srcImage is of type VK_IMAGE_TYPE_1D or VK_IMAGE_TYPE_2D, then for each element of pRegions, srcOffset.z must be 0 and extent.depth must be 1

- VUID-VkResolveImageInfo2-dstOffset-00274
  For each element of pRegions, dstOffset.x and (extent.width + dstOffset.x) must both be
greater than or equal to 0 and less than or equal to the width of the specified dstSubresource of dstImage

- VUID-VkResolveImageInfo2-dstOffset-00275
  For each element of pRegions, dstOffset.y and (extent.height + dstOffset.y) must both be greater than or equal to 0 and less than or equal to the height of the specified dstSubresource of dstImage

- VUID-VkResolveImageInfo2-dstImage-00276
  If dstImage is of type VK_IMAGE_TYPE_1D, then for each element of pRegions, dstOffset.y must be 0 and extent.height must be 1

- VUID-VkResolveImageInfo2-dstOffset-00277
  For each element of pRegions, dstOffset.z and (extent.depth + dstOffset.z) must both be greater than or equal to 0 and less than or equal to the depth of the specified dstSubresource of dstImage

- VUID-VkResolveImageInfo2-dstImage-00278
  If dstImage is of type VK_IMAGE_TYPE_1D or VK_IMAGE_TYPE_2D, then for each element of pRegions, dstOffset.z must be 0 and extent.depth must be 1

- VUID-VkResolveImageInfo2-srcImage-06762
  srcImage must have been created with VK_IMAGE_USAGE_TRANSFER_SRC_BIT usage flag

- VUID-VkResolveImageInfo2-srcImage-06763
  The format features of srcImage must contain VK_FORMAT_FEATURE_TRANSFER_SRC_BIT

- VUID-VkResolveImageInfo2-dstImage-06764
  dstImage must have been created with VK_IMAGE_USAGE_TRANSFER_DST_BIT usage flag

- VUID-VkResolveImageInfo2-dstImage-06765
  The format features of dstImage must contain VK_FORMAT_FEATURE_TRANSFER_DST_BIT

Valid Usage (Implicit)

- VUID-VkResolveImageInfo2-sType-sType
  sType must be VK_STRUCTURE_TYPE_RESOLVE_IMAGE_INFO_2

- VUID-VkResolveImageInfo2-pNext-pNext
  pNext must be NULL

- VUID-VkResolveImageInfo2-srcImage-parameter
  srcImage must be a valid VkImage handle

- VUID-VkResolveImageInfo2-srcImageLayout-parameter
  srcImageLayout must be a valid VkImageLayout value

- VUID-VkResolveImageInfo2-dstImage-parameter
  dstImage must be a valid VkImage handle

- VUID-VkResolveImageInfo2-dstImageLayout-parameter
  dstImageLayout must be a valid VkImageLayout value

- VUID-VkResolveImageInfo2-pRegions-parameter
  pRegions must be a valid pointer to an array of regionCount valid VkImageResolve2
structures

- **VUID-VkResolveImageInfo2-regionCount-arraylength**
  regionCount must be greater than 0

- **VUID-VkResolveImageInfo2-commonparent**
  Both of dstImage, and srcImage must have been created, allocated, or retrieved from the same VkDevice

The **VkImageResolve2** structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkImageResolve2 {
    VkStructureType sType;
    const void* pNext;
    VkImageSubresourceLayers srcSubresource;
    VkOffset3D srcOffset;
    VkImageSubresourceLayers dstSubresource;
    VkOffset3D dstOffset;
    VkExtent3D extent;
} VkImageResolve2;
```

or the equivalent

```c
// Provided by VK_KHR_copy_commands2
typedef VkImageResolve2 VkImageResolve2KHR;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **srcSubresource** and **dstSubresource** are **VkImageSubresourceLayers** structures specifying the image subresources of the images used for the source and destination image data, respectively. Resolve of depth/stencil images is not supported.
- **srcOffset** and **dstOffset** select the initial x, y, and z offsets in texels of the sub-regions of the source and destination image data.
- **extent** is the size in texels of the source image to resolve in width, height and depth.

### Valid Usage

- **VUID-VkImageResolve2-aspectMask-00266**
  The aspectMask member of srcSubresource and dstSubresource must only contain VK_IMAGE_ASPECT_COLOR_BIT

- **VUID-VkImageResolve2-maintenance5-08802**
  If the maintenance5 feature is not enabled, the layerCount member of srcSubresource or dstSubresource must not be VK_REMAINING_ARRAY_LAYERS

- **VUID-VkImageResolve2-layerCount-08803**
If neither of the \texttt{layerCount} members of \texttt{srcSubresource} or \texttt{dstSubresource} are \texttt{VK_REMAINING_ARRAY_LAYERS}, the \texttt{layerCount} members must match

- VUID-VkImageResolve2-layerCount-08804

If one of the \texttt{layerCount} members of \texttt{srcSubresource} or \texttt{dstSubresource} is \texttt{VK_REMAINING_ARRAY_LAYERS}, the other member must be either \texttt{VK_REMAINING_ARRAY_LAYERS} or equal to the \texttt{arrayLayers} member of the \texttt{VkImageCreateInfo} used to create the image minus \texttt{baseArrayLayer}

---

### Valid Usage (Implicit)

- VUID-VkImageResolve2-sType-sType
  \texttt{sType} must be \texttt{VK_STRUCTURE_TYPE_IMAGE_RESOLVE_2}

- VUID-VkImageResolve2-pNext-pNext
  \texttt{pNext} must be \texttt{NULL}

- VUID-VkImageResolve2-srcSubresource-parameter
  \texttt{srcSubresource} must be a valid \texttt{VkImageSubresourceLayers} structure

- VUID-VkImageResolve2-dstSubresource-parameter
  \texttt{dstSubresource} must be a valid \texttt{VkImageSubresourceLayers} structure

---

### 20.7. Buffer Markers

To write a 32-bit marker value into a buffer as a pipelined operation, call:

```c
// Provided by VK_KHR_synchronization2 with VK_AMD_buffer_marker
void vkCmdWriteBufferMarker2AMD(
    VkCommandBuffer commandBuffer,
    VkPipelineStageFlags2 stage,
    VkBuffer dstBuffer,
    VkDeviceSize dstOffset,
    uint32_t marker);
```

- \texttt{commandBuffer} is the command buffer into which the command will be recorded.
- \texttt{stage} specifies the pipeline stage whose completion triggers the marker write.
- \texttt{dstBuffer} is the buffer where the marker will be written.
- \texttt{dstOffset} is the byte offset into the buffer where the marker will be written.
- \texttt{marker} is the 32-bit value of the marker.

The command will write the 32-bit marker value into the buffer only after all preceding commands have finished executing up to at least the specified pipeline stage. This includes the completion of other preceding \texttt{vkCmdWriteBufferMarker2AMD} commands so long as their specified pipeline stages occur either at the same time or earlier than this command’s specified \texttt{stage}. 
While consecutive buffer marker writes with the same stage parameter implicitly complete in submission order, memory and execution dependencies between buffer marker writes and other operations must still be explicitly ordered using synchronization commands. The access scope for buffer marker writes falls under the VK_ACCESS_TRANSFER_WRITE_BIT, and the pipeline stages for identifying the synchronization scope must include both stage and VK_PIPELINE_STAGE_TRANSFER_BIT.

**Note**
Similar to vkCmdWriteTimestamp2, if an implementation is unable to write a marker at any specific pipeline stage, it may instead do so at any logically later stage.

**Note**
Implementations may only support a limited number of pipelined marker write operations in flight at a given time. Thus an excessive number of marker write operations may degrade command execution performance.

### Valid Usage

- **VUID-vkCmdWriteBufferMarker2AMD-stage-03929**
  If the geometryShader feature is not enabled, stage must not contain VK_PIPELINE_STAGE_2_GEOMETRY_SHADER_BIT

- **VUID-vkCmdWriteBufferMarker2AMD-stage-03930**
  If the tessellationShader feature is not enabled, stage must not contain VK_PIPELINE_STAGE_2_TESSELLATION_CONTROL_SHADER_BIT or VK_PIPELINE_STAGE_2_TESSELLATION_EVALUATION_SHADER_BIT

- **VUID-vkCmdWriteBufferMarker2AMD-stage-03931**
  If the conditionalRendering feature is not enabled, stage must not contain VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT

- **VUID-vkCmdWriteBufferMarker2AMD-stage-03932**
  If the fragmentDensityMap feature is not enabled, stage must not contain VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT

- **VUID-vkCmdWriteBufferMarker2AMD-stage-03933**
  If the transformFeedback feature is not enabled, stage must not contain VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT

- **VUID-vkCmdWriteBufferMarker2AMD-stage-03934**
  If the meshShader feature is not enabled, stage must not contain VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT

- **VUID-vkCmdWriteBufferMarker2AMD-stage-03935**
  If the taskShader feature is not enabled, stage must not contain VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT

- **VUID-vkCmdWriteBufferMarker2AMD-stage-07316**
  If neither the shadingRateImage or attachmentFragmentShadingRate are enabled, stage must not contain VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

- **VUID-vkCmdWriteBufferMarker2AMD-stage-04957**
If the `subpassShading` feature is not enabled, `stage` must not contain `VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI`.

- **VUID-vkCmdWriteBufferMarker2AMD-stage-04995**
  If the `invocationMask` feature is not enabled, `stage` must not contain `VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI`.

- **VUID-vkCmdWriteBufferMarker2AMD-stage-07946**
  If neither the `VK_NV_ray_tracing` extension or `rayTracingPipeline` feature are enabled, `stage` must not contain `VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR`.

- **VUID-vkCmdWriteBufferMarker2AMD-synchronization2-03893**
  The `synchronization2` feature must be enabled.

- **VUID-vkCmdWriteBufferMarker2AMD-stage-03894**
  `stage` must include only a single pipeline stage.

- **VUID-vkCmdWriteBufferMarker2AMD-stage-03895**
  `stage` must include only stages that are valid for the queue family that was used to create the command pool that `commandBuffer` was allocated from.

- **VUID-vkCmdWriteBufferMarker2AMD-dstOffset-03896**
  `dstOffset` must be less than or equal to the size of `dstBuffer` minus 4.

- **VUID-vkCmdWriteBufferMarker2AMD-dstBuffer-03897**
  `dstBuffer` must have been created with the `VK_BUFFER_USAGE_TRANSFER_DST_BIT` usage flag.

- **VUID-vkCmdWriteBufferMarker2AMD-dstBuffer-03898**
  If `dstBuffer` is non-sparse then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

- **VUID-vkCmdWriteBufferMarker2AMD-dstOffset-03899**
  `dstOffset` must be a multiple of 4.

---

**Valid Usage (Implicit)**

- **VUID-vkCmdWriteBufferMarker2AMD-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- **VUID-vkCmdWriteBufferMarker2AMD-stage-parameter**
  `stage` must be a valid combination of `VkPipelineStageFlagBits2` values.

- **VUID-vkCmdWriteBufferMarker2AMD-dstBuffer-parameter**
  `dstBuffer` must be a valid `VkBuffer` handle.

- **VUID-vkCmdWriteBufferMarker2AMD-commandBuffer-recording**
  `commandBuffer` must be in the `recording` state.

- **VUID-vkCmdWriteBufferMarker2AMD-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support transfer, graphics, or compute operations.

- **VUID-vkCmdWriteBufferMarker2AMD-videocoding**
  This command must only be called outside of a video coding scope.

- **VUID-vkCmdWriteBufferMarker2AMD-commonparent**
Both of `commandBuffer`, and `dstBuffer` must have been created, allocated, or retrieved from the same `VkDevice`.

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

### Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
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</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Both</td>
<td>Outside</td>
<td>Transfer Graphics Compute</td>
<td>Action</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To write a 32-bit marker value into a buffer as a pipelined operation, call:

```c
// Provided by VK_AMD_buffer_marker
void vkCmdWriteBufferMarkerAMD(
    VkCommandBuffer commandBuffer,
    VkPipelineStageFlagBits pipelineStage,
    VkBuffer dstBuffer,
    VkDeviceSize dstOffset,
    uint32_t marker);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `pipelineStage` is a `VkPipelineStageFlagBits` value specifying the pipeline stage whose completion triggers the marker write.
- `dstBuffer` is the buffer where the marker will be written to.
- `dstOffset` is the byte offset into the buffer where the marker will be written to.
- `marker` is the 32-bit value of the marker.

The command will write the 32-bit marker value into the buffer only after all preceding commands have finished executing up to at least the specified pipeline stage. This includes the completion of other preceding `vkCmdWriteBufferMarkerAMD` commands so long as their specified pipeline stages occur either at the same time or earlier than this command’s specified `pipelineStage`.

While consecutive buffer marker writes with the same `pipelineStage` parameter are implicitly complete in submission order, memory and execution dependencies between buffer marker writes and other operations must still be explicitly ordered using synchronization commands. The access...
scope for buffer marker writes falls under the \texttt{VK_ACCESS_TRANSFER_WRITE_BIT}, and the pipeline stages for identifying the synchronization scope \textbf{must} include both \texttt{pipelineStage} and \texttt{VK_PIPELINE_STAGE_TRANSFER_BIT}.

\textbf{Note}
Similar to \texttt{vkCmdWriteTimestamp}, if an implementation is unable to write a marker at any specific pipeline stage, it \textbf{may} instead do so at any logically later stage.

\textbf{Note}
Implementations \textbf{may} only support a limited number of pipelined marker write operations in flight at a given time, thus excessive number of marker write operations \textbf{may} degrade command execution performance.

\begin{itemize}
  \item \texttt{VUID-vkCmdWriteBufferMarkerAMD-pipelineStage-04074} \\
  \texttt{pipelineStage} \textbf{must} be a \texttt{valid stage} for the queue family that was used to create the command pool that \texttt{commandBuffer} was allocated from
  \item \texttt{VUID-vkCmdWriteBufferMarkerAMD-pipelineStage-04075} \\
  If the \texttt{geometryShader} feature is not enabled, \texttt{pipelineStage} \textbf{must} not be \texttt{VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT}
  \item \texttt{VUID-vkCmdWriteBufferMarkerAMD-pipelineStage-04076} \\
  If the \texttt{tessellationShader} feature is not enabled, \texttt{pipelineStage} \textbf{must} not be \texttt{VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT} or \texttt{VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT}
  \item \texttt{VUID-vkCmdWriteBufferMarkerAMD-pipelineStage-04077} \\
  If the \texttt{conditionalRendering} feature is not enabled, \texttt{pipelineStage} \textbf{must} not be \texttt{VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT}
  \item \texttt{VUID-vkCmdWriteBufferMarkerAMD-pipelineStage-04078} \\
  If the \texttt{fragmentDensityMap} feature is not enabled, \texttt{pipelineStage} \textbf{must} not be \texttt{VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT}
  \item \texttt{VUID-vkCmdWriteBufferMarkerAMD-pipelineStage-04079} \\
  If the \texttt{transformFeedback} feature is not enabled, \texttt{pipelineStage} \textbf{must} not be \texttt{VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT}
  \item \texttt{VUID-vkCmdWriteBufferMarkerAMD-pipelineStage-04080} \\
  If the \texttt{meshShader} feature is not enabled, \texttt{pipelineStage} \textbf{must} not be \texttt{VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT}
  \item \texttt{VUID-vkCmdWriteBufferMarkerAMD-pipelineStage-07077} \\
  If the \texttt{taskShader} feature is not enabled, \texttt{pipelineStage} \textbf{must} not be \texttt{VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT}
  \item \texttt{VUID-vkCmdWriteBufferMarkerAMD-shadingRateImage-07314} \\
  If neither the \texttt{shadingRateImage} or \texttt{attachmentFragmentShadingRate} are enabled, \texttt{pipelineStage} \textbf{must} not be \texttt{VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR}
\end{itemize}
• VUID-vkCmdWriteBufferMarkerAMD-synchronization2-06489
If the synchronization2 feature is not enabled, pipelineStage must not be VK_PIPELINE_STAGE_NONE

• VUID-vkCmdWriteBufferMarkerAMD-rayTracingPipeline-07943
If neither the VK_NV_ray_tracing extension or rayTracingPipeline feature are enabled, pipelineStage must not be VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR

• VUID-vkCmdWriteBufferMarkerAMD-dstOffset-01798
dstOffset must be less than or equal to the size of dstBuffer minus 4

• VUID-vkCmdWriteBufferMarkerAMD-dstBuffer-01799
dstBuffer must have been created with VK_BUFFER_USAGE_TRANSFER_DST_BIT usage flag

• VUID-vkCmdWriteBufferMarkerAMD-dstBuffer-01800
If dstBuffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

• VUID-vkCmdWriteBufferMarkerAMD-dstOffset-01801
dstOffset must be a multiple of 4

Valid Usage (Implicit)

• VUID-vkCmdWriteBufferMarkerAMD-commandBuffer-parameter
commandBuffer must be a valid VkCommandBuffer handle

• VUID-vkCmdWriteBufferMarkerAMD-pipelineStage-parameter
If pipelineStage is not 0, pipelineStage must be a valid VkPipelineStageFlagBits value

• VUID-vkCmdWriteBufferMarkerAMD-dstBuffer-parameter
dstBuffer must be a valid VkBuffer handle

• VUID-vkCmdWriteBufferMarkerAMD-commandBuffer-recording
commandBuffer must be in the recording state

• VUID-vkCmdWriteBufferMarkerAMD-commandBuffer-cmdpool
The VkCommandPool that commandBuffer was allocated from must support transfer, graphics, or compute operations

• VUID-vkCmdWriteBufferMarkerAMD-videocoding
This command must only be called outside of a video coding scope

• VUID-vkCmdWriteBufferMarkerAMD-commonparent
Both of commandBuffer, and dstBuffer must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
## Command Properties

<table>
<thead>
<tr>
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<td>Both</td>
<td>Outside</td>
<td>Transfer Graphics Compute</td>
<td>Action</td>
</tr>
</tbody>
</table>
Chapter 21. Drawing Commands

Drawing commands (commands with Draw in the name) provoke work in a graphics pipeline. Drawing commands are recorded into a command buffer and when executed by a queue, will produce work which executes according to the bound graphics pipeline, or if the shaderObject feature is enabled, any shader objects bound to graphics stages. A graphics pipeline or a combination of one or more graphics shader objects must be bound to a command buffer before any drawing commands are recorded in that command buffer.

Drawing can be achieved in two modes:

• Programmable Mesh Shading, the mesh shader assembles primitives, or
• Programmable Primitive Shading, the input primitives are assembled as follows.

Each draw is made up of zero or more vertices and zero or more instances, which are processed by the device and result in the assembly of primitives. Primitives are assembled according to the pInputAssemblyState member of the VkGraphicsPipelineCreateInfo structure, which is of type VkPipelineInputAssemblyStateCreateInfo:

```c
typedef struct VkPipelineInputAssemblyStateCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkPipelineInputAssemblyStateCreateFlags flags;
    VkPrimitiveTopology topology;
    VkBool32 primitiveRestartEnable;
} VkPipelineInputAssemblyStateCreateInfo;
```

• `sType` is a VkStructureType value identifying this structure.
• `pNext` is NULL or a pointer to a structure extending this structure.
• `flags` is reserved for future use.
• `topology` is a VkPrimitiveTopology defining the primitive topology, as described below.
• `primitiveRestartEnable` controls whether a special vertex index value is treated as restarting the assembly of primitives. This enable only applies to indexed draws (vkCmdDrawIndexed, vkCmdDrawMultiIndexedEXT, and vkCmdDrawIndexedIndirect), and the special index value is either 0xFFFFFFFF when the `indexType` parameter of `vkCmdBindIndexBuffer2KHR` or `vkCmdBindIndexBuffer` is equal to VK_INDEX_TYPE_UINT32, 0xFF when `indexType` is equal to VK_INDEX_TYPE_UINT8_EXT, or 0xFFFF when `indexType` is equal to VK_INDEX_TYPE_UINT16. Primitive restart is not allowed for “list” topologies, unless one of the features `primitiveTopologyPatchListRestart` (for VK_PRIMITIVE_TOPOLOGY_PATCH_LIST) or `primitiveTopologyListRestart` (for all other list topologies) is enabled.

Restarting the assembly of primitives discards the most recent index values if those elements formed an incomplete primitive, and restarts the primitive assembly using the subsequent indices, but only assembling the immediately following element through the end of the originally specified elements. The primitive restart index value comparison is performed before adding the
vertexOffset value to the index value.

### Valid Usage

- **VUID-VkPipelineInputAssemblyStateCreateInfo-topology-06252**
  If the `primitiveTopologyListRestart` feature is not enabled, and `topology` is `VK_PRIMITIVE_TOPOLOGY_POINT_LIST`, `VK_PRIMITIVE_TOPOLOGY_LINE_LIST`, `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST`, `VK_PRIMITIVE_TOPOLOGY_LINE_LIST_WITH_ADJACENCY`, or `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST_WITH_ADJACENCY`, `primitiveRestartEnable` must be `VK_FALSE`.

- **VUID-VkPipelineInputAssemblyStateCreateInfo-topology-06253**
  If the `primitiveTopologyPatchListRestart` feature is not enabled, and `topology` is `VK_PRIMITIVE_TOPOLOGY_PATCH_LIST`, `primitiveRestControllerEnable` must be `VK_FALSE`.

- **VUID-VkPipelineInputAssemblyStateCreateInfo-topology-00429**
  If the `geometryShader` feature is not enabled, `topology` must not be any of `VK_PRIMITIVE_TOPOLOGY_LINE_LIST_WITH_ADJACENCY`, `VK_PRIMITIVE_TOPOLOGY_LINE_STRIP_WITH_ADJACENCY`, `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST_WITH_ADJACENCY` or `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP_WITH_ADJACENCY`.

- **VUID-VkPipelineInputAssemblyStateCreateInfo-topology-00430**
  If the `tessellationShader` feature is not enabled, `topology` must not be `VK_PRIMITIVE_TOPOLOGY_PATCH_LIST`.

- **VUID-VkPipelineInputAssemblyStateCreateInfo-triangleFans-04452**
  If the `VK_KHR_portability_subset` extension is enabled, and `VkPhysicalDevicePortabilitySubsetFeaturesKHR::triangleFans` is `VK_FALSE`, `topology` must not be `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN`.

### Valid Usage (Implicit)

- **VUID-VkPipelineInputAssemblyStateCreateInfo-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_INPUT_ASSEMBLY_STATE_CREATE_INFO`.

- **VUID-VkPipelineInputAssemblyStateCreateInfo-pNext-pNext**
  `pNext` must be `NULL`.

- **VUID-VkPipelineInputAssemblyStateCreateInfo-flags-zerobitmask**
  `flags` must be `0`.

- **VUID-VkPipelineInputAssemblyStateCreateInfo-topology-parameter**
  `topology` must be a valid `VkPrimitiveTopology` value.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkPipelineInputAssemblyStateCreateFlags;

VkPipelineInputAssemblyStateCreateFlags` is a bitmask type for setting a mask, but is currently
To **dynamically control** whether a special vertex index value is treated as restarting the assembly of primitives, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdSetPrimitiveRestartEnable(
    VkCommandBuffer commandBuffer,  
    VkBool32 primitiveRestartEnable);
```

or the equivalent command

```c
// Provided by VK_EXT_extended_dynamic_state2, VK_EXT_shader_object
void vkCmdSetPrimitiveRestartEnableEXT(
    VkCommandBuffer commandBuffer,  
    VkBool32 primitiveRestartEnable);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `primitiveRestartEnable` controls whether a special vertex index value is treated as restarting the assembly of primitives. It behaves in the same way as `VkPipelineInputAssemblyStateCreateInfo::primitiveRestartEnable`

This command sets the primitive restart enable for subsequent drawing commands when drawing using **shader objects**, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineInputAssemblyStateCreateInfo::primitiveRestartEnable` value used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetPrimitiveRestartEnable-None-08970
  At least one of the following must be true:
  - the `extendedDynamicState2` feature is enabled
  - the `shaderObject` feature is enabled
  - the value of `VkApplicationInfo::apiVersion` used to create the `VkInstance` parent of `commandBuffer` is greater than or equal to Version 1.3

### Valid Usage (Implicit)

- VUID-vkCmdSetPrimitiveRestartEnable-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetPrimitiveRestartEnable-commandBuffer-recording
  `commandBuffer` must be in the recording state
21.1. Primitive Topologies

Primitive topology determines how consecutive vertices are organized into primitives, and determines the type of primitive that is used at the beginning of the graphics pipeline. The effective topology for later stages of the pipeline is altered by tessellation or geometry shading (if either is in use) and depends on the execution modes of those shaders. In the case of mesh shading the only effective topology is defined by the execution mode of the mesh shader.

The primitive topologies defined by VkPrimitiveTopology are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkPrimitiveTopology {
    VK_PRIMITIVE_TOPOLOGY_POINT_LIST = 0,
    VK_PRIMITIVE_TOPOLOGY_LINE_LIST = 1,
    VK_PRIMITIVE_TOPOLOGY_LINE_STRIP = 2,
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST = 3,
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP = 4,
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN = 5,
    VK_PRIMITIVE_TOPOLOGY_LINE_LIST_WITH_ADJACENCY = 6,
    VK_PRIMITIVE_TOPOLOGY_LINE_STRIP_WITH_ADJACENCY = 7,
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST_WITH_ADJACENCY = 8,
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP_WITH_ADJACENCY = 9,
    VK_PRIMITIVE_TOPOLOGY_PATCH_LIST = 10,
} VkPrimitiveTopology;
```
• **VK_PRIMITIVE_TOPOLOGY_POINT_LIST** specifies a series of separate point primitives.
• **VK_PRIMITIVE_TOPOLOGY_LINE_LIST** specifies a series of separate line primitives.
• **VK_PRIMITIVE_TOPOLOGY_LINE_STRIP** specifies a series of connected line primitives with consecutive lines sharing a vertex.
• **VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST** specifies a series of separate triangle primitives.
• **VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP** specifies a series of connected triangle primitives with consecutive triangles sharing an edge.
• **VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN** specifies a series of connected triangle primitives with all triangles sharing a common vertex. If the VK_KHR_portability_subset extension is enabled, and VkPhysicalDevicePortabilitySubsetFeaturesKHR::triangleFans is VK_FALSE, then triangle fans are not supported by the implementation, and **VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN** must not be used.
• **VK_PRIMITIVE_TOPOLOGY_LINE_LIST_WITH_ADJACENCY** specifies a series of separate line primitives with adjacency.
• **VK_PRIMITIVE_TOPOLOGY_LINE_STRIP_WITH_ADJACENCY** specifies a series of connected line primitives with adjacency, with consecutive primitives sharing three vertices.
• **VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST_WITH_ADJACENCY** specifies a series of separate triangle primitives with adjacency.
• **VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP_WITH_ADJACENCY** specifies connected triangle primitives with adjacency, with consecutive triangles sharing an edge.
• **VK_PRIMITIVE_TOPOLOGY_PATCH_LIST** specifies separate patch primitives.

Each primitive topology, and its construction from a list of vertices, is described in detail below with a supporting diagram, according to the following key:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>•</td>
<td>Vertex</td>
</tr>
<tr>
<td>5</td>
<td>Vertex Number</td>
</tr>
<tr>
<td>![Provoking Vertex]</td>
<td>Provoking Vertex</td>
</tr>
<tr>
<td>_______</td>
<td>Primitive Edge</td>
</tr>
<tr>
<td>_______</td>
<td>Adjacency Edge</td>
</tr>
<tr>
<td>![Winding Order]</td>
<td>Winding Order</td>
</tr>
</tbody>
</table>

The diagrams are supported with mathematical definitions where the vertices (v) and primitives (p) are numbered starting from 0; v_0 is the first vertex in the provided data and p_0 is the first primitive in the set of primitives defined by the vertices and topology.

To dynamically set primitive topology, call:
void vkCmdSetPrimitiveTopology(
    VkCommandBuffer commandBuffer,
    VkPrimitiveTopology primitiveTopology);

or the equivalent command

void vkCmdSetPrimitiveTopologyEXT(
    VkCommandBuffer commandBuffer,
    VkPrimitiveTopology primitiveTopology);

• commandBuffer is the command buffer into which the command will be recorded.
• primitiveTopology specifies the primitive topology to use for drawing.

This command sets the primitive topology for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY set in VkPipelineDynamicStateCreateInfo::pDynamicStates. Otherwise, this state is specified by the VkPipelineInputAssemblyStateCreateInfo::topology value used to create the currently active pipeline.

Valid Usage

• VUID-vkCmdSetPrimitiveTopology-None-08971
  At least one of the following must be true:
  ◦ the extendedDynamicState feature is enabled
  ◦ the shaderObject feature is enabled
  ◦ the value of VkApplicationInfo::apiVersion used to create the VkInstance parent of commandBuffer is greater than or equal to Version 1.3

Valid Usage (Implicit)

• VUID-vkCmdSetPrimitiveTopology-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle
• VUID-vkCmdSetPrimitiveTopology-primitiveTopology-parameter
  primitiveTopology must be a valid VkPrimitiveTopology value
• VUID-vkCmdSetPrimitiveTopology-commandBuffer-recording
  commandBuffer must be in the recording state
• VUID-vkCmdSetPrimitiveTopology-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations
• VUID-vkCmdSetPrimitiveTopology-videocoding
This command must only be called outside of a video coding scope.

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

**Command Properties**

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
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<td>Both</td>
<td>Outside</td>
<td>Graphics</td>
<td>State</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**21.1.1. Topology Class**

The primitive topologies are grouped into the following topology classes:

*Table 31. Topology classes*

<table>
<thead>
<tr>
<th>Topology Class</th>
<th>Primitive Topology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point</td>
<td><code>VK_PRIMITIVE_TOPOLOGY_POINT_LIST</code></td>
</tr>
<tr>
<td>Line</td>
<td><code>VK_PRIMITIVE_TOPOLOGY_LINE_LIST, VK_PRIMITIVE_TOPOLOGY_LINE_STRIP, VK_PRIMITIVE_TOPOLOGY_LINE_LIST_WITH_ADJACENCY, VK_PRIMITIVE_TOPOLOGY_LINE_STRIP_WITH_ADJACENCY</code></td>
</tr>
<tr>
<td>Triangle</td>
<td><code>VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST, VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP, VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN, VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST_WITH_ADJACENCY, VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP_WITH_ADJACENCY</code></td>
</tr>
<tr>
<td>Patch</td>
<td><code>VK_PRIMITIVE_TOPOLOGY_PATCH_LIST</code></td>
</tr>
</tbody>
</table>

**21.1.2. Point Lists**

When the topology is `VK_PRIMITIVE_TOPOLOGY_POINT_LIST`, each consecutive vertex defines a single point primitive, according to the equation:

\[ p_i = \{ v_i \} \]
As there is only one vertex, that vertex is the provoking vertex. The number of primitives generated is equal to `vertexCount`.

21.1.3. Line Lists

When the primitive topology is `VK_PRIMITIVE_TOPOLOGY_LINE_LIST`, each consecutive pair of vertices defines a single line primitive, according to the equation:

\[ p_i = \{v_{2i}, v_{2i+1}\} \]

The number of primitives generated is equal to \( \lfloor \text{vertexCount}/2 \rfloor \).

When the `provokingVertexMode` is `VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT`, the provoking vertex for \( p_i \) is \( v_{2i} \).

When the `provokingVertexMode` is `VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT`, the provoking vertex for \( p_i \) is \( v_{2i+1} \).

21.1.4. Line Strips

When the primitive topology is `VK_PRIMITIVE_TOPOLOGY_LINE_STRIP`, one line primitive is defined by each vertex and the following vertex, according to the equation:
The number of primitives generated is equal to \( \max(0, \text{vertexCount} - 1) \).

When the \texttt{provokingVertexMode} is \texttt{VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT}, the provoking vertex for \( p_i \) is \( v_i \).

When the \texttt{provokingVertexMode} is \texttt{VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT}, the provoking vertex for \( p_i \) is \( v_{i+1} \).

\textbf{21.1.5. Triangle Lists}

When the primitive topology is \texttt{VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST}, each consecutive set of three vertices defines a single triangle primitive, according to the equation:

\[
p_i = \{v_{3i}, v_{3i+1}, v_{3i+2}\}
\]

The number of primitives generated is equal to \( \lfloor \text{vertexCount}/3 \rfloor \).

When the \texttt{provokingVertexMode} is \texttt{VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT}, the provoking vertex for \( p_i \) is \( v_{3i} \).

When the \texttt{provokingVertexMode} is \texttt{VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT}, the provoking vertex for \( p_i \) is \( v_{3i+2} \).
21.1.6. Triangle Strips

When the primitive topology is `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP`, one triangle primitive is defined by each vertex and the two vertices that follow it, according to the equation:

\[ p_i = \{v_i, v_i+(1+i\%2), v_i+(2-i\%2)\} \]

The number of primitives generated is equal to \( \max(0, \text{vertexCount}-2) \).

When the `provokingVertexMode` is `VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT`, the provoking vertex for \( p_i \) is \( v_i \).

When the `provokingVertexMode` is `VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT`, the provoking vertex for \( p_i \) is \( v_{i+2} \).

*Note*

The ordering of the vertices in each successive triangle is reversed, so that the winding order is consistent throughout the strip.

21.1.7. Triangle Fans

When the primitive topology is `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN`, triangle primitives are defined around a shared common vertex, according to the equation:

\[ p_i = \{v_{i-1}, v_{i+2}, v_0\} \]

The number of primitives generated is equal to \( \max(0, \text{vertexCount}-2) \).

When the `provokingVertexMode` is `VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT`, the provoking vertex for \( p_i \) is \( v_{i+1} \).
When the `provokingVertexMode` is `VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT`, the provoking vertex for \( p_i \) is \( v_{i+2} \).

**Note**

If the `VK_KHR_portability_subset` extension is enabled, and `VkPhysicalDevicePortabilitySubsetFeaturesKHR::triangleFans` is `VK_FALSE`, then triangle fans are not supported by the implementation, and `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN` must not be used.

### 21.1.8. Line Lists With Adjacency

When the primitive topology is `VK_PRIMITIVE_TOPOLOGY_LINE_LIST_WITH_ADJACENCY`, each consecutive set of four vertices defines a single line primitive with adjacency, according to the equation:

\[
p_i = \{v_{4i}, v_{4i+1}, v_{4i+2}, v_{4i+3}\}
\]

A line primitive is described by the second and third vertices of the total primitive, with the remaining two vertices only accessible in a geometry shader.

The number of primitives generated is equal to \( \lfloor \text{vertexCount} / 4 \rfloor \).

When the `provokingVertexMode` is `VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT`, the provoking vertex for \( p_i \) is \( v_{4i+1} \).

When the `provokingVertexMode` is `VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT`, the provoking vertex
for $p_i$ is $v_{4i+2}$.

### 21.1.9. Line Strips With Adjacency

When the primitive topology is `VK_PRIMITIVE_TOPOLOGY_LINE_STRIP_WITH_ADJACENCY`, one line primitive with adjacency is defined by each vertex and the following vertex, according to the equation:

$$ p_i = \{v_i, v_{i+1}, v_{i+2}, v_{i+3}\} $$

A line primitive is described by the second and third vertices of the total primitive, with the remaining two vertices only accessible in a geometry shader.

The number of primitives generated is equal to $\max(0, \text{vertexCount}-3)$.

When the `provokingVertexMode` is `VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT`, the provoking vertex for $p_i$ is $v_{i+1}$.

When the `provokingVertexMode` is `VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT`, the provoking vertex for $p_i$ is $v_{i+2}$.

### 21.1.10. Triangle Lists With Adjacency

When the primitive topology is `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST_WITH_ADJACENCY`, each consecutive set of six vertices defines a single triangle primitive with adjacency, according to the equations:

$$ p_i = \{v_{6i}, v_{6i+1}, v_{6i+2}, v_{6i+3}, v_{6i+4}, v_{6i+5}\} $$

A triangle primitive is described by the first, third, and fifth vertices of the total primitive, with the remaining three vertices only accessible in a geometry shader.

The number of primitives generated is equal to $\lfloor \text{vertexCount}/6 \rfloor$.

When the `provokingVertexMode` is `VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT`, the provoking vertex
When the `provokingVertexMode` is `VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT`, the provoking vertex for \( p_i \) is \( v_{6i+4} \).

### 21.1.11. Triangle Strips With Adjacency

When the primitive topology is `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP_WITH_ADJACENCY`, one triangle primitive with adjacency is defined by each vertex and the following 5 vertices.

The number of primitives generated, \( n \), is equal to \( \lceil \text{max}(0, \text{vertexCount} - 4)/2 \rceil \).

If \( n=1 \), the primitive is defined as:

\[
p = \{v_0, v_1, v_2, v_5, v_4, v_3\}
\]

If \( n>1 \), the total primitive consists of different vertices according to where it is in the strip:

\[
p_i = \{v_{2i}, v_{2i+1}, v_{2i+2}, v_{2i+6}, v_{2i+4}, v_{2i+3}\} \text{ when } i=0
\]

\[
p_i = \{v_{2i}, v_{2i+3}, v_{2i+4}, v_{2i+6}, v_{2i+2}, v_{2i+1}\} \text{ when } i>0, i<n-1, \text{ and } i\%2=1
\]
\( p_i = \{v_{2i}, v_{2i+2}, v_{2i+6}, v_{2i+4}, v_{2i+3}\} \) when \( i > 0, \ i < n-1, \) and \( i \% 2 = 0 \)

\( p_i = \{v_{2i}, v_{2i+3}, v_{2i+4}, v_{2i+5}, v_{2i+2}, v_{2i+1}\} \) when \( i = n-1 \) and \( i \% 2 = 1 \)

\( p_i = \{v_{2i}, v_{2i+2}, v_{2i+3}, v_{2i+4}, v_{2i+5}, v_{2i+1}\} \) when \( i = n-1 \) and \( i \% 2 = 0 \)

A triangle primitive is described by the first, third, and fifth vertices of the total primitive in all cases, with the remaining three vertices only accessible in a geometry shader.

**Note**

The ordering of the vertices in each successive triangle is altered so that the winding order is consistent throughout the strip.

When the `provokingVertexMode` is `VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT`, the provoking vertex for \( p_i \) is always \( v_{2i} \).

When the `provokingVertexMode` is `VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT`, the provoking vertex for \( p_i \) is always \( v_{2i+4} \).
21.1.12. Patch Lists

When the primitive topology is `VK_PRIMITIVE_TOPOLOGY_PATCH_LIST`, each consecutive set of $m$ vertices defines a single patch primitive, according to the equation:

$$p_i = \{v_{mi}, v_{mi+1}, \ldots, v_{mi+(m-2)}, v_{mi+(m-1)}\}$$

where $m$ is equal to `VkPipelineTessellationStateCreateInfo::patchControlPoints`.

Patch lists are never passed to vertex post-processing, and as such no provoking vertex is defined for patch primitives. The number of primitives generated is equal to $\lfloor\text{vertexCount}/m\rfloor$.

The vertices comprising a patch have no implied geometry, and are used as inputs to tessellation shaders and the fixed-function tessellator to generate new point, line, or triangle primitives.

21.2. Primitive Order

Primitives generated by drawing commands progress through the stages of the graphics pipeline in primitive order. Primitive order is initially determined in the following way:

1. Submission order determines the initial ordering
2. For indirect drawing commands, the order in which accessed instances of the
**VkDrawIndirectCommand** are stored in buffer, from lower indirect buffer addresses to higher addresses.

3. If a drawing command includes multiple instances, the order in which instances are executed, from lower numbered instances to higher.

4. The order in which primitives are specified by a drawing command:
   
   - For non-indexed draws, from vertices with a lower numbered `vertexIndex` to a higher numbered `vertexIndex`.
   
   - For indexed draws, vertices sourced from a lower index buffer addresses to higher addresses.
   
   - For draws using mesh shaders, the order is provided by mesh shading.
   
   - For draws using cluster culling shaders, the order is provided by cluster culling shading.

Within this order implementations further sort primitives:

5. If tessellation shading is active, by an implementation-dependent order of new primitives generated by tessellation.

6. If geometry shading is active, by the order new primitives are generated by geometry shading.

7. If the polygon mode is not `VK_POLYGON_MODE_FILL`, or `VK_POLYGON_MODE_FILL_RECTANGLE_NV`, by an implementation-dependent ordering of the new primitives generated within the original primitive.

Primitive order is later used to define rasterization order, which determines the order in which fragments output results to a framebuffer.

### 21.3. Programmable Primitive Shading

Once primitives are assembled, they proceed to the vertex shading stage of the pipeline. If the draw includes multiple instances, then the set of primitives is sent to the vertex shading stage multiple times, once for each instance.

It is implementation-dependent whether vertex shading occurs on vertices that are discarded as part of incomplete primitives, but if it does occur then it operates as if they were vertices in complete primitives and such invocations can have side effects.

Vertex shading receives two per-vertex inputs from the primitive assembly stage - the `vertexIndex` and the `instanceIndex`. How these values are generated is defined below, with each command.

Drawing commands fall roughly into two categories:

- Non-indexed drawing commands present a sequential `vertexIndex` to the vertex shader. The sequential index is generated automatically by the device (see Fixed-Function Vertex Processing for details on both specifying the vertex attributes indexed by `vertexIndex`, as well as binding vertex buffers containing those attributes to a command buffer). These commands are:
  
  - `vkCmdDraw`
  
  - `vkCmdDrawIndirect`
- `vkCmdDrawIndirectCount`
- `vkCmdDrawIndirectCountKHR`
- `vkCmdDrawIndirectCountAMD`
- `vkCmdDrawMultiEXT`

Indexed drawing commands read index values from an *index buffer* and use this to compute the `vertexIndex` value for the vertex shader. These commands are:

- `vkCmdDrawIndexed`
- `vkCmdDrawIndexedIndirect`
- `vkCmdDrawIndexedIndirectCount`
- `vkCmdDrawIndexedIndirectCountKHR`
- `vkCmdDrawIndexedIndirectCountAMD`
- `vkCmdDrawMultiIndexedEXT`

To bind an index buffer to a command buffer, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdBindIndexBuffer(
    VkCommandBuffer commandBuffer,
    VkBuffer buffer,
    VkDeviceSize offset,
    VkIndexType indexType);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `buffer` is the buffer being bound.
- `offset` is the starting offset in bytes within `buffer` used in index buffer address calculations.
- `indexType` is a `VkIndexType` value specifying the size of the indices.

### Valid Usage

- **VUID-vkCmdBindIndexBuffer-offset-08782**
  *offset* must be less than the size of `buffer`

- **VUID-vkCmdBindIndexBuffer-offset-08783**
  The sum of *offset* and the base address of the range of `VkDeviceMemory` object that is backing `buffer`, must be a multiple of the size of the type indicated by `indexType`

- **VUID-vkCmdBindIndexBuffer-buffer-08784**
  *buffer* must have been created with the `VK_BUFFER_USAGE_INDEX_BUFFER_BIT` flag

- **VUID-vkCmdBindIndexBuffer-buffer-08785**
  If `buffer` is non-sparse then it must be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdBindIndexBuffer-indexType-08786**
**Valid Usage (Implicit)**

- VUID-vkCmdBindIndexBuffer-commandBuffer-parameter
  - `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdBindIndexBuffer-buffer-parameter
  - `buffer` must be a valid `VkBuffer` handle
- VUID-vkCmdBindIndexBuffer-indexType-parameter
  - `indexType` must be a valid `VkIndexType` value
- VUID-vkCmdBindIndexBuffer-commandBuffer-recording
  - `commandBuffer` must be in the recording state
- VUID-vkCmdBindIndexBuffer-commandBuffer-cmdpool
  - The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations
- VUID-vkCmdBindIndexBuffer-videocoding
  - This command must only be called outside of a video coding scope
- VUID-vkCmdBindIndexBuffer-commonparent
  - Both of `buffer`, and `commandBuffer` must have been created, allocated, or retrieved from the same `VkDevice`

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

**Command Properties**

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</table>

To bind an index buffer, along with its size, to a command buffer, call:

```c
// Provided by VK_KHR_maintenance5
void vkCmdBindIndexBuffer2KHR(
```
VkCommandBuffer commandBuffer, VkBuffer buffer, VkDeviceSize offset, VkDeviceSize size, VkIndexType indexType);

- **commandBuffer** is the command buffer into which the command is recorded.
- **buffer** is the buffer being bound.
- **offset** is the starting offset in bytes within buffer used in index buffer address calculations.
- **size** is the size in bytes of index data bound from buffer.
- **indexType** is a VkIndexType value specifying the size of the indices.

**size** specifies the bound size of the index buffer starting from **offset**. If **size** is **VK_WHOLE_SIZE** then the bound size is from **offset** to the end of the **buffer**.

### Valid Usage

- **VUID-vkCmdBindIndexBuffer2KHR-offset-08782**  
  **offset** must be less than the size of **buffer**

- **VUID-vkCmdBindIndexBuffer2KHR-offset-08783**  
  The sum of **offset** and the base address of the range of VkDeviceMemory object that is backing **buffer**, must be a multiple of the size of the type indicated by **indexType**

- **VUID-vkCmdBindIndexBuffer2KHR-buffer-08784**  
  **buffer** must have been created with the VkBufferUsageIndexBufferBit flag

- **VUID-vkCmdBindIndexBuffer2KHR-buffer-08785**  
  If **buffer** is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- **VUID-vkCmdBindIndexBuffer2KHR-indexType-08786**  
  **indexType** must not be VK_INDEX_TYPE_NONE_KHR

- **VUID-vkCmdBindIndexBuffer2KHR-indexType-08787**  
  If **indexType** is VK_INDEX_TYPE_UINT8_EXT, the indexTypeUint8 feature must be enabled

- **VUID-vkCmdBindIndexBuffer2KHR-size-08767**  
  If **size** is not VK_WHOLE_SIZE, **size** must be a multiple of the size of the type indicated by **indexType**

- **VUID-vkCmdBindIndexBuffer2KHR-size-08768**  
  If **size** is not VK_WHOLE_SIZE, the sum of **offset** and **size** must be less than or equal to the size of **buffer**

### Valid Usage (Implicit)

- **VUID-vkCmdBindIndexBuffer2KHR-commandBuffer-parameter**  
  **commandBuffer** must be a valid VkCommandBuffer handle
• VUID-vkCmdBindIndexBuffer2KHR-buffer-parameter
  buffer must be a valid VkBuffer handle

• VUID-vkCmdBindIndexBuffer2KHR-indexType-parameter
  indexType must be a valid VkIndexType value

• VUID-vkCmdBindIndexBuffer2KHR-commandBuffer-recording
  commandBuffer must be in the recording state

• VUID-vkCmdBindIndexBuffer2KHR-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

• VUID-vkCmdBindIndexBuffer2KHR-videocoding
  This command must only be called outside of a video coding scope

• VUID-vkCmdBindIndexBuffer2KHR-commonparent
  Both of buffer, and commandBuffer must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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<tr>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>

Possible values of vkCmdBindIndexBuffer2KHR::indexType and vkCmdBindIndexBuffer::indexType, specifying the size of indices, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkIndexType {
    VK_INDEX_TYPE_UINT16 = 0,
    VK_INDEX_TYPE_UINT32 = 1,
    // Provided by VK_KHR_acceleration_structure
    VK_INDEX_TYPE_NONE_KHR = 1000165000,
    // Provided by VK_EXT_index_type_uint8
    VK_INDEX_TYPE_UINT8_EXT = 1000265000,
    // Provided by VK_NV_ray_tracing
    VK_INDEX_TYPE_NONE_NV = VK_INDEX_TYPE_NONE_KHR,
};
```
• **VK_INDEX_TYPE_UINT16** specifies that indices are 16-bit unsigned integer values.
• **VK_INDEX_TYPE_UINT32** specifies that indices are 32-bit unsigned integer values.
• **VK_INDEX_TYPE_NONE_KHR** specifies that no indices are provided.
• **VK_INDEX_TYPE_UINT8_EXT** specifies that indices are 8-bit unsigned integer values.

The parameters for each drawing command are specified directly in the command or read from buffer memory, depending on the command. Drawing commands that source their parameters from buffer memory are known as *indirect* drawing commands.

All drawing commands interact with the `robustBufferAccess` feature.

To record a non-indexed draw, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdDraw(
    VkCommandBuffer commandBuffer,
    uint32_t vertexCount,
    uint32_t instanceCount,
    uint32_t firstVertex,
    uint32_t firstInstance);
```

• `commandBuffer` is the command buffer into which the command is recorded.
• `vertexCount` is the number of vertices to draw.
• `instanceCount` is the number of instances to draw.
• `firstVertex` is the index of the first vertex to draw.
• `firstInstance` is the instance ID of the first instance to draw.

When the command is executed, primitives are assembled using the current primitive topology and `vertexCount` consecutive vertex indices with the first `vertexIndex` value equal to `firstVertex`. The primitives are drawn `instanceCount` times with `instanceIndex` starting with `firstInstance` and increasing sequentially for each instance. The assembled primitives execute the bound graphics pipeline.

**Valid Usage**

• **VUID-vkCmdDraw-magFilter-04553**
  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's `format` features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`.

• **VUID-vkCmdDraw-mipmapMode-04770**
  If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and
compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

• VUID-vkCmdDraw-None-06479
  If a VkImageView is sampled with depth comparison, the image view's format features must contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT

• VUID-vkCmdDraw-None-02691
  If a VkImageView is accessed using atomic operations as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

• VUID-vkCmdDraw-None-07888
  If a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

• VUID-vkCmdDraw-None-02692
  If a VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT

• VUID-vkCmdDraw-None-02693
  If the VK_EXT_filter_cubic extension is not enabled and any VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, it must not have a VkImageViewType of VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

• VUID-vkCmdDraw-filterCubic-02694
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2

• VUID-vkCmdDraw-filterCubicMinmax-02695
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT with a reduction mode of either VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX as a result of this command must have a VkImageViewType and format that supports cubic filtering together with minmax filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax returned by vkGetPhysicalDeviceImageFormatProperties2

• VUID-vkCmdDraw-cubicRangeClamp-09212
  If the cubicRangeClamp feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must not have a VkSamplerReductionModeCreateInfo reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM

• VUID-vkCmdDraw-reductionMode-09213
  Any VkImageView being sampled with a VkSamplerReductionModeCreateInfo::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM as a result of this command must sample with VK_FILTER_CUBIC_EXT

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• VUID-vkCmdDraw-selectableCubicWeights-09214
If the selectableCubicWeights feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights equal to VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM.

• VUID-vkCmdDraw-flags-02696
Any VkImage created with a VkImageCreateInfo::flags containing VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV sampled as a result of this command must only be sampled using a VkSamplerAddressMode of VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE.

• VUID-vkCmdDraw-OpTypeImage-07027
For any VkImageView being written as a storage image where the image format field of the OpTypeImage is Unknown, the view’s format features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT.

• VUID-vkCmdDraw-OpTypeImage-07028
For any VkImageView being read as a storage image where the image format field of the OpTypeImage is Unknown, the view’s format features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT.

• VUID-vkCmdDraw-OpTypeImage-07029
Any VkBufferView being written as a storage texel buffer where the image format field of the OpTypeImage is Unknown then the view’s buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT.

• VUID-vkCmdDraw-OpTypeImage-07030
For each set n that is statically used by a bound shader, a descriptor set must have been bound to n at the same pipeline bind point, with a VkPipelineLayout that is compatible for set n, with the VkPipelineLayout or VkDescriptorSetLayout array that was used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility.

• VUID-vkCmdDraw-None-08600
For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility.

• VUID-vkCmdDraw-None-08601
If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility.

• VUID-vkCmdDraw-None-08114
Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, must be valid if they are statically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was not created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- **VUID-vkCmdDraw-None-08115**
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` must have been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- **VUID-vkCmdDraw-None-08116**
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- **VUID-vkCmdDraw-None-08604**
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command

- **VUID-vkCmdDraw-None-08117**
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdSetDescriptorBufferOffsetsEXT`, the bound `VkPipeline` must have been created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- **VUID-vkCmdDraw-None-08119**
  If a descriptor is dynamically used with a `VkPipeline` created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory must be resident

- **VUID-vkCmdDraw-None-08605**
  If a descriptor is dynamically used with a `VkShaderEXT` created with a `VkDescriptorSetLayout` that was created with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory must be resident

- **VUID-vkCmdDraw-None-08606**
  If the `shaderObject` feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command

- **VUID-vkCmdDraw-None-08607**
  If the `shaderObject` is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and `VK_NULL_HANDLE` shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- **VUID-vkCmdDraw-None-08608**
  If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the `VkPipeline` object bound to the pipeline bind point used by this command, since that pipeline was bound

- **VUID-vkCmdDraw-None-08609**
If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler must not be used to sample from any `VkImage` with a `VkImageView` of the type `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, `VK_IMAGE_VIEW_TYPE_1D_ARRAY`, `VK_IMAGE_VIEW_TYPE_2D_ARRAY` or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`, in any shader stage.

- **VUID-vkCmdDraw-None-08610**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V `OpImageSample*` or `OpImageSparseSample*` instructions with `ImplicitLod`, `Dref` or `Proj` in their name, in any shader stage.

- **VUID-vkCmdDraw-None-08611**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V `OpImageSample*` or `OpImageSparseSample*` instructions that includes a LOD bias or any offset values, in any shader stage.

- **VUID-vkCmdDraw-uniformBuffers-06935**
  If any stage of the `VkPipeline` object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT` or `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT` for `uniformBuffers`, and the `robustBufferAccess` feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdDraw-None-08612**
  If the `robustBufferAccess` feature is not enabled, and any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdDraw-storageBuffers-06936**
  If any stage of the `VkPipeline` object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT` or `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT` for `storageBuffers`, and the `robustBufferAccess` feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdDraw-None-08613**
  If the `robustBufferAccess` feature is not enabled, and any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdDraw-commandBuffer-02707**
If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, any resource accessed by bound shaders must not be a protected resource

- **VUID-vkCmdDraw-None-06550**
  If a bound shader accesses a `VkSampler` or `VkImageView` object that enables sampler Y’C₆C₈ conversion, that object must only be used with `OpImageSample*` or `OpImageSparseSample*` instructions

- **VUID-vkCmdDraw-ConstOffset-06551**
  If a bound shader accesses a `VkSampler` or `VkImageView` object that enables sampler Y’C₆C₈ conversion, that object must not use the `ConstOffset` and `Offset` operands

- **VUID-vkCmdDraw-viewType-07752**
  If a `VkImageView` is accessed as a result of this command, then the image view’s `viewType` must match the `Dim` operand of the `OpTypeImage` as described in Instruction/Sampler/Image View Validation

- **VUID-vkCmdDraw-format-07753**
  If a `VkImageView` is accessed as a result of this command, then the numeric type of the image view’s `format` and the `Sampled Type` operand of the `OpTypeImage` must match

- **VUID-vkCmdDraw-OpImageWrite-08795**
  If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have at least as many components as the image view’s `format`

- **VUID-vkCmdDraw-OpImageWrite-08796**
  If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have four components

- **VUID-vkCmdDraw-OpImageWrite-04469**
  If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have at least as many components as the buffer view’s `format`

- **VUID-vkCmdDraw-SampledType-04470**
  If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64

- **VUID-vkCmdDraw-SampledType-04471**
  If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 32

- **VUID-vkCmdDraw-SampledType-04472**
  If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64

- **VUID-vkCmdDraw-SampledType-04473**
  If a `VkBufferView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction...
instruction **must** have a **Width** of 32

- **VUID-vkCmdDraw-sparseImageInt64Atomics-04474**
  If the `sparseImageInt64Atomics` feature is not enabled, `VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` flag **must** not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a **Width** of 64 by this command

- **VUID-vkCmdDraw-sparseImageInt64Atomics-04475**
  If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag **must** not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a **Width** of 64 by this command

- **VUID-vkCmdDraw-OpImageWeightedSampleQCOM-06971**
  If `OpImageWeightedSampleQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`

- **VUID-vkCmdDraw-OpImageWeightedSampleQCOM-06972**
  If `OpImageWeightedSampleQCOM` uses a `VkImageView` as a sample weight image as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`

- **VUID-vkCmdDraw-OpImageBoxFilterQCOM-06973**
  If `OpImageBoxFilterQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM`

- **VUID-vkCmdDraw-OpImageBlockMatchSSDQCOM-06974**
  If `OpImageBlockMatchSSDQCOM` is used to read from an `VkImageView` as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`

- **VUID-vkCmdDraw-OpImageBlockMatchSADQCOM-06975**
  If `OpImageBlockMatchSADQCOM` or `OpImageBlockMatchSSDQCOM` is used to read from a reference image as result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation

- **VUID-vkCmdDraw-OpImageWeightedSampleQCOM-06977**
  If `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, or `OpImageBlockMatchSSDQCOM` uses a `VkSampler` as a result of this command, then the sampler **must** have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`

- **VUID-vkCmdDraw-OpImageWeightedSampleQCOM-06978**
  If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, or `OpImageBlockMatchSSDQCOM` uses a `VkSampler` as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`
command, then the sampler must not have been created with
VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM

- VUID-vkCmdDraw-OpImageBlockMatchWindow-09215
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdDraw-OpImageBlockMatchWindow-09216
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view’s format must be a single-component format.

- VUID-vkCmdDraw-OpImageBlockMatchWindow-09217
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- VUID-vkCmdDraw-None-07288
  Any shader invocation executed by this command must terminate

- VUID-vkCmdDraw-renderPass-02684
  The current render pass must be compatible with the renderPass member of the VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdDraw-subpass-02685
  The subpass index of the current render pass must be equal to the subpass member of the VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdDraw-None-07748
  If any shader statically accesses an input attachment, a valid descriptor must be bound to the pipeline via a descriptor set

- VUID-vkCmdDraw-OpTypeImage-07468
  If any shader executed by this pipeline accesses an OpTypeImage variable with a Dim operand of SubpassData, it must be decorated with an InputAttachmentIndex that corresponds to a valid input attachment in the current subpass

- VUID-vkCmdDraw-None-07469
  Input attachment views accessed in a subpass must be created with the same VkFormat as the corresponding subpass definition, and be created with a VkImageView that is compatible with the attachment referenced by the subpass’ pInputAttachments [InputAttachmentIndex] in the currently bound VkFramebuffer as specified by Fragment Input Attachment Compatibility

- VUID-vkCmdDraw-None-06537
  Memory backing image subresources used as attachments in the current render pass must not be written in any way other than as an attachment by this command

- VUID-vkCmdDraw-None-09000
  If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the
VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:

- the VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
- the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_COLOR_BIT and
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDraw-None-09001
If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:

- the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
- the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_DEPTH_BIT and
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDraw-None-09002
If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:

- the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
- the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_STENCIL_BIT and
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDraw-None-09003
If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command

- VUID-vkCmdDraw-None-06539
If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command must not write to that image subresource as an attachment
• VUID-vkCmdDraw-None-06886
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, **depth writes** must be disabled.

• VUID-vkCmdDraw-None-06887
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back **writeMask** are not zero, and stencil test is enabled, **all stencil ops** must be **VK_STENCIL_OP_KEEP**.

• VUID-vkCmdDraw-None-07831
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_VIEWPORT** dynamic state enabled then **vkCmdSetViewport** must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDraw-None-07832
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SCISSOR** dynamic state enabled then **vkCmdSetScissor** must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDraw-None-07833
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_LINE_WIDTH** dynamic state enabled then **vkCmdSetLineWidth** must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDraw-None-08617
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetPolygonModeEXT** in the current command buffer set **polygonMode** to **VK_POLYGON_MODE_LINE**, **vkCmdSetLineWidth** must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDraw-None-08618
  If a shader object is bound to the **VK_SHADER_STAGE_VERTEX_BIT** stage, and the most recent call to **vkCmdSetPrimitiveTopology** in the current command buffer set **primitiveTopology** to any line topology, **vkCmdSetLineWidth** must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDraw-None-08619
  If a shader object that outputs line primitives is bound to the **VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT** or **VK_SHADER_STAGE_GEOMETRY_BIT** stage, **vkCmdSetLineWidth** must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDraw-None-07834
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_DEPTH_BIAS** dynamic state enabled then **vkCmdSetDepthBias** or **vkCmdSetDepthBias2EXT** must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDraw-None-08620
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set **rasterizerDiscardEnable** to **VK_FALSE**, and the most recent call to **vkCmdSetDepthBiasEnable** in the current command buffer set **depthBiasEnable** to **VK_TRUE**, **vkCmdSetDepthBias** or **vkCmdSetDepthBias2EXT** must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the 
\texttt{VK\_DYNAMIC\_STATE\_BLEND\_CONSTANTS} dynamic state enabled then \texttt{vkCmdSetBlendConstants} 
\textbf{must} have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the \texttt{VK\_SHADER\_STAGE\_FRAGMENT\_BIT} stage, and the most recent 
call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set 
\texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, and the most recent call to 
\texttt{vkCmdSetColorBlendEnableEXT} in the current command buffer set any element of 
\texttt{pColorBlendEnables} to \texttt{VK\_TRUE}, and the most recent call to 
\texttt{vkCmdSetColorBlendEquationEXT} in the current command buffer set the same element of 
\texttt{pColorBlendEquations} to a \texttt{VkColorBlendEquationEXT} structure with any \texttt{VkBlendFactor} 
member with a value of \texttt{VK\_BLEND\_FACTOR\_CONSTANT\_COLOR}, 
\texttt{VK\_BLEND\_FACTOR\_ONE\_MINUS\_CONSTANT\_COLOR}, \texttt{VK\_BLEND\_FACTOR\_CONSTANT\_ALPHA}, or 
\texttt{VK\_BLEND\_FACTOR\_ONE\_MINUS\_CONSTANT\_ALPHA}, \texttt{vkCmdSetBlendConstants} \textbf{must} have been 
called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_DEPTH\_BOUNDS} 
dynamic state enabled then \texttt{vkCmdSetDepthBounds} \textbf{must} have been called in the current 
command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to 
\texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set 
\texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, and the most recent call to 
\texttt{vkCmdSetDepthBoundsTestEnable} in the current command buffer set 
\texttt{depthBoundsTestEnable} to \texttt{VK\_TRUE}, then \texttt{vkCmdSetDepthBounds} \textbf{must} have been called in 
the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_STENCIL\_COMPARE\_MASK} 
dynamic state enabled then \texttt{vkCmdSetStencilCompareMask} \textbf{must} have been called in the current command buffer 
before this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to 
\texttt{vkCmdSetStencilTestEnable} in the current command buffer set 
\texttt{stencilTestEnable} to \texttt{VK\_TRUE}, \texttt{vkCmdSetStencilCompareMask} \textbf{must} have been called in the current command 
buffer prior to this drawing command.

If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_STENCIL\_WRITE\_MASK} 
dynamic state enabled then \texttt{vkCmdSetStencilWriteMask} \textbf{must} have been called in the current command buffer prior 
to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDraw-None-07839
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_REFERENCE dynamic state enabled then vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDraw-None-08625
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDraw-maxMultiviewInstanceIndex-02688
  If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex.

- VUID-vkCmdDraw-sampleLocationsEnable-02689
  If the bound graphics pipeline was created with VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable set to VK_TRUE and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set.

- VUID-vkCmdDraw-None-06666
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT dynamic state enabled then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDraw-None-08626
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetSampleLocationsEnableEXT in the current command buffer set sampleLocationsEnable to VK_TRUE, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDraw-sampleLocationsPerPixel-07934
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples member of the VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with.

- VUID-vkCmdDraw-None-07840
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CULL_MODE dynamic state enabled then vkCmdSetCullMode must have been called in the current command buffer prior to this drawing command.
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled, then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` dynamic state enabled, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` dynamic state enabled, then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthTestEnable` in the current command buffer set `depthTestEnable` to `VK_TRUE`, then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.
prior to this drawing command

- VUID-vkCmdDraw-None-07846
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE` dynamic state enabled then
  `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer
  prior to this drawing command

- VUID-vkCmdDraw-None-08632
  If a shader object is bound to any graphics stage, and the `depthBounds` feature is enabled,
  and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command
  buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `vkCmdSetDepthBoundsTestEnable` must
  have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDraw-None-07847
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE` dynamic state enabled then
  `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior
  to this drawing command

- VUID-vkCmdDraw-None-08633
  If a shader object is bound to any graphics stage, and the most recent call to
  `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
  `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetStencilTestEnable` must have
  been called in the current command buffer prior to this drawing command

- VUID-vkCmdDraw-None-07848
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_OP`
  dynamic state enabled then `vkCmdSetStencilOp` must have been called in the current
  command buffer prior to this drawing command

- VUID-vkCmdDraw-None-08634
  If a shader object is bound to any graphics stage, and the most recent call to
  `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
  `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to
  `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to
  `VK_TRUE`, then `vkCmdSetStencilOp` must have been called in the current command buffer
  prior to this drawing command

- VUID-vkCmdDraw-viewportCount-03417
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT`
  dynamic state enabled, but not the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT`
  dynamic state enabled, then `vkCmdSetViewportWithCount` must have been called in the current
  command buffer prior to this drawing command, and the `viewportCount` parameter of
  `vkCmdSetViewportWithCount` must match the `VkPipelineViewportStateCreateInfo`::`scissorCount`
  of the pipeline

- VUID-vkCmdDraw-scissorCount-03418
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT`
  dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT`
  dynamic state enabled, then `vkCmdSetViewportWithCount` must have been called in the current
  command buffer prior
to this drawing command, and the \texttt{scissorCount} parameter of \texttt{vkCmdSetScissorWithCount} must match the \texttt{VkPipelineViewportStateCreateInfo::viewportCount} of the pipeline

- VUID-vkCmdDraw-viewportCount-03419
  If the bound graphics pipeline state was created with both the \texttt{VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT} and \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} dynamic states enabled then both \texttt{vkCmdSetViewportWithCount} and \texttt{vkCmdSetScissorWithCount} must have been called in the current command buffer prior to this drawing command, and the \texttt{viewportCount} parameter of \texttt{vkCmdSetViewportWithCount} must match the \texttt{scissorCount} parameter of \texttt{vkCmdSetScissorWithCount}

- VUID-vkCmdDraw-None-08635
  If a shader object is bound to any graphics stage, then both \texttt{vkCmdSetViewportWithCount} and \texttt{vkCmdSetScissorWithCount} must have been called in the current command buffer prior to this drawing command, and the \texttt{viewportCount} parameter of \texttt{vkCmdSetViewportWithCount} must match the \texttt{scissorCount} parameter of \texttt{vkCmdSetScissorWithCount}

- VUID-vkCmdDraw-viewportCount-04137
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} dynamic state enabled, but not the \texttt{VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV} dynamic state enabled, then the bound graphics pipeline must have been created with \texttt{VkPipelineViewportWScalingStateCreateInfoNV ::viewportCount} greater or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- VUID-vkCmdDraw-viewportCount-04138
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} and \texttt{VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV} dynamic states enabled then the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWScalingNV} must be greater than or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- VUID-vkCmdDraw-None-09232
  If a shader object is bound to any graphics stage, and the \texttt{VK_NV_clip_space_w_scaling} extension is enabled on the device, then \texttt{vkCmdSetViewportWScalingNV} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDraw-None-08636
  If a shader object is bound to any graphics stage, and the \texttt{VK_NV_clip_space_w_scaling} extension is enabled on the device, then the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWScalingNV} must be greater than or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- VUID-vkCmdDraw-viewportCount-04139
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} dynamic state enabled, but not the \texttt{VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV} dynamic state enabled, then the bound graphics pipeline must have been created with \texttt{VkPipelineViewportShadingRateImageStateCreateInfoNV ::viewportCount} greater or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- VUID-vkCmdDraw-viewportCount-04140
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDraw-shadingRateImage-09233**
  If the `shadingRateImage` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoarseSampleOrderNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDraw-shadingRateImage-09234**
  If a shader object is bound to any graphics stage, and the `shadingRateImage` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetShadingRateImageEnableNV` in the current command buffer set `shadingRateImageEnable` to `VK_TRUE`, then `vkCmdSetViewportShadingRatePaletteNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDraw-None-08637**
  If a shader object is bound to any graphics stage, and the `shadingRateImage` feature is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDraw-VkPipelineViewportCreateInfo-04141**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportSwizzleStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDraw-VkPipelineViewportCreateInfo-04142**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportExclusiveScissorStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline must have been created with `VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDraw-None-07878**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV` dynamic state enabled then `vkCmdSetExclusiveScissorEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDraw-None-07879**
  If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV dynamic state enabled then
vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDraw-exclusiveScissor-09235
  If a shader object is bound to any graphics stage, and the exclusiveScissor feature is
  enabled, then vkCmdSetExclusiveScissorEnableNV must have been called in the current
  command buffer prior to this drawing command

• VUID-vkCmdDraw-None-08638
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetExclusiveScissorEnableNV in the current command buffer set any element of
  pExclusiveScissorEnables to VK_TRUE, then vkCmdSetExclusiveScissorNV must have been
  called in the current command buffer prior to this drawing command

• VUID-vkCmdDraw-None-04876
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE dynamic state enabled then
  vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDraw-None-08639
  If a shader object is bound to any graphics stage, then vkCmdSetRasterizerDiscardEnable
  must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDraw-None-04877
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE dynamic state enabled then
  vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDraw-None-08640
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDepthBiasEnable must have been
  called in the current command buffer prior to this drawing command

• VUID-vkCmdDraw-logicOp-04878
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_EXT
  dynamic state enabled then vkCmdSetLogicOpEXT must have been called in the current
  command buffer prior to this drawing command and the logicOp must be a valid
  VkLogicOp value

• VUID-vkCmdDraw-logicOp-04879
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the logicOp
  feature is enabled on the device, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEXT must have been called in
  the current command buffer prior to this drawing command and the logicOp must be a valid
  VkLogicOp value

• VUID-vkCmdDraw-primitiveFragmentShadingRateWithMultipleViewports-04552
  If the primitiveFragmentShadingRateWithMultipleViewports limit is not supported, the
bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must be 1.

- **VUID-vkCmdDraw-primitiveFragmentShadingRateWithMultipleViewports-08642**
  If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, and any shader object bound to a graphics stage writes to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must be 1.

- **VUID-vkCmdDraw-blendEnable-04727**
  If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view's format features do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the `blendEnable` member of the corresponding element of the `pAttachments` member of `pColorBlendState` must be `VK_FALSE`.

- **VUID-vkCmdDraw-None-08643**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then for each color attachment in the render pass, if the corresponding image view’s format features do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the corresponding member of `pColorBlendEnables` in the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer that affected that attachment index must have been `VK_FALSE`.

- **VUID-vkCmdDraw-multisampledRenderToSingleSampled-07284**
  If rasterization is not disabled in the bound graphics pipeline, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then `rasterizationSamples` for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdDraw-None-08644**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then the most recent call to `vkCmdSetRasterizationSamplesEXT` in the current command buffer must have set `rasterizationSamples` to be the same as the number of samples for the current render pass color and/or depth/stencil attachments.

- **VUID-vkCmdDraw-None-08876**
  If a shader object is bound to any graphics stage, the current render pass instance must have been begun with `vkCmdBeginRendering`.

- **VUID-vkCmdDraw-imageView-06172**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView`
member of \( p\text{DepthAttachment} \) is not `VK_NULL_HANDLE`, and the `layout` member of \( p\text{DepthAttachment} \) is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the depth attachment

- **VUID-vkCmdDraw-imageView-06173**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of \( p\text{StencilAttachment} \) is not `VK_NULL_HANDLE`, and the `layout` member of \( p\text{StencilAttachment} \) is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the stencil attachment

- **VUID-vkCmdDraw-imageView-06174**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of \( p\text{DepthAttachment} \) is not `VK_NULL_HANDLE`, and the `layout` member of \( p\text{DepthAttachment} \) is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, this command **must** not write any values to the depth attachment

- **VUID-vkCmdDraw-imageView-06175**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of \( p\text{StencilAttachment} \) is not `VK_NULL_HANDLE`, and the `layout` member of \( p\text{StencilAttachment} \) is `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the stencil attachment

- **VUID-vkCmdDraw-imageView-06176**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of \( p\text{DepthAttachment} \) is not `VK_NULL_HANDLE`, and the `layout` member of \( p\text{DepthAttachment} \) is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, this command **must** not write any values to the depth attachment

- **VUID-vkCmdDraw-imageView-06177**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of \( p\text{StencilAttachment} \) is not `VK_NULL_HANDLE`, and the `layout` member of \( p\text{StencilAttachment} \) is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the stencil attachment

- **VUID-vkCmdDraw-viewMask-06178**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline **must** have been created with a `VkPipelineRenderingCreateInfo` ::`viewMask` equal to `VkRenderingInfo` ::`viewMask`

- **VUID-vkCmdDraw-colorAttachmentCount-06179**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline **must** have been created with a `VkPipelineRenderingCreateInfo` ::`colorAttachmentCount` equal to `VkRenderingInfo` ::`colorAttachmentCount`

- **VUID-vkCmdDraw-dynamicRenderingUnusedAttachments-08910**
  If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo` ::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo` ::`pColorAttachments` array with an `imageView` not equal to `VK_NULL_HANDLE` **must** have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo` ::`pColorAttachmentFormats` used to create the currently bound graphics pipeline
If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline, or the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`.

If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` must have the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then the `attachmentCount` parameter of `vkCmdSetColorWriteEnableEXT` must be greater than or equal to the `VkPipelineColorBlendStateCreateInfo::attachmentCount` of the currently bound graphics pipeline.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEXT` must have been called in the current command buffer prior to this drawing command.
prior to this drawing command for each discard rectangle in
\texttt{VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount}

- **VUID-vkCmdDraw-None-07880**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT} dynamic state enabled then \texttt{vkCmdSetDiscardRectangleEnableEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-rasterizerDiscardEnable-09236**
  If the \texttt{VK_EXT_discard_rectangles} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetDiscardRectangleEnableEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-08648**
  If the \texttt{VK_EXT_discard_rectangles} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetDiscardRectangleEnableEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-07881**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT} dynamic state enabled then \texttt{vkCmdSetDiscardRectangleModeEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-08649**
  If the \texttt{VK_EXT_discard_rectangles} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, and the most recent call to \texttt{vkCmdSetDiscardRectangleEnableEXT} in the current command buffer set \texttt{discardRectangleEnable} to \texttt{VK_TRUE}, then \texttt{vkCmdSetDiscardRectangleModeEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-dynamicRenderingUnusedAttachments-08913**
  If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{dynamicRenderingUnusedAttachments} feature is not enabled, and \texttt{VkRenderingInfo::pDepthAttachment->imageView} was \texttt{VK_NULL_HANDLE}, the value of \texttt{VkPipelineRenderingCreateInfo::depthAttachmentFormat} used to create the currently bound graphics pipeline must be equal to \texttt{VK_FORMAT_UNDEFINED}

- **VUID-vkCmdDraw-dynamicRenderingUnusedAttachments-08914**
  If current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{dynamicRenderingUnusedAttachments} feature is not enabled, and \texttt{VkRenderingInfo::pDepthAttachment->imageView} was not \texttt{VK_NULL_HANDLE}, the value of \texttt{VkPipelineRenderingCreateInfo::depthAttachmentFormat} used to create the currently bound graphics pipeline must be equal to the \texttt{VkFormat} used to create \texttt{VkRenderingInfo::pDepthAttachment->imageView}

- **VUID-vkCmdDraw-dynamicRenderingUnusedAttachments-08915**
If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo::pDepthAttachment->imageView`, the value of the format must be `VK_FORMAT_UNDEFINED`.  

- `VUID-vkCmdDraw-dynamicRenderingUnusedAttachments-08916`
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to `VK_FORMAT_UNDEFINED`.  

- `VUID-vkCmdDraw-dynamicRenderingUnusedAttachments-08917`
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to the `VkFormat` used to create `VkRenderingInfo::pStencilAttachment->imageView`.  

- `VUID-vkCmdDraw-dynamicRenderingUnusedAttachments-08918`
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo::pStencilAttachment->imageView`, the value of the format must be `VK_FORMAT_UNDEFINED`.  

- `VUID-vkCmdDraw-imageView-06183`
  If the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView` was not `VK_NULL_HANDLE`, the currently bound graphics pipeline must have been created with `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`.  

- `VUID-vkCmdDraw-imageView-06184`
  If the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView` was not `VK_NULL_HANDLE`, the currently bound graphics pipeline must have been created with `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT`.  

- `VUID-vkCmdDraw-colorAttachmentCount-06185`
  If the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the corresponding element of the `pColorAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline.
If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

If the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the value of `rasterizationSamples` for the currently bound graphics pipeline.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

If this command has been called inside a render pass instance started with `vkCmdBeginRendering`, and the `pNext` chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the value of
rasterizationSamples for the currently bound graphics pipeline must be equal to VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples

- **VUID-vkCmdDraw-renderPass-06198**
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline must have been created with a VkGraphicsPipelineCreateInfo::renderPass equal to VK_NULL_HANDLE

- **VUID-vkCmdDraw-pColorAttachments-08963**
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the VkRenderingInfo::pColorAttachments->imageView was not VK_NULL_HANDLE, then the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the pipeline must not be VK_FORMAT_UNDEFINED

- **VUID-vkCmdDraw-pDepthAttachment-08964**
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, then the VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the pipeline must not be VK_FORMAT_UNDEFINED

- **VUID-vkCmdDraw-pStencilAttachment-08965**
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound, stencil test is enabled and the VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, then the VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the pipeline must not be VK_FORMAT_UNDEFINED

- **VUID-vkCmdDraw-primitivesGeneratedQueryWithRasterizerDiscard-06708**
  If the primitivesGeneratedQueryWithRasterizerDiscard feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, rasterization discard must not be enabled

- **VUID-vkCmdDraw-primitivesGeneratedQueryWithNonZeroStreams-06709**
  If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, the bound graphics pipeline must not have been created with a non-zero value in VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream

- **VUID-vkCmdDraw-None-07619**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT dynamic state enabled then vkCmdSetTessellationDomainOriginEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-07620**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT dynamic state enabled then vkCmdSetDepthClampEnableEXT must have been called in the current command buffer prior to this drawing command
If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command.

If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` dynamic state enabled then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` dynamic state enabled then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled, and alphaToCoverageEnable was VK_TRUE in the last call to vkCmdSetAlphaToCoverageEnableEXT, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0

- **VUID-vkCmdDraw-None-08654**
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-alphaToCoverageEnable-08920**
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetAlphaToCoverageEnableEXT in the current command buffer set alphaToCoverageEnable to VK_TRUE, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0

- **VUID-vkCmdDraw-None-07625**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT dynamic state enabled then vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-08655**
  If the alphaToOne feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-07626**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT dynamic state enabled then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-08656**
  If the logicOp feature is enabled, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-07627**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-08657**
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorBlendEnableEXT must have
been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-07628**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-08658**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` for any attachment set that attachment's value in `pColorBlendEnables` to `VK_TRUE`, then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-07629**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-08659**
  If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-07630**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` dynamic state enabled then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-08660**
  If the `geometryStreams` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_GEOMETRY_BIT` stage, then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-07631**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-08661**
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDraw-None-07632**
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDraw-None-08662**
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetConservativeRasterizationModeEXT` in the current command buffer set `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`, then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDraw-None-07633**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDraw-None-08663**
  If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDraw-None-07634**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDraw-None-08664**
  If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDraw-None-07635**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDraw-None-07636**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT` dynamic state enabled then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDraw-None-08665**
  If the `VK_EXT_provoking_vertex` extension is enabled, and a shader object is bound to the
VK_SHADER_STAGE_VERTEX_BIT stage, then \textit{vkCmdSetProvokingVertexModeEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDraw-None-07637
  If the bound graphics pipeline state was created with the \textit{VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT} dynamic state enabled then \textit{vkCmdSetLineRasterizationModeEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDraw-None-08666
  If the \textit{VK_EXT_line_rasterization} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \textit{vkCmdSetPolygonModeEXT} in the current command buffer set \textit{polygonMode} to \textit{VK_POLYGON_MODE_LINE}, then \textit{vkCmdSetLineRasterizationModeEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDraw-None-08667
  If the \textit{VK_EXT_line_rasterization} extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to \textit{vkCmdSetPrimitiveTopology} in the current command buffer set \textit{primitiveTopology} to any line topology, then \textit{vkCmdSetLineRasterizationModeEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDraw-None-08668
  If the \textit{VK_EXT_line_rasterization} extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then \textit{vkCmdSetLineRasterizationModeEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDraw-None-07638
  If the bound graphics pipeline state was created with the \textit{VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT} dynamic state enabled then \textit{vkCmdSetLineStippleEnableEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDraw-None-08669
  If the \textit{VK_EXT_line_rasterization} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \textit{vkCmdSetPolygonModeEXT} in the current command buffer set \textit{polygonMode} to \textit{VK_POLYGON_MODE_LINE}, then \textit{vkCmdSetLineStippleEnableEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDraw-None-08670
  If the \textit{VK_EXT_line_rasterization} extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to \textit{vkCmdSetPrimitiveTopology} in the current command buffer set \textit{primitiveTopology} to any line topology, then \textit{vkCmdSetLineStippleEnableEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDraw-None-08671
  If the \textit{VK_EXT_line_rasterization} extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then \textit{vkCmdSetLineStippleEnableEXT} must have been called in the current command buffer...
prior to this drawing command

• VUID-vkCmdDraw-None-07849
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_LINE_STIPPLE_EXT dynamic state enabled then vkCmdSetLineStippleEXT
must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDraw-None-08672
If the VK_EXT_line_rasterization extension is enabled, and a shader object is bound to any
graphics stage, and the most recent call to vkCmdSetLineStippleEnableEXT in the current
command buffer set stippledLineEnable to VK_TRUE, then vkCmdSetLineStippleEXT must
have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDraw-None-07639
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT dynamic state enabled then
vkCmdSetDepthClipNegativeOneToOneEXT must have been called in the current
command buffer prior to this drawing command

• VUID-vkCmdDraw-None-08673
If the depthClipControl feature is enabled, and a shader object is bound to any graphics
stage, then vkCmdSetDepthClipNegativeOneToOneEXT must have been called in the
current command buffer prior to this drawing command

• VUID-vkCmdDraw-None-07640
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV dynamic state enabled then
vkCmdSetViewportWScalingEnableNV must have been called in the current command
buffer prior to this drawing command

• VUID-vkCmdDraw-None-08674
If the VK_NV_clip_space_w_scaling extension is enabled, and a shader object is bound to
any graphics stage, then vkCmdSetViewportWScalingEnableNV must have been called in the
current command buffer prior to this drawing command

• VUID-vkCmdDraw-None-07641
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic state enabled then
vkCmdSetViewportSwizzleNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDraw-None-08675
If the VK_NV_viewport_swizzle extension is enabled, and a shader object is bound to any
graphics stage, then vkCmdSetViewportSwizzleNV must have been called in the current
command buffer prior to this drawing command

• VUID-vkCmdDraw-None-07642
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV dynamic state enabled then
vkCmdSetCoverageToColorEnableNV must have been called in the current command
buffer prior to this drawing command

• VUID-vkCmdDraw-None-08676
If the VK_NV_fragment_coverage_to_color extension is enabled, and a shader object is
bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDraw-None-07643**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` dynamic state enabled then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDraw-None-08677**
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set `coverageToColorEnable` to `VK_TRUE`, then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDraw-None-07644**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDraw-None-08678**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDraw-None-07645**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDraw-None-08679**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationModeNV` in the current command buffer set `coverageModulationMode` to any value other than `VK_COVERAGE_MODULATION_MODE_NONE_NV`, then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDraw-None-07646**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDraw-None-08680**

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If the \texttt{VK_NV_framebuffer_mixed_samples} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, and the most recent call to \texttt{vkCmdSetCoverageModulationTableEnableNV} in the current command buffer set \texttt{coverageModulationTableEnable} to \texttt{VK_TRUE}, then \texttt{vkCmdSetCoverageModulationTableNV} must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDraw-None-07647
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV} dynamic state enabled then \texttt{vkCmdSetShadingRateImageEnableNV} must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDraw-pipelineFragmentShadingRate-09238
  If the \texttt{pipelineFragmentShadingRate} feature is enabled, and a shader object is bound to the \texttt{VK_SHADER_STAGE_FRAGMENT_BIT} stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetFragmentShadingRateKHR} must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDraw-None-08681
  If the \texttt{shadingRateImage} feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetShadingRateImageEnableNV} must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDraw-None-07648
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV} dynamic state enabled then \texttt{vkCmdSetRepresentativeFragmentTestEnableNV} must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDraw-None-08682
  If the \texttt{representativeFragmentTest} feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetRepresentativeFragmentTestEnableNV} must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDraw-None-07649
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV} dynamic state enabled then \texttt{vkCmdSetCoverageReductionModeNV} must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDraw-None-08683
  If the \texttt{coverageReductionMode} feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetCoverageReductionModeNV} must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT state enabled and the last call to 
vkCmdSetColorBlendEnableEXT set pColorBlendEnables for any attachment to VK_TRUE, 
then for those attachments in the subpass the corresponding image view's format features 
**must** contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT

If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, and the current subpass does 
do not use any color and/or depth/stencil attachments, then the rasterizationSamples in the 
last call to vkCmdSetRasterizationSamplesEXT **must** follow the rules for a zero-attachment subpass

If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_SAMPLE_MASK_EXT state enabled and the 
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state disabled, then the samples parameter in 
the last call to vkCmdSetSampleMaskEXT **must** be greater or equal to the 
VkPipelineMultisampleStateCreateInfo::rasterizationSamples parameter used to create 
the bound graphics pipeline

If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_SAMPLE_MASK_EXT state and 
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT states enabled, then the samples parameter in the last call to 
vkCmdSetSampleMaskEXT **must** be greater or equal to the rasterizationSamples parameter in the last call to 
vkCmdSetRasterizationSamplesEXT

If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, and neither the 
VK_AMD_mixed_attachment_samples nor the VK_NV_framebuffer_mixed_samples extensions are 
enabled, then the rasterizationSamples in the last call to 
vkCmdSetRasterizationSamplesEXT **must** be the same as the current subpass color and/or 
depth/stencil attachments

If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, or a shader object is bound to 
any graphics stage, and the current render pass instance includes a 
VkMultisampledRenderToSingleSampledInfoEXT structure with 
multisampledRenderToSingleSampledEnable equal to VK_TRUE, then the rasterizationSamples 
in the last call to vkCmdSetRasterizationSamplesEXT **must** be the same as the 
rasterizationSamples member of that structure

If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then 
vkCmdSetColorBlendEnableEXT **must** have been called in the current command buffer 
prior to this drawing command, and the attachments specified by the firstAttachment and
attachmentCount parameters of vkCmdSetColorBlendEnableEXT calls must specify an enable for all active color attachments in the current subpass

- VUID-vkCmdDraw-firstAttachment-07477
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT dynamic state enabled then vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendEquationEXT calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled

- VUID-vkCmdDraw-firstAttachment-07478
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT dynamic state enabled then vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorWriteMaskEXT calls must specify the color write mask for all active color attachments in the current subpass

- VUID-vkCmdDraw-firstAttachment-07479
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT dynamic state enabled then vkCmdSetColorBlendAdvancedEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendAdvancedEXT calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled

- VUID-vkCmdDraw-advancedBlendMaxColorAttachments-07480
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT and VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic states enabled and the last calls to vkCmdSetColorBlendEnableEXT and vkCmdSetColorBlendAdvancedEXT have enabled advanced blending, then the number of active color attachments in the current subpass must not exceed advancedBlendMaxColorAttachments

- VUID-vkCmdDraw-primitivesGeneratedQueryWithNonZeroStreams-07481
  If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, and the bound graphics pipeline was created with VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT state enabled, the last call to vkCmdSetRasterizationStreamEXT must have set the rasterizationStream to zero

- VUID-vkCmdDraw-sampleLocationsPerPixel-07482
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state disabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples member of the VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` parameter of the last call to `vkCmdSetRasterizationSamplesEXT`.

If the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, then the `sampleLocationsInfo.sampleLocationGridSize.width` in the last call to `vkCmdSetSampleLocationsEXT` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.width` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling `rasterizationSamples`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE.Ext` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.width` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.width` as returned by...
vkGetPhysicalDeviceMultisamplePropertiesEXT with a `samples` parameter equaling the value of `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`

- **VID-vkCmdDraw-sampleLocationsEnable-07937**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.height` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.height` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling the value of `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`

- **VID-vkCmdDraw-sampleLocationsEnable-07938**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationsPerPixel` must equal `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`

- **VID-vkCmdDraw-coverageModulationTableEnable-07488**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageModulationTableEnableNV` set `coverageModulationTableEnable` to `VK_TRUE`, then the `coverageModulationTableCount` parameter in the last call to `vkCmdSetCoverageModulationTableNV` must equal the current `rasterizationSamples` divided by the number of color samples in the current subpass

- **VID-vkCmdDraw-rasterizationSamples-07489**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current `rasterizationSamples` must be the same as the sample count of the depth/stencil attachment

- **VID-vkCmdDraw-coverageToColorEnable-07490**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageToColorEnableNV` set the `coverageToColorEnable` to `VK_TRUE`, then the current subpass must have a color attachment at the location selected by the last call to `vkCmdSetCoverageToColorLocationNV`, with a `VkFormat` of `VK_FORMAT_R8_UINT`, `VK_FORMAT_R8_SINT`, `VK_FORMAT_R16_UINT`, `VK_FORMAT_R16_SINT`, `VK_FORMAT_R32_UINT`, or `VK_FORMAT_R32_SINT`

- **VID-vkCmdDraw-coverageReductionMode-07491**
  If this `VK_NV_coverage_reduction_mode` extension is enabled, the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, the current coverage reduction mode `coverageReductionMode`, then the current `rasterizationSamples`, and the
sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by `vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV`.

- **VUID-vkCmdDraw-viewportCount-07492**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDraw-viewportCount-07493**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportSwizzleNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDraw-rasterizationSamples-07494**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if the current subpass has any color attachments and `rasterizationSamples` of the last call to `vkCmdSetRasterizationSamplesEXT` is greater than the number of color samples, then the pipeline `sampleShadingEnable` must be `VK_FALSE`.

- **VUID-vkCmdDraw-stippledLineEnable-07495**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT`, then the `stippledRectangularLines` feature must be enabled.

- **VUID-vkCmdDraw-stippledLineEnable-07496**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT`, then the `stippledBresenhamLines` feature must be enabled.

- **VUID-vkCmdDraw-stippledLineEnable-07497**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT`, then the `stippledSmoothLines` feature must be enabled.

- **VUID-vkCmdDraw-stippledLineEnable-07498**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or
If the current bound pipeline was created with the `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` dynamic state enabled, `vkCmdSetAttachmentFeedbackLoopEnableEXT` must have been called in the current command buffer prior to this drawing command.

If dynamic state was inherited from `VkCommandBufferInheritanceViewportScissorInfoNV`, it must be set in the current command buffer prior to this drawing command.

If there is no bound graphics pipeline, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_VERTEX_BIT`.

If there is no bound graphics pipeline, and the `tessellationShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`.

If there is no bound graphics pipeline, and the `tessellationShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`.

If there is no bound graphics pipeline, and the `geometryShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_GEOMETRY_BIT`.

If there is no bound graphics pipeline, `vkCmdBindShadersEXT` must have been called in the
current command buffer with \texttt{pStages} with an element of \texttt{VK_SHADER_STAGE_FRAGMENT_BIT}

- VUID-vkCmdDraw-None-08689
  If there is no bound graphics pipeline, and the \texttt{taskShader} feature is enabled, \texttt{vkCmdBindShaderEXT} \textbf{must} have been called in the current command buffer with \texttt{pStages} with an element of \texttt{VK_SHADER_STAGE_TASK_BIT_EXT}

- VUID-vkCmdDraw-None-08690
  If there is no bound graphics pipeline, and the \texttt{meshShader} feature is enabled, \texttt{vkCmdBindShaderEXT} \textbf{must} have been called in the current command buffer with \texttt{pStages} with an element of \texttt{VK_SHADER_STAGE_MESH_BIT_EXT}

- VUID-vkCmdDraw-None-08693
  If there is no bound graphics pipeline, and at least one of the \texttt{taskShader} and \texttt{meshShader} features is enabled, one of the \texttt{VK_SHADER_STAGE_VERTEX_BIT} or \texttt{VK_SHADER_STAGE_MESH_BIT_EXT} stages \textbf{must} have a valid \texttt{VkShaderEXT} bound, and the other \textbf{must} have no \texttt{VkShaderEXT} bound

- VUID-vkCmdDraw-None-08694
  If there is no bound graphics pipeline, and both the \texttt{taskShader} and \texttt{meshShader} features are enabled, and a valid \texttt{VkShaderEXT} is bound to the \texttt{VK_SHADER_STAGE_MESH_BIT_EXT} stage, and that \texttt{VkShaderEXT} was created without the \texttt{VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT} flag, a valid \texttt{VkShaderEXT} \textbf{must} be bound to the \texttt{VK_SHADER_STAGE_TASK_BIT_EXT} stage

- VUID-vkCmdDraw-None-08695
  If there is no bound graphics pipeline, and both the \texttt{taskShader} and \texttt{meshShader} features are enabled, and a valid \texttt{VkShaderEXT} is bound to the \texttt{VK_SHADER_STAGE_MESH_BIT_EXT} stage, and that \texttt{VkShaderEXT} was created with the \texttt{VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT} flag, there \textbf{must} be no \texttt{VkShaderEXT} bound to the \texttt{VK_SHADER_STAGE_TASK_BIT_EXT} stage

- VUID-vkCmdDraw-None-08696
  If there is no bound graphics pipeline, and a valid \texttt{VkShaderEXT} is bound to the \texttt{VK_SHADER_STAGE_VERTEX_BIT} stage, there \textbf{must} be no \texttt{VkShaderEXT} bound to either the \texttt{VK_SHADER_STAGE_TASK_BIT_EXT} stage or the \texttt{VK_SHADER_STAGE_MESH_BIT_EXT} stage

- VUID-vkCmdDraw-None-08698
  If any graphics shader is bound which was created with the \texttt{VK_SHADER_CREATE_LINK_STAGE_BIT_EXT} flag, then all shaders created with the \texttt{VK_SHADER_CREATE_LINK_STAGE_BIT_EXT} flag in the same \texttt{vkCreateShadersEXT} call \textbf{must} also be bound

- VUID-vkCmdDraw-None-08699
  If any graphics shader is bound which was created with the \texttt{VK_SHADER_CREATE_LINK_STAGE_BIT_EXT} flag, any stages in between stages whose shaders which did not create a shader with the \texttt{VK_SHADER_CREATE_LINK_STAGE_BIT_EXT} flag as part of the same \texttt{vkCreateShadersEXT} call \textbf{must} not have any \texttt{VkShaderEXT} bound

- VUID-vkCmdDraw-None-08878
  All bound graphics shader objects \textbf{must} have been created with identical or identically defined push constant ranges

- VUID-vkCmdDraw-None-08879
  All bound graphics shader objects \textbf{must} have been created with identical or identically
defined arrays of descriptor set layouts

- VUID-vkCmdDraw-None-08880
  If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage and the `attachmentFeedbackLoopDynamicState` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE` `vkCmdSetAttachmentFeedbackLoopEnableEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDraw-pDynamicStates-08715
  If the bound graphics pipeline state includes a fragment shader stage, was created with `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`, and the fragment shader declares the `EarlyFragmentTests` execution mode and uses `OpDepthAttachmentReadEXT`, the `depthWriteEnable` parameter in the last call to `vkCmdSetDepthWriteEnable` must be `VK_FALSE`.

- VUID-vkCmdDraw-pDynamicStates-08716
  If the bound graphics pipeline state includes a fragment shader stage, was created with `VK_DYNAMIC_STATE_STENCIL_WRITE_MASK` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`, and the fragment shader declares the `EarlyFragmentTests` execution mode and uses `OpStencilAttachmentReadEXT`, the `writeMask` parameter in the last call to `vkCmdSetStencilWriteMask` must be `0`.

- VUID-vkCmdDraw-None-09116
  If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT`, and the format of any color attachment is `VK_FORMAT_E5B9G9R9_UFLOAT_PACK32`, the corresponding element of the `pColorWriteMasks` parameter of `vkCmdSetColorWriteMaskEXT` must either include all of `VK_COLOR_COMPONENT_R_BIT`, `VK_COLOR_COMPONENT_G_BIT`, and `VK_COLOR_COMPONENT_B_BIT`, or none of them.

- VUID-vkCmdDraw-maxFragmentDualSrcAttachments-09239
  If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of `Location` for any output attachment statically used in the Fragment Execution Model executed by this command must be less than `maxFragmentDualSrcAttachments`.

- VUID-vkCmdDraw-commandBuffer-02712
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, any resource written to by the `VkPipeline` object bound to the pipeline bind point used by this command must not be an unprotected resource.

- VUID-vkCmdDraw-commandBuffer-02713
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, pipeline stages other than the framebuffer-space and compute stages in the `VkPipeline` object bound to the pipeline bind point used by this command must not write to any resource.

- VUID-vkCmdDraw-commandBuffer-04617
  If any of the shader stages of the `VkPipeline` bound to the pipeline bind point used by this command uses the `RayQueryKHR` capability, then `commandBuffer` must not be a protected command buffer.
All vertex input bindings accessed via vertex input variables declared in the vertex shader entry point’s interface must have either valid or VK_NULL_HANDLE buffers bound.

If the nullDescriptor feature is not enabled, all vertex input bindings accessed via vertex input variables declared in the vertex shader entry point’s interface must not be VK_NULL_HANDLE.

For a given vertex buffer binding, any attribute data fetched must be entirely contained within the corresponding vertex buffer binding, as described in Vertex Input Description.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled then vkCmdSetPrimitiveTopology must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled and the dynamicPrimitiveTopologyUnrestricted is VK_FALSE, then the primitiveTopology parameter of vkCmdSetPrimitiveTopology must be of the same topology class as the pipeline VkPipelineInputAssemblyStateCreateInfo::topology state.

If the bound graphics pipeline was created with both the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT and VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT dynamic states enabled, then vkCmdSetVertexInputEXT must have been called in the current command buffer prior to this draw command.

If the bound graphics pipeline was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT dynamic state enabled, but not the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, then vkCmdBindVertexBuffers2EXT must have been called in the current command buffer prior to this draw command, and the pStrides parameter of vkCmdBindVertexBuffers2EXT must not be NULL.

If a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, then vkCmdSetPrimitiveTopology must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, then vkCmdSetVertexInputEXT must have been called in the current command buffer prior to this draw command.

If the bound graphics pipeline state was created with the...
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then all variables with the `Input` storage class decorated with `Location` in the `Vertex Execution Model OpEntryPoint` must contain a location in `VkVertexInputAttributeDescription2EXT::location`.

- **VUID-vkCmdDraw-Input-08734**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then the numeric type associated with all `Input` variables of the corresponding `Location` in the `Vertex Execution Model OpEntryPoint` must be the same as `VkVertexInputAttributeDescription2EXT::format`.

- **VUID-vkCmdDraw-format-08936**
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and `VkVertexInputAttributeDescription2EXT::format` has a 64-bit component, then the scalar width associated with all `Input` variables of the corresponding `Location` in the `Vertex Execution Model OpEntryPoint` must be 64-bit.

- **VUID-vkCmdDraw-format-08937**
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and the scalar width associated with a `Location` decorated `Input` variable in the `Vertex Execution Model OpEntryPoint` is 64-bit, then the corresponding `VkVertexInputAttributeDescription2EXT::format` must have a 64-bit component.

- **VUID-vkCmdDraw-None-09203**
  If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetVertexInputEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDraw-None-08882**
  If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetPatchControlPointsEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDraw-None-04879**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE` dynamic state enabled then `vkCmdSetPrimitiveRestartEnable` must have been called in the current command buffer prior to this drawing command.
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, `vkCmdSetPrimitiveRestartEnable` must have been called in the current command buffer prior to this drawing command.

The bound graphics pipeline must not have been created with the `VkPipelineShaderStageCreateInfo::stage` member of an element of `VkGraphicsPipelineCreateInfo::pStages` set to `VK_SHADER_STAGE_TASK_BIT_EXT` or `VK_SHADER_STAGE_MESH_BIT_EXT`.

There must be no shader object bound to either of the `VK_SHADER_STAGE_TASK_BIT_EXT` or `VK_SHADER_STAGE_MESH_BIT_EXT` stages.

### Valid Usage (Implicit)

- **VUID-vkCmdDraw-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- **VUID-vkCmdDraw-commandBuffer-recording**
  `commandBuffer` must be in the recording state.

- **VUID-vkCmdDraw-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations.

- **VUID-vkCmdDraw-renderpass**
  This command must only be called inside of a render pass instance.

- **VUID-vkCmdDraw-videocoding**
  This command must only be called outside of a video coding scope.

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

### Command Properties

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To record an indexed draw, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdDrawIndexed(
    VkCommandBuffer commandBuffer,
    uint32_t indexCount,
    uint32_t instanceCount,
    uint32_t firstIndex,
    int32_t vertexOffset,
    uint32_t firstInstance);
```

• `commandBuffer` is the command buffer into which the command is recorded.
• `indexCount` is the number of vertices to draw.
• `instanceCount` is the number of instances to draw.
• `firstIndex` is the base index within the index buffer.
• `vertexOffset` is the value added to the vertex index before indexing into the vertex buffer.
• `firstInstance` is the instance ID of the first instance to draw.

When the command is executed, primitives are assembled using the current primitive topology and `indexCount` vertices whose indices are retrieved from the index buffer. The index buffer is treated as an array of tightly packed unsigned integers of size defined by the `vkCmdBindIndexBuffer2KHR::indexType` or the `vkCmdBindIndexBuffer::indexType` parameter with which the buffer was bound.

The first vertex index is at an offset of `firstIndex × indexSize + offset` within the bound index buffer, where `offset` is the offset specified by `vkCmdBindIndexBuffer` or `vkCmdBindIndexBuffer2KHR`, and `indexSize` is the byte size of the type specified by `indexType`. Subsequent index values are retrieved from consecutive locations in the index buffer. Indices are first compared to the primitive restart value, then zero extended to 32 bits (if the `indexType` is `VK_INDEX_TYPE_UINT8_EXT` or `VK_INDEX_TYPE_UINT16`) and have `vertexOffset` added to them, before being supplied as the `vertexIndex` value.

The primitives are drawn `instanceCount` times with `instanceIndex` starting with `firstInstance` and increasing sequentially for each instance. The assembled primitives execute the bound graphics pipeline.

### Valid Usage

- **VUID-vkCmdDrawIndexed-magFilter-04553**
  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- **VUID-vkCmdDrawIndexed-mipmapMode-04770**
  If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this
command, then the image view's format features must contain
VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- VUID-vkCmdDrawIndexed-None-06479
  If a VkImageView is sampled with depth comparison, the image view's format features must contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT

- VUID-vkCmdDrawIndexed-None-02691
  If a VkImageView is accessed using atomic operations as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

- VUID-vkCmdDrawIndexed-None-07888
  If a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

- VUID-vkCmdDrawIndexed-None-02692
  If a VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT

- VUID-vkCmdDrawIndexed-filterCubic-02694
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2

- VUID-vkCmdDrawIndexed-cubicRangeClamp-09212
  If the cubicRangeClamp feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must not have a VkSamplerReductionModeCreateInfo::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGE_CLAMP_QCOM

- VUID-vkCmdDrawIndexed-reductionMode-09213
  Any VkImageView being sampled with a VkSamplerReductionModeCreateInfo::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGE_CLAMP_QCOM as a result of this command must sample with VK_FILTER_CUBIC_EXT
• VUID-vkCmdDrawIndexed-selectableCubicWeights-09214
If the selectableCubicWeights feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights equal to VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM

• VUID-vkCmdDrawIndexed-flags-02696
Any VkImage created with a VkImageCreateInfo::flags containing VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV sampled as a result of this command must only be sampled using a VkSamplerAddressMode of VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE

• VUID-vkCmdDrawIndexed-OpTypeImage-07027
For any VkImageView being written as a storage image where the image format field of the OpTypeImage is Unknown, the view’s format features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

• VUID-vkCmdDrawIndexed-OpTypeImage-07028
For any VkImageView being read as a storage image where the image format field of the OpTypeImage is Unknown, the view’s format features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

• VUID-vkCmdDrawIndexed-OpTypeImage-07029
For any VkBufferView being written as a storage texel buffer where the image format field of the OpTypeImage is Unknown, the view’s buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

• VUID-vkCmdDrawIndexed-OpTypeImage-07030
Any VkBufferView being read as a storage texel buffer where the image format field of the OpTypeImage is Unknown then the view’s buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

• VUID-vkCmdDrawIndexed-None-08600
For each set n that is statically used by a bound shader, a descriptor set must have been bound to n at the same pipeline bind point, with a VkPipelineLayout that is compatible for set n, with the VkPipelineLayout or VkDescriptorSetLayout array that was used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

• VUID-vkCmdDrawIndexed-None-08601
For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

• VUID-vkCmdDrawIndexed-maintenance4-08602
If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

• VUID-vkCmdDrawIndexed-None-08114
Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, must be valid if they are statically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was not created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- **VUID-vkCmdDrawIndexed-None-08115**
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` must have been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- **VUID-vkCmdDrawIndexed-None-08116**
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- **VUID-vkCmdDrawIndexed-None-08604**
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command.

- **VUID-vkCmdDrawIndexed-None-08117**
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdSetDescriptorBufferOffsetsEXT`, the bound `VkPipeline` must have been created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- **VUID-vkCmdDrawIndexed-None-08605**
  If a descriptor is dynamically used with a `VkPipeline` created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory must be resident.

- **VUID-vkCmdDrawIndexed-None-08606**
  If the `shaderObject` feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command.

- **VUID-vkCmdDrawIndexed-None-08607**
  If the `shaderObject` is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and `VK_NULL_HANDLE` shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command.

- **VUID-vkCmdDrawIndexed-None-08608**
  If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the `VkPipeline` object bound to the pipeline bind point used by this command, since that pipeline was bound.

- **VUID-vkCmdDrawIndexed-None-08609**
If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler

**must** not be used to sample from any `VkImage` with a `VkImageView` of the type `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, `VK_IMAGE_VIEW_TYPE_1D_ARRAY`, `VK_IMAGE_VIEW_TYPE_2D_ARRAY` or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`, in any shader stage

- **VUID-vkCmdDrawIndexed-None-08610**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler
  **must** not be used with any of the SPIR-V `OpImageSample*` or `OpImageSparseSample*` instructions with `ImplicitLod`, `Dref` or `Proj` in their name, in any shader stage

- **VUID-vkCmdDrawIndexed-None-08611**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler
  **must** not be used with any of the SPIR-V `OpImageSample*` or `OpImageSparseSample*` instructions that includes a LOD bias or any offset values, in any shader stage

- **VUID-vkCmdDrawIndexed-uniformBuffers-06935**
  If any stage of the `VkPipeline` object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT` or `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT` for `uniformBuffers`, and the `robustBufferAccess` feature is not enabled, that stage **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawIndexed-None-08612**
  If the `robustBufferAccess` feature is not enabled, and any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawIndexed-storageBuffers-06936**
  If any stage of the `VkPipeline` object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT` or `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT` for `storageBuffers`, and the `robustBufferAccess` feature is not enabled, that stage **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawIndexed-None-08613**
  If the `robustBufferAccess` feature is not enabled, and any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawIndexed-commandBuffer-02707**
If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, any resource accessed by `bound shaders` must not be a protected resource.

- **VUID-vkCmdDrawIndexed-None-06550**
  If a `bound shader` accesses a `VkSampler` or `VkImageView` object that enables `sampler Y'CbCr conversion`, that object must only be used with `OpImageSample*` or `OpImageSparseSample*` instructions.

- **VUID-vkCmdDrawIndexed-ConstOffset-06551**
  If a `bound shader` accesses a `VkSampler` or `VkImageView` object that enables `sampler Y'CbCr conversion`, that object must not use the `ConstOffset` and `Offset` operands.

- **VUID-vkCmdDrawIndexed-viewType-07752**
  If a `VkImageView` is accessed as a result of this command, then the image view's `viewType` must match the `Dim` operand of the `OpTypeImage` as described in Instruction/Sampler/Image View Validation.

- **VUID-vkCmdDrawIndexed-format-07753**
  If a `VkImageView` is accessed as a result of this command, then the numeric type of the image view's `format` and the `Sampled Type` operand of the `OpTypeImage` must match.

- **VUID-vkCmdDrawIndexed-OpImageWrite-08795**
  If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have at least as many components as the image view's format.

- **VUID-vkCmdDrawIndexed-OpImageWrite-08796**
  If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have four components.

- **VUID-vkCmdDrawIndexed-OpImageWrite-04469**
  If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have at least as many components as the buffer view's format.

- **VUID-vkCmdDrawIndexed-SampledType-04470**
  If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64.

- **VUID-vkCmdDrawIndexed-SampledType-04471**
  If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 32.

- **VUID-vkCmdDrawIndexed-SampledType-04472**
  If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64.

- **VUID-vkCmdDrawIndexed-SampledType-04473**
  If a `VkBufferView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that
must have a Width of 32

- VUID-vkCmdDrawIndexed-sparseImageInt64Atomsics-04474
  If the sparseImageInt64Atomsics feature is not enabled, VkImage objects created with the VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- VUID-vkCmdDrawIndexed-sparseImageInt64Atomsics-04475
  If the sparseImageInt64Atomsics feature is not enabled, VkBuffer objects created with the VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- VUID-vkCmdDrawIndexed-OpImageWeightedSampleQCOM-06971
  If OpImageWeightedSampleQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM

- VUID-vkCmdDrawIndexed-OpImageWeightedSampleQCOM-06972
  If OpImageWeightedSampleQCOM uses a VkImageView as a sample weight image as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM

- VUID-vkCmdDrawIndexed-OpImageBoxFilterQCOM-06973
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM

- VUID-vkCmdDrawIndexed-OpImageBlockMatchSSDQCOM-06974
  If OpImageBlockMatchSSDQCOM is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdDrawIndexed-OpImageBlockMatchSADQCOM-06975
  If OpImageBlockMatchSADQCOM is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdDrawIndexed-OpImageBlockMatchSSDQCOM-06976
  If OpImageBlockMatchSSDQCOM or OpImageBlockMatchSADQCOM is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- VUID-vkCmdDrawIndexed-OpImageWeightedSampleQCOM-06977
  If OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this command, then the sampler must have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM

- VUID-vkCmdDrawIndexed-OpImageWeightedSampleQCOM-06978
  If any command other than OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this
command, then the sampler **must** not have been created with 
`VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`

- **VUID-vkCmdDrawIndexed-OpImageBlockMatchWindow-09215**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`

- **VUID-vkCmdDrawIndexed-OpImageBlockMatchWindow-09216**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format **must** be a single-component format.

- **VUID-vkCmdDrawIndexed-OpImageBlockMatchWindow-09217**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` read from a reference image as result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation

- **VUID-vkCmdDrawIndexed-None-07288**
  Any shader invocation executed by this command **must** terminate

- **VUID-vkCmdDrawIndexed-renderPass-02684**
  The current render pass **must** be compatible with the `renderPass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`

- **VUID-vkCmdDrawIndexed-subpass-02685**
  The subpass index of the current render pass **must** be equal to the `subpass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`

- **VUID-vkCmdDrawIndexed-None-07748**
  If any shader statically accesses an input attachment, a valid descriptor **must** be bound to the pipeline via a descriptor set

- **VUID-vkCmdDrawIndexed-OpTypeImage-07468**
  If any shader executed by this pipeline accesses an `OpTypeImage` variable with a `Dim` operand of `SubpassData`, it **must** be decorated with an `InputAttachmentIndex` that corresponds to a valid input attachment in the current subpass

- **VUID-vkCmdDrawIndexed-None-07469**
  Input attachment views accessed in a subpass **must** be created with the same `VkFormat` as the corresponding subpass definition, and be created with a `VkImageView` that is compatible with the attachment referenced by the subpass' `pInputAttachments[InputAttachmentIndex]` in the currently bound `VkFramebuffer` as specified by Fragment Input Attachment Compatibility

- **VUID-vkCmdDrawIndexed-None-06537**
  Memory backing image subresources used as attachments in the current render pass **must** not be written in any way other than as an attachment by this command

- **VUID-vkCmdDrawIndexed-None-09000**
  If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the
VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:

- the VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
- the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_COLOR_BIT and
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_Enable_EXT it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawIndexed-None-09001
  If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:

- the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
- the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_DEPTH_BIT and
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_Enable_EXT it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawIndexed-None-09002
  If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:

- the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
- the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_STENCIL_BIT and
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_Enable_EXT it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawIndexed-None-09003
  If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command

• VUID-vkCmdDrawIndexed-None-06539
  If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command must not write to that image subresource as an attachment
If the current render pass instance uses a depth/stencil attachment with a read-only
layout for the depth aspect, depth writes must be disabled.

If the current render pass instance uses a depth/stencil attachment with a read-only
layout for the stencil aspect, both front and back writeMask are not zero, and stencil test is
enabled, all stencil ops must be VK_STENCIL_OP_KEEP.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT
dynamic state enabled then vkCmdSetViewport must have been called in the current
command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SCISSOR
dynamic state enabled then vkCmdSetScissor must have been called in the current
command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_WIDTH
dynamic state enabled then vkCmdSetLineWidth must have been called in the current
command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetPolygonModeEXT in the current command buffer set polygonMode to
VK_POLYGON_MODE_LINE, vkCmdSetLineWidth must have been called in the current
command buffer prior to this drawing command.

If a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, and the most recent
call to vkCmdSetPrimitiveTopology in the current command buffer set primitiveTopology
to any line topology, vkCmdSetLineWidth must have been called in the current command
buffer prior to this drawing command.

If a shader object that outputs line primitives is bound to the
VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT stage,
vkCmdSetLineWidth must have been called in the current command buffer prior to this
drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BIAS
dynamic state enabled then vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have
been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to
vkCmdSetDepthBiasEnable in the current command buffer set depthBiasEnable to VK_TRUE,
vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current
command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-07835
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_BLEND_CONSTANTS` dynamic state enabled then `vkCmdSetBlendConstants` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08621
  If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer set any element of `pColorBlendEnables` to `VK_TRUE`, and the most recent call to `vkCmdSetColorBlendEquationEXT` in the current command buffer set the same element of `pColorBlendEquations` to a `VkColorBlendEquationEXT` structure with any `VkBlendFactor` member with a value of `VK_BLEND_FACTOR_CONSTANT_COLOR`, `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR`, `VK_BLEND_FACTOR_CONSTANT_ALPHA`, or `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA`, `vkCmdSetBlendConstants` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-07836
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS` dynamic state enabled then `vkCmdSetDepthBounds` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08622
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthBoundsTestEnable` in the current command buffer set `depthBoundsTestEnable` to `VK_TRUE`, then `vkCmdSetDepthBounds` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-07837
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK` dynamic state enabled then `vkCmdSetStencilCompareMask` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08623
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilCompareMask` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-07838
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_WRITE_MASK` dynamic state enabled then `vkCmdSetStencilWriteMask` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08624
  If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-07839
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_REFERENCE dynamic state enabled then vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08625
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-maxMultiviewInstanceIndex-02688
  If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex

- VUID-vkCmdDrawIndexed-None-06666
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT dynamic state enabled then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08626
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetSampleLocationsEnableEXT in the current command buffer set sampleLocationsEnable to VK_TRUE, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-sampleLocationsPerPixel-07934
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples member of the VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with

- VUID-vkCmdDrawIndexed-None-07840
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CULL_MODE dynamic state enabled then vkCmdSetCullMode must have been called in the current command buffer prior to this drawing command
• VUID-vkCmdDrawIndexed-None-08627
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexed-None-07841
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexed-None-08628
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexed-None-07843
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexed-None-08629
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexed-None-07844
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` dynamic state enabled then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexed-None-08630
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexed-None-07845
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP` dynamic state enabled then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexed-None-08631
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthTestEnable` in the current command buffer set `depthTestEnable` to `VK_TRUE`, then `vkCmdSetDepthCompareOp` must have been called in the current command buffer.
prior to this drawing command

• VUID-vkCmdDrawIndexed-None-07846
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE` dynamic state enabled then
  `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdDrawIndexed-None-08632
  If a shader object is bound to any graphics stage, and the `depthBounds` feature is enabled,
  and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command
  buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `vkCmdSetDepthBoundsTestEnable`
  must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexed-None-07847
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE` dynamic state enabled then
  `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior
  to this drawing command

• VUID-vkCmdDrawIndexed-None-08633
  If a shader object is bound to any graphics stage, and the most recent call to
  `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
  `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetStencilTestEnable` must have been
  called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexed-None-07848
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_OP`
  dynamic state enabled then `vkCmdSetStencilOp` must have been called in the current
  command buffer prior to this drawing command

• VUID-vkCmdDrawIndexed-None-08634
  If a shader object is bound to any graphics stage, and the most recent call to
  `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
  `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to
  `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to
  `VK_TRUE`, then `vkCmdSetStencilOp` must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdDrawIndexed-viewportCount-03417
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT`
  dynamic state enabled, but not the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, then
  `vkCmdSetViewportWithCount` must have been called in the current command buffer
  prior to this drawing command, and the `viewportCount` parameter of
  `vkCmdSetViewportWithCount` must match the `VkPipelineViewportStateCreateInfo`::`scissorCount`
  of the pipeline

• VUID-vkCmdDrawIndexed-scissorCount-03418
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT`
  dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, then
  `vkCmdSetScissorWithCount` must have been called in the current command buffer prior
to this drawing command, and the `scissorCount` parameter of `vkCmdSetScissorWithCount` must match the `VkPipelineViewportStateCreateInfo::viewportCount` of the pipeline.

- **VUID-vkCmdDrawIndexed-viewportCount-03419**
  If the bound graphics pipeline state was created with both the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic states enabled then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- **VUID-vkCmdDrawIndexed-None-08635**
  If a shader object is bound to any graphics stage, then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- **VUID-vkCmdDrawIndexed-viewportCount-04137**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportWScalingStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexed-viewportCount-04138**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexed-None-09232**
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then `vkCmdSetViewportWScalingNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexed-None-08636**
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexed-viewportCount-04139**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportShadingRateImageStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexed-viewportCount-04140**

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If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexed-shadingRateImage-09233**
  If the `shadingRateImage` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoarseSampleOrderNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexed-shadingRateImage-09234**
  If a shader object is bound to any graphics stage, and the `shadingRateImage` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetShadingRateImageEnableNV` in the current command buffer set `shadingRateImageEnable` to `VK_TRUE`, then `vkCmdSetViewportShadingRatePaletteNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexed-None-08637**
  If a shader object is bound to any graphics stage, and the `shadingRateImage` feature is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexed-VkPipelineViewportCreateInfo-04141**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportSwizzleStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexed-VkPipelineViewportCreateInfo-04142**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportExclusiveScissorStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline must have been created with `VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexed-None-07878**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV` dynamic state enabled then `vkCmdSetExclusiveScissorEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexed-None-07879**
  If the bound graphics pipeline state was created with the
If a shader object is bound to any graphics stage, and the `exclusiveScissor` feature is enabled, then `vkCmdSetExclusiveScissorEnableNV` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetExclusiveScissorEnableNV` in the current command buffer set any element of `pExclusiveScissorEnables` to `VK_TRUE`, then `vkCmdSetExclusiveScissorNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE` dynamic state enabled then `vkCmdSetRasterizerDiscardEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, then `vkCmdSetRasterizerDiscardEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE` dynamic state enabled then `vkCmdSetDepthBiasEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthBiasEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LOGIC_OP_EXT` dynamic state enabled then `vkCmdSetLogicOpEXT` must have been called in the current command buffer prior to this drawing command and the `logicOp` must be a valid `VkLogicOp` value.

If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the `logicOp` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEXT` must have been called in the current command buffer prior to this drawing command and the `logicOp` must be a valid `VkLogicOp` value.

If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, the
bound graphics pipeline was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the \texttt{PrimitiveShadingRateKHR} built-in, then \texttt{vkCmdSetViewportWithCount} must have been called in the current command buffer prior to this drawing command, and the \texttt{viewportCount} parameter of \texttt{vkCmdSetViewportWithCount} must be 1

- \textbf{VUID-vkCmdDrawIndexed-primitiveFragmentShadingRateWithMultipleViewports-08642}
  
  If the \texttt{primitiveFragmentShadingRateWithMultipleViewports} limit is not supported, and any shader object bound to a graphics stage writes to the \texttt{PrimitiveShadingRateKHR} built-in, then \texttt{vkCmdSetViewportWithCount} must have been called in the current command buffer prior to this drawing command, and the \texttt{viewportCount} parameter of \texttt{vkCmdSetViewportWithCount} must be 1

- \textbf{VUID-vkCmdDrawIndexed-blendEnable-04727}
  
  If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view’s \texttt{format features} do not contain \texttt{VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT}, then the \texttt{blendEnable} member of the corresponding element of the \texttt{pAttachments} member of \texttt{pColorBlendState} must be \texttt{VK_FALSE}

- \textbf{VUID-vkCmdDrawIndexed-None-08643}
  
  If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then for each color attachment in the render pass, if the corresponding image view’s \texttt{format features} do not contain \texttt{VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT}, then the corresponding member of \texttt{pColorBlendEnable} in the most recent call to \texttt{vkCmdSetColorBlendEnableEXT} in the current command buffer that affected that attachment index must have been \texttt{VK_FALSE}

- \textbf{VUID-vkCmdDrawIndexed-multisampledRenderToSingleSampled-07284}
  
  If rasterization is not disabled in the bound graphics pipeline, and none of the \texttt{VK_AMD_mixed_attachment_samples} extension, the \texttt{VK_NV_framebuffer_mixed_samples} extension, or the \texttt{multisampledRenderToSingleSampled} feature is enabled, then \texttt{rasterizationSamples} for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments

- \textbf{VUID-vkCmdDrawIndexed-None-08644}
  
  If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, and none of the \texttt{VK_AMD_mixed_attachment_samples} extension, the \texttt{VK_NV_framebuffer_mixed_samples} extension, or the \texttt{multisampledRenderToSingleSampled} feature is enabled, then the most recent call to \texttt{vkCmdSetRasterizationSamplesEXT} in the current command buffer must have set \texttt{rasterizationSamples} to be the same as the number of samples for the current render pass color and/or depth/stencil attachments

- \textbf{VUID-vkCmdDrawIndexed-None-08876}
  
  If a shader object is bound to any graphics stage, the current render pass instance must have been begun with \texttt{vkCmdBeginRendering}

- \textbf{VUID-vkCmdDrawIndexed-imageView-06172}
  
  If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{imageView}
member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the depth attachment

- VUID-vkCmdDrawIndexed-imageView-06173
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the stencil attachment

- VUID-vkCmdDrawIndexed-imageView-06174
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, this command **must** not write any values to the depth attachment

- VUID-vkCmdDrawIndexed-imageView-06175
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the stencil attachment

- VUID-vkCmdDrawIndexed-imageView-06176
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, this command **must** not write any values to the depth attachment

- VUID-vkCmdDrawIndexed-imageView-06177
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the stencil attachment

- VUID-vkCmdDrawIndexed-viewMask-06178
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline **must** have been created with a `VkPipelineRenderingCreateInfo`::`viewMask` equal to `VkRenderingInfo`::`viewMask`

- VUID-vkCmdDrawIndexed-colorAttachmentCount-06179
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline **must** have been created with a `VkPipelineRenderingCreateInfo`::`colorAttachmentCount` equal to `VkRenderingInfo`::`colorAttachmentCount`

- VUID-vkCmdDrawIndexed-dynamicRenderingUnusedAttachments-08910
  If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo`::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo`::`pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` **must** have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo`::`pColorAttachmentFormats` used to create the currently bound graphics pipeline
If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline, or the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`.

If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` must have the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEXT` must have been called in the current command buffer.

If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, the `attachmentCount` parameter of most recent call to `vkCmdSetColorWriteEnableEXT` in the current command buffer must be greater than or equal to the number of color attachments in the current render pass instance.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEXT` must have been called in the current command buffer.
prior to this drawing command for each discard rectangle in

\[ \text{VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount} \]

- **VID-vkCmdDrawIndexed-None-07880**
  If the bound graphics pipeline state was created with the \text{VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT} dynamic state enabled then \text{vkCmdSetDiscardRectangleEnableEXT} must have been called in the current command buffer prior to this drawing command

- **VID-vkCmdDrawIndexed-rasterizerDiscardEnable-09236**
  If the \text{VK_EXT_discard_rectangles} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \text{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \text{rasterizerDiscardEnable} to \text{VK_FALSE}, then \text{vkCmdSetDiscardRectangleEnableEXT} must have been called in the current command buffer prior to this drawing command

- **VID-vkCmdDrawIndexed-None-08648**
  If the \text{VK_EXT_discard_rectangles} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \text{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \text{rasterizerDiscardEnable} to \text{VK_FALSE}, then \text{vkCmdSetDiscardRectangleEnableEXT} must have been called in the current command buffer prior to this drawing command

- **VID-vkCmdDrawIndexed-None-07881**
  If the bound graphics pipeline state was created with the \text{VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT} dynamic state enabled then \text{vkCmdSetDiscardRectangleModeEXT} must have been called in the current command buffer prior to this drawing command

- **VID-vkCmdDrawIndexed-None-08649**
  If the \text{VK_EXT_discard_rectangles} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \text{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \text{rasterizerDiscardEnable} to \text{VK_FALSE}, and the most recent call to \text{vkCmdSetDiscardRectangleEnableEXT} in the current command buffer set \text{discardRectangleEnable} to \text{VK_TRUE}, then \text{vkCmdSetDiscardRectangleModeEXT} must have been called in the current command buffer prior to this drawing command

- **VID-vkCmdDrawIndexed-dynamicRenderingUnusedAttachments-08913**
  If the current render pass instance was begun with \text{vkCmdBeginRendering}, the \text{dynamicRenderingUnusedAttachments} feature is not enabled, and \text{VkRenderingInfo::pDepthAttachment->imageView} was \text{VK_NULL_HANDLE}, the value of \text{VkPipelineRenderingCreateInfo::depthAttachmentFormat} used to create the currently bound graphics pipeline must be equal to \text{VK_FORMAT_UNDEFINED}

- **VID-vkCmdDrawIndexed-dynamicRenderingUnusedAttachments-08914**
  If current render pass instance was begun with \text{vkCmdBeginRendering}, the \text{dynamicRenderingUnusedAttachments} feature is not enabled, and \text{VkRenderingInfo::pDepthAttachment->imageView} was not \text{VK_NULL_HANDLE}, the value of \text{VkPipelineRenderingCreateInfo::depthAttachmentFormat} used to create the currently bound graphics pipeline must be equal to the \text{VkFormat} used to create \text{VkRenderingInfo::pDepthAttachment->imageView}

- **VID-vkCmdDrawIndexed-dynamicRenderingUnusedAttachments-08915**
If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo::pDepthAttachment->imageView`, the value of the format **must** be `VK_FORMAT_UNDEFINED`.

- VUID-vkCmdDrawIndexed-dynamicRenderingUnusedAttachments-08916
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline **must** be equal to `VK_FORMAT_UNDEFINED`.

- VUID-vkCmdDrawIndexed-dynamicRenderingUnusedAttachments-08917
  If current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline **must** be equal to the `VkFormat` used to create `VkRenderingInfo::pStencilAttachment->imageView`.

- VUID-vkCmdDrawIndexed-dynamicRenderingUnusedAttachments-08918
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo::pStencilAttachment->imageView`, the value of the format **must** be `VK_FORMAT_UNDEFINED`.

- VUID-vkCmdDrawIndexed-imageView-06183
  If the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView` was not `VK_NULL_HANDLE`, the currently bound graphics pipeline **must** have been created with `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`.

- VUID-vkCmdDrawIndexed-imageView-06184
  If the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView` was not `VK_NULL_HANDLE`, the currently bound graphics pipeline **must** have been created with `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT`.

- VUID-vkCmdDrawIndexed-colorAttachmentCount-06185
  If the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` **must** have been created with a sample count equal to the corresponding element of the `pColorAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline.
If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

If the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the value of `rasterizationSamples` for the currently bound graphics pipeline.

If the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

If the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

If this command has been called inside a render pass instance started with `vkCmdBeginRendering`, and the `pNext` chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the value of
rasterizationSamples for the currently bound graphics pipeline must be equal to VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples

- VUID-vkCmdDrawIndexed-renderPass-06198
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline must have been created with a VkGraphicsPipelineCreateInfo::renderPass equal to VK_NULL_HANDLE

- VUID-vkCmdDrawIndexed-pColorAttachments-08963
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the VkRenderingInfo::pColorAttachments->imageView was not VK_NULL_HANDLE, then the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the pipeline must not be VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawIndexed-pDepthAttachment-08964
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, then the VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the pipeline must not be VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawIndexed-pStencilAttachment-08965
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound, stencil test is enabled and the VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, then the VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the pipeline must not be VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawIndexed-primitivesGeneratedQueryWithRasterizerDiscard-06708
  If the primitivesGeneratedQueryWithRasterizerDiscard feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, rasterization discard must not be enabled

- VUID-vkCmdDrawIndexed-primitivesGeneratedQueryWithNonZeroStreams-06709
  If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, the bound graphics pipeline must not have been created with a non-zero value in VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream

- VUID-vkCmdDrawIndexed-None-07619
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT dynamic state enabled then vkCmdSetTessellationDomainOriginEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-07620
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT dynamic state enabled then vkCmdSetDepthClampEnableEXT must have been called in the current command buffer prior to this drawing command
• **VUID-vkCmdDrawIndexed-None-09237**
  If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawIndexed-None-08650**
  If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawIndexed-None-07621**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawIndexed-None-08651**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawIndexed-None-07622**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` dynamic state enabled then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawIndexed-None-08652**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawIndexed-None-07623**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` dynamic state enabled then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawIndexed-None-08653**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawIndexed-None-07624**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawIndexed-alphaToCoverageEnable-08919**
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled, and
alphaToCoverageEnable was VK_TRUE in the last call to
vkCmdSetAlphaToCoverageEnableEXT, then the Fragment Output Interface must contain
a variable for the alpha Component word in Location 0 at Index 0

• VUID-vkCmdDrawIndexed-None-08654
If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToCoverageEnableEXT must
have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexed-alphaToCoverageEnable-08920
If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetAlphaToCoverageEnableEXT in the current command buffer set
alphaToCoverageEnable to VK_TRUE, then the Fragment Output Interface must contain a
variable for the alpha Component word in Location 0 at Index 0

• VUID-vkCmdDrawIndexed-None-07625
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT dynamic state enabled then
vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexed-None-08655
If the alphaToOne feature is enabled, and a shader object is bound to any graphics stage,
and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command
buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToOneEnableEXT must
have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexed-None-07626
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT dynamic state enabled then
vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexed-None-08656
If the logicOp feature is enabled, and a shader object is bound to the
VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEnableEXT must have been
called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexed-None-07627
If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent
call to vkCmdSetRasterizerDiscardEnable in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorBlendEnableEXT must have
been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexed-None-07628
If the bound graphics pipeline state was created with the 
\texttt{VK_DYNAMIC_STATE\_COLOR\_BLEND\_EQUATION\_EXT} dynamic state enabled then 
\texttt{vkCmdSetColorBlendEquationEXT} must have been called in the current command buffer 
before this drawing command

• VUID-vkCmdDrawIndexed-None-08658
If a shader object is bound to any graphics stage, and the most recent call to 
\texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set 
rasterizerDiscardEnable to \texttt{VK\_FALSE}, and the most recent call to 
\texttt{vkCmdSetColorBlendEnableEXT} for any attachment set that attachment's value in 
pColorBlendEnables to \texttt{VK\_TRUE}, then \texttt{vkCmdSetColorBlendEquationEXT} must have been 
called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexed-None-07629
If the bound graphics pipeline state was created with the 
\texttt{VK_DYNAMIC_STATE\_COLOR\_WRITE\_MASK\_EXT} dynamic state enabled then 
\texttt{vkCmdSetColorWriteMaskEXT} must have been called in the current command buffer 
before this drawing command

• VUID-vkCmdDrawIndexed-None-08659
If a shader object is bound to the \texttt{VK\_SHADER\_STAGE\_FRAGMENT\_BIT} stage, and the most recent 
call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set 
rasterizerDiscardEnable to \texttt{VK\_FALSE}, then \texttt{vkCmdSetColorWriteMaskEXT} must have been 
called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexed-None-07630
If the bound graphics pipeline state was created with the 
\texttt{VK_DYNAMIC_STATE\_RASTERIZATION\_STREAM\_EXT} dynamic state enabled then 
\texttt{vkCmdSetRasterizationStreamEXT} must have been called in the current command buffer 
before this drawing command

• VUID-vkCmdDrawIndexed-None-08660
If the \texttt{geometryStreams} feature is enabled, and a shader object is bound to the 
\texttt{VK\_SHADER\_STAGE\_GEOMETRY\_BIT} stage, then \texttt{vkCmdSetRasterizationStreamEXT} must have been 
called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexed-None-07631
If the bound graphics pipeline state was created with the 
\texttt{VK_DYNAMIC_STATE\_CONSERVATIVE\_RASTERIZATION\_MODE\_EXT} dynamic state enabled then 
\texttt{vkCmdSetConservativeRasterizationModeEXT} must have been called in the current command buffer 
before this drawing command

• VUID-vkCmdDrawIndexed-None-08661
If the \texttt{VK\_EXT\_conservative\_rasterization} extension is enabled, and a shader object is 
bound to any graphics stage, and the most recent call to 
\texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set 
rasterizerDiscardEnable to \texttt{VK\_FALSE}, then \texttt{vkCmdSetConservativeRasterizationModeEXT} must have been 
called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexed-None-07632
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexed-None-08662**
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetConservativeRasterizationModeEXT` in the current command buffer set `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`, then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexed-None-07633**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexed-None-08663**
  If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexed-None-07634**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexed-None-08664**
  If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexed-None-07635**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexed-None-08665**
  If the `VK_EXT_provoking_vertex` extension is enabled, and a shader object is bound to the...
VK_SHADER_STAGE_VERTEX_BIT stage, then \texttt{vkCmdSetProvokingVertexModeEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-07637
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT} dynamic state enabled then \texttt{vkCmdSetLineRasterizationModeEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08666
  If the \texttt{VK_EXT_line_rasterization} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetPolygonModeEXT} in the current command buffer set \texttt{polygonMode} to \texttt{VK_POLYGON_MODE_LINE}, then \texttt{vkCmdSetLineRasterizationModeEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08667
  If the \texttt{VK_EXT_line_rasterization} extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then \texttt{vkCmdSetLineRasterizationModeEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-07638
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT} dynamic state enabled then \texttt{vkCmdSetLineStippleEnableEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08669
  If the \texttt{VK_EXT_line_rasterization} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetPolygonModeEXT} in the current command buffer set \texttt{polygonMode} to \texttt{VK_POLYGON_MODE_LINE}, then \texttt{vkCmdSetLineStippleEnableEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08670
  If the \texttt{VK_EXT_line_rasterization} extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to \texttt{vkCmdSetPrimitiveTopology} in the current command buffer set \texttt{primitiveTopology} to any line topology, then \texttt{vkCmdSetLineStippleEnableEXT} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08671
  If the \texttt{VK_EXT_line_rasterization} extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then \texttt{vkCmdSetLineStippleEnableEXT} must have been called in the current command buffer
prior to this drawing command

- VUID-vkCmdDrawIndexed-None-07849
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_EXT` dynamic state enabled then `vkCmdSetLineStippleEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08672
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetLineStippleEnableEXT` in the current command buffer set `stippledLineEnable` to `VK_TRUE`, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-07639
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT` dynamic state enabled then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08673
  If the `depthClipControl` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-07640
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV` dynamic state enabled then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08674
  If the `VK_NV_clip_space_w_scaling` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-07641
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08675
  If the `VK_NV_viewport_swizzle` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-07642
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08676
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is
bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-07643**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-08677**
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set `coverageToColorEnable` to `VK_TRUE`, then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-07644**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-08678**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-07645**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-08679**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationModeNV` in the current command buffer set `coverageModulationMode` to any value other than `VK_COVERAGE_MODULATION_MODE_NONE_NV`, then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-07646**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-08680**
If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationTableEnableNV` in the current command buffer set `coverageModulationTableEnable` to `VK_TRUE`, then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-07647**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV` dynamic state enabled then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-pipelineFragmentShadingRate-09238**
  If the `pipelineFragmentShadingRate` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFragmentShadingRateKHR` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-08681**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV` dynamic state enabled then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-08682**
  If the `representativeFragmentTest` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-07649**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-08683**
  If the `coverageReductionMode` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` state enabled and the last call to `vkCmdSetColorBlendEnableEXT` set `pColorBlendEnables` for any attachment to `VK_TRUE`, then for those attachments in the subpass the corresponding image view's format features must contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must follow the rules for a zero-attachment subpass.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `VkPipelineMultisampleStateCreateInfo::rasterizationSamples` parameter used to create the bound graphics pipeline.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter in the last call to `vkCmdSetRasterizationSamplesEXT`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and neither the `VK_AMD_mixed_attachment_samples` nor the `VK_NV_framebuffer_mixed_samples` extensions are enabled, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the current subpass color and/or depth/stencil attachments.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the `rasterizationSamples` member of that structure.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and
attachmentCount parameters of vkCmdSetColorBlendEnableEXT calls **must** specify an enable for all active color attachments in the current subpass.

- **VUID-vkCmdDrawIndexed-firstAttachment-07477**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` **must** have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEquationEXT` calls **must** specify the blend equations for all active color attachments in the current subpass where blending is enabled.

- **VUID-vkCmdDrawIndexed-firstAttachment-07478**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` **must** have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorWriteMaskEXT` calls **must** specify the color write mask for all active color attachments in the current subpass where blending is enabled.

- **VUID-vkCmdDrawIndexed-firstAttachment-07479**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` **must** have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendAdvancedEXT` calls **must** specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled.

- **VUID-vkCmdDrawIndexed-advancedBlendMaxColorAttachments-07480**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` and `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic states enabled and the last calls to `vkCmdSetColorBlendEnableEXT` and `vkCmdSetColorBlendAdvancedEXT` have enabled advanced blending, then the number of active color attachments in the current subpass **must** not exceed `advancedBlendMaxColorAttachments`.

- **VUID-vkCmdDrawIndexed-primitivesGeneratedQueryWithNonZeroStreams-07481**
  If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, and the bound graphics pipeline was created with `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` state enabled, the last call to `vkCmdSetRasterizationStreamEXT` **must** have set the `rasterizationStream` to zero.

- **VUID-vkCmdDrawIndexed-sampleLocationsPerPixel-07482**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` **must** equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with.
• **VUID-vkCmdDrawIndexed-sampleLocationsPerPixel-07483**
  If the bound graphics pipeline state was created with the
  
  `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the
  `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, then the
  `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to
  `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` parameter of the last
  call to `vkCmdSetRasterizationSamplesEXT`.

• **VUID-vkCmdDrawIndexed-sampleLocationsEnable-07484**
  If the bound graphics pipeline was created with the
  `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and
  `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, and the current
  subpass has a depth/stencil attachment, then that attachment must have been created
  with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set.

• **VUID-vkCmdDrawIndexed-sampleLocationsEnable-07485**
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled and the
  `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled, and if
  `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, then the
  `sampleLocationsInfo.sampleLocationGridSize.width` in the last call to
  `vkCmdSetSampleLocationsEXT` must evenly divide `VkMultisamplePropertiesEXT`:
  `::sampleLocationGridSize.width` as returned by
  `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling
  `rasterizationSamples`.

• **VUID-vkCmdDrawIndexed-sampleLocationsEnable-07486**
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled and the
  `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if
  `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, then the
  `sampleLocationsInfo.sampleLocationGridSize.height` in the last call to
  `vkCmdSetSampleLocationsEXT` must evenly divide `VkMultisamplePropertiesEXT`:
  `::sampleLocationGridSize.height` as returned by
  `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling
  `rasterizationSamples`.

• **VUID-vkCmdDrawIndexed-sampleLocationsEnable-07487**
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if
  `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, the fragment shader
  code must not statically use the extended instruction `InterpolateAtSample`.

• **VUID-vkCmdDrawIndexed-sampleLocationsEnable-07936**
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the
  `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a
  `VkPipelineSampleLocationsStateCreateInfoEXT`::`sampleLocationsEnable` in the
  bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state
  enabled, then, `sampleLocationsInfo.sampleLocationGridSize.width` must evenly divide `VkMultisamplePropertiesEXT`::`sampleLocationGridSize.width` as returned by
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT`::sampleLocationsEnable in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.height` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.height` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling the value of `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT`::sampleLocationsEnable in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationsPerPixel` must equal `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageModulationTableEnableNV` set `coverageModulationTableEnable` to `VK_TRUE`, then the `coverageModulationTableCount` parameter in the last call to `vkCmdSetCoverageModulationTableNV` must equal the current `rasterizationSamples` divided by the number of color samples in the current subpass.

If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current `rasterizationSamples` must be the same as the sample count of the depth/stencil attachment.

If this `VK_NV_coverage_reduction_mode` extension is enabled, the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, the current coverage reduction mode `coverageReductionMode` is `VK_TRUE`, then the current `rasterizationSamples` must be equal to the current `rasterizationSamples`.
sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by \texttt{vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV}.

- **VUID-vkCmdDrawIndexed-viewportCount-07492**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} dynamic state enabled, but not the \texttt{VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV} dynamic state enabled, then the bound graphics pipeline must have been created with \texttt{VkPipelineViewportSwizzleStateCreateInfoNV} ::\texttt{viewportCount} greater or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}.

- **VUID-vkCmdDrawIndexed-viewportCount-07493**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} and \texttt{VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV} dynamic states enabled then the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportSwizzleNV} must be greater than or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}.

- **VUID-vkCmdDrawIndexed-rasterizationSamples-07494**
  If the \texttt{VK_NV_framebuffer_mixed_samples} extension is enabled, and if the current subpass has any color attachments and \texttt{rasterizationSamples} of the last call to \texttt{vkCmdSetRasterizationSamplesEXT} is greater than the number of color samples, then the pipeline \texttt{sampleShadingEnable} must be \texttt{VK_FALSE}.

- **VUID-vkCmdDrawIndexed-stippledLineEnable-07495**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT} or \texttt{VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT} dynamic states enabled, and if the current \texttt{stippledLineEnable} state is \texttt{VK_TRUE} and the current \texttt{lineRasterizationMode} state is \texttt{VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT}, then the \texttt{stippledRectangularLines} feature must be enabled.

- **VUID-vkCmdDrawIndexed-stippledLineEnable-07496**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT} or \texttt{VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT} dynamic states enabled, and if the current \texttt{stippledLineEnable} state is \texttt{VK_TRUE} and the current \texttt{lineRasterizationMode} state is \texttt{VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT}, then the \texttt{stippledBresenhamLines} feature must be enabled.

- **VUID-vkCmdDrawIndexed-stippledLineEnable-07497**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT} or \texttt{VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT} dynamic states enabled, and if the current \texttt{stippledLineEnable} state is \texttt{VK_TRUE} and the current \texttt{lineRasterizationMode} state is \texttt{VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT}, then the \texttt{stippledSmoothLines} feature must be enabled.

- **VUID-vkCmdDrawIndexed-stippledLineEnable-07498**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT} or
VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT, then the stippledRectangularLines feature must be enabled and VkPhysicalDeviceLimits::strictLines must be VK_TRUE

- VUID-vkCmdDrawIndexed-conservativePointAndLineRasterization-07499
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT dynamic state enabled, conservativePointAndLineRasterization is not supported, and the effective primitive topology output by the last pre-rasterization shader stage is a line or point, then the conservativeRasterizationMode set by the last call to vkCmdSetConservativeRasterizationModeEXT must be VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT

- VUID-vkCmdDrawIndexed-stage-07073
  If the currently bound pipeline was created with the VkPipelineShaderStageCreateInfo ::stage member of an element of VkGraphicsPipelineCreateInfo::pStages set to VK_SHADER_STAGE_VERTEX_BIT, VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT, VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT, then Mesh Shader Queries must not be active

- VUID-vkCmdDrawIndexed-None-08877
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT dynamic state vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-07850
  If dynamic state was inherited from VkCommandBufferInheritanceViewportScissorInfoNV, it must be set in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexed-None-08684
  If there is no bound graphics pipeline, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_VERTEX_BIT

- VUID-vkCmdDrawIndexed-None-08685
  If there is no bound graphics pipeline, and the tessellationShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT

- VUID-vkCmdDrawIndexed-None-08686
  If there is no bound graphics pipeline, and the tessellationShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT

- VUID-vkCmdDrawIndexed-None-08687
  If there is no bound graphics pipeline, and the geometryShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_GEOMETRY_BIT

- VUID-vkCmdDrawIndexed-None-08688
  If there is no bound graphics pipeline, vkCmdBindShadersEXT must have been called in the
current command buffer with pStages with an element of VK_SHADER_STAGE_FRAGMENT_BIT

- VUID-vkCmdDrawIndexed-None-08689
  If there is no bound graphics pipeline, and the taskShader feature is enabled, vkCmdBindShaderEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TASK_BIT_EXT

- VUID-vkCmdDrawIndexed-None-08690
  If there is no bound graphics pipeline, and the meshShader feature is enabled, vkCmdBindShaderEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_MESH_BIT_EXT

- VUID-vkCmdDrawIndexed-None-08693
  If there is no bound graphics pipeline, and at least one of the taskShader and meshShader features is enabled, one of the VK_SHADER_STAGE_VERTEX_BIT or VK_SHADER_STAGE_MESH_BIT_EXT stages must have a valid VkShaderEXT bound, and the other must have no VkShaderEXT bound

- VUID-vkCmdDrawIndexed-None-08694
  If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_MESH_BIT_EXT stage, and that VkShaderEXT was created without the VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT flag, a valid VkShaderEXT must be bound to the VK_SHADER_STAGE_TASK_BIT_EXT stage

- VUID-vkCmdDrawIndexed-None-08695
  If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_MESH_BIT_EXT stage, and that VkShaderEXT was created with the VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT flag, there must be no VkShaderEXT bound to the VK_SHADER_STAGE_TASK_BIT_EXT stage

- VUID-vkCmdDrawIndexed-None-08696
  If there is no bound graphics pipeline, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, there must be no VkShaderEXT bound to either the VK_SHADER_STAGE_TASK_BIT_EXT stage or the VK_SHADER_STAGE_MESH_BIT_EXT stage

- VUID-vkCmdDrawIndexed-None-08698
  If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, then all shaders created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag in the same vkCreateShadersEXT call must also be bound

- VUID-vkCmdDrawIndexed-None-08699
  If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, any stages in between stages whose shaders which did not create a shader with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag as part of the same vkCreateShadersEXT call must not have any VkShaderEXT bound

- VUID-vkCmdDrawIndexed-None-08878
  All bound graphics shader objects must have been created with identical or identically defined push constant ranges

- VUID-vkCmdDrawIndexed-None-08879
  All bound graphics shader objects must have been created with identical or identically
defined arrays of descriptor set layouts

- VUID-vkCmdDrawIndexed-None-08880
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage and the attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndexed-pDynamicStates-08715
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE set in VkPipelineDynamicStateCreateInfo ::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable parameter in the last call to vkCmdSetDepthWriteEnable must be VK_FALSE.

- VUID-vkCmdDrawIndexed-pDynamicStates-08716
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_STENCIL_WRITE_MASK set in VkPipelineDynamicStateCreateInfo ::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpStencilAttachmentReadEXT, the writeMask parameter in the last call to vkCmdSetStencilWriteMask must be 0.

- VUID-vkCmdDrawIndexed-None-09116
  If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT, and the format of any color attachment is VK_FORMAT_E5B9G9R9_UFLOAT_PACK32, the corresponding element of the pColorWriteMasks parameter of vkCmdSetColorWriteMask must either include all of VK_COLOR_COMPONENT_R_BIT, VK_COLOR_COMPONENT_G_BIT, and VK_COLOR_COMPONENT_B_BIT, or none of them.

- VUID-vkCmdDrawIndexed-maxFragmentDualSrcAttachments-09239
  If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of Location for any output attachment statically used in the Fragment Execution Model executed by this command must be less than maxFragmentDualSrcAttachments.

- VUID-vkCmdDrawIndexed-commandBuffer-02712
  If commandBuffer is a protected command buffer and protectedNoFault is not supported, any resource written to by the VkPipeline object bound to the pipeline bind point used by this command must not be an unprotected resource.

- VUID-vkCmdDrawIndexed-commandBuffer-02713
  If commandBuffer is a protected command buffer and protectedNoFault is not supported, pipeline stages other than the framebuffer-space and compute stages in the VkPipeline object bound to the pipeline bind point used by this command must not write to any resource.

- VUID-vkCmdDrawIndexed-commandBuffer-04617
  If any of the shader stages of the VkPipeline bound to the pipeline bind point used by this command uses the RayQueryKHR capability, then commandBuffer must not be a protected command buffer.
All vertex input bindings accessed via vertex input variables declared in the vertex shader entry point’s interface must have either valid or VK_NULL_HANDLE buffers bound.

If the nullDescriptor feature is not enabled, all vertex input bindings accessed via vertex input variables declared in the vertex shader entry point’s interface must not be VK_NULL_HANDLE.

For a given vertex buffer binding, any attribute data fetched must be entirely contained within the corresponding vertex buffer binding, as described in Vertex Input Description.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled, then vkCmdSetPrimitiveTopology must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled and the dynamicPrimitiveTopologyUnrestricted is VK_FALSE, then the primitiveTopology parameter of vkCmdSetPrimitiveTopology must be of the same topology class as the pipeline VkPipelineInputAssemblyStateCreateInfo::topology state.

If the bound graphics pipeline was created with both the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY and VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT dynamic states enabled, then vkCmdSetVertexInputEXT must have been called in the current command buffer prior to this draw command.

If the bound graphics pipeline was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT dynamic state enabled, but not the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, then vkCmdBindVertexBuffers2EXT must have been called in the current command buffer prior to this draw command, and the pStrides parameter of vkCmdBindVertexBuffers2EXT must not be NULL.

If a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, then vkCmdSetPrimitiveTopology must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, then vkCmdSetVertexInputEXT must have been called in the current command buffer prior to this draw command.

If the bound graphics pipeline state was created with the
**VK_DYNAMIC_STATE_VERTEX_INPUT_EXT** dynamic state enabled, then all variables with the Input storage class decorated with **Location** in the Vertex Execution Model OpEntryPoint **must** contain a location in **VkVertexInputAttributeDescription2EXT::location**

- **VUID-vkCmdDrawIndexed-Input-08734**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_VERTEX_INPUT_EXT** dynamic state enabled, then the numeric type associated with all Input variables of the corresponding **Location** in the Vertex Execution Model OpEntryPoint **must** be the same as **VkVertexInputAttributeDescription2EXT::format**

- **VUID-vkCmdDrawIndexed-format-08936**
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the **VK_DYNAMIC_STATE_VERTEX_INPUT_EXT** dynamic state enabled, and **VkVertexInputAttributeDescription2EXT::format** has a 64-bit component, then the scalar width associated with all Input variables of the corresponding **Location** in the Vertex Execution Model OpEntryPoint **must** be 64-bit

- **VUID-vkCmdDrawIndexed-format-08937**
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the **VK_DYNAMIC_STATE_VERTEX_INPUT_EXT** dynamic state enabled, and the scalar width associated with a **Location** decorated Input variable in the Vertex Execution Model OpEntryPoint is 64-bit, then the corresponding **VkVertexInputAttributeDescription2EXT::format must** have a 64-bit component

- **VUID-vkCmdDrawIndexed-None-09203**
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the **VK_DYNAMIC_STATE_VERTEX_INPUT_EXT** dynamic state enabled, and **VkVertexInputAttributeDescription2EXT::format** has a 64-bit component, then all Input variables at the corresponding **Location** in the Vertex Execution Model OpEntryPoint **must** not use components that are not present in the format

- **VUID-vkCmdDrawIndexed-None-08882**
  If a shader object is bound to the **VK_SHADER_STAGE_VERTEX_BIT** stage, then **vkCmdSetVertexInputEXT** **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-04875**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT** dynamic state enabled then **vkCmdSetPatchControlPointsEXT** **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-08883**
  If a shader object is bound to the **VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT** stage, then **vkCmdSetPatchControlPointsEXT** **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexed-None-04879**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE** dynamic state enabled then **vkCmdSetPrimitiveRestartEnable** **must** have been called in the current command buffer prior to this drawing command
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, `vkCmdSetPrimitiveRestartEnable` must have been called in the current command buffer prior to this drawing command.

The bound graphics pipeline must not have been created with the `VkPipelineShaderStageCreateInfo::stage` member of an element of `VkGraphicsPipelineCreateInfo::pStages` set to `VK_SHADER_STAGE_TASK_BIT_EXT` or `VK_SHADER_STAGE_MESH_BIT_EXT`.

There must be no shader object bound to either of the `VK_SHADER_STAGE_TASK_BIT_EXT` or `VK_SHADER_STAGE_MESH_BIT_EXT` stages.

An index buffer must be bound.

If `robustBufferAccess2` is not enabled, \((\text{indexSize} \times (\text{firstIndex} + \text{indexCount}) + \text{offset})\) must be less than or equal to the size of the bound index buffer, with `indexSize` being based on the type specified by `indexType`, where the index buffer, `indexType`, and `offset` are specified via `vkCmdBindIndexBuffer`.

If `robustBufferAccess2` is not enabled, \((\text{indexSize} \times (\text{firstIndex} + \text{indexCount}) + \text{offset})\) must be less than or equal to the size of the bound index buffer, with `indexSize` being based on the type specified by `indexType`, where the index buffer, `indexType`, and `offset` are specified via `vkCmdBindIndexBuffer` or `vkCmdBindIndexBuffer2KHR`. If `vkCmdBindIndexBuffer2KHR` is used to bind the index buffer, the size of the bound index buffer is `vkCmdBindIndexBuffer2KHR::size`.

Valid Usage (Implicit)

- `commandBuffer` must be a valid `VkCommandBuffer` handle
- `commandBuffer` must be in the recording state
- The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations
- This command must only be called inside of a render pass instance
- This command must only be called outside of a video coding scope
Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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To record an ordered sequence of draws which have no state changes between them, call:

```c
// Provided by VK_EXT_multi_draw
def void vkCmdDrawMultiEXT(
    VkCommandBuffer commandBuffer,
    uint32_t drawCount,
    const VkMultiDrawInfoEXT* pVertexInfo,
    uint32_t instanceCount,
    uint32_t firstInstance,
    uint32_t stride);
```

- commandBuffer is the command buffer into which the command is recorded.
- drawCount is the number of draws to execute, and can be zero.
- pVertexInfo is a pointer to an array of VkMultiDrawInfoEXT with vertex information to be drawn.
- instanceCount is the number of instances per draw.
- firstInstance is the instance ID of the first instance in each draw.
- stride is the byte stride between consecutive elements of pVertexInfo.

The number of draws recorded is drawCount, with each draw reading, sequentially, a firstVertex and a vertexCount from pVertexInfo. For each recorded draw, primitives are assembled as for vkCmdDraw, and drawn instanceCount times with instanceIndex starting with firstInstance and sequentially for each instance.

Valid Usage

- VUID-vkCmdDrawMultiEXT-magFilter-04553
  If a VkSampler created with magFilter or minFilter equal to VK_FILTER_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this
command, then the image view's format features must contain
VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- VUID-vkCmdDrawMultiEXT-mipmapMode-04770
  If a VkSampler created with mipmapMode equal to VK_SAMPLER_MIPMAP_MODE_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- VUID-vkCmdDrawMultiEXT-None-06479
  If a VkImageView is sampled with depth comparison, the image view's format features must contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT

- VUID-vkCmdDrawMultiEXT-None-02691
  If a VkImageView is accessed using atomic operations as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

- VUID-vkCmdDrawMultiEXT-None-07888
  If a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

- VUID-vkCmdDrawMultiEXT-None-02692
  If a VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT

- VUID-vkCmdDrawMultiEXT-None-02693
  If the VK_EXT_filter_cubic extension is not enabled and any VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, it must not have a VkImageViewType of VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

- VUID-vkCmdDrawMultiEXT-filterCubic-02694
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2

- VUID-vkCmdDrawMultiEXT-filterCubicMinmax-02695
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT with a reduction mode of either VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX as a result of this command must have a VkImageViewType and format that supports cubic filtering together with minmax filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax returned by vkGetPhysicalDeviceImageFormatProperties2

- VUID-vkCmdDrawMultiEXT-cubicRangeClamp-09212
  If the cubicRangeClamp feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must not have a VkSamplerReductionModeCreateInfo reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM
Any VkImageView being sampled with a VkSamplerReductionModeCreateInfo::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGE_CLAMP_QCOM as a result of this command must sample with VK_FILTER_CUBIC_EXT.

If the selectableCubicWeights feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights equal to VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM.

Any VkImage created with a VkImageCreateInfo::flags containing VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV sampled as a result of this command must only be sampled using a VkSamplerAddressMode of VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE.

For any VkImageView being written as a storage image where the image format field of the OpTypeImage is Unknown, the view's format features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT.

For any VkImageView being read as a storage image where the image format field of the OpTypeImage is Unknown, the view's format features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT.

For any VkBufferView being written as a storage texel buffer where the image format field of the OpTypeImage is Unknown, the view's buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT.

For any VkBufferView being read as a storage texel buffer where the image format field of the OpTypeImage is Unknown, then the view's buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT.

For each set n that is statically used by a bound shader, a descriptor set must have been bound to n at the same pipeline bind point, with a VkPipelineLayout that is compatible for set n, with the VkPipelineLayout or VkDescriptorSetLayout array that was used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility.

For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility.

If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the
VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMultiEXT-None-08114
  Descriptors in each bound descriptor set, specified via vkCmdBindDescriptorSets, must be valid if they are statically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was not created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMultiEXT-None-08115
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdBindDescriptorSets, the bound VkPipeline must have been created without VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMultiEXT-None-08116
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMultiEXT-None-08604
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDrawMultiEXT-None-08117
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdSetDescriptorBufferOffsetsEXT, the bound VkPipeline must have been created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMultiEXT-None-08119
  If a descriptor is dynamically used with a VkPipeline created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdDrawMultiEXT-None-08605
  If a descriptor is dynamically used with a VkShaderEXT created with a VkDescriptorSetLayout that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdDrawMultiEXT-None-08606
  If the shaderObject feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command

- VUID-vkCmdDrawMultiEXT-None-08607
  If the shaderObject is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and VK_NULL_HANDLE shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDrawMultiEXT-None-08608
  If a pipeline is bound to the pipeline bind point used by this command, there must not
have been any calls to dynamic state setting commands for any state not specified as
dynamic in the VkPipeline object bound to the pipeline bind point used by this command,
since that pipeline was bound

- VUID-vkCmdDrawMultiEXT-None-08609
  If the VkPipeline object bound to the pipeline bind point used by this command or any
  VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this
  command accesses a VkSampler object that uses unnormalized coordinates, that sampler
  must not be used to sample from any VkImage with a VkImageView of the type
  VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY,
  VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage

- VUID-vkCmdDrawMultiEXT-None-08610
  If the VkPipeline object bound to the pipeline bind point used by this command or any
  VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this
  command accesses a VkSampler object that uses unnormalized coordinates, that sampler
  must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample*
  instructions with ImplicitLod, Dref or Proj in their name, in any shader stage

- VUID-vkCmdDrawMultiEXT-None-08611
  If the VkPipeline object bound to the pipeline bind point used by this command or any
  VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this
  command accesses a VkSampler object that uses unnormalized coordinates, that sampler
  must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample*
  instructions that includes a LOD bias or any offset values, in any shader stage

- VUID-vkCmdDrawMultiEXT-uniformBuffers-06935
  If any stage of the VkPipeline object bound to the pipeline bind point used by this
  command accesses a uniform buffer, and that stage was created without enabling either
  VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT
  or
  VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT
  for uniformBuffers,
  and the robustBufferAccess feature is not enabled, that stage must not access values
  outside of the range of the buffer as specified in the descriptor set bound to the same
  pipeline bind point

- VUID-vkCmdDrawMultiEXT-None-08612
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage
  corresponding to the pipeline bind point used by this command accesses a uniform
  buffer, it must not access values outside of the range of the buffer as specified in the
  descriptor set bound to the same pipeline bind point

- VUID-vkCmdDrawMultiEXT-storageBuffers-06936
  If any stage of the VkPipeline object bound to the pipeline bind point used by this
  command accesses a storage buffer, and that stage was created without enabling either
  VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT
  or
  VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT
  for storageBuffers,
  and the robustBufferAccess feature is not enabled, that stage must not access values
  outside of the range of the buffer as specified in the descriptor set bound to the same
  pipeline bind point

- VUID-vkCmdDrawMultiEXT-None-08613
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage
corresponding to the pipeline bind point used by this command accesses a storage buffer, it **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawMultiEXT-commandBuffer-02707**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, any resource accessed by `bound shaders` **must** not be a protected resource

- **VUID-vkCmdDrawMultiEXT-None-06550**
  If a `bound shader` accesses a `VkSampler` or `VkImageView` object that enables sampler Y’C_aC_b conversion, that object **must** only be used with `OpImageSample*` or `OpImageSparseSample*` instructions

- **VUID-vkCmdDrawMultiEXT-ConstOffset-06551**
  If a `bound shader` accesses a `VkSampler` or `VkImageView` object that enables sampler Y’C_aC_b conversion, that object **must** not use the `ConstOffset` and `Offset` operands

- **VUID-vkCmdDrawMultiEXT-ConstOffset-07752**
  If a `VkImageView` is accessed as a result of this command, then the image view’s `viewType` **must** match the `Dim` operand of the `OpTypeImage` as described in Instruction/Sampler/Image View Validation

- **VUID-vkCmdDrawMultiEXT-ConstOffset-07753**
  If a `VkImageView` is accessed as a result of this command, then the numeric type of the image view’s `format` and the `Sampled Type` operand of the `OpTypeImage` **must** match

- **VUID-vkCmdDrawMultiEXT-OpImageWrite-08795**
  If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the image view’s `format`

- **VUID-vkCmdDrawMultiEXT-OpImageWrite-08796**
  If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have four components

- **VUID-vkCmdDrawMultiEXT-OpImageWrite-04469**
  If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the buffer view’s `format`

- **VUID-vkCmdDrawMultiEXT-SampledType-04470**
  If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 64

- **VUID-vkCmdDrawMultiEXT-SampledType-04471**
  If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 32

- **VUID-vkCmdDrawMultiEXT-SampledType-04472**
  If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 64
must have a Width of 64

- **VUID-vkCmdDrawMultiEXT-SampledType-04473**
  If a *VkBufferView* with a *VkFormat* that has a component width less than 64-bit is accessed as a result of this command, the *SampledType* of the *OpTypeImage* operand of that instruction must have a Width of 32

- **VUID-vkCmdDrawMultiEXT-sparseImageInt64Atomics-04474**
  If the *sparseImageInt64Atomics* feature is not enabled, *VkImage* objects created with the *VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT* flag must not be accessed by atomic instructions through an *OpTypeImage* with a *SampledType* with a Width of 64 by this command

- **VUID-vkCmdDrawMultiEXT-sparseImageInt64Atomics-04475**
  If the *sparseImageInt64Atomics* feature is not enabled, *VkBuffer* objects created with the *VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT* flag must not be accessed by atomic instructions through an *OpTypeImage* with a *SampledType* with a Width of 64 by this command

- **VUID-vkCmdDrawMultiEXT-OpImageWeightedSampleQCOM-06971**
  If *OpImageWeightedSampleQCOM* is used to sample a *VkImageView* as a result of this command, then the image view’s format features must contain *VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM*

- **VUID-vkCmdDrawMultiEXT-OpImageWeightedSampleQCOM-06972**
  If *OpImageWeightedSampleQCOM* uses a *VkImageView* as a sample weight image as a result of this command, then the image view’s format features must contain *VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM*

- **VUID-vkCmdDrawMultiEXT-OpImageBoxFilterQCOM-06973**
  If *OpImageBoxFilterQCOM* is used to sample a *VkImageView* as a result of this command, then the image view’s format features must contain *VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM*

- **VUID-vkCmdDrawMultiEXT-OpImageBlockMatchSSDQCOM-06974**
  If *OpImageBlockMatchSSDQCOM* is used to read from an *VkImageView* as a result of this command, then the image view’s format features must contain *VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM*

- **VUID-vkCmdDrawMultiEXT-OpImageBlockMatchSADQCOM-06975**
  If *OpImageBlockMatchSADQCOM* or *OpImageBlockMatchSSDQCOM* is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- **VUID-vkCmdDrawMultiEXT-OpImageWeightedSampleQCOM-06977**
  If *OpImageWeightedSampleQCOM*, *OpImageBoxFilterQCOM*, *OpImageBlockMatchWindowSSDQCOM*, *OpImageBlockMatchWindowSSDQCOM*, *OpImageBlockMatchGatherSSDQCOM*, or *OpImageBlockMatchSSDQCOM* uses a *VkSampler* as a result of this command, then the sampler must have been created with *VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM*
• VUID-vkCmdDrawMultiEXT-OpImageWeightedSampleQCOM-06978
  If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must not have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

• VUID-vkCmdDrawMultiEXT-OpImageBlockMatchWindow-09215
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

• VUID-vkCmdDrawMultiEXT-OpImageBlockMatchWindow-09216
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view’s format must be a single-component format.

• VUID-vkCmdDrawMultiEXT-OpImageBlockMatchWindow-09217
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.

• VUID-vkCmdDrawMultiEXT-None-07288
  Any shader invocation executed by this command must terminate.

• VUID-vkCmdDrawMultiEXT-renderPass-02684
  The current render pass must be compatible with the `renderPass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

• VUID-vkCmdDrawMultiEXT-subpass-02685
  The subpass index of the current render pass must be equal to the `subpass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

• VUID-vkCmdDrawMultiEXT-None-07748
  If any shader statically accesses an input attachment, a valid descriptor must be bound to the pipeline via a descriptor set.

• VUID-vkCmdDrawMultiEXT-OpTypeImage-07468
  If any shader executed by this pipeline accesses an `OpTypeImage` variable with a `Dim` operand of `SubpassData`, it must be decorated with an `InputAttachmentIndex` that corresponds to a valid input attachment in the current subpass.

• VUID-vkCmdDrawMultiEXT-None-07469
  Input attachment views accessed in a subpass must be created with the same `VkFormat` as the corresponding subpass definition, and be created with a `VkImageView` that is compatible with the attachment referenced by the subpass’ `pInputAttachments[InputAttachmentIndex]` in the currently bound `VkFramebuffer` as specified by `Fragment Input Attachment Compatibility`.

• VUID-vkCmdDrawMultiEXT-None-06537
  Memory backing image subresources used as attachments in the current render pass...
must not be written in any way other than as an attachment by this command

• VUID-vkCmdDrawMultiEXT-None-09000
If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:
  ◦ the `VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
  ◦ the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_COLOR_BIT` and
    ▪ there is no currently bound graphics pipeline or
    ▪ the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawMultiEXT-None-09001
If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:
  ◦ the `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
  ◦ the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_DEPTH_BIT` and
    ▪ there is no currently bound graphics pipeline or
    ▪ the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawMultiEXT-None-09002
If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:
  ◦ the `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
  ◦ the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_STENCIL_BIT` and
    ▪ there is no currently bound graphics pipeline or
    ▪ the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawMultiEXT-None-09003
If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command
• VUID-vkCmdDrawMultiEXT-None-06539
  If any previously recorded command in the current subpass accessed an image
  subresource used as an attachment in this subpass in any way other than as an
  attachment, this command **must** not write to that image subresource as an attachment

• VUID-vkCmdDrawMultiEXT-None-06886
  If the current render pass instance uses a depth/stencil attachment with a read-only
  layout for the depth aspect, **depth writes must be disabled**

• VUID-vkCmdDrawMultiEXT-None-06887
  If the current render pass instance uses a depth/stencil attachment with a read-only
  layout for the stencil aspect, both front and back **writeMask** are not zero, and stencil test is
  enabled, **all stencil ops must be** **VK_STENCIL_OP_KEEP**

• VUID-vkCmdDrawMultiEXT-None-07831
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_VIEWPORT**
  dynamic state enabled then **vkCmdSetViewport** **must** have been called in the current
  command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-07832
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SCISSOR**
  dynamic state enabled then **vkCmdSetScissor** **must** have been called in the current
  command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-07833
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_LINE_WIDTH**
  dynamic state enabled then **vkCmdSetLineWidth** **must** have been called in the current
  command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-08617
  If a shader object is bound to any graphics stage, and the most recent call to
  **vkCmdSetPolygonModeEXT** in the current command buffer set **polygonMode** to
  **VK_POLYGON_MODE_LINE**, **vkCmdSetLineWidth** **must** have been called in the current
  command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-08618
  If a shader object is bound to the **VK_SHADER_STAGE_VERTEX_BIT** stage, and the most recent call to
  **vkCmdSetPrimitiveTopology** in the current command buffer set **primitiveTopology**
  to any line topology, **vkCmdSetLineWidth** **must** have been called in the current
  command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-08619
  If a shader object that outputs line primitives is bound to the
  **VK_SHADER_STAGE_TESSellation_EVALUATION_BIT** or **VK_SHADER_STAGE_GEOMETRY_BIT** stage,
  **vkCmdSetLineWidth** **must** have been called in the current command buffer prior to this
  drawing command

• VUID-vkCmdDrawMultiEXT-None-07834
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_DEPTH_BIAS**
  dynamic state enabled then **vkCmdSetDepthBias** or **vkCmdSetDepthBias2EXT** **must** have
  been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-08620
  If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDepthBiasEnable in the current command buffer set depthBiasEnable to VK_TRUE, vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-07835
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_BLEND_CONSTANTS dynamic state enabled then vkCmdSetBlendConstants must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-08621
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetColorBlendEnableEXT in the current command buffer set any element of pColorBlendEnables to VK_TRUE, and the most recent call to vkCmdSetColorBlendEquationEXT in the current command buffer set the same element of pColorBlendEquations to a VkColorBlendEquationEXT structure with any VkBlendFactor member with a value of VK_BLEND_FACTOR_CONSTANT_COLOR, VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR, VK_BLEND_FACTOR_CONSTANT_ALPHA, or VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA, vkCmdSetBlendConstants must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-07836
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BOUNDS dynamic state enabled then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-08622
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDepthBoundsTestEnable in the current command buffer set depthBoundsTestEnable to VK_TRUE, then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-07837
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK dynamic state enabled then vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-08623
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-07838
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_WRITE_MASK dynamic state enabled then
**vkCmdSetStencilWriteMask** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-None-08624**  
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetStencilTestEnable** in the current command buffer set *stencilTestEnable* to **VK_TRUE**, **vkCmdSetStencilWriteMask** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-None-07839**  
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_STENCIL_REFERENCE** dynamic state enabled then **vkCmdSetStencilReference** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-None-08625**  
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetStencilTestEnable** in the current command buffer set *stencilTestEnable* to **VK_TRUE**, **vkCmdSetStencilReference** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-maxMultiviewInstanceIndex-02688**  
  If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to **VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex**.

- **VUID-vkCmdDrawMultiEXT-sampleLocationsEnable-02689**  
  If the bound graphics pipeline was created with **VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable** set to **VK_TRUE** and the current subpass has a depth/stencil attachment, then that attachment must have been created with the **VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT** bit set.

- **VUID-vkCmdDrawMultiEXT-None-06666**  
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT** dynamic state enabled then **vkCmdSetSampleLocationsEXT** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-None-08626**  
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetSampleLocationsEnableEXT** in the current command buffer set *sampleLocationsEnable* to **VK_TRUE**, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set *rasterizerDiscardEnable* to **VK_FALSE**, then **vkCmdSetSampleLocationsEXT** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-sampleLocationsPerPixel-07934**  
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT** state enabled, then the *sampleLocationsPerPixel* member of **pSampleLocationsInfo** in the last call to **vkCmdSetSampleLocationsEXT** must equal the *rasterizationSamples* member of the **VkPipelineMultisampleStateCreateInfo** structure the bound graphics pipeline has been created with.
• VUID-vkCmdDrawMultiEXT-None-07840
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CULL_MODE` dynamic state enabled then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiEXT-None-08627
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiEXT-None-07841
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiEXT-None-08628
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiEXT-None-07843
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiEXT-None-08629
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiEXT-None-07844
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` dynamic state enabled then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiEXT-None-08630
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiEXT-None-07845
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP` dynamic state enabled then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiEXT-None-08631
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthTestEnable` in the current command buffer set `depthTestEnable` to `VK_TRUE`, then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-07846**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-08632**
  If a shader object is bound to any graphics stage, and the `depthBounds` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-08632**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE` dynamic state enabled then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-08633**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-08633**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_OP` dynamic state enabled then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-08634**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-viewportCount-03417**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `VkPipelineViewportStateCreateInfo::scissorCount` of the pipeline
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, then `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `scissorCount` parameter of `vkCmdSetScissorWithCount` must match the `VkPipelineViewportStateCreateInfo::viewportCount` of the pipeline.

If the bound graphics pipeline state was created with both the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic states enabled then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

If a shader object is bound to any graphics stage, then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportWScalingStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then `vkCmdSetViewportWScalingNV` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, then `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `scissorCount` parameter of `vkCmdSetScissorWithCount` must match the `VkPipelineViewportStateCreateInfo::viewportCount` of the pipeline.
VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV dynamic state enabled, then the bound graphics pipeline must have been created with VkPipelineViewportShadingRateImageStateCreateInfoNV::viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

- VUID-vkCmdDrawMultiEXT-viewportCount-04140
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV dynamic states enabled then the viewportCount parameter in the last call to vkCmdSetViewportShadingRatePaletteNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

- VUID-vkCmdDrawMultiEXT-shadingRateImage-09233
  If the shadingRateImage feature is enabled, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCoarseSampleOrderNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-shadingRateImage-09234
  If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetShadingRateImageEnableNV in the current command buffer set shadingRateImageEnable to VK_TRUE, then vkCmdSetViewportShadingRatePaletteNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-08637
  If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, then the viewportCount parameter in the last call to vkCmdSetViewportShadingRatePaletteNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

- VUID-vkCmdDrawMultiEXT-VkPipelineViewportCreateInfo-04141
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled and a VkPipelineViewportSwizzleStateCreateInfoNV structure chained from VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have been created with VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

- VUID-vkCmdDrawMultiEXT-VkPipelineViewportCreateInfo-04142
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled and a VkPipelineViewportExclusiveScissorStateCreateInfoNV structure chained from VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have been created with VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

- VUID-vkCmdDrawMultiEXT-None-07878
  If the bound graphics pipeline state was created with the
**VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV**

Dynamic state enabled then `vkCmdSetExclusiveScissorEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-None-07879**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV** dynamic state enabled then `vkCmdSetExclusiveScissorNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-exclusiveScissor-09235**
  If a shader object is bound to any graphics stage, and the `exclusiveScissor` feature is enabled, then `vkCmdSetExclusiveScissorEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-None-08638**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetExclusiveScissorEnableNV` in the current command buffer set any element of `pExclusiveScissorEnables` to **VK_TRUE**, then `vkCmdSetExclusiveScissorNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-None-04876**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE** dynamic state enabled then `vkCmdSetRasterizerDiscardEnable` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-None-08639**
  If a shader object is bound to any graphics stage, then `vkCmdSetRasterizerDiscardEnable` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-None-08640**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE** dynamic state enabled then `vkCmdSetDepthBiasEnable` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-None-08641**
  If a shader object is bound to the **VK_SHADER_STAGE_FRAGMENT_BIT** stage, and the `logicOp` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view's format features do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the `blendEnable` member of the corresponding element of the `pAttachments` member of `pColorBlendState` must be `VK_FALSE`.

- **VUID-vkCmdDrawMultiEXT-multisampledRenderToSingleSampled-07284**
  If rasterization is not disabled in the bound graphics pipeline, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then `rasterizationSamples` for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawMultiEXT-None-08644**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then the most recent call to `vkCmdSetRasterizationSamplesEXT` in the current command buffer must have set `rasterizationSamples` to be the same as the number of samples for the current render pass color and/or depth/stencil attachments.
If a shader object is bound to any graphics stage, the current render pass instance must have been begun with `vkCmdBeginRendering`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo::viewMask` equal to `VkRenderingInfo::viewMask`.

If the dynamicRenderingUnusedAttachments feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo`.
If the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline, or the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`.

- **VUID-vkCmdDrawMultiEXT-dynamicRenderingUnusedAttachments-08911**
  If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline, or the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`.

- **VUID-vkCmdDrawMultiEXT-dynamicRenderingUnusedAttachments-08912**
  If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` must have the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`.

- **VUID-vkCmdDrawMultiEXT-None-07749**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-None-08646**
  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-attachmentCount-07750**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then the `attachmentCount` parameter of `vkCmdSetColorWriteEnableEXT` must be greater than or equal to the `VkPipelineColorBlendStateCreateInfo::attachmentCount` of the currently bound graphics pipeline.

- **VUID-vkCmdDrawMultiEXT-None-08647**
  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `attachmentCount` parameter of most recent call to `vkCmdSetColorWriteEnableEXT` in the current command buffer must be greater than 1779.
or equal to the number of color attachments in the current render pass instance

- **VUID-vkCmdDrawMultiEXT-None-07751**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT} dynamic state enabled then \texttt{vkCmdSetDiscardRectangleEXT} must have been called in the current command buffer prior to this drawing command for each discard rectangle in \texttt{VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount}

- **VUID-vkCmdDrawMultiEXT-None-07880**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT} dynamic state enabled then \texttt{vkCmdSetDiscardRectangleEnableEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-rasterizerDiscardEnable-09236**
  If the \texttt{VK_EXT_discard_rectangles} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetDiscardRectangleEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-08648**
  If the \texttt{VK_EXT_discard_rectangles} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetDiscardRectangleEnableEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-07881**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT} dynamic state enabled then \texttt{vkCmdSetDiscardRectangleModeEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-08649**
  If the \texttt{VK_EXT_discard_rectangles} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, and the most recent call to \texttt{vkCmdSetDiscardRectangleEnableEXT} in the current command buffer set \texttt{discardRectangleEnable} to \texttt{VK_TRUE}, then \texttt{vkCmdSetDiscardRectangleModeEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-dynamicRenderingUnusedAttachments-08913**
  If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{dynamicRenderingUnusedAttachments} feature is not enabled, and \texttt{VkRenderingInfo::pDepthAttachment->imageView} was \texttt{VK_NULL_HANDLE}, the value of \texttt{VkPipelineRenderingCreateInfo::depthAttachmentFormat} used to create the currently bound graphics pipeline must be equal to \texttt{VK_FORMAT_UNDEFINED}

- **VUID-vkCmdDrawMultiEXT-dynamicRenderingUnusedAttachments-08914**
  If current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{dynamicRenderingUnusedAttachments} feature is not enabled, and \texttt{VkRenderingInfo::pDepthAttachment->imageView} was \texttt{VK_NULL_HANDLE}, the value of \texttt{VkPipelineRenderingCreateInfo::depthAttachmentFormat} used to create the currently bound graphics pipeline must be equal to \texttt{VK_FORMAT_UNDEFINED}
::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to the VkFormat used to create VkRenderingInfo::pDepthAttachment->imageView

• VUID-vkCmdDrawMultiEXT-dynamicRenderingUnusedAttachments-08915
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pDepthAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawMultiEXT-dynamicRenderingUnusedAttachments-08916
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pStencilAttachment->imageView was VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline must be equal to VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawMultiEXT-dynamicRenderingUnusedAttachments-08917
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pStencilAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawMultiEXT-dynamicRenderingUnusedAttachments-08918
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pStencilAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawMultiEXT-imageView-06183
  If the current render pass instance was begun with vkCmdBeginRendering and VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

• VUID-vkCmdDrawMultiEXT-imageView-06184
  If the current render pass instance was begun with vkCmdBeginRendering and VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT

• VUID-vkCmdDrawMultiEXT-colorAttachmentCount-06185
  If the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount
If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the corresponding element of the `pColorAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline.

- **VUID-vkCmdDrawMultiEXT-pDepthAttachment-06186**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

- **VUID-vkCmdDrawMultiEXT-pStencilAttachment-06187**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

- **VUID-vkCmdDrawMultiEXT-multisampledRenderToSingleSampled-07285**
  If the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the value of `rasterizationSamples` for the currently bound graphics pipeline.

- **VUID-vkCmdDrawMultiEXT-multisampledRenderToSingleSampled-07286**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

- **VUID-vkCmdDrawMultiEXT-multisampledRenderToSingleSampled-07287**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`. 

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If this command has been called inside a render pass instance started with `vkCmdBeginRendering`, and the `pNext` chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the value of `rasterizationSamples` for the currently bound graphics pipeline **must** be equal to `VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline **must** have been created with a `VkGraphicsPipelineCreateInfo::renderPass` equal to `VK_NULL_HANDLE`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the `VkRenderingInfo::pColorAttachments->imageView` was not `VK_NULL_HANDLE`, then the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the pipeline **must** not be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the pipeline **must** not be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, stencil test is enabled and the `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the pipeline **must** not be `VK_FORMAT_UNDEFINED`.

If the `primitivesGeneratedQueryWithRasterizerDiscard` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, **rasterization discard must not be enabled**.

If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, the bound graphics pipeline **must not have been created with a non-zero value in `VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream`**.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT` dynamic state enabled then `vkCmdSetTessellationDomainOriginEXT` **must** have been called in the current command buffer prior to this drawing command.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `pNext` chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the value of `rasterizationSamples` for the currently bound graphics pipeline **must** be equal to `VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the `VkRenderingInfo::pColorAttachments->imageView` was not `VK_NULL_HANDLE`, then the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the pipeline **must** not be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the pipeline **must** not be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, stencil test is enabled and the `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the pipeline **must** not be `VK_FORMAT_UNDEFINED`.

If the `primitivesGeneratedQueryWithRasterizerDiscard` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, **rasterization discard must not be enabled**.

If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, the bound graphics pipeline **must not have been created with a non-zero value in `VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream`**.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT` dynamic state enabled then `vkCmdSetTessellationDomainOriginEXT` **must** have been called in the current command buffer prior to this drawing command.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `pNext` chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the value of `rasterizationSamples` for the currently bound graphics pipeline **must** be equal to `VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples`.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-09237
  If a shader object is bound to the `VK_SHADER_STAGE_TESSIONEVALUATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-08650
  If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-07621
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-08651
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-07622
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` dynamic state enabled then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-08652
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-07623
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` dynamic state enabled then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-08653
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-07624
  If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT  dynamic state enabled then
vkCmdSetAlphaToCoverageEnableEXT  must have been called in the current command
buffer prior to this drawing command

•  VUID-vkCmdDrawMultiEXT-alphaToCoverageEnable-08919
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT  dynamic state enabled, and
alphaToCoverageEnable was VK_TRUE in the last call to
vkCmdSetAlphaToCoverageEnableEXT, then the Fragment Output Interface must contain a
variable for the alpha Component word in Location 0 at Index 0

•  VUID-vkCmdDrawMultiEXT-None-08654
If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToCoverageEnableEXT must
have been called in the current command buffer prior to this drawing command

•  VUID-vkCmdDrawMultiEXT-alphaToCoverageEnable-08920
If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetAlphaToCoverageEnableEXT in the current command buffer set
alphaToCoverageEnable to VK_TRUE, then the Fragment Output Interface must contain a
variable for the alpha Component word in Location 0 at Index 0

•  VUID-vkCmdDrawMultiEXT-None-07625
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT  dynamic state enabled then
vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer
prior to this drawing command

•  VUID-vkCmdDrawMultiEXT-None-08655
If the alphaToOne feature is enabled, and a shader object is bound to any graphics stage,
and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command
buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToOneEnableEXT must
have been called in the current command buffer prior to this drawing command

•  VUID-vkCmdDrawMultiEXT-None-07626
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT  dynamic state enabled then
vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior
to this drawing command

•  VUID-vkCmdDrawMultiEXT-None-08656
If the logicOp feature is enabled, and a shader object is bound to the
VK_SHADER_STAGE_FRAGMENT_BIT  stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEnableEXT must have been
called in the current command buffer prior to this drawing command

•  VUID-vkCmdDrawMultiEXT-None-07627
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT  dynamic state enabled then
vkCmdSetColorBlendEnableEXT must have been called in the current command buffer
prior to this drawing command
If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to VK_FALSE, then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to VK_FALSE, and the most recent call to `vkCmdSetColorBlendEnableEXT` for any attachment set that attachment's value in `pColorBlendEnables` to VK_TRUE, then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to VK_FALSE, then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT dynamic state enabled then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

If the geometryStreams feature is enabled, and a shader object is bound to the VK_SHADER_STAGE_GEOMETRY_BIT stage, then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT dynamic state enabled then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

If the VK_EXT_conservative_rasterization extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then \texttt{vkCmdSetConservativeRasterizationModeEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-07632**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT} dynamic state enabled then \texttt{vkCmdSetExtraPrimitiveOverestimationSizeEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-08662**
  If the \texttt{VK_EXT_conservative_rasterization} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to \texttt{vkCmdSetConservativeRasterizationModeEXT} in the current command buffer set conservativeRasterizationMode to VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT, then \texttt{vkCmdSetExtraPrimitiveOverestimationSizeEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-07633**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT} dynamic state enabled then \texttt{vkCmdSetDepthClipEnableEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-08663**
  If the depthClipEnable feature is enabled, and a shader object is bound to any graphics stage, then \texttt{vkCmdSetDepthClipEnableEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-07634**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT} dynamic state enabled then \texttt{vkCmdSetSampleLocationsEnableEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-08664**
  If the \texttt{VK_EXT_sample_locations} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then \texttt{vkCmdSetSampleLocationsEnableEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-07635**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT} dynamic state enabled then \texttt{vkCmdSetColorBlendAdvancedEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-07636**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT} dynamic state enabled then \texttt{vkCmdSetProvokingVertexModeEXT} must have been called in the current command
buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-08665
  If the `VK_EXT_provoking_vertex` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMultiEXT-None-07637
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMultiEXT-None-08666
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMultiEXT-None-08667
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMultiEXT-None-08668
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMultiEXT-None-08669
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMultiEXT-None-08670
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.
If the VK_EXT_line_rasterization extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_EXT dynamic state enabled then `vkCmdSetLineStippleEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT dynamic state enabled then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV dynamic state enabled then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic state enabled then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.
vkCmdSetCoverageToColorEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-08676
  If the VK_NV_fragment_coverage_to_color extension is enabled, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCoverageToColorEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-07643
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV dynamic state enabled then vkCmdSetCoverageToColorLocationNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-08677
  If the VK_NV_fragment_coverage_to_color extension is enabled, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetCoverageToColorEnableNV in the current command buffer set coverageToColorEnable to VK_TRUE, then vkCmdSetCoverageToColorLocationNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-07644
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV dynamic state enabled then vkCmdSetCoverageModulationModeNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-08678
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCoverageModulationModeNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-07645
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV dynamic state enabled then vkCmdSetCoverageModulationTableEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-08679
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetCoverageModulationModeNV in the current command buffer set coverageModulationMode to any value other than VK_COVERAGE_MODULATION_MODE_NONE_NV, then vkCmdSetCoverageModulationTableEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiEXT-None-07646
  If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV  dynamic state enabled then
vkCmdSetCoverageModulationTableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-08680
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetCoverageModulationTableEnableNV in the current command buffer set coverageModulationTableEnable to VK_TRUE, then vkCmdSetCoverageModulationTableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-07647
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV dynamic state enabled then vkCmdSetShadingRateImageEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-pipelineFragmentShadingRate-09238
  If the pipelineFragmentShadingRate feature is enabled, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetFragmentShadingRateKHR must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-08681
  If the shadingRateImage feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetShadingRateImageEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-07648
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV dynamic state enabled then vkCmdSetRepresentativeFragmentTestEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-08682
  If the representativeFragmentTest feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetRepresentativeFragmentTestEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-07649
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV dynamic state enabled then vkCmdSetCoverageReductionModeNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-None-08683
  If the coverageReductionMode feature is enabled, and a shader object is bound to any
graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiEXT-pColorBlendEnables-07470**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` state enabled and the last call to `vkCmdColorBlendEnableEXT` set `pColorBlendEnables` for any attachment to `VK_TRUE`, then for those attachments in the subpass the corresponding image view's format features must contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`.

- **VUID-vkCmdDrawMultiEXT-rasterizationSamples-07471**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must follow the rules for a zero-attachment subpass.

- **VUID-vkCmdDrawMultiEXT-samples-07472**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter used to create the bound graphics pipeline.

- **VUID-vkCmdDrawMultiEXT-samples-07473**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawMultiEXT-rasterizationSamples-07474**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and neither the `VK_AMD_mixed_attachment_samples` nor the `VK_NV_framebuffer_mixed_samples` extensions are enabled, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawMultiEXT-None-09211**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the `rasterizationSamples` member of that structure.

- **VUID-vkCmdDrawMultiEXT-firstAttachment-07476**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the `rasterizationSamples` member of that structure.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEnableEXT` calls must specify an enable for all active color attachments in the current subpass

- **VUID-vkCmdDrawMultiEXT-firstAttachment-07477**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEquationEXT` calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled

- **VUID-vkCmdDrawMultiEXT-firstAttachment-07478**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorWriteMaskEXT` calls must specify the color write mask for all active color attachments in the current subpass

- **VUID-vkCmdDrawMultiEXT-firstAttachment-07479**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendAdvancedEXT` calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled

- **VUID-vkCmdDrawMultiEXT-advancedBlendMaxColorAttachments-07480**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` and `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic states enabled and the last calls to `vkCmdSetColorBlendEnableEXT` and `vkCmdSetColorBlendAdvancedEXT` have enabled advanced blending, then the number of active color attachments in the current subpass must not exceed `advancedBlendMaxColorAttachments`

- **VUID-vkCmdDrawMultiEXT-primitivesGeneratedQueryWithNonZeroStreams-07481**
  If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, and the bound graphics pipeline was created with `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` state enabled, the last call to `vkCmdSetRasterizationStreamEXT` must have set the `rasterizationStream` to zero

- **VUID-vkCmdDrawMultiEXT-sampleLocationsPerPixel-07482**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the
sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples member of the VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with

• VUID-vkCmdDrawMultiEXT-sampleLocationsPerPixel-07483
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples parameter of the last call to vkCmdSetRasterizationSamplesEXT

• VUID-vkCmdDrawMultiEXT-sampleLocationsEnable-07484
If the bound graphics pipeline was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set

• VUID-vkCmdDrawMultiEXT-sampleLocationsEnable-07485
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the sampleLocationsInfo.sampleLocationGridSize.width in the last call to vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples

• VUID-vkCmdDrawMultiEXT-sampleLocationsEnable-07486
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the sampleLocationsInfo.sampleLocationGridSize.height in the last call to vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples

• VUID-vkCmdDrawMultiEXT-sampleLocationsEnable-07487
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, the fragment shader code must not statically use the extended instruction InterpolateAtSample

• VUID-vkCmdDrawMultiEXT-sampleLocationsEnable-07936
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.width must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

• VUID-vkCmdDrawMultiEXT-sampleLocationsEnable-07937
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.height must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

• VUID-vkCmdDrawMultiEXT-sampleLocationsEnable-07938
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationsPerPixel must equal rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

• VUID-vkCmdDrawMultiEXT-coverageModulationTableEnable-07488
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV state enabled and the last call to vkCmdSetCoverageModulationTableEnableNV set coverageModulationTableEnable to VK_TRUE, then the coverageModulationTableCount parameter in the last call to vkCmdSetCoverageModulationTableNV must equal the current rasterizationSamples divided by the number of color samples in the current subpass

• VUID-vkCmdDrawMultiEXT-rasterizationSamples-07489
If the VK_NV_framebuffer_mixed_samples extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current rasterizationSamples must be the same as the sample count of the depth/stencil attachment

• VUID-vkCmdDrawMultiEXT-coverageToColorEnable-07490
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV state enabled and the last call to vkCmdSetCoverageToColorEnableNV set the coverageToColorEnable to VK_TRUE, then the current subpass must have a color attachment at the location selected by the last call to vkCmdSetCoverageToColorLocationNV coverageToColorLocation, with a VkFormat of VK_FORMAT_R8_UINT, VK_FORMAT_R8_SINT, VK_FORMAT_R16_UINT, VK_FORMAT_R16_SINT, VK_FORMAT_R32_UINT, or VK_FORMAT_R32_SINT
If this \texttt{VK_NVCoverageReductionMode} extension is enabled, the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV} and \texttt{VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT} states enabled, the current coverage reduction mode \texttt{coverageReductionMode}, then the current \texttt{rasterizationSamples}, and the sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by \texttt{vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV}

If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} dynamic state enabled, but not the \texttt{VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV} dynamic state enabled, then the bound graphics pipeline must have been created with \texttt{VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount} greater or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} and \texttt{VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV} dynamic states enabled then the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportSwizzleNV} must be greater than or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

If the \texttt{VK_NV_framebuffer_mixed_samples} extension is enabled, and if the current subpass has any color attachments and \texttt{rasterizationSamples} of the last call to \texttt{vkCmdSetRasterizationSamplesEXT} is greater than the number of color samples, then the pipeline \texttt{sampleShadingEnable} must be \texttt{VK_FALSE}

If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT} or \texttt{VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT} dynamic states enabled, and if the current \texttt{stippledLineEnable} state is \texttt{VK_TRUE} and the current \texttt{lineRasterizationMode} state is \texttt{VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT}, then the \texttt{stippledRectangularLines} feature must be enabled

If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT} or \texttt{VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT} dynamic states enabled, and if the current \texttt{stippledLineEnable} state is \texttt{VK_TRUE} and the current \texttt{lineRasterizationMode} state is \texttt{VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT}, then the \texttt{stippledBresenhamLines} feature must be enabled

If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT} or \texttt{VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT} dynamic states enabled, and if the current \texttt{stippledLineEnable} state is \texttt{VK_TRUE} and the current \texttt{lineRasterizationMode} state is
**VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT**, then the **stippledSmoothLines** feature **must** be enabled

- **VUID-vkCmdDrawMultiEXT-stippledLineEnable-07498**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT** or **VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT** dynamic states enabled, and if the current **stippledLineEnable** state is **VK_TRUE** and the current **lineRasterizationMode** state is **VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT**, then the **stippledRectangularLines** feature **must** be enabled and **VkPhysicalDeviceLimits::strictLines must be VK_TRUE**

- **VUID-vkCmdDrawMultiEXT-conservativePointAndLineRasterization-07499**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT** dynamic state enabled, **conservativePointAndLineRasterization** is not supported, and the effective primitive topology output by the last pre-rasterization shader stage is a line or point, then the **conservativeRasterizationMode** set by the last call to **vkCmdSetConservativeRasterizationModeEXT** **must** be **VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT**

- **VUID-vkCmdDrawMultiEXT-stage-07073**
  If the currently bound pipeline was created with the **VkPipelineShaderStageCreateInfo::stage** member of an element of **VkGraphicsPipelineCreateInfo::pStages** set to **VK_SHADER_STAGE_VERTEX_BIT**, **VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT**, **VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT** or **VK_SHADER_STAGE_GEOMETRY_BIT**, then **Mesh Shader Queries must not be active**

- **VUID-vkCmdDrawMultiEXT-None-08877**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT** dynamic state **vkCmdSetAttachmentFeedbackLoopEnableEXT** **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-07850**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT** dynamic state **vkCmdSetAttachmentFeedbackLoopEnableEXT** **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiEXT-None-08684**
  If there is no bound graphics pipeline, **vkCmdBindShadersEXT** **must** have been called in the current command buffer with **pStages** with an element of **VK_SHADER_STAGE_VERTEX_BIT**

- **VUID-vkCmdDrawMultiEXT-None-08685**
  If there is no bound graphics pipeline, and the **tessellationShader** feature is enabled, **vkCmdBindShadersEXT** **must** have been called in the current command buffer with **pStages** with an element of **VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT**

- **VUID-vkCmdDrawMultiEXT-None-08686**
  If there is no bound graphics pipeline, and the **tessellationShader** feature is enabled, **vkCmdBindShadersEXT** **must** have been called in the current command buffer with **pStages** with an element of **VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT**

- **VUID-vkCmdDrawMultiEXT-None-08687**
If there is no bound graphics pipeline, and the `geometryShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_GEOMETRY_BIT`

• VUID-vkCmdDrawMultiEXT-None-08688
  If there is no bound graphics pipeline, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_FRAGMENT_BIT`

• VUID-vkCmdDrawMultiEXT-None-08689
  If there is no bound graphics pipeline, and the `taskShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TASK_BIT_EXT`

• VUID-vkCmdDrawMultiEXT-None-08690
  If there is no bound graphics pipeline, and the `meshShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_MESH_BIT_EXT`

• VUID-vkCmdDrawMultiEXT-None-08693
  If there is no bound graphics pipeline, and at least one of the `taskShader` and `meshShader` features is enabled, one of the `VK_SHADER_STAGE_VERTEX_BIT` or `VK_SHADER_STAGE_MESH_BIT_EXT` stages must have a valid `VkShaderEXT` bound, and the other must have no `VkShaderEXT` bound

• VUID-vkCmdDrawMultiEXT-None-08694
  If there is no bound graphics pipeline, and both the `taskShader` and `meshShader` features are enabled, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that `VkShaderEXT` was created without the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, a valid `VkShaderEXT` must be bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage

• VUID-vkCmdDrawMultiEXT-None-08695
  If there is no bound graphics pipeline, and both the `taskShader` and `meshShader` features are enabled, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that `VkShaderEXT` was created with the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, there must be no `VkShaderEXT` bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage

• VUID-vkCmdDrawMultiEXT-None-08696
  If there is no bound graphics pipeline, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, there must be no `VkShaderEXT` bound to either the `VK_SHADER_STAGE_TASK_BIT_EXT` stage or the `VK_SHADER_STAGE_MESH_BIT_EXT` stage

• VUID-vkCmdDrawMultiEXT-None-08698
  If any graphics shader is bound which was created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag, then all shaders created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag in the same `vkCreateShadersEXT` call must also be bound

• VUID-vkCmdDrawMultiEXT-None-08699
  If any graphics shader is bound which was created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag, any stages in between stages whose shaders which did not create a shader with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag as part of the same `vkCreateShadersEXT` call must not have any `VkShaderEXT` bound
• VUID-vkCmdDrawMultiEXT-None-08878
All bound graphics shader objects must have been created with identical or identically defined push constant ranges

• VUID-vkCmdDrawMultiEXT-None-08879
All bound graphics shader objects must have been created with identical or identically defined arrays of descriptor set layouts

• VUID-vkCmdDrawMultiEXT-None-08880
If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage and the attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-pDynamicStates-08715
If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE set in VkPipelineDynamicStateCreateInfo ::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable parameter in the last call to vkCmdSetDepthWriteEnable must be VK_FALSE

• VUID-vkCmdDrawMultiEXT-pDynamicStates-08716
If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_STENCIL_WRITE_MASK set in VkPipelineDynamicStateCreateInfo ::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpStencilAttachmentReadEXT, the writeMask parameter in the last call to vkCmdSetStencilWriteMask must be 0

• VUID-vkCmdDrawMultiEXT-None-09116
If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT, and the format of any color attachment is VK_FORMAT_E5B9G9R9_UFLOAT_PACK32, the corresponding element of the pColorWriteMasks parameter of vkCmdSetColorWriteMaskEXT must either include all of VK_COLOR_COMPONENT_R_BIT, VK_COLOR_COMPONENT_G_BIT, and VK_COLOR_COMPONENT_B_BIT, or none of them

• VUID-vkCmdDrawMultiEXT-maxFragmentDualSrcAttachments-09239
If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of Location for any output attachment statically used in the Fragment Execution Model executed by this command must be less than maxFragmentDualSrcAttachments

• VUID-vkCmdDrawMultiEXT-commandBuffer-02712
If commandBuffer is a protected command buffer and protectedNoFault is not supported, any resource written to by the VkPipeline object bound to the pipeline bind point used by this command must not be an unprotected resource

• VUID-vkCmdDrawMultiEXT-commandBuffer-02713
If commandBuffer is a protected command buffer and protectedNoFault is not supported, pipeline stages other than the framebuffer-space and compute stages in the VkPipeline object bound to the pipeline bind point used by this command must not write to any
If any of the shader stages of the VkPipeline bound to the pipeline bind point used by this command uses the RayQueryKHR capability, then commandBuffer must not be a protected command buffer.

All vertex input bindings accessed via vertex input variables declared in the vertex shader entry point’s interface must have either valid or VK_NULL_HANDLE buffers bound.

If the nullDescriptor feature is not enabled, all vertex input bindings accessed via vertex input variables declared in the vertex shader entry point’s interface must not be VK_NULL_HANDLE.

For a given vertex buffer binding, any attribute data fetched must be entirely contained within the corresponding vertex buffer binding, as described in Vertex Input Description.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled then vkCmdSetPrimitiveTopology must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled and the dynamicPrimitiveTopologyUnrestricted is VK_FALSE, then the primitiveTopology parameter of vkCmdSetPrimitiveTopology must be of the same topology class as the pipeline VkPipelineInputAssemblyStateCreateInfo::topology state.

If the bound graphics pipeline was created with both the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT and VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT dynamic states enabled, then vkCmdSetVertexInputEXT must have been called in the current command buffer prior to this draw command.

If the bound graphics pipeline was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT dynamic state enabled, but not the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, then vkCmdBindVertexBuffers2EXT must have been called in the current command buffer prior to this draw command, and the pStrides parameter of vkCmdBindVertexBuffers2EXT must not be NULL.

If a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, then vkCmdSetPrimitiveTopology must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then `vkCmdSetVertexInputEXT` must have been called in the current command buffer prior to this draw command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then all variables with the `Input` storage class decorated with `Location` in the `Vertex` Execution `Model OpEntryPoint` must contain a location in `VkVertexInputAttributeDescription2EXT::location`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then the numeric type associated with all `Input` variables of the corresponding `Location` in the `Vertex` Execution `Model OpEntryPoint` must be the same as `VkVertexInputAttributeDescription2EXT::format`.

If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and `VkVertexInputAttributeDescription2EXT::format` has a 64-bit component, then the scalar width associated with all `Input` variables of the corresponding `Location` in the `Vertex` Execution `Model OpEntryPoint` must be 64-bit.

If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and the scalar width associated with a `Location` decorated `Input` variable in the `Vertex` Execution `Model OpEntryPoint` is 64-bit, then the corresponding `VkVertexInputAttributeDescription2EXT::format` must have a 64-bit component.

If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and `VkVertexInputAttributeDescription2EXT::format` has a 64-bit component, then all `Input` variables at the corresponding `Location` in the `Vertex` Execution `Model OpEntryPoint` must not use components that are not present in the format.

If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetVertexInputEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT` dynamic state enabled then `vkCmdSetPatchControlPointsEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetPatchControlPointsEXT` must have been called in the current command buffer prior to this drawing command.
• VUID-vkCmdDrawMultiEXT-None-04879
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE dynamic state enabled then
  vkCmdSetPrimitiveRestartEnable must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdDrawMultiEXT-rasterizerDiscardEnable-08884
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, vkCmdSetPrimitiveRestartEnable must have been
  called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiEXT-stage-06481
  The bound graphics pipeline must not have been created with the
  VkPipelineShaderStageCreateInfo::stage member of an element of
  VkGraphicsPipelineCreateInfo::pStages set to VK_SHADER_STAGE_TASK_BIT_EXT or
  VK_SHADER_STAGE_MESH_BIT_EXT

• VUID-vkCmdDrawMultiEXT-None-08885
  There must be no shader object bound to either of the VK_SHADER_STAGE_TASK_BIT_EXT or
  VK_SHADER_STAGE_MESH_BIT_EXT stages

• VUID-vkCmdDrawMultiEXT-None-04933
  The multiDraw feature must be enabled

• VUID-vkCmdDrawMultiEXT-drawCount-04934
  drawCount must be less than VkPhysicalDeviceMultiDrawPropertiesEXT::maxMultiDrawCount

• VUID-vkCmdDrawMultiEXT-drawCount-04935
  If drawCount is greater than zero, pVertexInfo must be a valid pointer to memory
  containing one or more valid instances of VkMultiDrawInfoEXT structures

• VUID-vkCmdDrawMultiEXT-stride-04936
  stride must be a multiple of 4

Valid Usage (Implicit)

• VUID-vkCmdDrawMultiEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

• VUID-vkCmdDrawMultiEXT-commandBuffer-recording
  commandBuffer must be in the recording state

• VUID-vkCmdDrawMultiEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics
  operations

• VUID-vkCmdDrawMultiEXT-renderpass
  This command must only be called inside of a render pass instance

• VUID-vkCmdDrawMultiEXT-videocoding
  This command must only be called outside of a video coding scope
Host Synchronization

- Host access to `commandBuffer` **must** be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized.

Command Properties

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To record an ordered sequence of indexed draws which have no state changes between them, call:

```c
// Provided by VK_EXT_multi_draw
void vkCmdDrawMultiIndexedEXT(
    VkCommandBuffer commandBuffer, 
    uint32_t drawCount, 
    const VkMultiDrawIndexedInfoEXT* pIndexInfo, 
    uint32_t instanceCount, 
    uint32_t firstInstance, 
    uint32_t stride, 
    const int32_t* pVertexOffset);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `drawCount` is the number of draws to execute, and **can** be zero.
- `pIndexInfo` is a pointer to an array of `VkMultiDrawIndexedInfoEXT` with index information to be drawn.
- `instanceCount` is the number of instances per draw.
- `firstInstance` is the instance ID of the first instance in each draw.
- `stride` is the byte stride between consecutive elements of `pIndexInfo`.
- `pVertexOffset` is NULL or a pointer to the value added to the vertex index before indexing into the vertex buffer. When specified, `VkMultiDrawIndexedInfoEXT::offset` is ignored.

The number of draws recorded is `drawCount`, with each draw reading, sequentially, a `firstIndex` and an `indexCount` from `pIndexInfo`. For each recorded draw, primitives are assembled as for `vkCmdDrawIndexed`, and drawn `instanceCount` times with `instanceIndex` starting with `firstInstance` and sequentially for each instance. If `pVertexOffset` is NULL, a `vertexOffset` is also read from `pIndexInfo`, otherwise the value from dereferencing `pVertexOffset` is used.
Valid Usage

• VUID-vkCmdDrawMultiIndexedEXT-magFilter-04553
If a VkSampler created with magFilter or minFilter equal to VK_FILTER_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

• VUID-vkCmdDrawMultiIndexedEXT-mipmapMode-04770
If a VkSampler created with.mipmapMode equal to VK_SAMPLER_MIPMAP_MODE_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

• VUID-vkCmdDrawMultiIndexedEXT-None-06479
If a VkImageView is sampled with depth comparison, the image view's format features must contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT

• VUID-vkCmdDrawMultiIndexedEXT-None-02691
If a VkImageView is accessed using atomic operations as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

• VUID-vkCmdDrawMultiIndexedEXT-None-07888
If a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

• VUID-vkCmdDrawMultiIndexedEXT-None-02692
If a VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT

• VUID-vkCmdDrawMultiIndexedEXT-None-02693
If the VK_EXT_filter_cubic extension is not enabled and any VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, it must not have a VkImageViewType of VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

• VUID-vkCmdDrawMultiIndexedEXT-filterCubic-02694
Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2

• VUID-vkCmdDrawMultiIndexedEXT-filterCubicMinmax-02695
Any VkImageView being sampled with VK_FILTER_CUBIC_EXT with a reduction mode of either VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX as a result of this command must have a VkImageViewType and format that supports cubic filtering together with minmax filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax returned by vkGetPhysicalDeviceImageFormatProperties2

• VUID-vkCmdDrawMultiIndexedEXT-cubicRangeClamp-09212
If the `cubicRangeClamp` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command **must not have a `VkSamplerReductionModeCreateInfo`**

\[
\text{reductionMode} \text{ equal to } \text{VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM}
\]

- VUID-vkCmdDrawMultiIndexedEXT-reductionMode-09213
  Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command **must** sample with `VK_FILTER_CUBIC_EXT`

- VUID-vkCmdDrawMultiIndexedEXT-selectableCubicWeights-09214
  If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command **must have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`**

- VUID-vkCmdDrawMultiIndexedEXT-flags-02696
  Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command **must** only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`

- VUID-vkCmdDrawMultiIndexedEXT-OpTypeImage-07027
  For any `VkImageView` being written as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view’s format features **must** contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`

- VUID-vkCmdDrawMultiIndexedEXT-OpTypeImage-07028
  For any `VkImageView` being read as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view’s format features **must** contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`

- VUID-vkCmdDrawMultiIndexedEXT-OpTypeImage-07029
  For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view’s buffer features **must** contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`

- VUID-vkCmdDrawMultiIndexedEXT-OpTypeImage-07030
  Any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown` then the view’s buffer features **must** contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`

- VUID-vkCmdDrawMultiIndexedEXT-None-08600
  For each set \( n \) that is statically used by a **bound shader**, a descriptor set **must** have been bound to \( n \) at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set \( n \), with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in **Pipeline Layout Compatibility**

- VUID-vkCmdDrawMultiIndexedEXT-None-08601
  For each push constant that is statically used by a **bound shader**, a push constant value **must** have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as
described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMultiIndexedEXT-maintenance4-08602
  If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMultiIndexedEXT-None-08114
  Descriptors in each bound descriptor set, specified via vkCmdBindDescriptorSets, must be valid if they are statically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was not created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMultiIndexedEXT-None-08115
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdBindDescriptorSets, the bound VkPipeline must have been created without VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMultiIndexedEXT-None-08116
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMultiIndexedEXT-None-08604
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDrawMultiIndexedEXT-None-08117
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdSetDescriptorBufferOffsetsEXT, the bound VkPipeline must have been created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMultiIndexedEXT-None-08119
  If a descriptor is dynamically used with a VkPipeline created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdDrawMultiIndexedEXT-None-08605
  If a descriptor is dynamically used with a VkShaderEXT created with a VkDescriptorsetLayout that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdDrawMultiIndexedEXT-None-08606
  If the shaderObject feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command

- VUID-vkCmdDrawMultiIndexedEXT-None-08607
  If the shaderObject is enabled, either a valid pipeline must be bound to the pipeline bind
point used by this command, or a valid combination of valid and **VK_NULL_HANDLE** shader objects **must** be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- **VUID-vkCmdDrawMultiIndexedEXT-None-08608**
  If a pipeline is bound to the pipeline bind point used by this command, there **must** not have been any calls to dynamic state setting commands for any state not specified as dynamic in the **VkPipeline** object bound to the pipeline bind point used by this command, since that pipeline was bound

- **VUID-vkCmdDrawMultiIndexedEXT-None-08609**
  If the **VkPipeline** object bound to the pipeline bind point used by this command or any **VkShaderEXT** bound to a stage corresponding to the pipeline bind point used by this command accesses a **VkSampler** object that uses unnormalized coordinates, that sampler **must** not be used to sample from any **VkImage** with a **VkImageView** of the type **VK_IMAGE_VIEW_TYPE_3D**, **VK_IMAGE_VIEW_TYPE_CUBE**, **VK_IMAGE_VIEW_TYPE_1D_ARRAY**, **VK_IMAGE_VIEW_TYPE_2D_ARRAY** or **VK_IMAGE_VIEW_TYPE_CUBE_ARRAY**, in any shader stage

- **VUID-vkCmdDrawMultiIndexedEXT-None-08610**
  If the **VkPipeline** object bound to the pipeline bind point used by this command or any **VkShaderEXT** bound to a stage corresponding to the pipeline bind point used by this command accesses a **VkSampler** object that uses unnormalized coordinates, that sampler **must** not be used with any of the SPIR-V **OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage

- **VUID-vkCmdDrawMultiIndexedEXT-None-08611**
  If the **VkPipeline** object bound to the pipeline bind point used by this command or any **VkShaderEXT** bound to a stage corresponding to the pipeline bind point used by this command accesses a **VkSampler** object that uses unnormalized coordinates, that sampler **must** not be used with any of the SPIR-V **OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage

- **VUID-vkCmdDrawMultiIndexedEXT-uniformBuffers-06935**
  If any stage of the **VkPipeline** object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either **VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT** or **VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT** for **uniformBuffers**, and the **robustBufferAccess** feature is not enabled, that stage **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawMultiIndexedEXT-None-08612**
  If the **robustBufferAccess** feature is not enabled, and any **VkShaderEXT** bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawMultiIndexedEXT-storageBuffers-06936**
  If any stage of the **VkPipeline** object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either **VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT** or **VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT** for **storageBuffers**, and the **robustBufferAccess** feature is not enabled, that stage **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point
and the `robustBufferAccess` feature is not enabled, that stage **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawMultiIndexedEXT-None-08613**
  If the `robustBufferAccess` feature is not enabled, and any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawMultiIndexedEXT-commandBuffer-02707**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, any resource accessed by **bound shaders** **must** not be a protected resource

- **VUID-vkCmdDrawMultiIndexedEXT-None-06550**
  If a **bound shader** accesses a `VkSampler` or `VkImageView` object that enables `sampler Y′C′R′aC Conversion`, that object **must** only be used with `OpImageSample*` or `OpImageSparseSample*` instructions

- **VUID-vkCmdDrawMultiIndexedEXT-ConstOffset-06551**
  If a **bound shader** accesses a `VkSampler` or `VkImageView` object that enables `sampler Y′C′R′aC Conversion`, that object **must** not use the `ConstOffset` and `Offset` operands

- **VUID-vkCmdDrawMultiIndexedEXT-viewType-07752**
  If a `VkImageView` is accessed as a result of this command, then the image view’s `viewType` **must** match the `Dim` operand of the `OpTypeImage` as described in Instruction/Sampler/Image View Validation

- **VUID-vkCmdDrawMultiIndexedEXT-format-07753**
  If a `VkImageView` is accessed as a result of this command, then the numeric type of the image view’s `format` and the `Sampled Type` operand of the `OpTypeImage` **must** match

- **VUID-vkCmdDrawMultiIndexedEXT-OpImageWrite-08795**
  If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the image view’s `format`

- **VUID-vkCmdDrawMultiIndexedEXT-OpImageWrite-08796**
  If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have four components

- **VUID-vkCmdDrawMultiIndexedEXT-OpImageWrite-04469**
  If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the buffer view’s `format`

- **VUID-vkCmdDrawMultiIndexedEXT-SampledType-04470**
  If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 64

- **VUID-vkCmdDrawMultiIndexedEXT-SampledType-04471**
  If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is
accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction **must** have a Width of 32

- **VUID-vkCmdDrawMultiIndexedEXT-SampledType-04472**
  If a VkBufferView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction **must** have a Width of 64

- **VUID-vkCmdDrawMultiIndexedEXT-SampledType-04473**
  If a VkBufferView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction **must** have a Width of 32

- **VUID-vkCmdDrawMultiIndexedEXT-sparseImageInt64Atomics-04474**
  If the sparseImageInt64Atomics feature is not enabled, VkImage objects created with the VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT flag **must** not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- **VUID-vkCmdDrawMultiIndexedEXT-sparseImageInt64Atomics-04475**
  If the sparseImageInt64Atomics feature is not enabled, VkBuffer objects created with the VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT flag **must** not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- **VUID-vkCmdDrawMultiIndexedEXT-OpImageWeightedSampleQCOM-06971**
  If OpImageWeightedSampleQCOM is used to sample a VkImageView as a result of this command, then the image view’s format features **must** contain VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM

- **VUID-vkCmdDrawMultiIndexedEXT-OpImageWeightedSampleQCOM-06972**
  If OpImageWeightedSampleQCOM uses a VkImageView as a sample weight image as a result of this command, then the image view’s format features **must** contain VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM

- **VUID-vkCmdDrawMultiIndexedEXT-OpImageBoxFilterQCOM-06973**
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view’s format features **must** contain VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM

- **VUID-vkCmdDrawMultiIndexedEXT-OpImageBlockMatchSSDQCOM-06974**
  If OpImageBlockMatchSSDQCOM is used to read from an VkImageView as a result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation

- **VUID-vkCmdDrawMultiIndexedEXT-OpImageBlockMatchSADQCOM-06975**
  If OpImageBlockMatchSADQCOM or OpImageBlockMatchSSDQCOM is used to read from a reference image as result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation

- **VUID-vkCmdDrawMultiIndexedEXT-OpImageWeightedSampleQCOM-06977**
If `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

- VUID-vkCmdDrawMultiIndexedEXT-OpImageWeightedSampleQCOM-06978
  If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must not have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

- VUID-vkCmdDrawMultiIndexedEXT-OpImageBlockMatchWindow-09215
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

- VUID-vkCmdDrawMultiIndexedEXT-OpImageBlockMatchWindow-09216
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view’s format must be a single-component format.

- VUID-vkCmdDrawMultiIndexedEXT-OpImageBlockMatchWindow-09217
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from a reference image as a result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.

- VUID-vkCmdDrawMultiIndexedEXT-None-07288
  Any shader invocation executed by this command must terminate.

- VUID-vkCmdDrawMultiIndexedEXT-renderPass-02684
  The current render pass must be compatible with the `renderPass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

- VUID-vkCmdDrawMultiIndexedEXT-subpass-02685
  The subpass index of the current render pass must be equal to the `subpass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

- VUID-vkCmdDrawMultiIndexedEXT-None-07748
  If any shader statically accesses an input attachment, a valid descriptor must be bound to the pipeline via a descriptor set.

- VUID-vkCmdDrawMultiIndexedEXT-OpTypeImage-07468
  If any shader executed by this pipeline accesses an `OpTypeImage` variable with a `Dim` operand of `SubpassData`, it must be decorated with an `InputAttachmentIndex` that corresponds to a valid input attachment in the current subpass.

- VUID-vkCmdDrawMultiIndexedEXT-None-07469
  Input attachment views accessed in a subpass must be created with the same `VkFormat` as the corresponding subpass definition, and be created with a `VkImageView` that is
compatible with the attachment referenced by the subpass' pInputAttachments [InputAttachmentIndex] in the currently bound VkFramebuffer as specified by Fragment Input Attachment Compatibility

- VUID-vkCmdDrawMultiIndexedEXT-None-06537
  Memory backing image subresources used as attachments in the current render pass must not be written in any way other than as an attachment by this command

- VUID-vkCmdDrawMultiIndexedEXT-None-09000
  If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:
  - the VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
  - the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_COLOR_BIT and
    - there is no currently bound graphics pipeline or
    - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawMultiIndexedEXT-None-09001
  If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:
  - the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
  - the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_DEPTH_BIT and
    - there is no currently bound graphics pipeline or
    - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawMultiIndexedEXT-None-09002
  If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:
  - the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
  - the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_STENCIL_BIT and
    - there is no currently bound graphics pipeline or
    - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in...
any way other than as an attachment by this command

• VUID-vkCmdDrawMultiIndexedEXT-None-09003
  If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it **must** not be accessed in any way other than as an attachment, storage image, or sampled image by this command

• VUID-vkCmdDrawMultiIndexedEXT-None-06539
  If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command **must** not write to that image subresource as an attachment

• VUID-vkCmdDrawMultiIndexedEXT-None-06886
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, **depth writes must be disabled**

• VUID-vkCmdDrawMultiIndexedEXT-None-06887
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back **writeMask** are not zero, and stencil test is enabled, **all stencil ops must be** **VK_STENCIL_OP_KEEP**

• VUID-vkCmdDrawMultiIndexedEXT-None-07831
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_VIEWPORT** dynamic state enabled then **vkCmdSetViewport** **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-07832
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SCISSOR** dynamic state enabled then **vkCmdSetScissor** **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-07833
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_LINE_WIDTH** dynamic state enabled then **vkCmdSetLineWidth** **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08617
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetPolygonModeEXT** in the current command buffer set **polygonMode** to **VK_POLYGON_MODE_LINE**, **vkCmdSetLineWidth** **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08618
  If a shader object is bound to the **VK_SHADER_STAGE_VERTEX_BIT** stage, and the most recent call to **vkCmdSetPrimitiveTopology** in the current command buffer set **primitiveTopology** to any line topology, **vkCmdSetLineWidth** **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08619
  If a shader object that outputs line primitives is bound to the **VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT** or **VK_SHADER_STAGE_GEOMETRY_BIT** stage, **vkCmdSetLineWidth** **must** have been called in the current command buffer prior to this drawing command
• VUID-vkCmdDrawMultiIndexedEXT-None-07834
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BIAS` dynamic state enabled then `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiIndexedEXT-None-08620
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthBiasEnable` in the current command buffer set `depthBiasEnable` to `VK_TRUE`, `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiIndexedEXT-None-07835
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_BLEND_CONSTANTS` dynamic state enabled then `vkCmdSetBlendConstants` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiIndexedEXT-None-08621
  If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer set any element of `pColorBlendEnables` to `VK_TRUE`, and the most recent call to `vkCmdSetColorBlendEquationEXT` in the current command buffer set the same element of `pColorBlendEquations` to a `VkColorBlendEquationEXT` structure with any `VkBlendFactor` member with a value of `VK_BLEND_FACTOR_CONSTANT_COLOR`, `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR`, `VK_BLEND_FACTOR_CONSTANT_ALPHA`, or `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA`, `vkCmdSetBlendConstants` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiIndexedEXT-None-07836
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS` dynamic state enabled then `vkCmdSetDepthBounds` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiIndexedEXT-None-08622
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthBoundsTestEnable` in the current command buffer set `depthBoundsTestEnable` to `VK_TRUE`, then `vkCmdSetDepthBounds` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiIndexedEXT-None-07837
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK` dynamic state enabled then `vkCmdSetStencilCompareMask` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMultiIndexedEXT-None-08623
  If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-07838
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_WRITE_MASK dynamic state enabled then vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08624
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-07839
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_REFERENCE dynamic state enabled then vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08625
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-maxMultiviewInstanceIndex-02688
  If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex

• VUID-vkCmdDrawMultiIndexedEXT-sampleLocationsEnable-02689
  If the bound graphics pipeline was created with VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable set to VK_TRUE and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set

• VUID-vkCmdDrawMultiIndexedEXT-None-06666
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT dynamic state enabled then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08626
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetSampleLocationsEnableEXT in the current command buffer set sampleLocationsEnable to VK_TRUE, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CULL_MODE` dynamic state enabled then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` dynamic state enabled then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.
• VUID-vkCmdDrawMultiIndexedEXT-None-07845
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_DEPTH_COMPARE_OP  dynamic state enabled then
  vkCmdSetDepthCompareOp must have been called in the current command buffer prior
  to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08631
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, and the most recent call to
  vkCmdSetDepthTestEnable in the current command buffer set depthTestEnable to VK_TRUE,
  then vkCmdSetDepthCompareOp must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-07846
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE dynamic state enabled then
  vkCmdSetDepthBoundsTestEnable must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08632
  If a shader object is bound to any graphics stage, and the depthBounds feature is enabled,
  and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command
  buffer set rasterizerDiscardEnable to VK_FALSE, then the vkCmdSetDepthBoundsTestEnable
  must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-07847
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE dynamic state enabled then
  vkCmdSetStencilTestEnable must have been called in the current command buffer prior
  to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08633
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, then the vkCmdSetStencilTestEnable must have been
  called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-07848
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_STENCIL_OP dynamic state enabled then
  vkCmdSetStencilOp must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08634
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, and the most recent call to
  vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to
  VK_TRUE, then vkCmdSetStencilOp must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-viewportCount-03417
  If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT dynamic state enabled, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `viewportCount` parameter of `VkPipelineViewportStateCreateInfo::viewportCount` of the pipeline.

- **VUID-vkCmdDrawMultiIndexedEXT-scissorCount-03418**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, then `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `scissorCount` parameter of `vkCmdSetScissorWithCount` must match the `viewportCount` parameter of `VkPipelineViewportStateCreateInfo::viewportCount` of the pipeline.

- **VUID-vkCmdDrawMultiIndexedEXT-viewportCount-03419**
  If the bound graphics pipeline state was created with both the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic states enabled then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- **VUID-vkCmdDrawMultiIndexedEXT-None-08635**
  If a shader object is bound to any graphics stage, then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- **VUID-vkCmdDrawMultiIndexedEXT-viewportCount-04137**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportWScalingStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMultiIndexedEXT-viewportCount-04138**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV dynamic states enabled then the bound graphics pipeline must have been created with `VkPipelineViewportWScalingStateCreateInfoNV::viewportCount` greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV`.

- **VUID-vkCmdDrawMultiIndexedEXT-None-09232**
  If a shader object is bound to any graphics stage, and the VK_NV_clip_space_w_scaling extension is enabled on the device, then `vkCmdSetViewportWScalingNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiIndexedEXT-None-08636**
  If a shader object is bound to any graphics stage, and the VK_NV_clip_space_w_scaling extension is enabled on the device, then `vkCmdSetViewportWScalingNV` must have been called in the current command buffer prior to this drawing command.
extension is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMultiIndexedEXT-viewportCount-04139**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportShadingRateImageStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMultiIndexedEXT-viewportCount-04140**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMultiIndexedEXT-shadingRateImage-09233**
  If the `shadingRateImage` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoarseSampleOrderNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiIndexedEXT-shadingRateImage-09234**
  If a shader object is bound to any graphics stage, and the `shadingRateImage` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetShadingRateImageEnableNV` in the current command buffer set `shadingRateImageEnable` to `VK_TRUE`, then `vkCmdSetViewportShadingRatePaletteNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiIndexedEXT-None-08637**
  If a shader object is bound to any graphics stage, and the `shadingRateImage` feature is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMultiIndexedEXT-VkPipelineVieportCreateInfo-04141**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportSwizzleStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMultiIndexedEXT-VkPipelineVieportCreateInfo-04142**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportExclusiveScissorStateCreateInfoNV` structure chained from
 VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have been created with VkPipelineViewportExclusiveScissorStateCreateInfoNV ::exclusiveScissorCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawMultiIndexedEXT-None-07878
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV dynamic state enabled then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-07879
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV dynamic state enabled then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-exclusiveScissor-09235
  If a shader object is bound to any graphics stage, and the exclusiveScissor feature is enabled, then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08638
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetExclusiveScissorEnableNV in the current command buffer set any element of pExclusiveScissorEnables to VK_TRUE, then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-04876
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE dynamic state enabled then vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08639
  If a shader object is bound to any graphics stage, then vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-04877
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE dynamic state enabled then vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08640
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-logicOp-04878
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_EXT dynamic state enabled then vkCmdSetLogicOpEXT must have been called in the current
command buffer prior to this drawing command and the \texttt{logicOp must} be a valid VkLogicOp value

- **VUID-vkCmdDrawMultiIndexedEXT-None-08641**
  If a shader object is bound to the \texttt{VK_SHADER_STAGE_FRAGMENT_BIT} stage, and the \texttt{logicOp} feature is enabled on the device, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetLogicOpEXT must} have been called in the current command buffer prior to this drawing command and the \texttt{logicOp must} be a valid \texttt{VkLogicOp} value

- **VUID-vkCmdDrawMultiIndexedEXT-PrimitiveFragmentShadingRateWithMultipleViewports-04552**
  If the \texttt{primitiveFragmentShadingRateWithMultipleViewports} limit is not supported, the bound graphics pipeline was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the \texttt{PrimitiveShadingRateKHR} built-in, then \texttt{vkCmdSetViewportWithCount must} have been called in the current command buffer prior to this drawing command, and the \texttt{viewportCount parameter of vkCmdSetViewportWithCount must be 1}

- **VUID-vkCmdDrawMultiIndexedEXT-blendEnable-04727**
  If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view's \texttt{format features} do not contain \texttt{VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT}, then the \texttt{blendEnable member of the corresponding element of the pAttachments member of pColorBlendState must be VK_FALSE}

- **VUID-vkCmdDrawMultiIndexedEXT-None-08644**
  If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then for each color attachment in the render pass, if the corresponding image view's \texttt{format features} do not contain \texttt{VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT}, then the corresponding member of \texttt{pColorBlendEnables} in the most recent call to \texttt{vkCmdSetColorBlendEnableEXT} in the current command buffer that affected that attachment index \texttt{must have been VK_FALSE}

- **VUID-vkCmdDrawMultiIndexedEXT-multisampledRenderToSingleSampled-07284**
  If rasterization is not disabled in the bound graphics pipeline, and none of the \texttt{VK_AMD_mixed_attachment_samples} extension, the \texttt{VK_NV_framebuffer_mixed_samples} extension, or the \texttt{multisampledRenderToSingleSampled} feature is enabled, then \texttt{rasterizationSamples for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments}

- **VUID-vkCmdDrawMultiIndexedEXT-None-08644**
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then the most recent call to `vkCmdSetRasterizationSamplesEXT` in the current command buffer must have set `rasterizationSamples` to be the same as the number of samples for the current render pass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawMultiIndexedEXT-None-08876**
  If a shader object is bound to any graphics stage, the current render pass instance must have been begun with `vkCmdBeginRendering`.

- **VUID-vkCmdDrawMultiIndexedEXT-imageView-06172**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the layout member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment.

- **VUID-vkCmdDrawMultiIndexedEXT-imageView-06173**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the layout member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment.

- **VUID-vkCmdDrawMultiIndexedEXT-imageView-06174**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the layout member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment.

- **VUID-vkCmdDrawMultiIndexedEXT-imageView-06175**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the layout member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment.

- **VUID-vkCmdDrawMultiIndexedEXT-imageView-06176**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the layout member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment.

- **VUID-vkCmdDrawMultiIndexedEXT-viewMask-06178**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo::viewMask` equal to `VkRenderingInfo::viewMask.`
If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo::colorAttachmentCount` equal to `VkRenderingInfo::colorAttachmentCount`.

If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline.

If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline, or the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`.

If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` must have the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then the `attachmentCount` parameter of `vkCmdSetColorWriteEnableEXT` must be greater than or equal to the `VkPipelineColorBlendStateCreateInfo::attachmentCount` of the currently bound graphics pipeline.

If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then the `attachmentCount` parameter of `vkCmdSetColorWriteEnableEXT` must be greater than or equal to the `VkPipelineColorBlendStateCreateInfo::attachmentCount` of the currently bound graphics pipeline.
pipeline

• VUID-vkCmdDrawMultiIndexedEXT-None-08647  
If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `attachmentCount` parameter of most recent call to `vkCmdSetColorWriteEnableEXT` in the current command buffer **must** be greater than or equal to the number of color attachments in the current render pass instance

• VUID-vkCmdDrawMultiIndexedEXT-None-07751  
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEXT` **must** have been called in the current command buffer prior to this drawing command for each discard rectangle in `VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount`

• VUID-vkCmdDrawMultiIndexedEXT-None-07880  
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEnableEXT` **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-rasterizerDiscardEnable-09236  
If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDiscardRectangleEXT` **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08648  
If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDiscardRectangleEnableEXT` in the current command buffer set `discardRectangleEnable` to `VK_TRUE`, then `vkCmdSetDiscardRectangleModeEXT` **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08649  
If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDiscardRectangleEnableEXT` in the current command buffer set `discardRectangleEnable` to `VK_TRUE`, then `vkCmdSetDiscardRectangleModeEXT` **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-dynamicRenderingUnusedAttachments-08913  
If the current render pass instance was begun with `vkCmdBeginRendering`, the
If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{dynamicRenderingUnusedAttachments} feature is not enabled, and \texttt{VkRenderingInfo::pDepthAttachment->imageView} was \texttt{VK_NULL_HANDLE}, the value of \texttt{VkPipelineRenderingCreateInfo::depthAttachmentFormat} used to create the currently bound graphics pipeline \textbf{must} be equal to \texttt{VK_FORMAT_UNDEFINED}.

- \textbf{VUID-vkCmdDrawMultiIndexedEXT-dynamicRenderingUnusedAttachments-08914}

  If current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{dynamicRenderingUnusedAttachments} feature is not enabled, and \texttt{VkRenderingInfo::pDepthAttachment->imageView} was not \texttt{VK_NULL_HANDLE}, the value of \texttt{VkPipelineRenderingCreateInfo::depthAttachmentFormat} used to create the currently bound graphics pipeline \textbf{must} be equal to the \texttt{VkFormat} used to create \texttt{VkRenderingInfo::pDepthAttachment->imageView}.

- \textbf{VUID-vkCmdDrawMultiIndexedEXT-dynamicRenderingUnusedAttachments-08915}

  If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{dynamicRenderingUnusedAttachments} feature is enabled, \texttt{VkRenderingInfo::pDepthAttachment->imageView} was \texttt{VK_NULL_HANDLE}, and the value of \texttt{VkPipelineRenderingCreateInfo::depthAttachmentFormat} used to create the currently bound graphics pipeline was not equal to the \texttt{VkFormat} used to create \texttt{VkRenderingInfo::pDepthAttachment->imageView}, the value of the format \textbf{must} be \texttt{VK_FORMAT_UNDEFINED}.

- \textbf{VUID-vkCmdDrawMultiIndexedEXT-dynamicRenderingUnusedAttachments-08916}

  If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{dynamicRenderingUnusedAttachments} feature is not enabled, and \texttt{VkRenderingInfo::pStencilAttachment->imageView} was \texttt{VK_NULL_HANDLE}, the value of \texttt{VkPipelineRenderingCreateInfo::stencilAttachmentFormat} used to create the currently bound graphics pipeline \textbf{must} be equal to \texttt{VK_FORMAT_UNDEFINED}.

- \textbf{VUID-vkCmdDrawMultiIndexedEXT-dynamicRenderingUnusedAttachments-08917}

  If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{dynamicRenderingUnusedAttachments} feature is not enabled, and \texttt{VkRenderingInfo::pStencilAttachment->imageView} was not \texttt{VK_NULL_HANDLE}, and the value of \texttt{VkPipelineRenderingCreateInfo::stencilAttachmentFormat} used to create the currently bound graphics pipeline was not equal to the \texttt{VkFormat} used to create \texttt{VkRenderingInfo::pStencilAttachment->imageView}, the value of the format \textbf{must} be \texttt{VK_FORMAT_UNDEFINED}.

- \textbf{VUID-vkCmdDrawMultiIndexedEXT-dynamicRenderingUnusedAttachments-08918}

  If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{dynamicRenderingUnusedAttachments} feature is enabled, \texttt{VkRenderingInfo::pStencilAttachment->imageView} was \texttt{VK_NULL_HANDLE}, and the value of \texttt{VkPipelineRenderingCreateInfo::stencilAttachmentFormat} used to create the currently bound graphics pipeline was not equal to the \texttt{VkFormat} used to create \texttt{VkRenderingInfo::pStencilAttachment->imageView}, the value of the format \textbf{must} be \texttt{VK_FORMAT_UNDEFINED}.

- \textbf{VUID-vkCmdDrawMultiIndexedEXT-imageView-06183}

  If the current render pass instance was begun with \texttt{vkCmdBeginRendering} and \texttt{VkPipelineRenderingCreateInfo::depthAttachmentFormat} was not \texttt{VK_NULL_HANDLE}, the currently bound graphics pipeline \textbf{must} have been created with \texttt{VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR}.

- \textbf{VUID-vkCmdDrawMultiIndexedEXT-imageView-06184}

  If the current render pass instance was begun with \texttt{vkCmdBeginRendering} and
VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline **must** have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT

- VUID-vkCmdDrawMultiIndexedEXT-colorAttachmentCount-06185
  If the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE **must** have been created with a sample count equal to the corresponding element of the pColorAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline

- VUID-vkCmdDrawMultiIndexedEXT-pDepthAttachment-06186
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of the depthStencilAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline **must** be equal to the sample count used to create VkRenderingInfo::pDepthAttachment->imageView

- VUID-vkCmdDrawMultiIndexedEXT-pStencilAttachment-06187
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, the value of the depthStencilAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline **must** be equal to the sample count used to create VkRenderingInfo::pStencilAttachment->imageView

- VUID-vkCmdDrawMultiIndexedEXT-multisampledRenderToSingleSampled-07285
  If the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled feature is not enabled, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE **must** have been created with a sample count equal to the value of rasterizationSamples for the currently bound graphics pipeline

- VUID-vkCmdDrawMultiIndexedEXT-multisampledRenderToSingleSampled-07286
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of rasterizationSamples for the currently bound graphics pipeline **must** be equal to the sample count used to create VkRenderingInfo::pDepthAttachment->imageView
If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

If this command has been called inside a render pass instance started with `vkCmdBeginRendering`, and the `pNext` chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to `VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline must have been created with a `VkGraphicsPipelineCreateInfo::renderPass` equal to `VK_NULL_HANDLE`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the `VkRenderingInfo::pColorAttachments->imageView` was not `VK_NULL_HANDLE`, then the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, stencil test is enabled and the `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

If the `VkMultisampledRenderToSingleSampledInfoEXT::multisampledRenderToSingleSampledEnable` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, rasterization discard must not be enabled.

If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, rasterization discard must not be enabled.
If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, the bound graphics pipeline must not have been created with a non-zero value in VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream

- **VUID-vkCmdDrawMultiIndexedEXT-None-07619**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT` dynamic state enabled then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-07620**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-09237**
  If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-08650**
  If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-07621**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-08651**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-07622**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` dynamic state enabled then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-08652**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-07623**
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_SAMPLE_MASK_EXT dynamic state enabled then 
vkCmdSetSampleMaskEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08653
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, then 
vkCmdSetSampleMaskEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-07624
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled then
  vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-alphaToCoverageEnable-08919
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled, and
  alphaToCoverageEnable was VK_TRUE in the last call to
  vkCmdSetAlphaToCoverageEnableEXT, then the Fragment Output Interface must contain
  a variable for the alpha Component word in Location 0 at Index 0

• VUID-vkCmdDrawMultiIndexedEXT-None-08654
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, then 
vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-alphaToCoverageEnable-08920
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetAlphaToCoverageEnableEXT in the current command buffer set
  alphaToCoverageEnable to VK_TRUE, then the Fragment Output Interface must contain a
  variable for the alpha Component word in Location 0 at Index 0

• VUID-vkCmdDrawMultiIndexedEXT-None-07625
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT dynamic state enabled then
  vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-08655
  If the alphaToOne feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, then 
vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMultiIndexedEXT-None-07626
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT dynamic state enabled then
  vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command
If the `logicOp` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` for any attachment set that attachment's value in `pColorBlendEnables` to `VK_TRUE`, then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

If the `geometryStreams` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` dynamic state enabled then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

If the `geometryStreams` feature is enabled, and a shader object is bound to the
VK_SHADER_STAGE_GEOMETRY_BIT stage, then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiIndexedEXT-None-07631**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiIndexedEXT-None-08661**
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiIndexedEXT-None-07632**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiIndexedEXT-None-08662**
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetConservativeRasterizationModeEXT` in the current command buffer set `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`, then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiIndexedEXT-None-07633**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiIndexedEXT-None-08663**
  If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMulti IndexedEXT-None-07634**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiIndexedEXT-None-08664**
  If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then
vkCmdSetSampleLocationsEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-07635
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT dynamic state enabled then vkCmdSetColorBlendAdvancedEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-07636
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT dynamic state enabled then vkCmdSetProvokingVertexModeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-08665
  If the VK_EXT_provoking_vertex extension is enabled, and a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, then vkCmdSetProvokingVertexModeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-07637
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic state enabled then vkCmdSetLineRasterizationModeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-08666
  If the VK_EXT_line_rasterization extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetPolygonModeEXT in the current command buffer set polygonMode to VK_POLYGON_MODE_LINE, then vkCmdSetLineRasterizationModeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-08667
  If the VK_EXT_line_rasterization extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to vkCmdSetPrimitiveTopology in the current command buffer set primitiveTopology to any line topology, then vkCmdSetLineRasterizationModeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-08668
  If the VK_EXT_line_rasterization extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then vkCmdSetLineRasterizationModeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-07638
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT dynamic state enabled then vkCmdSetLineStippleEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-08669
If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-08670
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-08671
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-07849
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_EXT` dynamic state enabled then `vkCmdSetLineStippleEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-08672
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetLineStippleEnableEXT` in the current command buffer set `stippledLineEnable` to `VK_TRUE`, then `vkCmdSetLineStippleEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-07639
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT` dynamic state enabled then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-08673
  If the `depthClipControl` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-07640
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV` dynamic state enabled then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-08674
  If the `VK_NV_clip_space_w_scaling` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-07641
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-08675**
  If the `VK_NV_viewport_swizzle` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-07642**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-08676**
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-07643**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` dynamic state enabled then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-08677**
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set `coverageToColorEnable` to `VK_TRUE`, then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-07644**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-08678**
  If the `VK_NV-framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-07645**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command
command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-08679**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationModeNV` in the current command buffer set `coverageModulationMode` to any value other than `VK_COVERAGE_MODULATION_MODE_NONE_NV`, then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-07646**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-08680**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationTableEnableNV` in the current command buffer set `coverageModulationTableEnable` to `VK_TRUE`, then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-07647**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV` dynamic state enabled then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-pipelineFragmentShadingRate-09238**
  If the `pipelineFragmentShadingRate` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFragmentShadingRateKHR` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-08681**
  If the `shadingRateImage` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-07648**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV` dynamic state enabled then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-08682**
  If the `representativeFragmentTest` feature is enabled, and a shader object is bound to any
graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-07649**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-None-08683**
  If the `coverageReductionMode` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMultiIndexedEXT-pColorBlendEnables-07470**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` state enabled and the last call to `vkCmdSetColorBlendEnableEXT` set `pColorBlendEnables` for any attachment to `VK_TRUE`, then for those attachments in the subpass the corresponding image view's format features must contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`

- **VUID-vkCmdDrawMultiIndexedEXT-rasterizationSamples-07471**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must follow the rules for a zero-attachment subpass

- **VUID-vkCmdDrawMultiIndexedEXT-samples-07472**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter used to create the bound graphics pipeline

- **VUID-vkCmdDrawMultiIndexedEXT-samples-07473**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter in the last call to `vkCmdSetRasterizationSamplesEXT`

- **VUID-vkCmdDrawMultiIndexedEXT-rasterizationSamples-07474**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and neither the `VK_AMD_mixed_attachment_samples` nor the `VK_NV_framebuffer_mixed_samples` extensions are enabled, then the `rasterizationSamples` in the last call to
vkCmdSetRasterizationSamplesEXT must be the same as the current subpass color and/or depth/stencil attachments

- VUID-vkCmdDrawMultiIndexedEXT-None-09211
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a VkMultisampledRenderToSingleSampledInfoEXT structure with multisampledRenderToSingleSampledEnable equal to VK_TRUE, then the rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT must be the same as the rasterizationSamples member of that structure

- VUID-vkCmdDrawMultiIndexedEXT-firstAttachment-07476
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendEnableEXT calls must specify an enable for all active color attachments in the current subpass

- VUID-vkCmdDrawMultiIndexedEXT-firstAttachment-07477
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT dynamic state enabled then vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendEquationEXT calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled

- VUID-vkCmdDrawMultiIndexedEXT-firstAttachment-07478
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT dynamic state enabled then vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorWriteMaskEXT calls must specify the color write mask for all active color attachments in the current subpass

- VUID-vkCmdDrawMultiIndexedEXT-firstAttachment-07479
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT dynamic state enabled then vkCmdSetColorBlendAdvancedEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendAdvancedEXT calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled

- VUID-vkCmdDrawMultiIndexedEXT-advancedBlendMaxColorAttachments-07480
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT and VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic states enabled and the last calls to vkCmdSetColorBlendEnableEXT and vkCmdSetColorBlendAdvancedEXT have enabled advanced blending, then the number of
active color attachments in the current subpass must not exceed advancedBlendMaxColorAttachments

• VUID-vkCmdDrawMultiIndexedEXT-primitivesGeneratedQueryWithNonZeroStreams-07481
If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, and the bound graphics pipeline was created with VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT state enabled, the last call to vkCmdSetRasterizationStreamEXT must have set the rasterizationStream to zero.

• VUID-vkCmdDrawMultiIndexedEXT-sampleLocationsPerPixel-07482
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state disabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples member of the VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with.

• VUID-vkCmdDrawMultiIndexedEXT-sampleLocationsPerPixel-07483
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples parameter of the last call to vkCmdSetRasterizationSamplesEXT.

• VUID-vkCmdDrawMultiIndexedEXT-sampleLocationsEnable-07484
If the bound graphics pipeline was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set.

• VUID-vkCmdDrawMultiIndexedEXT-sampleLocationsEnable-07485
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled and the sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the sampleLocationsInfo.sampleLocationGridSize.width in the last call to vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples.

• VUID-vkCmdDrawMultiIndexedEXT-sampleLocationsEnable-07486
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the sampleLocationsInfo.sampleLocationGridSize.height in the last call to
vkCmdSetSampleLocationsEXT **must** evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.height` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling `rasterizationSamples`.

- **VUID-vkCmdDrawMultiIndexedEXT-sampleLocationsEnable-07487**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, the fragment shader code **must** not statically use the extended instruction `InterpolateAtSample`.

- **VUID-vkCmdDrawMultiIndexedEXT-sampleLocationsEnable-07936**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.width` **must** evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.width` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling the value of `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawMultiIndexedEXT-sampleLocationsEnable-07937**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.height` **must** evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.height` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling the value of `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawMultiIndexedEXT-sampleLocationsEnable-07938**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationsPerPixel` **must** equal `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawMultiIndexedEXT-coverageModulationTableEnable-07488**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageModulationTableEnableNV` set `coverageModulationTableEnable` to `VK_TRUE`, then the `coverageModulationTableCount` parameter in the last call to `vkCmdSetCoverageModulationTableNV` **must** equal the current `rasterizationSamples` divided by the number of color samples in the current subpass.

- **VUID-vkCmdDrawMultiIndexedEXT-rasterizationSamples-07489**
If the \texttt{VK_NV_framebuffer_mixed_samples} extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current \texttt{rasterizationSamples} must be the same as the sample count of the depth/stencil attachment.

- VUID-vkCmdDrawMultiIndexedEXT-coverageToColorEnable-07490
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV} state enabled and the last call to \texttt{vkCmdSetCoverageToColorEnableNV} set the \texttt{coverageToColorEnable} to \texttt{VK_TRUE}, then the current subpass must have a color attachment at the location selected by the last call to \texttt{vkCmdSetCoverageToColorLocationNV} \texttt{coverageToColorLocation}, with a \texttt{VkFormat} of \texttt{VK_FORMAT_R8_UINT}, \texttt{VK_FORMAT_R8_SINT}, \texttt{VK_FORMAT_R16_UINT}, \texttt{VK_FORMAT_R16_SINT}, \texttt{VK_FORMAT_R32_UINT}, or \texttt{VK_FORMAT_R32_SINT}.

- VUID-vkCmdDrawMultiIndexedEXT-coverageReductionMode-07491
  If this \texttt{VK_NV_coverage_reduction_mode} extension is enabled, the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV} and \texttt{VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT} states enabled, the current coverage reduction mode \texttt{coverageReductionMode}, then the current \texttt{rasterizationSamples}, and the sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by \texttt{vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV}.

- VUID-vkCmdDrawMultiIndexedEXT-viewportCount-07492
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} dynamic state enabled, but not the \texttt{VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV} dynamic state enabled, then the bound graphics pipeline must have been created with \texttt{VkPipelineViewportSwizzleStateCreateInfoNV} \texttt{viewportCount} greater or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}.

- VUID-vkCmdDrawMultiIndexedEXT-viewportCount-07493
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} and \texttt{VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV} dynamic states enabled then the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportSwizzleNV} must be greater than or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}.

- VUID-vkCmdDrawMultiIndexedEXT-rasterizationSamples-07494
  If the \texttt{VK_NV_framebuffer_mixed_samples} extension is enabled, and if the current subpass has any color attachments and \texttt{rasterizationSamples} of the last call to \texttt{vkCmdSetRasterizationSamplesEXT} is greater than the number of color samples, then the pipeline \texttt{sampleShadingEnable} must be \texttt{VK_FALSE}.

- VUID-vkCmdDrawMultiIndexedEXT-stippledLineEnable-07495
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT} or \texttt{VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT} dynamic states enabled, and if the current \texttt{stippledLineEnable} state is \texttt{VK_TRUE} and the current \texttt{lineRasterizationMode} state is \texttt{VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT}, then the \texttt{stippledRectangularLines} feature must be enabled.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT`, then the `stippledBresenhamLines` feature must be enabled.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT`, then the `stippledSmoothLines` feature must be enabled.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT`, then the `stippledRectangularLines` feature must be enabled and `VkPhysicalDeviceLimits::strictLines` must be `VK_TRUE`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled, `conservativePointAndLineRasterization` is not supported, and the effective primitive topology output by the last pre-rasterization shader stage is a line or point, then the `conservativeRasterizationMode` set by the last call to `vkCmdSetConservativeRasterizationModeEXT` must be `VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT`.

If the currently bound pipeline was created with the `VkPipelineShaderStageCreateInfo::stage` member of an element of `VkGraphicsPipelineCreateInfo::pStages` set to `VK_SHADER_STAGE_VERTEX_BIT`, `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`, `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` or `VK_SHADER_STAGE_GEOMETRY_BIT`, then Mesh Shader Queries must not be active.

If dynamic state was inherited from `VkCommandBufferInheritanceViewportScissorInfoNV`, it must be set in the current command buffer prior to this drawing command.

If dynamic state was inherited from `VkCommandBufferInheritanceViewportScissorInfoNV`, it must be set in the current command buffer prior to this drawing command.

If dynamic state was inherited from `VkCommandBufferInheritanceViewportScissorInfoNV`, it must be set in the current command buffer prior to this drawing command.
If there is no bound graphics pipeline, **vkCmdBindShadersEXT must** have been called in the current command buffer with pStages with an element of **VK_SHADER_STAGE_VERTEX_BIT**

- **VUID-vkCmdDrawMultiIndexedEXT-None-08685**
  If there is no bound graphics pipeline, and the tessellationShader feature is enabled, **vkCmdBindShadersEXT must** have been called in the current command buffer with pStages with an element of **VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT**

- **VUID-vkCmdDrawMultiIndexedEXT-None-08686**
  If there is no bound graphics pipeline, and the tessellationShader feature is enabled, **vkCmdBindShadersEXT must** have been called in the current command buffer with pStages with an element of **VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT**

- **VUID-vkCmdDrawMultiIndexedEXT-None-08687**
  If there is no bound graphics pipeline, and the geometryShader feature is enabled, **vkCmdBindShadersEXT must** have been called in the current command buffer with pStages with an element of **VK_SHADER_STAGE_GEOMETRY_BIT**

- **VUID-vkCmdDrawMultiIndexedEXT-None-08688**
  If there is no bound graphics pipeline, **vkCmdBindShadersEXT must** have been called in the current command buffer with pStages with an element of **VK_SHADER_STAGE_FRAGMENT_BIT**

- **VUID-vkCmdDrawMultiIndexedEXT-None-08689**
  If there is no bound graphics pipeline, and the taskShader feature is enabled, **vkCmdBindShadersEXT must** have been called in the current command buffer with pStages with an element of **VK_SHADER_STAGE_TASK_BIT_EXT**

- **VUID-vkCmdDrawMultiIndexedEXT-None-08690**
  If there is no bound graphics pipeline, and the meshShader feature is enabled, **vkCmdBindShadersEXT must** have been called in the current command buffer with pStages with an element of **VK_SHADER_STAGE_MESH_BIT_EXT**

- **VUID-vkCmdDrawMultiIndexedEXT-None-08693**
  If there is no bound graphics pipeline, and at least one of the taskShader and meshShader features is enabled, one of the **VK_SHADER_STAGE_VERTEX_BIT** or **VK_SHADER_STAGE_MESH_BIT_EXT** stages **must** have a valid VkShaderEXT bound, and the other **must** have no VkShaderEXT bound

- **VUID-vkCmdDrawMultiIndexedEXT-None-08694**
  If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound to the **VK_SHADER_STAGE_MESH_BIT_EXT** stage, and that VkShaderEXT was created without the **VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT** flag, a valid VkShaderEXT **must** be bound to the **VK_SHADER_STAGE_TASK_BIT_EXT** stage

- **VUID-vkCmdDrawMultiIndexedEXT-None-08695**
  If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound to the **VK_SHADER_STAGE_MESH_BIT_EXT** stage, and that VkShaderEXT was created with the **VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT** flag, there **must** be no VkShaderEXT bound to the **VK_SHADER_STAGE_TASK_BIT_EXT** stage

- **VUID-vkCmdDrawMultiIndexedEXT-None-08696**
  If there is no bound graphics pipeline, and a valid VkShaderEXT is bound to the **VK_SHADER_STAGE_VERTEX_BIT** stage, there **must** be no VkShaderEXT bound to either the
VK_SHADER_STAGE_TASK_BIT_EXT stage or the VK_SHADER_STAGE_MESH_BIT_EXT stage

- **VUID-vkCmdDrawMultiIndexedEXT-None-08698**
  If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, then all shaders created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag in the same vkCreateShadersEXT call must also be bound.

- **VUID-vkCmdDrawMultiIndexedEXT-None-08699**
  If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, any stages in between stages whose shaders did not create a shader with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag as part of the same vkCreateShadersEXT call must not have any VkShaderEXT bound.

- **VUID-vkCmdDrawMultiIndexedEXT-None-08878**
  All bound graphics shader objects must have been created with identical or identically defined push constant ranges.

- **VUID-vkCmdDrawMultiIndexedEXT-None-08879**
  All bound graphics shader objects must have been created with identical or identically defined arrays of descriptor set layouts.

- **VUID-vkCmdDrawMultiIndexedEXT-None-08880**
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage and the attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMultiIndexedEXT-pDynamicStates-08715**
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE set in VkPipelineDynamicStateCreateInfo ::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable parameter in the last call to vkCmdSetDepthWriteEnable must be VK_FALSE.

- **VUID-vkCmdDrawMultiIndexedEXT-pDynamicStates-08716**
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_STENCIL_WRITE_MASK set in VkPipelineDynamicStateCreateInfo ::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpStencilAttachmentReadEXT, the writeMask parameter in the last call to vkCmdSetStencilWriteMask must be 0.

- **VUID-vkCmdDrawMultiIndexedEXT-None-09116**
  If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT, and the format of any color attachment is VK_FORMAT_E5B9G9R9_UFLOAT_PACK32, the corresponding element of the pColorWriteMasks parameter of vkCmdSetColorWriteMaskEXT must either include all of VK_COLOR_COMPONENT_R_BIT, VK_COLOR_COMPONENT_G_BIT, and VK_COLOR_COMPONENT_B_BIT, or none of them.

- **VUID-vkCmdDrawMultiIndexedEXT-maxFragmentDualSrcAttachments-09239**
  If blending is enabled for any attachment where either the source or destination blend...
factors for that attachment use the secondary color input, the maximum value of Location for any output attachment statically used in the Fragment Execution Model executed by this command must be less than maxFragmentDualSrcAttachments

- VUID-vkCmdDrawMultiIndexedEXT-commandBuffer-02712
  If commandBuffer is a protected command buffer and protectedNoFault is not supported, any resource written to by the VkPipeline object bound to the pipeline bind point used by this command must not be an unprotected resource

- VUID-vkCmdDrawMultiIndexedEXT-commandBuffer-02713
  If commandBuffer is a protected command buffer and protectedNoFault is not supported, pipeline stages other than the framebuffer-space and compute stages in the VkPipeline object bound to the pipeline bind point used by this command must not write to any resource

- VUID-vkCmdDrawMultiIndexedEXT-commandBuffer-04617
  If any of the shader stages of the VkPipeline bound to the pipeline bind point used by this command uses the RayQueryKHR capability, then commandBuffer must not be a protected command buffer

- VUID-vkCmdDrawMultiIndexedEXT-None-04007
  All vertex input bindings accessed via vertex input variables declared in the vertex shader entry point’s interface must have either valid or VK_NULL_HANDLE buffers bound

- VUID-vkCmdDrawMultiIndexedEXT-None-04008
  If the nullDescriptor feature is not enabled, all vertex input bindings accessed via vertex input variables declared in the vertex shader entry point’s interface must not be VK_NULL_HANDLE

- VUID-vkCmdDrawMultiIndexedEXT-None-02721
  For a given vertex buffer binding, any attribute data fetched must be entirely contained within the corresponding vertex buffer binding, as described in Vertex Input Description

- VUID-vkCmdDrawMultiIndexedEXT-None-07842
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled then vkCmdSetPrimitiveTopology must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-dynamicPrimitiveTopologyUnrestricted-07500
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled and the dynamicPrimitiveTopologyUnrestricted is VK_FALSE, then the primitiveTopology parameter of vkCmdSetPrimitiveTopology must be of the same topology class as the pipeline VkPipelineInputAssemblyStateCreateInfo::topology state

- VUID-vkCmdDrawMultiIndexedEXT-None-04912
  If the bound graphics pipeline was created with both the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT and VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT dynamic states enabled, then vkCmdSetVertexInputEXT must have been called in the current command buffer prior to this draw command
If the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then `vkCmdBindVertexBuffers2EXT` must have been called in the current command buffer prior to this draw command, and the `pStrides` parameter of `vkCmdBindVertexBuffers2EXT` must not be `NULL`.

If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetPrimitiveTopology` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then `vkCmdSetVertexInputEXT` must have been called in the current command buffer prior to this draw command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, all variables with the `Input` storage class decorated with `Location` in the Vertex Execution Model `OpEntryPoint` must contain a location in `VkVertexInputAttributeDescription2EXT::location`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then the numeric type associated with all `Input` variables of the corresponding `Location` in the Vertex Execution Model `OpEntryPoint` must be the same as `VkVertexInputAttributeDescription2EXT::format`.

If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and `VkVertexInputAttributeDescription2EXT::format` has a 64-bit component, then the scalar width associated with all `Input` variables of the corresponding `Location` in the Vertex Execution Model `OpEntryPoint` must be 64-bit.

If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and the scalar width associated with a `Location` decorated `Input` variable in the Vertex Execution Model `OpEntryPoint` is 64-bit, then the corresponding `VkVertexInputAttributeDescription2EXT::format` must have a 64-bit component.

If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and `VkVertexInputAttributeDescription2EXT::format` has a 64-bit component, then all `Input` variables at the corresponding `Location` in the Vertex Execution Model `OpEntryPoint` must not use components that are not present in the format.

If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and `VkVertexInputAttributeDescription2EXT::format` has a 64-bit component, then all `Input` variables at the corresponding `Location` in the Vertex Execution Model `OpEntryPoint` must not use components that are not present in the format.

If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then...
vkCmdSetVertexInputEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-04875
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT dynamic state enabled then vkCmdSetPatchControlPointsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-08883
  If a shader object is bound to the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT stage, then vkCmdSetPatchControlPointsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-None-04879
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE dynamic state enabled then vkCmdSetPrimitiveRestartEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-rasterizerDiscardEnable-08884
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, vkCmdSetPrimitiveRestartEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMultiIndexedEXT-stage-06481
  The bound graphics pipeline must not have been created with the VkPipelineShaderStageCreateInfo::stage member of an element of VkGraphicsPipelineCreateInfo::pStages set to VK_SHADER_STAGE_TASK_BIT_EXT or VK_SHADER_STAGE_MESH_BIT_EXT

- VUID-vkCmdDrawMultiIndexedEXT-None-08885
  There must be no shader object bound to either of the VK_SHADER_STAGE_TASK_BIT_EXT or VK_SHADER_STAGE_MESH_BIT_EXT stages

- VUID-vkCmdDrawMultiIndexedEXT-None-07312
  An index buffer must be bound

- VUID-vkCmdDrawMultiIndexedEXT-robustBufferAccess2-07825
  If robustBufferAccess2 is not enabled, \((indexSize \times (firstIndex + indexCount) + offset)\) must be less than or equal to the size of the bound index buffer, with indexSize being based on the type specified by indexType, where the index buffer, indexType, and offset are specified via vkCmdBindIndexBuffer

- VUID-vkCmdDrawMultiIndexedEXT-robustBufferAccess2-08798
  If robustBufferAccess2 is not enabled, \((indexSize \times (firstIndex + indexCount) + offset)\) must be less than or equal to the size of the bound index buffer, with indexSize being based on the type specified by indexType, where the index buffer, indexType, and offset are specified via vkCmdBindIndexBuffer or vkCmdBindIndexBuffer2KHR. If vkCmdBindIndexBuffer2KHR is used to bind the index buffer, the size of the bound index buffer is vkCmdBindIndexBuffer2KHR::size
The `VkMultiDrawInfoEXT` structure is defined as:

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The `VkMultiDrawInfoEXT` structure is defined as:
typedef struct VkMultiDrawInfoEXT {
uint32_t firstVertex;
uint32_t vertexCount;
} VkMultiDrawInfoEXT;

- `firstVertex` is the first vertex to draw.
- `vertexCount` is the number of vertices to draw.

The members of `VkMultiDrawInfoEXT` have the same meaning as the `firstVertex` and `vertexCount` parameters in `vkCmdDraw`.

The `VkMultiDrawIndexedInfoEXT` structure is defined as:

typedef struct VkMultiDrawIndexedInfoEXT {
uint32_t firstIndex;
uint32_t indexCount;
int32_t vertexOffset;
} VkMultiDrawIndexedInfoEXT;

- `firstIndex` is the first index to draw.
- `indexCount` is the number of vertices to draw.
- `vertexOffset` is the value added to the vertex index before indexing into the vertex buffer for indexed multidraws.

The `firstIndex`, `indexCount`, and `vertexOffset` members of `VkMultiDrawIndexedInfoEXT` have the same meaning as the `firstIndex`, `indexCount`, and `vertexOffset` parameters, respectively, of `vkCmdDrawIndexed`.

To record a non-indexed indirect drawing command, call:

void vkCmdDrawIndirect(
    VkCommandBuffer commandBuffer,  // Provided by VK_VERSION_1_0
    VkBuffer buffer,                // Provided by VK_VERSION_1_0
    VkDeviceSize offset,            // Provided by VK_VERSION_1_0
    uint32_t drawCount,             // Provided by VK_VERSION_1_0
    uint32_t stride)

- `commandBuffer` is the command buffer into which the command is recorded.
- `buffer` is the buffer containing draw parameters.
- `offset` is the byte offset into `buffer` where parameters begin.
- `drawCount` is the number of draws to execute, and can be zero.
• stride is the byte stride between successive sets of draw parameters.

vkCmdDrawIndirect behaves similarly to vkCmdDraw except that the parameters are read by the device from a buffer during execution. drawCount draws are executed by the command, with parameters taken from buffer starting at offset and increasing by stride bytes for each successive draw. The parameters of each draw are encoded in an array of VkDrawIndirectCommand structures. If drawCount is less than or equal to one, stride is ignored.

Valid Usage

• VUID-vkCmdDrawIndirect-magFilter-04553
  If a VkSampler created with magFilter or minFilter equal to VK_FILTER_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

• VUID-vkCmdDrawIndirect-mipmapMode-04770
  If a VkSampler created with mipmapMode equal to VK_SAMPLER_MIPMAP_MODE_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

• VUID-vkCmdDrawIndirect-None-06479
  If a VkImageView is sampled with depth comparison, the image view’s format features must contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT

• VUID-vkCmdDrawIndirect-None-02691
  If a VkImageView is accessed using atomic operations as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

• VUID-vkCmdDrawIndirect-None-07888
  If a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer’s format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

• VUID-vkCmdDrawIndirect-None-02692
  If a VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT

• VUID-vkCmdDrawIndirect-None-02693
  If the VK_EXT_filter_cubic extension is not enabled and any VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, it must not have a VkImageViewType of VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

• VUID-vkCmdDrawIndirect-filterCubic-02694
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2
Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` with a reduction mode of either `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX` as a result of this command **must** have a `VkImageViewType` and format that supports cubic filtering together with minmax filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

If the `cubicRangeClamp` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command **must** not have a `VkSamplerReductionModeCreateInfo` `reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`.

If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command **must** have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`.

Any `VkImage` created with a `VkImageCreateInfo` `flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command **must** only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

For any `VkImageView` being written as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view's format features **must** contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view's buffer features **must** contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

For each set `n` that is statically used by a bound shader, a descriptor set **must** have been...
bound to a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

• VUID-vkCmdDrawIndirect-None-08114
Descriptors in each bound descriptor set, specified via vkCmdBindDescriptorSets, must be valid if they are statically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was not created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

• VUID-vkCmdDrawIndirect-None-08115
If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdBindDescriptorSets, the bound VkPipeline must have been created without VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

• VUID-vkCmdDrawIndirect-None-08116
Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

• VUID-vkCmdDrawIndirect-None-08604
Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command

• VUID-vkCmdDrawIndirect-None-08117
If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdSetDescriptorBufferOffsetsEXT, the bound VkPipeline must have been created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

• VUID-vkCmdDrawIndirect-None-08119
If a descriptor is dynamically used with a VkPipeline created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

• VUID-vkCmdDrawIndirect-None-08605
If a descriptor is dynamically used with a VkShaderEXT created with a
VkDescriptorSetLayout that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

• VUID-vkCmdDrawIndirect-None-08606
If the shaderObject feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command

• VUID-vkCmdDrawIndirect-None-08607
If the shaderObject is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and VK_NULL_HANDLE shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command

• VUID-vkCmdDrawIndirect-None-08608
If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the VkPipeline object bound to the pipeline bind point used by this command, since that pipeline was bound

• VUID-vkCmdDrawIndirect-None-08609
If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used to sample from any VkImage with a VkImageView of the type VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY, VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage

• VUID-vkCmdDrawIndirect-None-08610
If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage

• VUID-vkCmdDrawIndirect-None-08611
If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage

• VUID-vkCmdDrawIndirect-uniformBuffers-06935
If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawIndirect-None-08612
If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage
corresponding to the pipeline bind point used by this command accesses a uniform buffer, it **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawIndirect-storageBuffers-06936**
  If any stage of the `VkPipeline` object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT` or `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT` for `storageBuffers`, and the `robustBufferAccess` feature is not enabled, that stage **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawIndirect-None-08613**
  If the `robustBufferAccess` feature is not enabled, and any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawIndirect-commandBuffer-02707**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, any resource accessed by **bound shaders** **must** not be a protected resource

- **VUID-vkCmdDrawIndirect-None-06550**
  If a **bound shader** accesses a `VkSampler` or `VkImageView` object that enables `sampler Y'CbCr conversion`, that object **must** only be used with `OpImageSample*` or `OpImageSparseSample*` instructions

- **VUID-vkCmdDrawIndirect-ConstOffset-06551**
  If a **bound shader** accesses a `VkSampler` or `VkImageView` object that enables `sampler Y'CbCr conversion`, that object **must** not use the `ConstOffset` and `Offset` operands

- **VUID-vkCmdDrawIndirect-viewType-07752**
  If a `VkImageView` is accessed as a result of this command, then the image view’s `viewType` **must** match the `Dim` operand of the `OpTypeImage` as described in Instruction/Sampler/Image View Validation

- **VUID-vkCmdDrawIndirect-format-07753**
  If a `VkImageView` is accessed as a result of this command, then the numeric type of the image view’s `format` and the `Sampled Type` operand of the `OpTypeImage` **must** match

- **VUID-vkCmdDrawIndirect-OpImageWrite-08795**
  If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the image view’s format

- **VUID-vkCmdDrawIndirect-OpImageWrite-08796**
  If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have four components

- **VUID-vkCmdDrawIndirect-OpImageWrite-04469**
  If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as
the buffer view’s format

• VUID-vkCmdDrawIndirect-SampledType-04470
  If a VkImageView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64

• VUID-vkCmdDrawIndirect-SampledType-04471
  If a VkImageView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

• VUID-vkCmdDrawIndirect-SampledType-04472
  If a VkBufferView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64

• VUID-vkCmdDrawIndirect-SampledType-04473
  If a VkBufferView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

• VUID-vkCmdDrawIndirect-sparseImageInt64Atomics-04474
  If the sparseImageInt64Atomics feature is not enabled, VkImage objects created with the VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

• VUID-vkCmdDrawIndirect-sparseImageInt64Atomics-04475
  If the sparseImageInt64Atomics feature is not enabled, VkBuffer objects created with the VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

• VUID-vkCmdDrawIndirect-OpImageWeightedSampleQCOM-06971
  If OpImageWeightedSampleQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM

• VUID-vkCmdDrawIndirect-OpImageWeightedSampleQCOM-06972
  If OpImageWeightedSampleQCOM uses a VkImageView as a sample weight image as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM

• VUID-vkCmdDrawIndirect-OpImageBoxFilterQCOM-06973
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM

• VUID-vkCmdDrawIndirect-OpImageBlockMatchSSDQCOM-06974
  If OpImageBlockMatchSSDQCOM is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

• VUID-vkCmdDrawIndirect-OpImageBlockMatchSADQCOM-06975
  If OpImageBlockMatchSADQCOM is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM
command, then the image view's format features must contain VK_FORMAT_FEATURE_2 Block Matching Bit QCOM

- VUID-vkCmdDrawIndirect-OpImageBlockMatchSADQCOM-06976
  If OpImageBlockMatchSADQCOM or OpImageBlockMatchSSDQCOM is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- VUID-vkCmdDrawIndirect-OpImageWeightedSampleQCOM-06977
  If OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, OpImageBlockMatchSSDQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this command, then the sampler must have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT QCOM

- VUID-vkCmdDrawIndirect-OpImageWeightedSampleQCOM-06978
  If any command other than OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, OpImageBlockMatchSSDQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this command, then the sampler must not have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT QCOM

- VUID-vkCmdDrawIndirect-OpImageBlockMatchWindow-09215
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2 Block Matching Bit QCOM

- VUID-vkCmdDrawIndirect-OpImageBlockMatchWindow-09216
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view's format must be a single-component format.

- VUID-vkCmdDrawIndirect-OpImageBlockMatchWindow-09217
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- VUID-vkCmdDrawIndirect-None-07288
  Any shader invocation executed by this command must terminate

- VUID-vkCmdDrawIndirect-renderPass-02684
  The current render pass must be compatible with the renderPass member of the VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdDrawIndirect-subpass-02685
  The subpass index of the current render pass must be equal to the subpass member of the VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdDrawIndirect-None-07748
  If any shader statically accesses an input attachment, a valid descriptor must be bound to the pipeline via a descriptor set
If any shader executed by this pipeline accesses an `OpTypeImage` variable with a `Dim` operand of `SubpassData`, it **must** be decorated with an `InputAttachmentIndex` that corresponds to a valid input attachment in the current subpass.

Input attachment views accessed in a subpass **must** be created with the same `VkFormat` as the corresponding subpass definition, and be created with a `VkImageView` that is compatible with the attachment referenced by the subpass' `pInputAttachments[InputAttachmentIndex]` in the currently bound `VkFramebuffer` as specified by Fragment Input Attachment Compatibility.

Memory backing image subresources used as attachments in the current render pass **must not** be written in any way other than as an attachment by this command.

If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:

- the `VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
- the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_COLOR_BIT` and
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it **must** not be accessed in any way other than as an attachment by this command.

If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:

- the `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
- the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_DEPTH_BIT` and
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it **must** not be accessed in any way other than as an attachment by this command.

If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:

- the `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
currently bound pipeline or
  ◦ the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_STENCIL_BIT` and
    ◦ there is no currently bound graphics pipeline or
    ◦ the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawIndirect-None-09003
  If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command

• VUID-vkCmdDrawIndirect-None-06539
  If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command must not write to that image subresource as an attachment

• VUID-vkCmdDrawIndirect-None-06886
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, depth writes must be disabled

• VUID-vkCmdDrawIndirect-None-06887
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back writeMask are not zero, and stencil test is enabled, all stencil ops must be `VK_STENCIL_OP_KEEP`

• VUID-vkCmdDrawIndirect-None-07831
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT` dynamic state enabled then `vkCmdSetViewport` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07832
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SCISSOR` dynamic state enabled then `vkCmdSetScissor` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07833
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_WIDTH` dynamic state enabled then `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-08617
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-08618
  If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, `vkCmdSetLineWidth` must have been called in the current command
buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-08619
  If a shader object that outputs line primitives is bound to the
  VK_SHADER_STAGE_TESSSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT stage,
  vkCmdSetLineWidth must have been called in the current command buffer prior to this
drawing command

• VUID-vkCmdDrawIndirect-None-07834
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BIAS
dynamic state enabled then vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have
been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-08620
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, and the most recent call to
  vkCmdSetDepthBiasEnable in the current command buffer set depthBiasEnable to VK_TRUE,
  vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current
  command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07835
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_BLEND_CONSTANTS dynamic state enabled then vkCmdSetBlendConstants
  must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-08621
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent
call to vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, and the most recent call to
  vkCmdSetColorBlendEnableEXT in the current command buffer set any element of
  pColorBlendEnables to VK_TRUE, and the most recent call to
  vkCmdSetColorBlendEquationEXT in the current command buffer set the same element of
  pColorBlendEquations to a VkColorBlendEquationEXT structure with any VkBlendFactor
  member with a value of VK_BLEND_FACTOR_CONSTANT_COLOR,
  VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR, VK_BLEND_FACTOR_CONSTANT_ALPHA, or
  VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA, vkCmdSetBlendConstants must have
  been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07836
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BOUNDS
dynamic state enabled then vkCmdSetDepthBounds must have been called in the current
  command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-08622
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, and the most recent call to
  vkCmdSetDepthBoundsTestEnable in the current command buffer set
  depthBoundsTestEnable to VK_TRUE, then vkCmdSetDepthBounds must have been called in
  the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07837
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK` dynamic state enabled then `vkCmdSetStencilCompareMask` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirect-None-08623
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilCompareMask` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirect-None-07838
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_WRITE_MASK` dynamic state enabled then `vkCmdSetStencilWriteMask` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirect-None-08624
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilWriteMask` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirect-None-07839
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_REFERENCE` dynamic state enabled then `vkCmdSetStencilReference` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirect-None-08625
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilReference` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirect-maxMultiviewInstanceIndex-02688
  If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to `VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex`.

- VUID-vkCmdDrawIndirect-sampleLocationsEnable-02689
  If the bound graphics pipeline was created with `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` set to `VK_TRUE` and the current subpass has a depth/stencil attachment, then that attachment must have been created with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set.

- VUID-vkCmdDrawIndirect-None-06666
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirect-None-08626
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetSampleLocationsEnableEXT` in the current command buffer set `sampleLocationsEnable` to `VK_TRUE`, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-sampleLocationsPerPixel-07934**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with.

- **VUID-vkCmdDrawIndirect-None-07840**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CULL_MODE` dynamic state enabled then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-08627**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07841**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-08628**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07843**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-08629**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07844**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` dynamic state enabled then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.
• VUID-vkCmdDrawIndirect-None-08630
If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDepthWriteEnable must have been
called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07845
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_DEPTH_COMPARE_OP dynamic state enabled then
vkCmdSetDepthCompareOp must have been called in the current command buffer prior to
this drawing command

• VUID-vkCmdDrawIndirect-None-08631
If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, and the most recent call to
vkCmdSetDepthTestEnable in the current command buffer set depthTestEnable to VK_TRUE,
then vkCmdSetDepthCompareOp must have been called in the current command buffer prior to
this drawing command

• VUID-vkCmdDrawIndirect-None-07846
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE dynamic state enabled then
vkCmdSetDepthBoundsTestEnable must have been called in the current command buffer prior to
this drawing command

• VUID-vkCmdDrawIndirect-None-08632
If a shader object is bound to any graphics stage, and the depthBounds feature is enabled,
and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command
buffer set rasterizerDiscardEnable to VK_FALSE, then the vkCmdSetDepthBoundsTestEnable
must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07847
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE dynamic state enabled then
vkCmdSetStencilTestEnable must have been called in the current command buffer prior to
this drawing command

• VUID-vkCmdDrawIndirect-None-08633
If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetStencilTestEnable must have been
called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07848
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_OP
dynamic state enabled then vkCmdSetStencilOp must have been called in the current command buffer prior to
this drawing command

• VUID-vkCmdDrawIndirect-None-08634
If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, and the most recent call to
vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, then vkCmdSetStencilOp must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirect-viewportCount-03417
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT dynamic state enabled, then vkCmdSetViewportWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must match the VkPipelineViewportStateCreateInfo::scissorCount of the pipeline.

- VUID-vkCmdDrawIndirect-scissorCount-03418
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, then vkCmdSetScissorWithCount must have been called in the current command buffer prior to this drawing command, and the scissorCount parameter of vkCmdSetScissorWithCount must match the VkPipelineViewportStateCreateInfo::viewportCount of the pipeline.

- VUID-vkCmdDrawIndirect-viewportCount-03419
  If the bound graphics pipeline state was created with both the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic states enabled then both vkCmdSetViewportWithCount and vkCmdSetScissorWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must match the scissorCount parameter of vkCmdSetScissorWithCount.

- VUID-vkCmdDrawIndirect-None-08635
  If a shader object is bound to any graphics stage, then both vkCmdSetViewportWithCount and vkCmdSetScissorWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must match the scissorCount parameter of vkCmdSetScissorWithCount.

- VUID-vkCmdDrawIndirect-viewportCount-04137
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV dynamic state enabled, then the bound graphics pipeline must have been created with VkPipelineViewportWScalingStateCreateInfoNV::viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount.

- VUID-vkCmdDrawIndirect-viewportCount-04138
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV dynamic states enabled then the viewportCount parameter in the last call to vkCmdSetViewportWScalingNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount.

- VUID-vkCmdDrawIndirect-None-09232
If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then `vkCmdSetViewportWScalingNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-08636**
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndirect-viewportCount-04139**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportShadingRateImageStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndirect-viewportCount-04140**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndirect-shadingRateImage-09233**
  If the shadingRateImage feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set rasterizerDiscardEnable to `VK_FALSE`, then `vkCmdSetCoarseSampleOrderNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-shadingRateImage-09234**
  If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set rasterizerDiscardEnable to `VK_FALSE`, and the most recent call to `vkCmdSetShadingRateImageEnableNV` in the current command buffer set shadingRateImageEnable to `VK_TRUE`, then `vkCmdSetViewportShadingRatePaletteNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-08637**
  If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndirect-VkPipelineVieportCreateInfo-04141**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportSwizzleStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount` greater or
equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`

- **VUID-vkCmdDrawIndirect-VkPipelineViewportCreateInfo-04142**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportExclusiveScissorStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline **must** have been created with `VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`

- **VUID-vkCmdDrawIndirect-None-07878**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV` dynamic state enabled then `vkCmdSetExclusiveScissorEnableNV` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirect-None-07879**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV` dynamic state enabled then `vkCmdSetExclusiveScissorNV` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirect-exclusiveScissor-09235**
  If a shader object is bound to any graphics stage, and the `exclusiveScissor` feature is enabled, then `vkCmdSetExclusiveScissorEnableNV` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirect-None-08638**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetExclusiveScissorEnableNV` in the current command buffer set any element of `pExclusiveScissorEnables` to `VK_TRUE`, then `vkCmdSetExclusiveScissorNV` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirect-None-04876**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE` dynamic state enabled then `vkCmdSetRasterizerDiscardEnable` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirect-None-08639**
  If a shader object is bound to any graphics stage, then `vkCmdSetRasterizerDiscardEnable` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirect-None-04877**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE` dynamic state enabled then `vkCmdSetDepthBiasEnable` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirect-None-08640**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then \texttt{vkCmdSetDepthBiasEnable} must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-logicOp-04878**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LOGIC_OP_EXT} dynamic state enabled then \texttt{vkCmdSetLogicOpEXT} must have been called in the current command buffer prior to this drawing command and the logicOp must be a valid \texttt{VkLogicOp} value.

- **VUID-vkCmdDrawIndirect-None-08641**
  If a shader object is bound to the \texttt{VK_SHADER_STAGE_FRAGMENT_BIT} stage, and the logicOp feature is enabled on the device, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then \texttt{vkCmdSetLogicOpEXT} must have been called in the current command buffer prior to this drawing command and the logicOp must be a valid \texttt{VkLogicOp} value.

- **VUID-vkCmdDrawIndirect-primitiveFragmentShadingRateWithMultipleViewports-04552**
  If the \texttt{primitiveFragmentShadingRateWithMultipleViewports} limit is not supported, the bound graphics pipeline was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the PrimitiveShadingRateKHR built-in, then \texttt{vkCmdSetViewportWithCount} must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of \texttt{vkCmdSetViewportWithCount} must be 1.

- **VUID-vkCmdDrawIndirect-primitiveFragmentShadingRateWithMultipleViewports-08642**
  If the \texttt{primitiveFragmentShadingRateWithMultipleViewports} limit is not supported, and any shader object bound to a graphics stage writes to the PrimitiveShadingRateKHR built-in, then \texttt{vkCmdSetViewportWithCount} must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of \texttt{vkCmdSetViewportWithCount} must be 1.

- **VUID-vkCmdDrawIndirect-blendEnable-04727**
  If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view's format features do not contain \texttt{VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT}, then the blendEnable member of the \texttt{pAttachments} member of \texttt{pColorBlendState} must be VK_FALSE.

- **VUID-vkCmdDrawIndirect-None-08643**
  If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then for each color attachment in the render pass, if the corresponding image view's format features do not contain \texttt{VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT}, then the corresponding member of \texttt{pColorBlendEnables} in the most recent call to \texttt{vkCmdSetColorBlendEnableEXT} in the current command buffer that affected that attachment index must have been VK_FALSE.

- **VUID-vkCmdDrawIndirect-multisampledRenderToSingleSampled-07284**
  If rasterization is not disabled in the bound graphics pipeline, and none of the \texttt{VK_AMD_mixed_attachment_samples} extension, the \texttt{VK_NV_framebuffer_mixed_samples} extension, or the \texttt{multisampledRenderToSingleSampled} feature is enabled, then
rasterizationSamples for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments

• VUID-vkCmdDrawIndirect-None-08644
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and none of the VK_AMD_mixed_attachment_samples extension, the VK_NV_framebuffer_mixed_samples extension, or the multisampledRenderToSingleSampled feature is enabled, then the most recent call to vkCmdSetRasterizationSamplesEXT in the current command buffer must have set rasterizationSamples to be the same as the number of samples for the current render pass color and/or depth/stencil attachments

• VUID-vkCmdDrawIndirect-None-08876
  If a shader object is bound to any graphics stage, the current render pass instance must have been begun with vkCmdBeginRendering

• VUID-vkCmdDrawIndirect-imageView-06172
  If the current render pass instance was begun with vkCmdBeginRendering, the imageView member of pDepthAttachment is not VK_NULL_HANDLE, and the layout member of pDepthAttachment is VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL, this command must not write any values to the depth attachment

• VUID-vkCmdDrawIndirect-imageView-06173
  If the current render pass instance was begun with vkCmdBeginRendering, the imageView member of pStencilAttachment is not VK_NULL_HANDLE, and the layout member of pStencilAttachment is VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL, this command must not write any values to the stencil attachment

• VUID-vkCmdDrawIndirect-imageView-06174
  If the current render pass instance was begun with vkCmdBeginRendering, the imageView member of pDepthAttachment is not VK_NULL_HANDLE, and the layout member of pDepthAttachment is VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL, this command must not write any values to the stencil attachment

• VUID-vkCmdDrawIndirect-imageView-06175
  If the current render pass instance was begun with vkCmdBeginRendering, the imageView member of pStencilAttachment is not VK_NULL_HANDLE, and the layout member of pStencilAttachment is VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL, this command must not write any values to the stencil attachment

• VUID-vkCmdDrawIndirect-imageView-06176
  If the current render pass instance was begun with vkCmdBeginRendering, the imageView member of pDepthAttachment is not VK_NULL_HANDLE, and the layout member of pDepthAttachment is VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL, this command must not write any values to the depth attachment

• VUID-vkCmdDrawIndirect-imageView-06177
  If the current render pass instance was begun with vkCmdBeginRendering, the imageView member of pStencilAttachment is not VK_NULL_HANDLE, and the layout member of pStencilAttachment is VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL, this command must not write any values to the stencil attachment
• VUID-vkCmdDrawIndirect-viewMask-06178
If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline **must** have been created with a `VkPipelineRenderingCreateInfo` ::`viewMask` equal to `VkRenderingInfo` ::`viewMask`

• VUID-vkCmdDrawIndirect-colorAttachmentCount-06179
If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline **must** have been created with a `VkPipelineRenderingCreateInfo` ::`colorAttachmentCount` equal to `VkRenderingInfo` ::`colorAttachmentCount`

• VUID-vkCmdDrawIndirect-dynamicRenderingUnusedAttachments-08910
If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo` ::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo` ::`pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` **must** have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo` ::`pColorAttachmentFormats` used to create the currently bound graphics pipeline

• VUID-vkCmdDrawIndirect-dynamicRenderingUnusedAttachments-08911
If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo` ::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo` ::`pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` **must** have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo` ::`pColorAttachmentFormats` used to create the currently bound graphics pipeline, or the corresponding element of `VkPipelineRenderingCreateInfo` ::`pColorAttachmentFormats`, if it exists, **must** be `VK_FORMAT_UNDEFINED`

• VUID-vkCmdDrawIndirect-dynamicRenderingUnusedAttachments-08912
If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo` ::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo` ::`pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` **must** have the corresponding element of `VkPipelineRenderingCreateInfo` ::`pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`

• VUID-vkCmdDrawIndirect-attachmentCount-07750
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorWriteEnableEXT` **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07749
If the colorWriteEnable feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteEnableEXT` **must** have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then the `attachmentCount` parameter of `vkCmdSetColorWriteEnableEXT` must be greater than or equal to the `VkPipelineColorBlendStateCreateInfo::attachmentCount` of the currently bound graphics pipeline.

- **VUID-vkCmdDrawIndirect-None-08647**
  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `attachmentCount` parameter of most recent call to `vkCmdSetColorWriteEnableEXT` in the current command buffer must be greater than or equal to the number of color attachments in the current render pass instance.

- **VUID-vkCmdDrawIndirect-None-07751**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEXT` must have been called in the current command buffer prior to this drawing command for each discard rectangle in `VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount`.

- **VUID-vkCmdDrawIndirect-None-07880**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-rasterizerDiscardEnable-09236**
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDiscardRectangleEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-08648**
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDiscardRectangleEnableEXT` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDiscardRectangleEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07881**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-08649**
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDiscardRectangleEnableEXT` in the current command buffer set...
discardRectangleEnable to VK_TRUE, then vkCmdSetDiscardRectangleModeEXT must have been called in the current command buffer prior to this drawing command.

- **VID-vkCmdDrawIndirect-dynamicRenderingUnusedAttachments-08913**
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to VK_FORMAT_UNDEFINED.

- **VID-vkCmdDrawIndirect-dynamicRenderingUnusedAttachments-08914**
  If current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to the VkFormat used to create VkRenderingInfo::pDepthAttachment->imageView.

- **VID-vkCmdDrawIndirect-dynamicRenderingUnusedAttachments-08915**
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pDepthAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED.

- **VID-vkCmdDrawIndirect-dynamicRenderingUnusedAttachments-08916**
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pStencilAttachment->imageView was VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline must be equal to VK_FORMAT_UNDEFINED.

- **VID-vkCmdDrawIndirect-dynamicRenderingUnusedAttachments-08917**
  If current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pStencilAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED.

- **VID-vkCmdDrawIndirect-dynamicRenderingUnusedAttachments-08918**
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pStencilAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED.

- **VID-vkCmdDrawIndirect-dynamicRenderingUnusedAttachments-08919**
  If the current render pass instance was begun with vkCmdBeginRendering and VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView was not
VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

• VUID-vkCmdDrawIndirect-imageView-06184
  If the current render pass instance was begun with vkCmdBeginRendering and VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT

• VUID-vkCmdDrawIndirect-colorAttachmentCount-06185
  If the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a sample count equal to the corresponding element of the pColorAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline

• VUID-vkCmdDrawIndirect-pDepthAttachment-06186
  If the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of the depthStencilAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline must be equal to the sample count used to create VkRenderingInfo::pDepthAttachment->imageView

• VUID-vkCmdDrawIndirect-pStencilAttachment-06187
  If the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled feature is not enabled, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a sample count equal to the value of rasterizationSamples for the currently bound graphics pipeline

• VUID-vkCmdDrawIndirect-multisampledRenderToSingleSampled-07285
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled feature is not enabled, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a sample count equal to the value of rasterizationSamples for the currently bound graphics pipeline

• VUID-vkCmdDrawIndirect-multisampledRenderToSingleSampled-07286
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled feature is not enabled, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a sample count equal to the value of rasterizationSamples for the currently bound graphics pipeline
feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`

- **VUID-vkCmdDrawIndirect-multisampledRenderToSingleSampled-07287**
  If the current render pass instance was begun with *vkCmdBeginRendering*, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`

- **VUID-vkCmdDrawIndirect-pNext-07935**
  If this command has been called inside a render pass instance started with *vkCmdBeginRendering*, and the `pNext` chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to `VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples`

- **VUID-vkCmdDrawIndirect-renderPass-06198**
  If the current render pass instance was begun with *vkCmdBeginRendering*, the currently bound pipeline must have been created with a `VkGraphicsPipelineCreateInfo::renderPass` equal to `VK_NULL_HANDLE`

- **VUID-vkCmdDrawIndirect-pColorAttachments-08963**
  If the current render pass instance was begun with *vkCmdBeginRendering*, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the `VkRenderingInfo::pColorAttachments->imageView` was not `VK_NULL_HANDLE`, then the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdDrawIndirect-pDepthAttachment-08964**
  If the current render pass instance was begun with *vkCmdBeginRendering*, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdDrawIndirect-pStencilAttachment-08965**
  If the current render pass instance was begun with *vkCmdBeginRendering*, there is a graphics pipeline bound, stencil test is enabled and the `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdDrawIndirect-primitivesGeneratedQueryWithRasterizerDiscard-06708**
  If the `primitivesGeneratedQueryWithRasterizerDiscard` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, `rasterization discard` must not be
• VUID-vkCmdDrawIndirect-primitivesGeneratedQueryWithNonZeroStreams-06709
If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, the bound graphics pipeline must not have been created with a non-zero value in `VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream`

• VUID-vkCmdDrawIndirect-None-07619
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT` dynamic state enabled then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07620
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-09237
If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-08650
If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07621
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-08651
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07622
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` dynamic state enabled then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-08652
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRasterizationSamplesEXT` must have
been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07623
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_MASK_EXT dynamic state enabled then vkCmdSetSampleMaskEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-08653
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleMaskEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07624
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled then vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-alphaToCoverageEnable-08919
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled, and alphaToCoverageEnable was VK_TRUE in the last call to vkCmdSetAlphaToCoverageEnableEXT, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0

• VUID-vkCmdDrawIndirect-None-08654
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-alphaToCoverageEnable-08920
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetAlphaToCoverageEnableEXT in the current command buffer set alphaToCoverageEnable to VK_TRUE, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0

• VUID-vkCmdDrawIndirect-None-07625
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT dynamic state enabled then vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-08655
  If the alphaToOne feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07626
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT dynamic state enabled then
vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-08656
  If the logicOp feature is enabled, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-07627
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-08657
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-07628
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT dynamic state enabled then vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-08658
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetColorBlendEnableEXT for any attachment set that attachment's value in pColorBlendEnables to VK_TRUE, then vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-07629
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT dynamic state enabled then vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-08659
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-07630
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT dynamic state enabled then vkCmdSetRasterizationStreamEXT must have been called in the current command buffer prior to this drawing command
• VUID-vkCmdDrawIndirect-None-08660
If the `geometryStreams` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_GEOMETRY_BIT` stage, then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndirect-None-07631
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndirect-None-08661
If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndirect-None-07632
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndirect-None-08662
If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetConservativeRasterizationModeEXT` in the current command buffer set `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`, then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndirect-None-07633
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndirect-None-08663
If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndirect-None-07634
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndirect-None-08664
If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any...
The most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07635**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07636**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT` dynamic state enabled then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07637**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07638**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` dynamic state enabled then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07639**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_PATTERN_EXT` dynamic state enabled then `vkCmdSetLineStipplePatternEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07640**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_PATTERN_INDEX_EXT` dynamic state enabled then `vkCmdSetLineStipplePatternIndexEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07641**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_PATTERN_INDEX_COUNT_EXT` dynamic state enabled then `vkCmdSetLineStipplePatternIndexCountEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07642**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_PATTERN_INDEX_COUNT_EXT` dynamic state enabled then `vkCmdSetLineStipplePatternIndexCountEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07643**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_PATTERN_INDEX_COUNT_EXT` dynamic state enabled then `vkCmdSetLineStipplePatternIndexCountEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07644**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_PATTERN_INDEX_COUNT_EXT` dynamic state enabled then `vkCmdSetLineStipplePatternIndexCountEXT` must have been called in the current command buffer prior to this drawing command.
If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_EXT` dynamic state enabled then `vkCmdSetLineStippleEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetLineStippleEnableEXT` in the current command buffer set `stippledLineEnable` to `VK_TRUE`, then `vkCmdSetLineStippleEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT` dynamic state enabled then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command.

If the `depthClipControl` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_clip_space_w_scaling` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_clip_space_w_scaling` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_viewport_swizzle` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set `coverageToColorEnable` to `VK_TRUE`, then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.
vkCmdSetCoverageModulationTableEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-08679
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetCoverageModulationModeNV in the current command buffer set coverageModulationMode to any value other than VK_COVERAGE_MODULATION_MODE_NONE_NV, then vkCmdSetCoverageModulationTableEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-07646
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV dynamic state enabled then vkCmdSetCoverageModulationTableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-08680
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetCoverageModulationTableEnableNV in the current command buffer set coverageModulationTableEnable to VK_TRUE, then vkCmdSetCoverageModulationTableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-07647
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV dynamic state enabled then vkCmdSetShadingRateImageEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-pipelineFragmentShadingRate-09238
  If the pipelineFragmentShadingRate feature is enabled, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetFragmentShadingRateKHR must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-08681
  If the shadingRateImage feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetShadingRateImageEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-07648
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV dynamic state enabled then vkCmdSetRepresentativeFragmentTestEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-08682
If the `representativeFragmentTest` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-07649**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-None-08683**
  If the `coverageReductionMode` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-pColorBlendEnables-07470**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` state enabled and the last call to `vkCmdSetColorBlendEnableEXT` set `pColorBlendEnables` for any attachment to `VK_TRUE`, then for those attachments in the subpass the corresponding image view’s `format features` must contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`.

- **VUID-vkCmdDrawIndirect-rasterizationSamples-07471**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must follow the rules for a zero-attachment subpass.

- **VUID-vkCmdDrawIndirect-samples-07472**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter used to create the bound graphics pipeline.

- **VUID-vkCmdDrawIndirect-samples-07473**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawIndirect-rasterizationSamples-07474**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and neither the `VK_AMD_mixed_attachment_samples` nor the `VK_NV_framebuffer_mixed_samples` extensions are
enabled, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the current subpass color and/or depth/stencil attachments

• **VUID-vkCmdDrawIndirect-None-09211**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the `rasterizationSamples` member of that structure.

• **VUID-vkCmdDrawIndirect-firstAttachment-07476**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEnableEXT` calls must specify an enable for all active color attachments in the current subpass.

• **VUID-vkCmdDrawIndirect-firstAttachment-07477**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEquationEXT` calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled.

• **VUID-vkCmdDrawIndirect-firstAttachment-07478**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorWriteMaskEXT` calls must specify the color write mask for all active color attachments in the current subpass.

• **VUID-vkCmdDrawIndirect-firstAttachment-07479**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendAdvancedEXT` calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled.

• **VUID-vkCmdDrawIndirect-advancedBlendMaxColorAttachments-07480**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` and `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic states enabled and the last calls to `vkCmdSetColorBlendEnableEXT` and
vkCmdSetColorBlendAdvancedEXT have enabled advanced blending, then the number of active color attachments in the current subpass **must** not exceed `advancedBlendMaxColorAttachments`.

- **VUID-vkCmdDrawIndirect-primitivesGeneratedQueryWithNonZeroStreams-07481**
  If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, and the bound graphics pipeline was created with `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` state enabled, the last call to `vkCmdSetRasterizationStreamEXT` **must** have set the `rasterizationStream` to zero.

- **VUID-vkCmdDrawIndirect-sampleLocationsPerPixel-07482**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` **must** equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with.

- **VUID-vkCmdDrawIndirect-sampleLocationsPerPixel-07483**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` **must** equal the `rasterizationSamples` parameter of the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawIndirect-sampleLocationsEnable-07484**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, and the current subpass has a depth/stencil attachment, then that attachment **must** have been created with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set.

- **VUID-vkCmdDrawIndirect-sampleLocationsEnable-07485**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, then the `sampleLocationsInfo.sampleLocationGridSize.width` in the last call to `vkCmdSetSampleLocationsEXT` **must** evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.width` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling `rasterizationSamples`.

- **VUID-vkCmdDrawIndirect-sampleLocationsEnable-07486**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, then the `sampleLocationsInfo.sampleLocationGridSize.height` in the last call to...
vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples

- VUID-vkCmdDrawIndirect-sampleLocationsEnable-07487
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, the fragment shader code must not statically use the extended instruction InterpolateAtSample

- VUID-vkCmdDrawIndirect-sampleLocationsEnable-07936
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.width must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawIndirect-sampleLocationsEnable-07937
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.height must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawIndirect-sampleLocationsEnable-07938
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationsPerPixel must equal rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawIndirect-coverageModulationTableEnable-07488
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV state enabled and the last call to vkCmdSetCoverageModulationTableEnableNV set coverageModulationTableEnable to VK_TRUE, then the coverageModulationTableCount parameter in the last call to vkCmdSetCoverageModulationTableNV must equal the current rasterizationSamples divided by the number of color samples in the current subpass

- VUID-vkCmdDrawIndirect-rasterizationSamples-07489
If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current rasterizationSamples must be the same as the sample count of the depth/stencil attachment

- VUID-vkCmdDrawIndirect-coverageToColorEnable-07490
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageToColorEnableNV` set the coverageToColorEnable to `VK_TRUE`, then the current subpass must have a color attachment at the location selected by the last call to `vkCmdSetCoverageToColorLocationNV` coverageToColorLocation, with a VkFormat of `VK_FORMAT_R8_UINT`, `VK_FORMAT_R8_SINT`, `VK_FORMAT_R16_UINT`, `VK_FORMAT_R16_SINT`, `VK_FORMAT_R32_UINT`, or `VK_FORMAT_R32_SINT`

- VUID-vkCmdDrawIndirect-coverageReductionMode-07491
  If this `VK_NV_coverage_reduction_mode` extension is enabled, the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, the current coverage reduction mode `coverageReductionMode`, then the current rasterizationSamples, and the sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by `vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV`

- VUID-vkCmdDrawIndirect-viewportCount-07492
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV` ::viewportCount greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`

- VUID-vkCmdDrawIndirect-viewportCount-07493
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportSwizzleNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`

- VUID-vkCmdDrawIndirect-rasterizationSamples-07494
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if the current subpass has any color attachments and rasterizationSamples of the last call to `vkCmdSetRasterizationSamplesEXT` is greater than the number of color samples, then the pipeline sampleShadingEnable must be `VK_FALSE`

- VUID-vkCmdDrawIndirect-stippledLineEnable-07495
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current stippledLineEnable state is `VK_TRUE` and the current lineRasterizationMode state is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT`, then the stippledRectangularLines feature must be enabled
• VUID-vkCmdDrawIndirect-stippledLineEnable-07496
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT
or
VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT
dynamic states enabled, and if the current
stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is
VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT, then the stippledBresenhamLines feature must
be enabled

• VUID-vkCmdDrawIndirect-stippledLineEnable-07497
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT
or
VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT
dynamic states enabled, and if the current
stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is
VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT, then the stippledSmoothLines feature must
be enabled

• VUID-vkCmdDrawIndirect-stippledLineEnable-07498
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT
or
VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT
dynamic states enabled, and if the current
stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is
VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT, then the stippledRectangularLines feature must
be enabled and VkPhysicalDeviceLimits::strictLines must be VK_TRUE

• VUID-vkCmdDrawIndirect-conservativePointAndLineRasterization-07499
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT
dynamic state enabled, conservativePointAndLineRasterization is not supported, and the effective primitive
topology output by the last pre-rasterization shader stage is a line or point, then the
conservativeRasterizationMode set by the last call to
vkCmdSetConservativeRasterizationModeEXT must be
VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT

• VUID-vkCmdDrawIndirect-stage-07073
If the currently bound pipeline was created with the VkPipelineShaderStageCreateInfo
::stage member of an element of VkGraphicsPipelineCreateInfo::pStages set to
VK_SHADER_STAGE_VERTEX_BIT, VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT,
VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT, then Mesh
Shader Queries must not be active

• VUID-vkCmdDrawIndirect-None-08877
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT
dynamic state
vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current
command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-07850
If dynamic state was inherited from
VkCommandBufferInheritanceViewportScissorInfoNV, it must be set in the current
command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-08684
If there is no bound graphics pipeline, *vkCmdBindShadersEXT must* have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_VERTEX_BIT`.

- **VUID-vkCmdDrawIndirect-None-08685**
  If there is no bound graphics pipeline, and the `tessellationShader` feature is enabled, *vkCmdBindShadersEXT must* have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`.

- **VUID-vkCmdDrawIndirect-None-08686**
  If there is no bound graphics pipeline, and the `tessellationShader` feature is enabled, *vkCmdBindShadersEXT must* have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`.

- **VUID-vkCmdDrawIndirect-None-08687**
  If there is no bound graphics pipeline, and the `geometryShader` feature is enabled, *vkCmdBindShadersEXT must* have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_GEOMETRY_BIT`.

- **VUID-vkCmdDrawIndirect-None-08688**
  If there is no bound graphics pipeline, *vkCmdBindShadersEXT must* have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_FRAGMENT_BIT`.

- **VUID-vkCmdDrawIndirect-None-08689**
  If there is no bound graphics pipeline, and the `taskShader` feature is enabled, *vkCmdBindShadersEXT must* have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TASK_BIT_EXT`.

- **VUID-vkCmdDrawIndirect-None-08690**
  If there is no bound graphics pipeline, and the `meshShader` feature is enabled, *vkCmdBindShadersEXT must* have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_MESH_BIT_EXT`.

- **VUID-vkCmdDrawIndirect-None-08693**
  If there is no bound graphics pipeline, and at least one of the `taskShader` and `meshShader` features is enabled, one of the `VK_SHADER_STAGE_VERTEX_BIT` or `VK_SHADER_STAGE_MESH_BIT_EXT` stages *must* have a valid `VkShaderEXT` bound, and the other *must* have no `VkShaderEXT` bound.

- **VUID-vkCmdDrawIndirect-None-08694**
  If there is no bound graphics pipeline, and both the `taskShader` and `meshShader` features are enabled, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that `VkShaderEXT` was created without the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, a valid `VkShaderEXT` *must* be bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage.

- **VUID-vkCmdDrawIndirect-None-08695**
  If there is no bound graphics pipeline, and both the `taskShader` and `meshShader` features are enabled, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that `VkShaderEXT` was created with the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, there *must* be no `VkShaderEXT` bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage.

- **VUID-vkCmdDrawIndirect-None-08696**
  If there is no bound graphics pipeline, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, there *must* be no `VkShaderEXT` bound to either the...
VK_SHADER_STAGE_TASK_BIT_EXT stage or the VK_SHADER_STAGE_MESH_BIT_EXT stage

• VUID-vkCmdDrawIndirect-None-08698
  If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, then all shaders created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag in the same vkCreateShadersEXT call must also be bound

• VUID-vkCmdDrawIndirect-None-08699
  If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, any stages in between stages whose shaders which did not create a shader with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag as part of the same vkCreateShadersEXT call must not have any VkShaderEXT bound

• VUID-vkCmdDrawIndirect-None-08878
  All bound graphics shader objects must have been created with identical or identically defined push constant ranges

• VUID-vkCmdDrawIndirect-None-08879
  All bound graphics shader objects must have been created with identical or identically defined arrays of descriptor set layouts

• VUID-vkCmdDrawIndirect-None-08880
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage and the attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-pDynamicStates-08715
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable parameter in the last call to vkCmdSetDepthWriteEnable must be VK_FALSE

• VUID-vkCmdDrawIndirect-pDynamicStates-08716
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_STENCIL_WRITE_MASK set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpStencilAttachmentReadEXT, the writeMask parameter in the last call to vkCmdSetStencilWriteMask must be 0

• VUID-vkCmdDrawIndirect-None-09116
  If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT, and the format of any color attachment is VK_FORMAT_E5B9G9R9_UFLOAT_PACK32, the corresponding element of the pColorWriteMasks parameter of vkCmdSetColorWriteMaskEXT must either include all of VK_COLOR_COMPONENT_R_BIT, VK_COLOR_COMPONENT_G_BIT, and VK_COLOR_COMPONENT_B_BIT, or none of them

• VUID-vkCmdDrawIndirect-maxFragmentDualSrcAttachments-09239
  If blending is enabled for any attachment where either the source or destination blend
factors for that attachment use the secondary color input, the maximum value of Location for any output attachment statically used in the Fragment Execution Model executed by this command must be less than maxFragmentDualSrcAttachments

- VUID-vkCmdDrawIndirect-None-04007
  All vertex input bindings accessed via vertex input variables declared in the vertex shader entry point’s interface must have either valid or VK_NULL_HANDLE buffers bound

- VUID-vkCmdDrawIndirect-None-04008
  If the nullDescriptor feature is not enabled, all vertex input bindings accessed via vertex input variables declared in the vertex shader entry point’s interface must not be VK_NULL_HANDLE

- VUID-vkCmdDrawIndirect-None-02721
  For a given vertex buffer binding, any attribute data fetched must be entirely contained within the corresponding vertex buffer binding, as described in Vertex Input Description

- VUID-vkCmdDrawIndirect-None-07842
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled then vkCmdSetPrimitiveTopology must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-dynamicPrimitiveTopologyUnrestricted-07500
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled and the dynamicPrimitiveTopologyUnrestricted is VK_FALSE, then the primitiveTopology parameter of vkCmdSetPrimitiveTopology must be of the same topology class as the pipeline VkPipelineInputAssemblyStateCreateInfo::topology state

- VUID-vkCmdDrawIndirect-None-04912
  If the bound graphics pipeline was created with both the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT and VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT dynamic states enabled, then vkCmdSetVertexInputEXT must have been called in the current command buffer prior to this draw command

- VUID-vkCmdDrawIndirect-pStrides-04913
  If the bound graphics pipeline was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT dynamic state enabled, but not the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, then vkCmdBindVertexBuffers2EXT must have been called in the current command buffer prior to this draw command, and the pStrides parameter of vkCmdBindVertexBuffers2EXT must not be NULL

- VUID-vkCmdDrawIndirect-None-08881
  If a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, then vkCmdSetPrimitiveTopology must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirect-None-04914
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, then vkCmdSetVertexInputEXT
must have been called in the current command buffer prior to this draw command

• VUID-vkCmdDrawIndirect-Input-07939
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, then all variables with the Input storage class decorated with Location in the Vertex Execution Model OpEntryPoint must contain a location in VkVertexInputAttributeDescription2EXT::location

• VUID-vkCmdDrawIndirect-Input-08734
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, then the numeric type associated with all Input variables of the corresponding Location in the Vertex Execution Model OpEntryPoint must be the same as VkVertexInputAttributeDescription2EXT::format

• VUID-vkCmdDrawIndirect-format-08936
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, and VkVertexInputAttributeDescription2EXT::format has a 64-bit component, then the scalar width associated with all Input variables of the corresponding Location in the Vertex Execution Model OpEntryPoint must be 64-bit

• VUID-vkCmdDrawIndirect-format-08937
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, and the scalar width associated with a Location decorated Input variable in the Vertex Execution Model OpEntryPoint is 64-bit, then the corresponding VkVertexInputAttributeDescription2EXT::format must have a 64-bit component

• VUID-vkCmdDrawIndirect-None-09203
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, and VkVertexInputAttributeDescription2EXT::format has a 64-bit component, then all Input variables at the corresponding Location in the Vertex Execution Model OpEntryPoint must not use components that are not present in the format

• VUID-vkCmdDrawIndirect-None-08882
  If a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, then vkCmdSetVertexInputEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-04875
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT dynamic state enabled then vkCmdSetPatchControlPointsEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-08883
  If a shader object is bound to the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT stage, then vkCmdSetPatchControlPointsEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirect-None-04879
  If the bound graphics pipeline state was created with the
**VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE**

Dynamic state enabled then `vkCmdSetPrimitiveRestartEnable` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-rasterizerDiscardEnable-08884**
  
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, `vkCmdSetPrimitiveRestartEnable` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirect-stage-06481**
  
  The bound graphics pipeline must not have been created with the `VkPipelineShaderStageCreateInfo::stage` member of an element of `VkGraphicsPipelineCreateInfo::pStages` set to `VK_SHADER_STAGE_TASK_BIT_EXT` or `VK_SHADER_STAGE_MESH_BIT_EXT`.

- **VUID-vkCmdDrawIndirect-None-08885**
  
  There must be no shader object bound to either of the `VK_SHADER_STAGE_TASK_BIT_EXT` or `VK_SHADER_STAGE_MESH_BIT_EXT` stages.

- **VUID-vkCmdDrawIndirect-buffer-02708**
  
  If `buffer` is non-sparse then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

- **VUID-vkCmdDrawIndirect-buffer-02709**
  
  `buffer` must have been created with the `VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT` bit set.

- **VUID-vkCmdDrawIndirect-offset-02710**
  
  `offset` must be a multiple of 4.

- **VUID-vkCmdDrawIndirect-commandBuffer-02711**
  
  `commandBuffer` must not be a protected command buffer.

- **VUID-vkCmdDrawIndirect-drawCount-02718**
  
  If the `multiDrawIndirect` feature is not enabled, `drawCount` must be 0 or 1.

- **VUID-vkCmdDrawIndirect-drawCount-02719**
  
  `drawCount` must be less than or equal to `VkPhysicalDeviceLimits::maxDrawIndirectCount`.

- **VUID-vkCmdDrawIndirect-drawCount-00476**
  
  If `drawCount` is greater than 1, `stride` must be a multiple of 4 and `must` be greater than or equal to `sizeof(VkDrawIndirectCommand)`.

- **VUID-vkCmdDrawIndirect-drawCount-00487**
  
  If `drawCount` is equal to 1, `(offset + sizeof(VkDrawIndirectCommand))` must be less than or equal to the size of `buffer`.

- **VUID-vkCmdDrawIndirect-drawCount-00488**
  
  If `drawCount` is greater than 1, `(stride × (drawCount - 1) + offset + sizeof(VkDrawIndirectCommand))` must be less than or equal to the size of `buffer`.
Valid Usage (Implicit)

- VUID-vkCmdDrawIndirect-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdDrawIndirect-buffer-parameter
  `buffer` must be a valid `VkBuffer` handle

- VUID-vkCmdDrawIndirect-commandBuffer-recording
  `commandBuffer` must be in the recording state

- VUID-vkCmdDrawIndirect-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations

- VUID-vkCmdDrawIndirect-renderpass
  This command must only be called inside of a render pass instance

- VUID-vkCmdDrawIndirect-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdDrawIndirect-commonparent
  Both of `buffer`, and `commandBuffer` must have been created, allocated, or retrieved from the same `VkDevice`

Host Synchronization

- Host access to `commandBuffer` must be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

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The `VkDrawIndirectCommand` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkDrawIndirectCommand {
    uint32_t vertexCount;
    uint32_t instanceCount;
    uint32_t firstVertex;
    uint32_t firstInstance;
};
```
VkDrawIndirectCommand;

- `vertexCount` is the number of vertices to draw.
- `instanceCount` is the number of instances to draw.
- `firstVertex` is the index of the first vertex to draw.
- `firstInstance` is the instance ID of the first instance to draw.

The members of `VkDrawIndirectCommand` have the same meaning as the similarly named parameters of `vkCmdDraw`.

### Valid Usage

- **VUID-VkDrawIndirectCommand-None-00500**
  For a given vertex buffer binding, any attribute data fetched *must* be entirely contained within the corresponding vertex buffer binding, as described in [Vertex Input Description](#).

- **VUID-VkDrawIndirectCommand-firstInstance-00501**
  If the `drawIndirectFirstInstance` feature is not enabled, `firstInstance` *must* be 0.

To record a non-indexed draw call with a draw call count sourced from a buffer, call:

```c
// Provided by VK_VERSION_1_2
void vkCmdDrawIndirectCount(
    VkCommandBuffer commandBuffer,
    VkBuffer buffer,
    VkDeviceSize offset,
    VkBuffer countBuffer,
    VkDeviceSize countBufferOffset,
    uint32_t maxDrawCount,
    uint32_t stride);
```

or the equivalent command

```c
// Provided by VK_KHR_draw_indirect_count
void vkCmdDrawIndirectCountKHR(
    VkCommandBuffer commandBuffer,
    VkBuffer buffer,
    VkDeviceSize offset,
    VkBuffer countBuffer,
    VkDeviceSize countBufferOffset,
    uint32_t maxDrawCount,
    uint32_t stride);
```

or the equivalent command
// Provided by VK_AMD_draw_indirect_count

```c
void vkCmdDrawIndirectCountAMD(
    VkCommandBuffer commandBuffer,
    VkBuffer buffer,
    VkDeviceSize offset,
    VkBuffer countBuffer,
    VkDeviceSize countBufferOffset,
    uint32_t maxDrawCount,
    uint32_t stride);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `buffer` is the buffer containing draw parameters.
- `offset` is the byte offset into `buffer` where parameters begin.
- `countBuffer` is the buffer containing the draw count.
- `countBufferOffset` is the byte offset into `countBuffer` where the draw count begins.
- `maxDrawCount` specifies the maximum number of draws that will be executed. The actual number of executed draw calls is the minimum of the count specified in `countBuffer` and `maxDrawCount`.
- `stride` is the byte stride between successive sets of draw parameters.

`vkCmdDrawIndirectCount` behaves similarly to `vkCmdDrawIndirect` except that the draw count is read by the device from a buffer during execution. The command will read an unsigned 32-bit integer from `countBuffer` located at `countBufferOffset` and use this as the draw count.

### Valid Usage

- **VUID-vkCmdDrawIndirectCount-magFilter-04553**
  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- **VUID-vkCmdDrawIndirectCount-mipmapMode-04770**
  If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- **VUID-vkCmdDrawIndirectCount-None-06479**
  If a `VkImageView` is sampled with depth comparison, the image view's format features must contain `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT`

- **VUID-vkCmdDrawIndirectCount-None-02691**
  If a `VkImageView` is accessed using atomic operations as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT`

- **VUID-vkCmdDrawIndirectCount-None-07888**
If a `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER` descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain `VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT`.

- **VUID-vkCmdDrawIndirectCount-None-02692**
  If a `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`.

- **VUID-vkCmdDrawIndirectCount-None-02693**
  If the `VK_EXT_filter_cubic` extension is not enabled and any `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, it must not have a `VkImageViewType` of `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`.

- **VUID-vkCmdDrawIndirectCount-filterCubic-02694**
  Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

- **VUID-vkCmdDrawIndirectCount-filterCubicMinmax-02695**
  Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` with a reduction mode of either `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering together with minmax filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

- **VUID-vkCmdDrawIndirectCount-cubicRangeClamp-09212**
  If the `cubicRangeClamp` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must not have a `VkSamplerReductionModeCreateInfo` `reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGE_CLAMP_QCOM`.

- **VUID-vkCmdDrawIndirectCount-reductionMode-09213**
  Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGE_CLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

- **VUID-vkCmdDrawIndirectCount-selectableCubicWeights-09214**
  If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`.

- **VUID-vkCmdDrawIndirectCount-flags-02696**
  Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

- **VUID-vkCmdDrawIndirectCount-OpTypeImage-07027**
  For any `VkImageView` being written as a storage image where the image format field of
the `OpTypeImage` is `Unknown`, the view's `format features` must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

- **VUID-vkCmdDrawIndirectCount-OpTypeImage-07028**
  For any `VkImageView` being read as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view's `format features` must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`.

- **VUID-vkCmdDrawIndirectCount-OpTypeImage-07029**
  For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view's `buffer features` must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

- **VUID-vkCmdDrawIndirectCount-OpTypeImage-07030**
  Any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown` then the view's `buffer features` must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`.

- **VUID-vkCmdDrawIndirectCount-None-08600**
  For each set \( n \) that is statically used by a bound shader, a descriptor set must have been bound to \( n \) at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set \( n \), with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

- **VUID-vkCmdDrawIndirectCount-None-08601**
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

- **VUID-vkCmdDrawIndirectCount-None-08602**
  If the `maintenance4` feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

- **VUID-vkCmdDrawIndirectCount-None-08114**
  Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, must be valid if they are statically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was not created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- **VUID-vkCmdDrawIndirectCount-None-08115**
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` must have been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- **VUID-vkCmdDrawIndirectCount-None-08116**
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by the
VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawIndirectCount-None-08604
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDrawIndirectCount-None-08117
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdSetDescriptorBufferOffsetsEXT, the bound VkPipeline must have been created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawIndirectCount-None-08119
  If a descriptor is dynamically used with a VkPipeline created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdDrawIndirectCount-None-08605
  If a descriptor is dynamically used with a VkShaderEXT created with a VkDescriptorSetLayout that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdDrawIndirectCount-None-08606
  If the shaderObject feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command

- VUID-vkCmdDrawIndirectCount-None-08607
  If the shaderObject is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and VK_NULL_HANDLE shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDrawIndirectCount-None-08608
  If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the VkPipeline object bound to the pipeline bind point used by this command, since that pipeline was bound

- VUID-vkCmdDrawIndirectCount-None-08609
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used to sample from any VkImage with a VkImageView of the type VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY, VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage

- VUID-vkCmdDrawIndirectCount-None-08610
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample*
instructions with ImplicitLod, Dref or Proj in their name, in any shader stage

- VUID-vkCmdDrawIndirectCount-None-08611
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage

- VUID-vkCmdDrawIndirectCount-uniformBuffers-06935
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDrawIndirectCount-None-08612
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDrawIndirectCount-storageBuffers-06936
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDrawIndirectCount-None-08613
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDrawIndirectCount-commandBuffer-02707
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource

- VUID-vkCmdDrawIndirectCount-None-06550
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y'C _a_C' conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions

- VUID-vkCmdDrawIndirectCount-ConstOffset-06551
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y'C _a_C' conversion, that object must not use the ConstOffset and Offset operands

- VUID-vkCmdDrawIndirectCount-viewType-07752
If a `VkImageView` is accessed as a result of this command, then the image view's `viewType` must match the `Dim` operand of the `OpTypeImage` as described in Instruction/Sampler/Image View Validation

- VUID-vkCmdDrawIndirectCount-format-07753
  If a `VkImageView` is accessed as a result of this command, then the numeric type of the image view's `format` and the `Sampled Type` operand of the `OpTypeImage` must match

- VUID-vkCmdDrawIndirectCount-OpImageWrite-08795
  If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have at least as many components as the image view's `format`

- VUID-vkCmdDrawIndirectCount-OpImageWrite-08796
  If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have four components

- VUID-vkCmdDrawIndirectCount-OpImageWrite-04469
  If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have at least as many components as the buffer view's `format`

- VUID-vkCmdDrawIndirectCount-SampledType-04470
  If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64

- VUID-vkCmdDrawIndirectCount-SampledType-04471
  If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 32

- VUID-vkCmdDrawIndirectCount-SampledType-04472
  If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64

- VUID-vkCmdDrawIndirectCount-SampledType-04473
  If a `VkBufferView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 32

- VUID-vkCmdDrawIndirectCount-sparseImageInt64Atomics-04474
  If the `sparseImageInt64Atomics` feature is not enabled, `VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command

- VUID-vkCmdDrawIndirectCount-sparseImageInt64Atomics-04475
  If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command

- VUID-vkCmdDrawIndirectCount-OpImageWeightedSampleQCOM-06971
If `OpImageWeightedSampleQCOM` is used to sample a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`.

- **VUID-vkCmdDrawIndirectCount-OpImageWeightedSampleQCOM-06972**
  If `OpImageWeightedSampleQCOM` uses a `VkImageView` as a sample weight image as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`.

- **VUID-vkCmdDrawIndirectCount-OpImageBoxFilterQCOM-06973**
  If `OpImageBoxFilterQCOM` is used to sample a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM`.

- **VUID-vkCmdDrawIndirectCount-OpImageBlockMatchSSDQCOM-06974**
  If `OpImageBlockMatchSSDQCOM` is used to read from a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

- **VUID-vkCmdDrawIndirectCount-OpImageBlockMatchSADQCOM-06975**
  If `OpImageBlockMatchSADQCOM` is used to read from a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

- **VUID-vkCmdDrawIndirectCount-OpImageBlockMatchWindowSSDQCOM-06976**
  If `OpImageBlockMatchWindowSSDQCOM` or `OpImageBlockMatchWindowSADQCOM` is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.

- **VUID-vkCmdDrawIndirectCount-OpImageBlockMatchWindow-09215**
  If an `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view’s format must be a single-component format.

If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

- **VUID-vkCmdDrawIndirectCount-OpImageBlockMatchWindow-09216**
  If an `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view’s format must be a single-component format.
If a `OpImageBlockMatchWindow` or `OpImageBlockMatchGather` read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.

Any shader invocation executed by this command must terminate.

The current render pass must be compatible with the `renderPass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

The subpass index of the current render pass must be equal to the `subpass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

If any shader statically accesses an input attachment, a valid descriptor must be bound to the pipeline via a descriptor set.

If any shader executed by this pipeline accesses an `OpTypeImage` variable with a `Dim` operand of `SubpassData`, it must be decorated with an `InputAttachmentIndex` that corresponds to a valid input attachment in the current subpass.

Input attachment views accessed in a subpass must be created with the same `VkFormat` as the corresponding subpass definition, and be created with a `VkImageView` that is compatible with the attachment referenced by the subpass' `pInputAttachments[InputAttachmentIndex]` in the currently bound `VkFramebuffer` as specified by Fragment Input Attachment Compatibility.

Memory backing image subresources used as attachments in the current render pass must not be written in any way other than as an attachment by this command.

If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:

- the `VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
- the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_COLOR_BIT` and
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command.

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If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:

- the `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
- the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_DEPTH_BIT`
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawIndirectCount-None-09002

If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:

- the `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
- the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_STENCIL_BIT`
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawIndirectCount-None-09003

If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command

- VUID-vkCmdDrawIndirectCount-None-06539

If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, storage image, or sampled image by this command it must not write to that image subresource as an attachment

- VUID-vkCmdDrawIndirectCount-None-06886

If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, depth writes must be disabled

- VUID-vkCmdDrawIndirectCount-None-06887

If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back `writeMask` are not zero, and stencil test is enabled, all stencil ops must be `VK_STENCIL_OP_KEEP`

- VUID-vkCmdDrawIndirectCount-None-07831

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT` dynamic state enabled then `vkCmdSetViewport` must have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SCISSOR` dynamic state enabled then `vkCmdSetScissor` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_WIDTH` dynamic state enabled then `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command.

If a shader object that outputs line primitives is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` or `VK_SHADER_STAGE_GEOMETRY_BIT` stage, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BIAS` dynamic state enabled then `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthBiasEnable` in the current command buffer set `depthBiasEnable` to `VK_TRUE`, `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_BLEND_CONSTANTS` dynamic state enabled then `vkCmdSetBlendConstants` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer set any element of `pColorBlendEnables` to `VK_TRUE`, and the most recent call to `vkCmdSetColorBlendEquationEXT` in the current command buffer set the same element of
pColorBlendEquations to a VkColorBlendEquationEXT structure with any VkBlendFactor member with a value of VK_BLEND_FACTOR_CONSTANT_COLOR, VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR, VK_BLEND_FACTOR_CONSTANT_ALPHA, or VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA, vkCmdSetBlendConstants must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-07836**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BOUNDS dynamic state enabled then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-08622**
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDepthBoundsTestEnable in the current command buffer set depthBoundsTestEnable to VK_TRUE, then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-07837**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK dynamic state enabled then vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-08623**
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-07838**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_WRITE_MASK dynamic state enabled then vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-08624**
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-07839**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_REFERENCE dynamic state enabled then vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-08625**
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command.
prior to this drawing command

• VUID-vkCmdDrawIndirectCount-maxMultiviewInstanceIndex-02688
  If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index **must** be less than or equal to `VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex`

• VUID-vkCmdDrawIndirectCount-sampleLocationsEnable-02689
  If the bound graphics pipeline was created with `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` set to `VK_TRUE` and the current subpass has a depth/stencil attachment, then that attachment **must** have been created with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set

• VUID-vkCmdDrawIndirectCount-None-06666
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEXT` **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectCount-None-08626
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetSampleLocationsEnableEXT` in the current command buffer set `sampleLocationsEnable` to `VK_TRUE`, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEXT` **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectCount-sampleLocationsPerPixel-07934
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` **must** equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with

• VUID-vkCmdDrawIndirectCount-None-07840
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CULL_MODE` dynamic state enabled then `vkCmdSetCullMode` **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectCount-None-08627
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCullMode` **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectCount-None-07841
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled then `vkCmdSetFrontFace` **must** have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectCount-None-08628
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then **vkCmdSetFrontFace** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-07843**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE** dynamic state enabled then **vkCmdSetDepthTestEnable** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-08629**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then **vkCmdSetDepthTestEnable** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-07844**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE** dynamic state enabled then **vkCmdSetDepthWriteEnable** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-08630**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then **vkCmdSetDepthWriteEnable** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-07845**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_DEPTH_COMPARE_OP** dynamic state enabled then **vkCmdSetDepthCompareOp** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-08631**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to **vkCmdSetDepthTestEnable** in the current command buffer set depthTestEnable to VK_TRUE, then **vkCmdSetDepthCompareOp** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-07846**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE** dynamic state enabled then **vkCmdSetDepthBoundsTestEnable** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-08632**
  If a shader object is bound to any graphics stage, and the **depthBounds** feature is enabled, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then the **vkCmdSetDepthBoundsTestEnable** must have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE` dynamic state enabled then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_OP` dynamic state enabled then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `VkPipelineViewportStateCreateInfo::scissorCount` of the pipeline.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, then `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `scissorCount` parameter of `vkCmdSetScissorWithCount` must match the `VkPipelineViewportStateCreateInfo::viewportCount` of the pipeline.

If the bound graphics pipeline state was created with both the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic states enabled then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

If a shader object is bound to any graphics stage, then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command.
and \texttt{vkCmdSetScissorWithCount} must have been called in the current command buffer prior to this drawing command, and the \texttt{viewportCount} parameter of \texttt{vkCmdSetViewportWithCount} must match the \texttt{scissorCount} parameter of \texttt{vkCmdSetScissorWithCount}

- **VUID-vkCmdDrawIndirectCount-viewportCount-04137**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} dynamic state enabled, but not the \texttt{VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV} dynamic state enabled, then the bound graphics pipeline must have been created with \texttt{VkPipelineViewportWScalingStateCreateInfoNV} ::\texttt{viewportCount} greater or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- **VUID-vkCmdDrawIndirectCount-viewportCount-04138**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} and \texttt{VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV} dynamic states enabled then the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWScalingNV} must be greater than or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- **VUID-vkCmdDrawIndirectCount-None-09232**
  If a shader object is bound to any graphics stage, and the \texttt{VK_NV_clip_space_w_scaling} extension is enabled on the device, then \texttt{vkCmdSetViewportWScalingNV} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-08636**
  If a shader object is bound to any graphics stage, and the \texttt{VK_NV_clip_space_w_scaling} extension is enabled on the device, then the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWScalingNV} must be greater than or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- **VUID-vkCmdDrawIndirectCount-viewportCount-04139**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} dynamic state enabled, but not the \texttt{VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV} dynamic state enabled, then the bound graphics pipeline must have been created with \texttt{VkPipelineViewportShadingRateImageStateCreateInfoNV} ::\texttt{viewportCount} greater or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- **VUID-vkCmdDrawIndirectCount-viewportCount-04140**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} and \texttt{VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV} dynamic states enabled then the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportShadingRatePaletteNV} must be greater than or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- **VUID-vkCmdDrawIndirectCount-shadingRateImage-09233**
  If the shadingRateImage feature is enabled, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set rasterizerDiscardEnable to \texttt{VK_FALSE}, then \texttt{vkCmdSetCoarseSampleOrderNV} must have been called in the current command buffer prior to this drawing command
If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetShadingRateImageEnableNV in the current command buffer set shadingRateImageEnable to VK_TRUE, then vkCmdSetViewportShadingRatePaletteNV must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, then the viewportCount parameter in the last call to vkCmdSetViewportShadingRatePaletteNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled and a VkPipelineViewportSwizzleStateCreateInfoNV structure chained from VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have been created with VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV dynamic state enabled then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV dynamic state enabled then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the exclusiveScissor feature is enabled, then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetExclusiveScissorEnableNV in the current command buffer set any element of pExclusiveScissorEnables to VK_TRUE, then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command.
called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectCount-None-04876
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE` dynamic state enabled then `vkCmdSetRasterizerDiscardEnable` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-08639
  If a shader object is bound to any graphics stage, then `vkCmdSetRasterizerDiscardEnable` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-04877
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE` dynamic state enabled then `vkCmdSetDepthBiasEnable` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-08640
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthBiasEnable` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-logicOp-04878
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LOGIC_OP_EXT` dynamic state enabled then `vkCmdSetLogicOpEXT` must have been called in the current command buffer prior to this drawing command and the `logicOp` must be a valid `VkLogicOp` value.

- VUID-vkCmdDrawIndirectCount-None-08641
  If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the `logicOp` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEXT` must have been called in the current command buffer prior to this drawing command and the `logicOp` must be a valid `VkLogicOp` value.

- VUID-vkCmdDrawIndirectCount-primitiveFragmentShadingRateWithMultipleViewports-04552
  If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must be 1.

- VUID-vkCmdDrawIndirectCount-primitiveFragmentShadingRateWithMultipleViewports-08642
  If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, and any shader object bound to a graphics stage writes to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of
vkCmdSetViewportWithCount must be 1

- VUID-vkCmdDrawIndirectCount-blendEnable-04727
  If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view's format features do not contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT, then the blendEnable member of the pAttachments member of pColorBlendState must be VK_FALSE

- VUID-vkCmdDrawIndirectCount-None-08643
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then for each color attachment in the render pass, if the corresponding image view's format features do not contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT, then the corresponding member of pColorBlendEnables in the most recent call to vkCmdSetColorBlendEnableEXT in the current command buffer that affected that attachment index must have been VK_FALSE

- VUID-vkCmdDrawIndirectCount-multisampledRenderToSingleSampled-07284
  If rasterization is not disabled in the bound graphics pipeline, and none of the VK_AMD_mixed_attachment_samples extension, the VK_NV_framebuffer_mixed_samples extension, or the multisampledRenderToSingleSampled feature is enabled, then rasterizationSamples for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments

- VUID-vkCmdDrawIndirectCount-None-08644
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and none of the VK_AMD_mixed_attachment_samples extension, the VK_NV_framebuffer_mixed_samples extension, or the multisampledRenderToSingleSampled feature is enabled, then the most recent call to vkCmdSetRasterizationSamplesEXT in the current command buffer must have set rasterizationSamples to be the same as the number of samples for the current render pass color and/or depth/stencil attachments

- VUID-vkCmdDrawIndirectCount-None-08876
  If a shader object is bound to any graphics stage, the current render pass instance must have been begun with vkCmdBeginRendering

- VUID-vkCmdDrawIndirectCount-imageView-06172
  If the current render pass instance was begun with vkCmdBeginRendering, the imageView member of pDepthAttachment is not VK_NULL_HANDLE, and the layout member of pDepthAttachment is VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL, this command must not write any values to the depth attachment

- VUID-vkCmdDrawIndirectCount-imageView-06173
  If the current render pass instance was begun with vkCmdBeginRendering, the imageView member of pStencilAttachment is not VK_NULL_HANDLE, and the layout member of pStencilAttachment is VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL, this command must not write any values to the stencil attachment

- VUID-vkCmdDrawIndirectCount-imageView-06174
  If the current render pass instance was begun with vkCmdBeginRendering, the imageView
member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, this command must not write any values to the depth attachment

- **VUID-vkCmdDrawIndirectCount-imageView-06175**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment

- **VUID-vkCmdDrawIndirectCount-imageView-06176**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, this command must not write any values to the depth attachment

- **VUID-vkCmdDrawIndirectCount-imageView-06177**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment

- **VUID-vkCmdDrawIndirectCount-viewMask-06178**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo`::`viewMask` equal to `VkRenderingInfo::viewMask`

- **VUID-vkCmdDrawIndirectCount-colorAttachmentCount-06179**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo`::`colorAttachmentCount` equal to `VkRenderingInfo::colorAttachmentCount`

- **VUID-vkCmdDrawIndirectCount-dynamicRenderingUnusedAttachments-08910**
  If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo`::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo`::`pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo`::`pColorAttachmentFormats` used to create the currently bound graphics pipeline

- **VUID-vkCmdDrawIndirectCount-dynamicRenderingUnusedAttachments-08911**
  If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo`::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo`::`pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo`::`pColorAttachmentFormats` used to create the currently bound graphics pipeline, or the corresponding element of `VkPipelineRenderingCreateInfo`::`pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdDrawIndirectCount-dynamicRenderingUnusedAttachments-08912**
If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` must have the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdDrawIndirectCount-None-07749**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-08646**
  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-attachmentCount-07750**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then the `attachmentCount` parameter of `vkCmdSetColorWriteEnableEXT` must be greater than or equal to the `VkPipelineColorBlendStateCreateInfo::attachmentCount` of the currently bound graphics pipeline

- **VUID-vkCmdDrawIndirectCount-None-08647**
  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `attachmentCount` parameter of most recent call to `vkCmdSetColorWriteEnableEXT` in the current command buffer must be greater than or equal to the number of color attachments in the current render pass instance

- **VUID-vkCmdDrawIndirectCount-None-07751**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEXT` must have been called in the current command buffer prior to this drawing command for each discard rectangle in `VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount`

- **VUID-vkCmdDrawIndirectCount-None-07880**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-rasterizerDiscardEnable-09236**
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then
vkCmdSetDiscardRectangleEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectCount-None-08648
  If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDiscardRectangleEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectCount-None-07881
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT dynamic state enabled then vkCmdSetDiscardRectangleModeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectCount-None-08649
  If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDiscardRectangleEnableEXT in the current command buffer set discardRectangleEnable to VK_TRUE, then vkCmdSetDiscardRectangleModeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectCount-dynamicRenderingUnusedAttachments-08913
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawIndirectCount-dynamicRenderingUnusedAttachments-08914
  If current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to the VkFormat used to create VkRenderingInfo::pDepthAttachment->imageView

- VUID-vkCmdDrawIndirectCount-dynamicRenderingUnusedAttachments-08915
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pDepthAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawIndirectCount-dynamicRenderingUnusedAttachments-08916
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pStencilAttachment->imageView was VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound
bound graphics pipeline must be equal to `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdDrawIndirectCount-dynamicRenderingUnusedAttachments-08917**
  If current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to the `VkFormat` used to create `VkRenderingInfo::pStencilAttachment->imageView`

- **VUID-vkCmdDrawIndirectCount-dynamicRenderingUnusedAttachments-08918**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo::pStencilAttachment->imageView`, the value of the format must be `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdDrawIndirectCount-imageView-06183**
  If the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView` was not `VK_NULL_HANDLE`, the currently bound graphics pipeline must have been created with `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`

- **VUID-vkCmdDrawIndirectCount-imageView-06184**
  If the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView` was not `VK_NULL_HANDLE`, the currently bound graphics pipeline must have been created with `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT`

- **VUID-vkCmdDrawIndirectCount-colorAttachmentCount-06185**
  If the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the corresponding element of the `pColorAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline

- **VUID-vkCmdDrawIndirectCount-pDepthAttachment-06186**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`

- **VUID-vkCmdDrawIndirectCount-pStencilAttachment-06187**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to the `VkFormat` used to create `VkRenderingInfo::pStencilAttachment->imageView`
If the currently bound graphics pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::pColorAttachments` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with an `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the value of `rasterizationSamples` for the currently bound graphics pipeline.

*VUID-vkCmdDrawIndirectCount-multisampledRenderToSingleSampled-07286*

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

*VUID-vkCmdDrawIndirectCount-multisampledRenderToSingleSampled-07287*

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

*VUID-vkCmdDrawIndirectCount-pNext-07935*

If this command has been called inside a render pass instance started with `vkCmdBeginRendering`, and the `pNext` chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to `VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples`.

*VUID-vkCmdDrawIndirectCount-renderPass-06198*

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline must have been created with a `VkGraphicsPipelineCreateInfo::renderPass` equal to `VK_NULL_HANDLE`.

*VUID-vkCmdDrawIndirectCount-pColorAttachments-08963*

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the...
corresponding element of the `VkRenderingInfo::pColorAttachments->imageView` was not `VK_NULL_HANDLE`, then the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the pipeline **must** not be `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdDrawIndirectCount-pDepthAttachment-08964**
  If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, depth test is enabled, and the `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the pipeline **must** not be `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdDrawIndirectCount-pStencilAttachment-08965**
  If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, stencil test is enabled and the `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the pipeline **must** not be `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdDrawIndirectCount-primitivesGeneratedQueryWithRasterizerDiscard-06708**
  If the `primitivesGeneratedQueryWithRasterizerDiscard` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, **rasterization discard must not be enabled**

- **VUID-vkCmdDrawIndirectCount-primitivesGeneratedQueryWithNonZeroStreams-06709**
  If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, the bound graphics pipeline **must not have been created with a non-zero value in VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream**

- **VUID-vkCmdDrawIndirectCount-None-07619**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT` dynamic state enabled then `vkCmdSetTessellationDomainOriginEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-07620**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClampEnableEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-09237**
  If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-08650**
  If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-07621**
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-08651**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-07622**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` dynamic state enabled then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-08652**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-07623**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` dynamic state enabled then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-08653**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-07624**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-alphaToCoverageEnable-08919**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled, and `alphaToCoverageEnable` was `VK_TRUE` in the last call to `vkCmdSetAlphaToCoverageEnableEXT`, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0

- **VUID-vkCmdDrawIndirectCount-None-08654**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetAlphaToCoverageEnableEXT` in the current command buffer set `alphaToCoverageEnable` to `VK_TRUE`, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT` dynamic state enabled then `vkCmdSetAlphaToOneEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `alphaToOne` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetAlphaToOneEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT` dynamic state enabled then `vkCmdSetLogicOpEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `logicOp` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to
vkCmdSetColorBlendEnableEXT for any attachment set that attachment’s value in pColorBlendEnables to VK_TRUE, then vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-07629
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT dynamic state enabled then vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-08659
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-07630
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT dynamic state enabled then vkCmdSetRasterizationStreamEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-08660
  If the geometryStreams feature is enabled, and a shader object is bound to the VK_SHADER_STAGE_GEOMETRY_BIT stage, then vkCmdSetRasterizationStreamEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-07631
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT dynamic state enabled then vkCmdSetConservativeRasterizationModeEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-08661
  If the VK_EXT_conservative_rasterization extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetConservativeRasterizationModeEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-07632
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT dynamic state enabled then vkCmdSetExtraPrimitiveOverestimationSizeEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-08662
  If the VK_EXT_conservative_rasterization extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetConservativeRasterizationModeEXT in the current command buffer set conservativeRasterizationMode to VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT,
then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-07633**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-08663**
  If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-07634**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-08664**
  If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEnableEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-07635**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-07636**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT` dynamic state enabled then `vkCmdSetProvokingVertexModeEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-08665**
  If the `VK_EXT_provoking_vertex` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetProvokingVertexModeEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-07637**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetLineRasterizationModeEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectCount-None-08666**
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer
command buffer set polygonMode to VK_POLYGON_MODE_LINE, then vkCmdSetLineRasterizationModeEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectCount-None-08667 If the VK_EXT_line_rasterization extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to vkCmdSetPrimitiveTopology in the current command buffer set primitiveTopology to any line topology, then vkCmdSetLineRasterizationModeEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectCount-None-08668 If the VK_EXT_line_rasterization extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then vkCmdSetLineRasterizationModeEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectCount-None-07638 If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT dynamic state enabled then vkCmdSetLineStippleEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectCount-None-08669 If the VK_EXT_line_rasterization extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetPolygonModeEXT in the current command buffer set polygonMode to VK_POLYGON_MODE_LINE, then vkCmdSetLineStippleEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectCount-None-08670 If the VK_EXT_line_rasterization extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to vkCmdSetPrimitiveTopology in the current command buffer set primitiveTopology to any line topology, then vkCmdSetLineStippleEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectCount-None-08671 If the VK_EXT_line_rasterization extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then vkCmdSetLineStippleEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectCount-None-07849 If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_EXT dynamic state enabled then vkCmdSetLineStippleEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectCount-None-08672 If the VK_EXT_line_rasterization extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetLineStippleEnableEXT in the current command buffer set stippledLineEnable to VK_TRUE, then vkCmdSetLineStippleEXT must have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT` dynamic state enabled then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command.

If the `depthClipControl` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV` dynamic state enabled then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_clip_space_w_scaling` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` dynamic state enabled then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` dynamic state enabled then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.
If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set `coverageToColorEnable` to `VK_TRUE`, then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-07644**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-08678**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-07645**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-08679**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationModeNV` in the current command buffer set `coverageModulationMode` to any value other than `VK_COVERAGE_MODULATION_MODE_NONE_NV`, then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-07646**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-08680**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationTableEnableNV` in the current command buffer set `coverageModulationTableEnable` to `VK_TRUE`, then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-None-07647**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV` dynamic state enabled then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command.
buffer prior to this drawing command

- VUID-vkCmdDrawIndirectCount-pipelineFragmentShadingRate-09238
  If the `pipelineFragmentShadingRate` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFragmentShadingRateKHR` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-08681
  If the `shadingRateImage` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-07648
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV` dynamic state enabled, then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-08682
  If the `representativeFragmentTest` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-07649
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV` dynamic state enabled, then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-None-08683
  If the `coverageReductionMode` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectCount-pColorBlendEnables-07470
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` state enabled and the last call to `vkCmdSetColorBlendEnableEXT` set `pColorBlendEnables` for any attachment to `VK_TRUE`, then for those attachments in the subpass the corresponding image view's format features must contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`.

- VUID-vkCmdDrawIndirectCount-rasterizationSamples-07471
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the `rasterizationSamples` in the
last call to `vkCmdSetRasterizationSamplesEXT` must follow the rules for a zero-attachment subpass

- **VUID-vkCmdDrawIndirectCount-samples-07472**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `VulkanPipelineMultisampleStateCreateInfo::rasterizationSamples` parameter used to create the bound graphics pipeline.

- **VUID-vkCmdDrawIndirectCount-samples-07473**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawIndirectCount-rasterizationSamples-07474**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and neither the `VK_AMD_mixed_attachment_samples` nor the `VK_NV_framebuffer_mixed_samples` extensions are enabled, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawIndirectCount-None-09211**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the `rasterizationSamples` member of that structure.

- **VUID-vkCmdDrawIndirectCount-firstAttachment-07476**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEnableEXT` calls must specify an enable for all active color attachments in the current subpass.

- **VUID-vkCmdDrawIndirectCount-firstAttachment-07477**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEquationEXT` calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorWriteMaskEXT` calls must specify the color write mask for all active color attachments in the current subpass.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendAdvancedEXT` calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` and `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic states enabled and the last calls to `vkCmdSetColorBlendEnableEXT` and `vkCmdSetColorBlendAdvancedEXT` have enabled advanced blending, then the number of active color attachments in the current subpass must not exceed `advancedBlendMaxColorAttachments`.

If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, and the bound graphics pipeline was created with `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` state enabled, the last call to `vkCmdSetRasterizationStreamEXT` must have set the `rasterizationStream` to zero.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` parameter of the last call to `vkCmdSetRasterizationSamplesEXT`.

If the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and `sampleLocationsEnable`
was **VK_TRUE** in the last call to `vkCmdSetSampleLocationsEnableEXT`, and the current subpass has a depth/stencil attachment, then that attachment **must** have been created with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set

- **VUID-vkCmdDrawIndirectCount-sampleLocationsEnable-07485**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable` was **VK_TRUE** in the last call to `vkCmdSetSampleLocationsEnableEXT`, then the `sampleLocationsInfo.sampleLocationGridSize.width` in the last call to `vkCmdSetSampleLocationsEXT` **must** evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.width` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling `rasterizationSamples`

- **VUID-vkCmdDrawIndirectCount-sampleLocationsEnable-07486**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable` was **VK_TRUE** in the last call to `vkCmdSetSampleLocationsEnableEXT`, then the `sampleLocationsInfo.sampleLocationGridSize.height` in the last call to `vkCmdSetSampleLocationsEXT` **must** evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.height` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling `rasterizationSamples`

- **VUID-vkCmdDrawIndirectCount-sampleLocationsEnable-07487**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable` was **VK_TRUE** in the last call to `vkCmdSetSampleLocationsEnableEXT`, the fragment shader code **must** not statically use the extended instruction `InterpolateAtSample`

- **VUID-vkCmdDrawIndirectCount-sampleLocationsEnable-07936**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled and the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is **VK_TRUE** or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.width` **must** evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.width` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling the value of `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`

- **VUID-vkCmdDrawIndirectCount-sampleLocationsEnable-07937**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled and the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is **VK_TRUE** or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.height` **must** evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.height` as returned by
vkGetPhysicalDeviceMultisamplePropertiesEXT with a `samples` parameter equaling the value of `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`

- **VUID-vkCmdDrawIndirectCount-sampleLocationsEnable-07938**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT`::`sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationsPerPixel` must equal `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`

- **VUID-vkCmdDrawIndirectCount-coverageModulationTableEnable-07488**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageModulationTableEnableNV` set `coverageModulationTableEnable` to `VK_TRUE`, then the `coverageModulationTableCount` parameter in the last call to `vkCmdSetCoverageModulationTableNV` must equal the current `rasterizationSamples` divided by the number of color samples in the current subpass

- **VUID-vkCmdDrawIndirectCount-rasterizationSamples-07489**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current `rasterizationSamples` must be the same as the sample count of the depth/stencil attachment

- **VUID-vkCmdDrawIndirectCount-coverageToColorEnable-07490**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageToColorEnableNV` set the `coverageToColorEnable` to `VK_TRUE`, then the current subpass must have a color attachment at the location selected by the last call to `vkCmdSetCoverageToColorLocationNV` `coverageToColorLocation`, with a `VkFormat` of `VK_FORMAT_R8_UINT`, `VK_FORMAT_R8_SINT`, `VK_FORMAT_R16_UINT`, `VK_FORMAT_R16_SINT`, `VK_FORMAT_R32_UINT`, or `VK_FORMAT_R32_SINT`

- **VUID-vkCmdDrawIndirectCount-coverageReductionMode-07491**
  If this `VK_NV_coverage_reduction_mode` extension is enabled, the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, the current coverage reduction mode `coverageReductionMode`, then the current `rasterizationSamples`, and the sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by `vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV`

- **VUID-vkCmdDrawIndirectCount-viewportCount-07492**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORTSWGIZZLE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV`::`viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportSwizzleNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if the current subpass has any color attachments and `rasterizationSamples` of the last call to `vkCmdSetRasterizationSamplesEXT` is greater than the number of color samples, then the pipeline `sampleShadingEnable` must be `VK_FALSE`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT`, then the `stippledRectangularLines` feature must be enabled.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT`, then the `stippledBresenhamLines` feature must be enabled.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT`, then the `stippledSmoothLines` feature must be enabled.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT`, then the `stippledRectangularLines` feature must be enabled and `VkPhysicalDeviceLimits::strictLines` must be `VK_TRUE`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled, `conservativePointAndLineRasterization` is not supported, and the effective primitive topology output by the last pre-rasterization shader stage is a line or point, then the `conservativeRasterizationMode` set by the last call to...
vkCmdSetConservativeRasterizationModeEXT must be VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT

- VUID-vkCmdDrawIndirectCount-stage-07073
  If the currently bound pipeline was created with the VkPipelineShaderStageCreateInfo::stage member of an element of VkGraphicsPipelineCreateInfo::pStages set to VK_SHADER_STAGE_VERTEX_BIT, VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT, VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT, then Mesh Shader Queries must not be active

- VUID-vkCmdDrawIndirectCount-None-08877
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT dynamic state vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectCount-None-07850
  If dynamic state was inherited from VkCommandBufferInheritanceViewportScissorInfoNV, it must be set in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectCount-None-08684
  If there is no bound graphics pipeline, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_VERTEX_BIT

- VUID-vkCmdDrawIndirectCount-None-08685
  If there is no bound graphics pipeline, and the tessellationShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT

- VUID-vkCmdDrawIndirectCount-None-08686
  If there is no bound graphics pipeline, and the tessellationShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT

- VUID-vkCmdDrawIndirectCount-None-08687
  If there is no bound graphics pipeline, and the geometryShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_GEOMETRY_BIT

- VUID-vkCmdDrawIndirectCount-None-08688
  If there is no bound graphics pipeline, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_FRAGMENT_BIT

- VUID-vkCmdDrawIndirectCount-None-08689
  If there is no bound graphics pipeline, and the taskShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TASK_BIT_EXT

- VUID-vkCmdDrawIndirectCount-None-08690
  If there is no bound graphics pipeline, and the meshShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_MESH_BIT_EXT
If there is no bound graphics pipeline, and at least one of the taskShader and meshShader features is enabled, one of the VK_SHADER_STAGE_VERTEX_BIT or VK_SHADER_STAGE_MESH_BIT_EXT stages must have a valid VkShaderEXT bound, and the other must have no VkShaderEXT bound.

If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_MESH_BIT_EXT stage, and that VkShaderEXT was created without the VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT flag, a valid VkShaderEXT must be bound to the VK_SHADER_STAGE_TASK_BIT_EXT stage.

If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_MESH_BIT_EXT stage, and that VkShaderEXT was created with the VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT flag, there must be no VkShaderEXT bound to the VK_SHADER_STAGE_TASK_BIT_EXT stage.

If there is no bound graphics pipeline, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, there must be no VkShaderEXT bound to either the VK_SHADER_STAGE_TASK_BIT_EXT stage or the VK_SHADER_STAGE_MESH_BIT_EXT stage.

If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, then all shaders created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag in the same vkCreateShadersEXT call must also be bound.

If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, any stages in between stages whose shaders which did not create a shader with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag as part of the same vkCreateShadersEXT call must not have any VkShaderEXT bound.

All bound graphics shader objects must have been created with identical or identically defined push constant ranges.

All bound graphics shader objects must have been created with identical or identically defined arrays of descriptor set layouts.

If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage and the attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state includes a fragment shader stage, was created with
**VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE** set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`, and the fragment shader declares the `EarlyFragmentTests` execution mode and uses `OpDepthAttachmentReadEXT`, the `depthWriteEnable` parameter in the last call to `vkCmdSetDepthWriteEnable` must be `VK_FALSE`.

- **VUID-vkCmdDrawIndirectCount-pDynamicStates-08716**
  If the bound graphics pipeline state includes a fragment shader stage, was created with `VK_DYNAMIC_STATE_STENCIL_WRITE_MASK` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`, and the fragment shader declares the `EarlyFragmentTests` execution mode and uses `OpStencilAttachmentReadEXT`, the `writeMask` parameter in the last call to `vkCmdSetStencilWriteMask` must be 0.

- **VUID-vkCmdDrawIndirectCount-None-09116**
  If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT`, and the format of any color attachment is `VK_FORMAT_E5B9G9R9_UFLOAT_PACK32`, the corresponding element of the `pColorWriteMasks` parameter of `vkCmdSetColorWriteMaskEXT` must either include all of `VK_COLOR_COMPONENT_R_BIT`, `VK_COLOR_COMPONENT_G_BIT`, and `VK_COLOR_COMPONENT_B_BIT`, or none of them.

- **VUID-vkCmdDrawIndirectCount-maxFragmentDualSrcAttachments-09239**
  If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of `Location` for any output attachment statically used in the Fragment Execution Model executed by this command must be less than `maxFragmentDualSrcAttachments`.

- **VUID-vkCmdDrawIndirectCount-None-04007**
  All vertex input bindings accessed via vertex input variables declared in the vertex shader entry point's interface must have either valid or `VK_NULL_HANDLE` buffers bound.

- **VUID-vkCmdDrawIndirectCount-None-04008**
  If the `nullDescriptor` feature is not enabled, all vertex input bindings accessed via vertex input variables declared in the vertex shader entry point's interface must not be `VK_NULL_HANDLE`.

- **VUID-vkCmdDrawIndirectCount-None-02721**
  For a given vertex buffer binding, any attribute data fetched must be entirely contained within the corresponding vertex buffer binding, as described in Vertex Input Description.

- **VUID-vkCmdDrawIndirectCount-None-07842**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY` dynamic state enabled, then `vkCmdSetPrimitiveTopology` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectCount-dynamicPrimitiveTopologyUnrestricted-07500**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY` dynamic state enabled and the `dynamicPrimitiveTopologyUnrestricted` is `VK_FALSE`, then the `primitiveTopology` parameter of `vkCmdSetPrimitiveTopology` must be of the same topology class as the pipeline `VkPipelineInputAssemblyStateCreateInfo::topology` state.
If the bound graphics pipeline state was created with both the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` and `VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT` dynamic states enabled, then `vkCmdSetVertexInputEXT` must have been called in the current command buffer prior to the draw command.

If the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then `vkCmdBindVertexBuffers2EXT` must have been called in the current command buffer prior to this draw command, and the `pStrides` parameter of `vkCmdBindVertexBuffers2EXT` must not be `NULL`.

If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and `VkVertexInputAttributeDescription2EXT::format` has a 64-bit component, then the scalar width associated with all `Input` variables of the corresponding `Location` in the `Vertex Execution Model OpEntryPoint` must be 64-bit.
and \texttt{VkVertexInputAttributeDescription2EXT::format} has a 64-bit component, then all \texttt{Input} variables at the corresponding \texttt{Location} in the \texttt{Vertex Execution Model OpEntryPoint} \textbf{must} not use components that are not present in the format

- \textbf{VUID-vkCmdDrawIndirectCount-None-08882}
  If a shader object is bound to the \texttt{VK_shader_stage_vertex_bit} stage, then \texttt{vkCmdSetVertexInputEXT} \textbf{must} have been called in the current command buffer prior to this drawing command

- \textbf{VUID-vkCmdDrawIndirectCount-None-04875}
  If the bound graphics pipeline state was created with the \texttt{VK_dynamic_state_patch_control_points_EXT} dynamic state enabled then \texttt{vkCmdSetPatchControlPointsEXT} \textbf{must} have been called in the current command buffer prior to this drawing command

- \textbf{VUID-vkCmdDrawIndirectCount-None-08883}
  If a shader object is bound to the \texttt{VK_shader_stage_tessellation_evaluation_bit} stage, then \texttt{vkCmdSetPatchControlPointsEXT} \textbf{must} have been called in the current command buffer prior to this drawing command

- \textbf{VUID-vkCmdDrawIndirectCount-None-04879}
  If the bound graphics pipeline state was created with the \texttt{VK_dynamic_state_primitive_restart_enable} dynamic state enabled then \texttt{vkCmdSetPrimitiveRestartEnable} \textbf{must} have been called in the current command buffer prior to this drawing command

- \textbf{VUID-vkCmdDrawIndirectCount-rasterizerDiscardEnable-08884}
  If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, \texttt{vkCmdSetPrimitiveRestartEnable} \textbf{must} have been called in the current command buffer prior to this drawing command

- \textbf{VUID-vkCmdDrawIndirectCount-stage-06481}
  The bound graphics pipeline \textbf{must} not have been created with the \texttt{VkPipelineShaderStageCreateInfo::stage} member of an element of \texttt{VkGraphicsPipelineCreateInfo::pStages} set to \texttt{VK_shader_stage_task_bit_EXT} or \texttt{VK_shader_stage_mesh_bit_EXT}

- \textbf{VUID-vkCmdDrawIndirectCount-None-08885}
  There \textbf{must} be no shader object bound to either of the \texttt{VK_shader_stage_task_bit_EXT} or \texttt{VK_shader_stage_mesh_bit_EXT} stages

- \textbf{VUID-vkCmdDrawIndirectCount-buffer-02708}
  If \texttt{buffer} is non-sparse then it \textbf{must} be bound completely and contiguously to a single \texttt{VkDeviceMemory} object

- \textbf{VUID-vkCmdDrawIndirectCount-buffer-02709}
  \texttt{buffer} \textbf{must} have been created with the \texttt{VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT} bit set

- \textbf{VUID-vkCmdDrawIndirectCount-offset-02710}
  \texttt{offset} \textbf{must} be a multiple of \texttt{4}

- \textbf{VUID-vkCmdDrawIndirectCount-commandBuffer-02711}
  \texttt{commandBuffer} \textbf{must} not be a protected command buffer
If `countBuffer` is non-sparse then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object.

`countBuffer` must have been created with the `VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT` bit set.

`countBufferOffset` must be a multiple of 4.

The count stored in `countBuffer` must be less than or equal to `VkPhysicalDeviceLimits::maxDrawIndirectCount`.

`(countBufferOffset + sizeof(uint32_t))` must be less than or equal to the size of `countBuffer`.

If `drawIndirectCount` is not enabled this function **must** not be used.

`stride` must be a multiple of 4 and **must** be greater than or equal to `sizeof(VkDrawIndirectCommand)`.

If `maxDrawCount` is greater than or equal to 1, `(stride × (maxDrawCount - 1) + offset + sizeof(VkDrawIndirectCommand))` must be less than or equal to the size of `buffer`.

If the count stored in `countBuffer` is equal to 1, `(offset + sizeof(VkDrawIndirectCommand))` must be less than or equal to the size of `buffer`.

If the count stored in `countBuffer` is greater than 1, `(stride × (drawCount - 1) + offset + sizeof(VkDrawIndirectCommand))` must be less than or equal to the size of `buffer`.

**Valid Usage (Implicit)**

- `commandBuffer` must be a valid `VkCommandBuffer` handle.
- `buffer` must be a valid `VkBuffer` handle.
- `countBuffer` must be a valid `VkBuffer` handle.
- `commandBuffer` must be in the recording state.
- The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations.
- `renderpass`
This command **must** only be called inside of a render pass instance

- VUID-vkCmdDrawIndirectCount-videocoding
  This command **must** only be called outside of a video coding scope

- VUID-vkCmdDrawIndirectCount-commonparent
  Each of `buffer`, `commandBuffer`, and `countBuffer` **must** have been created, allocated, or retrieved from the same `VkDevice`

---

**Host Synchronization**

- Host access to `commandBuffer` **must** be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized

---

**Command Properties**

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To record an indexed indirect drawing command, call:

```cpp
// Provided by VK_VERSION_1_0
void vkCmdDrawIndexedIndirect(
    VkCommandBuffer commandBuffer,
    VkBuffer buffer,
    VkDeviceSize offset,
    uint32_t drawCount,
    uint32_t stride);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `buffer` is the buffer containing draw parameters.
- `offset` is the byte offset into `buffer` where parameters begin.
- `drawCount` is the number of draws to execute, and can be zero.
- `stride` is the byte stride between successive sets of draw parameters.

`vkCmdDrawIndexedIndirect` behaves similarly to `vkCmdDrawIndexed` except that the parameters are read by the device from a buffer during execution. `drawCount` draws are executed by the command, with parameters taken from `buffer` starting at `offset` and increasing by `stride` bytes for each successive draw. The parameters of each draw are encoded in an array of `VkDrawIndexedIndirectCommand` structures. If `drawCount` is less than or equal to one, `stride` is
Valid Usage

- VUID-vkCmdDrawIndexedIndirect-magFilter-04553
  If a VkSampler created with magFilter or minFilter equal to VK_FILTER_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- VUID-vkCmdDrawIndexedIndirect-mipmapMode-04770
  If a VkSampler created with mipmapMode equal to VK_SAMPLER_MIPMAP_MODE_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- VUID-vkCmdDrawIndexedIndirect-None-06479
  If a VkImageView is sampled with depth comparison, the image view's format features must contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT

- VUID-vkCmdDrawIndexedIndirect-None-02691
  If a VkImageView is accessed using atomic operations as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

- VUID-vkCmdDrawIndexedIndirect-None-07888
  If a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

- VUID-vkCmdDrawIndexedIndirect-None-02692
  If a VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT

- VUID-vkCmdDrawIndexedIndirect-None-02693
  If the VK_EXT_filter_cubic extension is not enabled and any VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, it must not have a VkImageViewType of VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

- VUID-vkCmdDrawIndexedIndirect-filterCubic-02694
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT:filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2

- VUID-vkCmdDrawIndexedIndirect-filterCubicMinmax-02695
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT with a reduction mode of either VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX as a result of this command must have a VkImageViewType and format that supports cubic filtering together with minmax filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT:filterCubicMinmax returned by
If the `cubicRangeClamp` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command **must not have a `VkSamplerReductionModeCreateInfo`**

\[
\text{reductionMode} \quad \text{equal to} \quad \text{VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM}
\]

Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command **must** sample with `VK_FILTER_CUBIC_EXT`

If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command **must** have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`

Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command **must** only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`

For any `VkImageView` being written as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view’s format features **must** contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`

For any `VkImageView` being read as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view’s buffer features **must** contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`

For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view’s buffer features **must** contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`

For any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown` then the view’s buffer features **must** contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`

For each set \( n \) that is statically used by a **bound shader**, a descriptor set **must** have been bound to \( n \) at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set \( n \), with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in **Pipeline Layout Compatibility**

For each push constant that is statically used by a **bound shader**, a push constant value
must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in **Pipeline Layout Compatibility**

- **VUID-vkCmdDrawIndexedIndirect-maintenance4-08602**
  If the `maintenance4` feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in **Pipeline Layout Compatibility**

- **VUID-vkCmdDrawIndexedIndirect-None-08114**
  Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, must be valid if they are statically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was not created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- **VUID-vkCmdDrawIndexedIndirect-None-08115**
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` must have been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- **VUID-vkCmdDrawIndexedIndirect-None-08116**
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- **VUID-vkCmdDrawIndexedIndirect-None-08604**
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command

- **VUID-vkCmdDrawIndexedIndirect-None-08117**
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdSetDescriptorBufferOffsetsEXT`, the bound `VkPipeline` must have been created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- **VUID-vkCmdDrawIndexedIndirect-None-08119**
  If a descriptor is dynamically used with a `VkPipeline` created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory must be resident

- **VUID-vkCmdDrawIndexedIndirect-None-08605**
  If a descriptor is dynamically used with a `VkShaderEXT` created with a `VkDescriptorSetLayout` that was created with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory must be resident

- **VUID-vkCmdDrawIndexedIndirect-None-08606**
  If the `shaderObject` feature is not enabled, a valid pipeline must be bound to the pipeline
bind point used by this command

- **VUID-vkCmdDrawIndexedIndirect-None-08607**
  If the `shaderObject` is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and `VK_NULL_HANDLE` shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- **VUID-vkCmdDrawIndexedIndirect-None-08608**
  If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the `VkPipeline` object bound to the pipeline bind point used by this command, since that pipeline was bound

- **VUID-vkCmdDrawIndexedIndirect-None-08609**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler must not be used to sample from any `VkImage` with a `VkImageView` of the type `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, `VK_IMAGE_VIEW_TYPE_1D_ARRAY`, `VK_IMAGE_VIEW_TYPE_2D_ARRAY` or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`, in any shader stage

- **VUID-vkCmdDrawIndexedIndirect-None-08610**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V `OpImageSample*` or `OpImageSparseSample*` instructions with `ImplicitLod`, `Dref` or `Proj` in their name, in any shader stage

- **VUID-vkCmdDrawIndexedIndirect-None-08611**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V `OpImageSample*` or `OpImageSparseSample*` instructions that includes a LOD bias or any offset values, in any shader stage

- **VUID-vkCmdDrawIndexedIndirect-uniformBuffers-06935**
  If any stage of the `VkPipeline` object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT` or `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT` for `uniformBuffers`, and the `robustBufferAccess` feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawIndexedIndirect-None-08612**
  If the `robustBufferAccess` feature is not enabled, and any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawIndexedIndirect-storageBuffers-06936**
  If any stage of the `VkPipeline` object bound to the pipeline bind point used by this
command accesses a storage buffer, and that stage was created without enabling either `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT` or `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT` for `storageBuffers`, and the `robustBufferAccess` feature is not enabled, that stage **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawIndexedIndirect-None-08613**
  If the `robustBufferAccess` feature is not enabled, and any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawIndexedIndirect-commandBuffer-02707**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, any resource accessed by **bound shaders** **must** not be a protected resource

- **VUID-vkCmdDrawIndexedIndirect-None-06550**
  If a **bound shader** accesses a `VkSampler` or `VkImageView` object that enables `sampler YC aC bC` conversion, that object **must** only be used with `OpImageSample*` or `OpImageSparseSample*` instructions

- **VUID-vkCmdDrawIndexedIndirect-ConstOffset-06551**
  If a **bound shader** accesses a `VkSampler` or `VkImageView` object that enables `sampler YC aC bC` conversion, that object **must** not use the `ConstOffset` and `Offset` operands

- **VUID-vkCmdDrawIndexedIndirect-viewType-07752**
  If a `VkImageView` is accessed as a result of this command, then the image view's `viewType` **must** match the `Dim` operand of the `OpTypeImage` as described in Instruction/Sampler/Image View Validation

- **VUID-vkCmdDrawIndexedIndirect-format-07753**
  If a `VkImageView` is accessed as a result of this command, then the numeric type of the image view's `format` and the `Sampled Type` operand of the `OpTypeImage` **must** match

- **VUID-vkCmdDrawIndexedIndirect-OpImageWrite-08795**
  If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the image view's format

- **VUID-vkCmdDrawIndexedIndirect-OpImageWrite-08796**
  If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have four components

- **VUID-vkCmdDrawIndexedIndirect-OpImageWrite-04469**
  If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the buffer view's format

- **VUID-vkCmdDrawIndexedIndirect-SampledType-04470**
  If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 64
If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 32.

If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64.

If a `VkBufferView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 32.

If the `sparseImageInt64Atomics` feature is not enabled, `VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

If `OpImageWeightedSampleQCOM` is used to sample a `VkImageView` as a result of this command, then the image view’s `format features` must contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`.

If `OpImageWeightedSampleQCOM` uses a `VkImageView` as a sample weight image as a result of this command, then the image view’s `format features` must contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`.

If `OpImageBoxFilterQCOM` is used to sample a `VkImageView` as a result of this command, then the image view’s `format features` must contain `VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM`.

If `OpImageBlockMatchSSDQCOM` or `OpImageBlockMatchSADQCOM` is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.
If `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, or `OpImageBlockMatchSSDQCOM` or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`

If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, or `OpImageBlockMatchSSDQCOM` or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must not have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`

If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`

If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format must be a single-component format.

If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.

Any shader invocation executed by this command must terminate.

The current render pass must be compatible with the `renderPass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

The subpass index of the current render pass must be equal to the `subpass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

If any shader statically accesses an input attachment, a valid descriptor must be bound to the pipeline via a descriptor set.

If any shader executed by this pipeline accesses an `OpTypeImage` variable with a `Dim` operand of `SubpassData`, it must be decorated with an `InputAttachmentIndex` that corresponds to a valid input attachment in the current subpass.

Input attachment views accessed in a subpass must be created with the same `VkFormat`
as the corresponding subpass definition, and be created with a VkImageView that is compatible with the attachment referenced by the subpass' pInputAttachments [InputAttachmentIndex] in the currently bound VkFramebuffer as specified by Fragment Input Attachment Compatibility

- VUID-vkCmdDrawIndexedIndirect-None-06537
  Memory backing image subresources used as attachments in the current render pass **must** not be written in any way other than as an attachment by this command

- VUID-vkCmdDrawIndexedIndirect-None-09000
  If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:
  - the VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
  - the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_COLOR_BIT and
    - there is no currently bound graphics pipeline or
    - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it **must** not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawIndexedIndirect-None-09001
  If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:
  - the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
  - the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_DEPTH_BIT and
    - there is no currently bound graphics pipeline or
    - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it **must** not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawIndexedIndirect-None-09002
  If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:
  - the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
  - the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_STENCIL_BIT and
    - there is no currently bound graphics pipeline or
    - the currently bound graphics pipeline was created with
VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawIndexedIndirect-None-09003
  If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command

- VUID-vkCmdDrawIndexedIndirect-None-06539
  If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command must not write to that image subresource as an attachment

- VUID-vkCmdDrawIndexedIndirect-None-06886
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, depth writes must be disabled

- VUID-vkCmdDrawIndexedIndirect-None-06887
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back writeMask are not zero, and stencil test is enabled, all stencil ops must be VK_STENCIL_OP_KEEP

- VUID-vkCmdDrawIndexedIndirect-None-07831
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT dynamic state enabled then vkCmdSetViewport must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-07832
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SCISSOR dynamic state enabled then vkCmdSetScissor must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-07833
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_WIDTH dynamic state enabled then vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-08617
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetPolygonModeEXT in the current command buffer set polygonMode to VK_POLYGON_MODE_LINE, vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-08618
  If a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, and the most recent call to vkCmdSetPrimitiveTopology in the current command buffer set primitiveTopology to any line topology, vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-08619
  If a shader object that outputs line primitives is bound to the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT stage, vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command
• VUID-vkCmdDrawIndexedIndirect-None-07834
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BIAS dynamic state enabled then vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-None-08620
If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDepthBiasEnable in the current command buffer set depthBiasEnable to VK_TRUE, vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-None-07835
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_BLEND_CONSTANTS dynamic state enabled then vkCmdSetBlendConstants must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-None-08621
If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetColorBlendEnableEXT in the current command buffer set any element of pColorBlendEnables to VK_TRUE, and the most recent call to vkCmdSetColorBlendEquationEXT in the current command buffer set the same element of pColorBlendEquations to a VkColorBlendEquationEXT structure with any VkBlendFactor member with a value of VK_BLEND_FACTOR_CONSTANT_COLOR, VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR, VK_BLEND_FACTOR_CONSTANT_ALPHA, or VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA, vkCmdSetBlendConstants must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-None-07836
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BOUNDS dynamic state enabled then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-None-08622
If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDepthBoundsTestEnable in the current command buffer set depthBoundsTestEnable to VK_TRUE, then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-None-07837
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK dynamic state enabled then vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-None-08623
If a shader object is bound to any graphics stage, and the most recent call to
**vkCmdSetStencilTestEnable** in the current command buffer set **stencilTestEnable** to **VK_TRUE**, **vkCmdSetStencilCompareMask** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-07838**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_STENCIL_WRITE_MASK** dynamic state enabled then **vkCmdSetStencilWriteMask** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-08624**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetStencilTestEnable** in the current command buffer set **stencilTestEnable** to **VK_TRUE**, **vkCmdSetStencilWriteMask** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-07839**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_STENCIL_REFERENCE** dynamic state enabled then **vkCmdSetStencilReference** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-08625**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetStencilTestEnable** in the current command buffer set **stencilTestEnable** to **VK_TRUE**, **vkCmdSetStencilReference** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-maxMultiviewInstanceIndex-02688**
  If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to **VkPhysicalDeviceMultiviewProperties.maxMultiviewInstanceIndex**

- **VUID-vkCmdDrawIndexedIndirect-sampleLocationsEnable-02689**
  If the bound graphics pipeline was created with **VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable** set to **VK_TRUE** and the current subpass has a depth/stencil attachment, then that attachment must have been created with the **VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT** bit set

- **VUID-vkCmdDrawIndexedIndirect-None-06666**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT** dynamic state enabled then **vkCmdSetSampleLocationsEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-08626**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetSampleLocationsEnableEXT** in the current command buffer set **sampleLocationsEnable** to **VK_TRUE**, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set **rasterizerDiscardEnable** to **VK_FALSE**, then **vkCmdSetSampleLocationsEXT** must have been called in the current command buffer prior to this drawing command
• VUID-vkCmdDrawIndexedIndirect-sampleLocationsPerPixel-07934
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with.

• VUID-vkCmdDrawIndexedIndirect-None-07840
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CULL_MODE` dynamic state enabled then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexedIndirect-None-08627
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexedIndirect-None-07841
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexedIndirect-None-08628
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexedIndirect-None-07843
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexedIndirect-None-08629
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexedIndirect-None-07844
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` dynamic state enabled then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndexedIndirect-None-08630
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP` dynamic state enabled then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthTestEnable` in the current command buffer set `depthTestEnable` to `VK_TRUE`, then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the depthBounds feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE` dynamic state enabled then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_OP` dynamic state enabled then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.
VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT dynamic state enabled, then vkCmdSetViewportWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must match the VkPipelineViewportStateCreateInfo::viewportCount of the pipeline

• VUID-vkCmdDrawIndexedIndirect-scissorCount-03418
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, then vkCmdSetScissorWithCount must have been called in the current command buffer prior to this drawing command, and the scissorCount parameter of vkCmdSetScissorWithCount must match the VkPipelineViewportStateCreateInfo::viewportCount of the pipeline

• VUID-vkCmdDrawIndexedIndirect-viewportCount-03419
If the bound graphics pipeline state was created with both the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic states enabled then both vkCmdSetViewportWithCount and vkCmdSetScissorWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must match the scissorCount parameter of vkCmdSetScissorWithCount

• VUID-vkCmdDrawIndexedIndirect-viewportCount-04137
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV dynamic state enabled, then the bound graphics pipeline must have been created with VkPipelineViewportWScalingStateCreateInfoNV::viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawIndexedIndirect-viewportCount-04138
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV dynamic states enabled then the bound graphics pipeline must have been created with VkPipelineViewportWScalingStateCreateInfoNV::viewportCount greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWScalingNV

• VUID-vkCmdDrawIndexedIndirect-None-09232
If a shader object is bound to any graphics stage, and the VK_NV_clip_space_w_scaling extension is enabled on the device, then vkCmdSetViewportWScalingNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-None-08636
If a shader object is bound to any graphics stage, and the VK_NV_clip_space_w_scaling extension is enabled on the device, then vkCmdSetViewportWScalingNV must have been called in the current command buffer prior to this drawing command
extension is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexedIndirect-viewportCount-04139**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportShadingRateImageStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexedIndirect-viewportCount-04140**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexedIndirect-shadingRateImage-09233**
  If the shadingRateImage feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set rasterizerDiscardEnable to `VK_FALSE`, then `vkCmdSetCoarseSampleOrderNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-shadingRateImage-09234**
  If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set rasterizerDiscardEnable to `VK_FALSE`, and the most recent call to `vkCmdSetShadingRateImageEnableNV` in the current command buffer set shadingRateImageEnable to `VK_TRUE`, then `vkCmdSetViewportShadingRatePaletteNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-08637**
  If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexedIndirect-VkPipelineViewportCreateInfo-04141**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportSwizzleStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexedIndirect-VkPipelineViewportCreateInfo-04142**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportExclusiveScissorStateCreateInfoNV` structure chained from...
 VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have been created with VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawIndexedIndirect-None-07878
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV dynamic state enabled then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-None-07879
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV dynamic state enabled then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-exclusiveScissor-09235
  If a shader object is bound to any graphics stage, and the exclusiveScissor feature is enabled, then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-None-08638
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetExclusiveScissorEnableNV in the current command buffer set any element of pExclusiveScissorEnables to VK_TRUE, then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-None-04876
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE dynamic state enabled then vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-None-08639
  If a shader object is bound to any graphics stage, then vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-None-04877
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE dynamic state enabled then vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-None-08640
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirect-logicOp-04878
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_EXT dynamic state enabled then vkCmdSetLogicOpEXT must have been called in the current
command buffer prior to this drawing command and the `logicOp` must be a valid `VkLogicOp` value

- **VUID-vkCmdDrawIndexedIndirect-None-08641**
  If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the `logicOp` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEXT` must have been called in the current command buffer prior to this drawing command and the `logicOp` must be a valid `VkLogicOp` value

- **VUID-vkCmdDrawIndexedIndirect-None-08642**
  If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must be 1

- **VUID-vkCmdDrawIndexedIndirect-None-08643**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then for each color attachment in the render pass, if the corresponding image view's format features do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the `blendEnable` member of the corresponding element of the `pAttachments` member of `pColorBlendState` must be `VK_FALSE`
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then the most recent call to `vkCmdSetRasterizationSamplesEXT` in the current command buffer must have set `rasterizationSamples` to be the same as the number of samples for the current render pass color and/or depth/stencil attachments

- **VUID-vkCmdDrawIndexedIndirect-None-08876**
  If a shader object is bound to any graphics stage, the current render pass instance must have been begun with `vkCmdBeginRendering`

- **VUID-vkCmdDrawIndexedIndirect-imageView-06172**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment

- **VUID-vkCmdDrawIndexedIndirect-imageView-06173**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment

- **VUID-vkCmdDrawIndexedIndirect-imageView-06174**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, this command must not write any values to the depth attachment

- **VUID-vkCmdDrawIndexedIndirect-imageView-06175**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment

- **VUID-vkCmdDrawIndexedIndirect-viewMask-06178**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo`.

- **VUID-vkCmdDrawIndexedIndirect-imageView-06176**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment

- **VUID-vkCmdDrawIndexedIndirect-viewMask-06177**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment

- **VUID-vkCmdDrawIndexedIndirect-viewMask-06178**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo`.
• VUID-vkCmdDrawIndexedIndirect-colorAttachmentCount-06179
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo::colorAttachmentCount` equal to `VkRenderingInfo::colorAttachmentCount`.

• VUID-vkCmdDrawIndexedIndirect-dynamicRenderingUnusedAttachments-08910
  If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline.

• VUID-vkCmdDrawIndexedIndirect-dynamicRenderingUnusedAttachments-08911
  If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline, or the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`.

• VUID-vkCmdDrawIndexedIndirect-dynamicRenderingUnusedAttachments-08912
  If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` must have the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`.

• VUID-vkCmdDrawIndexedIndirect-attachmentCount-07750
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then the `attachmentCount` parameter of `vkCmdSetColorWriteEnableEXT` must be greater than or equal to the `VkPipelineColorBlendStateCreateInfo::attachmentCount` of the currently bound graphics pipeline.
pipeline

- VUID-vkCmdDrawIndexedIndirect-None-08647
  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `attachmentCount` parameter of most recent call to `vkCmdSetColorWriteEnableEXT` in the current command buffer must be greater than or equal to the number of color attachments in the current render pass instance.

- VUID-vkCmdDrawIndexedIndirect-None-07751
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEXT` must have been called in the current command buffer prior to this drawing command for each discard rectangle in `VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount`.

- VUID-vkCmdDrawIndexedIndirect-None-07880
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEnableEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndexedIndirect-rasterizerDiscardEnable-09236
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDiscardRectangleEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndexedIndirect-None-08648
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDiscardRectangleEnableEXT` in the current command buffer set `discardRectangleEnable` to `VK_TRUE`, then `vkCmdSetDiscardRectangleModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndexedIndirect-dynamicRenderingUnusedAttachments-08913
  If the current render pass instance was begun with `vkCmdBeginRendering`, the
dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawIndexedIndirect-dynamicRenderingUnusedAttachments-08914
If current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to the VkFormat used to create VkRenderingInfo::pDepthAttachment->imageView

• VUID-vkCmdDrawIndexedIndirect-dynamicRenderingUnusedAttachments-08915
If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pDepthAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawIndexedIndirect-dynamicRenderingUnusedAttachments-08916
If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pStencilAttachment->imageView was VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline must be equal to VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawIndexedIndirect-dynamicRenderingUnusedAttachments-08917
If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pStencilAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawIndexedIndirect-dynamicRenderingUnusedAttachments-08918
If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pStencilAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawIndexedIndirect-imageView-06183
If the current render pass instance was begun with vkCmdBeginRendering and VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

• VUID-vkCmdDrawIndexedIndirect-imageView-06184
If the current render pass instance was begun with vkCmdBeginRendering and
VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT

- VUID-vkCmdDrawIndexedIndirect-colorAttachmentCount-06185
  If the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a sample count equal to the corresponding element of the pColorAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline

- VUID-vkCmdDrawIndexedIndirect-pDepthAttachment-06186
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of the depthStencilAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline must be equal to the sample count used to create VkRenderingInfo::pDepthAttachment->imageView

- VUID-vkCmdDrawIndexedIndirect-pStencilAttachment-06187
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, the value of the depthStencilAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline must be equal to the sample count used to create VkRenderingInfo::pStencilAttachment->imageView

- VUID-vkCmdDrawIndexedIndirect-multisampledRenderToSingleSampled-07285
  If the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled feature is not enabled, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a sample count equal to the value of rasterizationSamples for the currently bound graphics pipeline

- VUID-vkCmdDrawIndexedIndirect-multisampledRenderToSingleSampled-07286
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of rasterizationSamples for the currently bound graphics pipeline must be equal to the sample count used to create VkRenderingInfo::pDepthAttachment->imageView
If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

If this command has been called inside a render pass instance started with `vkCmdBeginRendering`, and the `pNext` chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to `VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline must have been created with a `VkGraphicsPipelineCreateInfo::renderPass` equal to `VK_NULL_HANDLE`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the `VkRenderingInfo::pColorAttachments->imageView` was not `VK_NULL_HANDLE`, then the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, stencil test is enabled and the `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

If the `primitivesGeneratedQueryWithRasterizerDiscard` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, rasterization discard must not be enabled.

If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, non-zero stream queries must not be enabled.
If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, the bound graphics pipeline must not have been created with a non-zero value in `VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream` .

- VUID-vkCmdDrawIndexedIndirect-None-07619
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT` dynamic state enabled then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndexedIndirect-None-07620
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndexedIndirect-None-09237
  If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndexedIndirect-None-07621
  If the depthClamp feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndexedIndirect-None-08650
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndexedIndirect-None-07622
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndexedIndirect-None-08651
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndexedIndirect-None-07623
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` dynamic state enabled then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndexedIndirect-None-08652
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` dynamic state enabled then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-08653**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-07624**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-alphaToCoverageEnable-08919**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled, and `alphaToCoverageEnable` was `VK_TRUE` in the last call to `vkCmdSetAlphaToCoverageEnableEXT`, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0.

- **VUID-vkCmdDrawIndexedIndirect-None-08654**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-alphaToCoverageEnable-08920**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetAlphaToCoverageEnableEXT` in the current command buffer set `alphaToCoverageEnable` to `VK_TRUE`, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0.

- **VUID-vkCmdDrawIndexedIndirect-None-07625**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT` dynamic state enabled then `vkCmdSetAlphaToOneEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-08655**
  If the `alphaToOne` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetAlphaToOneEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-07626**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT` dynamic state enabled then `vkCmdSetLogicOpEnableEXT` must have been called in the current command buffer prior to this drawing command.
If the logicOp feature is enabled, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT dynamic state enabled then vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetColorBlendEnableEXT for any attachment set that attachment's value in pColorBlendEnables to VK_TRUE, then vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT dynamic state enabled then vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetColorBlendEnableEXT for any attachment set that attachment's value in pColorBlendEnables to VK_TRUE, then vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command.

If the geometryStreams feature is enabled, and a shader object is bound to the
VK_SHADER_STAGE_GEOMETRY_BIT stage, then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-07631**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-08661**
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-07632**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-08662**
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetConservativeRasterizationModeEXT` in the current command buffer set `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`, then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-07633**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-08663**
  If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-07634**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-08664**
  If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then...
**vkCmdSetSampleLocationsEnableEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-07635**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT** dynamic state enabled then **vkCmdSetColorBlendAdvancedEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-07636**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT** dynamic state enabled then **vkCmdSetProvokingVertexModeEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-08665**
  If the **VK_EXT_provoking_vertex** extension is enabled, and a shader object is bound to the **VK_SHADER_STAGE_VERTEX_BIT** stage, then **vkCmdSetProvokingVertexModeEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-08666**
  If the **VK_EXT_line_rasterization** extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetPolygonModeEXT** in the current command buffer set **polygonMode** to **VK_POLYGON_MODE_LINE**, then **vkCmdSetLineRasterizationModeEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-08667**
  If the **VK_EXT_line_rasterization** extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to **vkCmdSetPrimitiveTopology** in the current command buffer set **primitiveTopology** to any line topology, then **vkCmdSetLineRasterizationModeEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-08668**
  If the **VK_EXT_line_rasterization** extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then **vkCmdSetLineRasterizationModeEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-07638**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT** dynamic state enabled then **vkCmdSetLineStippleEnableEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-08669**
If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-08670
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-08671
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-07849
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_EXT` dynamic state enabled then `vkCmdSetLineStippleEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-08672
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetLineStippleEnableEXT` in the current command buffer set `stippledLineEnable` to `VK_TRUE`, then `vkCmdSetLineStippleEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-07639
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT` dynamic state enabled then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-08673
  If the `depthClipControl` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-07640
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV` dynamic state enabled then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-08674
  If the `VK_NV_clip_space_w_scaling` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-07641
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-08675**
  If the `VK_NV_viewport_swizzle` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-07642**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-08676**
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-07643**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` dynamic state enabled then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-08677**
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set `coverageToColorEnable` to `VK_TRUE`, then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-07644**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-08678**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirect-None-07645**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.
command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-08679**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationModeNV` in the current command buffer set `coverageModulationMode` to any value other than `VK_COVERAGE_MODULATION_MODE_NONE_NV`, then `vkCmdSetCoverageModulationTableEnableNV` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-07646**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableNV` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-08680**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationTableEnableNV` in the current command buffer set `coverageModulationTableEnable` to `VK_TRUE`, then `vkCmdSetCoverageModulationTableNV` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-07647**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV` dynamic state enabled then `vkCmdSetShadingRateImageEnableNV` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-pipelineFragmentShadingRate-09238**
  If the `pipelineFragmentShadingRate` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFragmentShadingRateKHR` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-08681**
  If the `shadingRateImage` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetShadingRateImageEnableNV` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-07648**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV` dynamic state enabled then `vkCmdSetRepresentativeFragmentTestEnableNV` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-08682**
  If the `representativeFragmentTest` feature is enabled, and a shader object is bound to any
graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-07649**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-08683**
  If the `coverageReductionMode` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-pColorBlendEnables-07470**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` state enabled and the last call to `vkCmdSetColorBlendEnableEXT` set `pColorBlendEnables` for any attachment to `VK_TRUE`, then for those attachments in the subpass the corresponding image view's format features must contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`

- **VUID-vkCmdDrawIndexedIndirect-rasterizationSamples-07471**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must follow the rules for a zero-attachment subpass

- **VUID-vkCmdDrawIndexedIndirect-samples-07472**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter used to create the bound graphics pipeline

- **VUID-vkCmdDrawIndexedIndirect-samples-07473**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter in the last call to `vkCmdSetRasterizationSamplesEXT`

- **VUID-vkCmdDrawIndexedIndirect-rasterizationSamples-07474**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and neither the `VK_AMD_mixed_attachment_samples` nor the `VK_NV_framebuffer_mixed_samples` extensions are enabled, then the `rasterizationSamples` in the last call to
\textbf{vkCmdSetRasterizationSamplesEXT} must be the same as the current subpass color and/or depth/stencil attachments

- **VUID-vkCmdDrawIndexedIndirect-None-09211**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the `rasterizationSamples` member of that structure.

- **VUID-vkCmdDrawIndexedIndirect-firstAttachment-07476**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` state enabled, then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEnableEXT` calls must specify an enable for all active color attachments in the current subpass.

- **VUID-vkCmdDrawIndexedIndirect-firstAttachment-07477**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` state enabled, then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEquationEXT` calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled.

- **VUID-vkCmdDrawIndexedIndirect-firstAttachment-07478**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` state enabled, then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorWriteMaskEXT` calls must specify the color write mask for all active color attachments in the current subpass.

- **VUID-vkCmdDrawIndexedIndirect-firstAttachment-07479**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` state enabled, then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendAdvancedEXT` calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled.

- **VUID-vkCmdDrawIndexedIndirect-advancedBlendMaxColorAttachments-07480**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` and `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic states enabled and the last calls to `vkCmdSetColorBlendEnableEXT` and `vkCmdSetColorBlendAdvancedEXT` have enabled advanced blending, then the number of
active color attachments in the current subpass must not exceed advancedBlendMaxColorAttachments

- VUID-vkCmdDrawIndexedIndirect-primitivesGeneratedQueryWithNonZeroStreams-07481
  If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, and the bound graphics pipeline was created with VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT state enabled, the last call to vkCmdSetRasterizationStreamEXT must have set the rasterizationStream to zero

- VUID-vkCmdDrawIndexedIndirect-sampleLocationsPerPixel-07482
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state disabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples member of the VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with

- VUID-vkCmdDrawIndexedIndirect-sampleLocationsPerPixel-07483
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples parameter of the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawIndexedIndirect-sampleLocationsEnable-07484
  If the bound graphics pipeline was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set

- VUID-vkCmdDrawIndexedIndirect-sampleLocationsEnable-07485
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the sampleLocationsInfo.sampleLocationGridSize.width in the last call to vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples

- VUID-vkCmdDrawIndexedIndirect-sampleLocationsEnable-07486
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the sampleLocationsInfo.sampleLocationGridSize.height in the last call to
vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples.

- VUID-vkCmdDrawIndexedIndirect-sampleLocationsEnable-07487
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, the fragment shader code must not statically use the extended instruction InterpolateAtSample.

- VUID-vkCmdDrawIndexedIndirect-sampleLocationsEnable-07936
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.width must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT.

- VUID-vkCmdDrawIndexedIndirect-sampleLocationsEnable-07937
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.height must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT.

- VUID-vkCmdDrawIndexedIndirect-sampleLocationsEnable-07938
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationsPerPixel must equal rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT.

- VUID-vkCmdDrawIndexedIndirect-coverageModulationTableEnable-07488
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV state enabled and the last call to vkCmdSetCoverageModulationTableEnableNV set coverageModulationTableEnable to VK_TRUE, then the coverageModulationTableCount parameter in the last call to vkCmdSetCoverageModulationTableNV must equal the current rasterizationSamples divided by the number of color samples in the current subpass.

- VUID-vkCmdDrawIndexedIndirect-rasterizationSamples-07489
If the VK_NV_framebuffer_mixed_samples extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current rasterizationSamples must be the same as the sample count of the depth/stencil attachment.

- VUID-vkCmdDrawIndexedIndirect-coverageToColorEnable-07490
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV state enabled and the last call to vkCmdSetCoverageToColorEnableNV set the coverageToColorEnable to VK_TRUE, then the current subpass must have a color attachment at the location selected by the last call to vkCmdSetCoverageToColorLocationNV coverageToColorLocation, with a VkFormat of VK_FORMAT_R8_UINT, VK_FORMAT_R8_SINT, VK_FORMAT_R16_UINT, VK_FORMAT_R16_SINT, VK_FORMAT_R32_UINT, or VK_FORMAT_R32_SINT.

- VUID-vkCmdDrawIndexedIndirect-coverageReductionMode-07491
  If this VK_NV_coverage_reduction_mode extension is enabled, the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV and VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT states enabled, the current coverage reduction mode coverageReductionMode, then the current rasterizationSamples, and the sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV.

- VUID-vkCmdDrawIndexedIndirect-viewportCount-07492
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic state enabled, then the bound graphics pipeline must have been created with VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount.

- VUID-vkCmdDrawIndexedIndirect-viewportCount-07493
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic states enabled then the viewportCount parameter in the last call to vkCmdSetViewportSwizzleNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount.

- VUID-vkCmdDrawIndexedIndirect-rasterizationSamples-07494
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and if the current subpass has any color attachments and rasterizationSamples of the last call to vkCmdSetRasterizationSamplesEXT is greater than the number of color samples, then the pipeline sampleShadingEnable must be VK_FALSE.

- VUID-vkCmdDrawIndexedIndirect-stippledLineEnable-07495
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT, then the stippledRectangularLines feature must be enabled.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT`, then the `stippledBresenhamLines` feature must be enabled.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT`, then the `stippledSmoothLines` feature must be enabled.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT`, then the `stippledRectangularLines` feature must be enabled and `VkPhysicalDeviceLimits::strictLines` must be `VK_TRUE`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled, `conservativePointAndLineRasterization` is not supported, and the effective primitive topology output by the last pre-rasterization shader stage is a line or point, then the `conservativeRasterizationMode` set by the last call to `vkCmdSetConservativeRasterizationModeEXT` must be `VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT`.

If the currently bound pipeline was created with the `VkPipelineShaderStageCreateInfo::stage` member of an element of `VkGraphicsPipelineCreateInfo::pStages` set to `VK_SHADER_STAGE_VERTEX_BIT`, `VK_SHADER_STAGE_TESSSELLATION_CONTROL_BIT`, `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` or `VK_SHADER_STAGE_GEOMETRY_BIT`, then Mesh Shader Queries must not be active.

If dynamic state was inherited from `VkCommandBufferInheritanceViewportScissorInfoNV`, it must be set in the current command buffer prior to this drawing command.

If dynamic state was inherited, it must be set in the current command buffer prior to this drawing command.
If there is no bound graphics pipeline, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_VERTEX_BIT`

- **VUID-vkCmdDrawIndexedIndirect-None-08685**
  If there is no bound graphics pipeline, and the `tessellationShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`

- **VUID-vkCmdDrawIndexedIndirect-None-08686**
  If there is no bound graphics pipeline, and the `tessellationShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`

- **VUID-vkCmdDrawIndexedIndirect-None-08687**
  If there is no bound graphics pipeline, and the `geometryShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_GEOMETRY_BIT`

- **VUID-vkCmdDrawIndexedIndirect-None-08688**
  If there is no bound graphics pipeline, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_FRAGMENT_BIT`

- **VUID-vkCmdDrawIndexedIndirect-None-08689**
  If there is no bound graphics pipeline, and the `taskShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TASK_BIT_EXT`

- **VUID-vkCmdDrawIndexedIndirect-None-08690**
  If there is no bound graphics pipeline, and the `meshShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_MESH_BIT_EXT`

- **VUID-vkCmdDrawIndexedIndirect-None-08693**
  If there is no bound graphics pipeline, and at least one of the `taskShader` and `meshShader` features is enabled, one of the `VK_SHADER_STAGE_VERTEX_BIT` or `VK_SHADER_STAGE_MESH_BIT_EXT` stages must have a valid VkShaderEXT bound, and the other must have no VkShaderEXT bound

- **VUID-vkCmdDrawIndexedIndirect-None-08694**
  If there is no bound graphics pipeline, and both the `taskShader` and `meshShader` features are enabled, and a valid VkShaderEXT is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that VkShaderEXT was created without the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, a valid VkShaderEXT must be bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage

- **VUID-vkCmdDrawIndexedIndirect-None-08695**
  If there is no bound graphics pipeline, and both the `taskShader` and `meshShader` features are enabled, and a valid VkShaderEXT is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that VkShaderEXT was created with the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, there must be no VkShaderEXT bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage

- **VUID-vkCmdDrawIndexedIndirect-None-08696**
  If there is no bound graphics pipeline, and a valid VkShaderEXT is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, there must be no VkShaderEXT bound to either the
VK_SHADER_STAGE_TASK_BIT_EXT stage or the VK_SHADER_STAGE_MESH_BIT_EXT stage

- VUID-vkCmdDrawIndexedIndirect-None-08698
  If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, then all shaders created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag in the same vkCreateShadersEXT call must also be bound.

- VUID-vkCmdDrawIndexedIndirect-None-08699
  If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, any stages in between stages whose shaders which did not create a shader with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag as part of the same vkCreateShadersEXT call must not have any VkShaderEXT bound.

- VUID-vkCmdDrawIndexedIndirect-None-08878
  All bound graphics shader objects must have been created with identical or identically defined push constant ranges.

- VUID-vkCmdDrawIndexedIndirect-None-08879
  All bound graphics shader objects must have been created with identical or identically defined arrays of descriptor set layouts.

- VUID-vkCmdDrawIndexedIndirect-None-08880
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage and the attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndexedIndirect-pDynamicStates-08715
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable parameter in the last call to vkCmdSetDepthWriteEnable must be VK_FALSE.

- VUID-vkCmdDrawIndexedIndirect-pDynamicStates-08716
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_STENCIL_WRITE_MASK set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpStencilAttachmentReadEXT, the writeMask parameter in the last call to vkCmdSetStencilWriteMask must be 0.

- VUID-vkCmdDrawIndexedIndirect-None-09116
  If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT, and the format of any color attachment is VK_FORMAT_E5B9G9R9_UFLOAT_PACK32, the corresponding element of the pColorWriteMasks parameter of vkCmdSetColorWriteMaskEXT must either include all of VK_COLOR_COMPONENT_R_BIT, VK_COLOR_COMPONENT_G_BIT, and VK_COLOR_COMPONENT_B_BIT, or none of them.

- VUID-vkCmdDrawIndexedIndirect-maxFragmentDualSrcAttachments-09239
  If blending is enabled for any attachment where either the source or destination blend...
factors for that attachment use the secondary color input, the maximum value of Location for any output attachment statically used in the Fragment Execution Model executed by this command must be less than maxFragmentDualSrcAttachments

- VUID-vkCmdDrawIndexedIndirect-None-04007
  All vertex input bindings accessed via vertex input variables declared in the vertex shader entry point's interface must have either valid or VK_NULL_HANDLE buffers bound

- VUID-vkCmdDrawIndexedIndirect-None-04008
  If the nullDescriptor feature is not enabled, all vertex input bindings accessed via vertex input variables declared in the vertex shader entry point's interface must not be VK_NULL_HANDLE

- VUID-vkCmdDrawIndexedIndirect-None-02721
  For a given vertex buffer binding, any attribute data fetched must be entirely contained within the corresponding vertex buffer binding, as described in Vertex Input Description

- VUID-vkCmdDrawIndexedIndirect-None-07842
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled then vkCmdSetPrimitiveTopology must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-dynamicPrimitiveTopologyUnrestricted-07500
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled and the dynamicPrimitiveTopologyUnrestricted is VK_FALSE, then the primitiveTopology parameter of vkCmdSetPrimitiveTopology must be of the same topology class as the pipeline VkPipelineInputAssemblyStateCreateInfo::topology state

- VUID-vkCmdDrawIndexedIndirect-None-04912
  If the bound graphics pipeline was created with both the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT and VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT dynamic states enabled, then vkCmdSetVertexInputEXT must have been called in the current command buffer prior to this draw command

- VUID-vkCmdDrawIndexedIndirect-pStrides-04913
  If the bound graphics pipeline was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT dynamic state enabled, but not the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, then vkCmdBindVertexBuffer2EXT must have been called in the current command buffer prior to this draw command, and the pStrides parameter of vkCmdBindVertexBuffer2EXT must not be NULL

- VUID-vkCmdDrawIndexedIndirect-None-08881
  If a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, then vkCmdSetPrimitiveTopology must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirect-None-04914
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, then vkCmdSetVertexInputEXT
must have been called in the current command buffer prior to this draw command

- **VUID-vkCmdDrawIndexedIndirect-Input-07939**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then all variables with the `Input` storage class decorated with `Location` in the Vertex Execution Model OpEntryPoint must contain a location in `VkVertexInputAttributeDescription2EXT::location`

- **VUID-vkCmdDrawIndexedIndirect-Input-08734**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then the numeric type associated with all `Input` variables of the corresponding `Location` in the Vertex Execution Model OpEntryPoint must be the same as `VkVertexInputAttributeDescription2EXT::format`

- **VUID-vkCmdDrawIndexedIndirect-format-08936**
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and `VkVertexInputAttributeDescription2EXT::format` has a 64-bit component, then the scalar width associated with all `Input` variables of the corresponding `Location` in the Vertex Execution Model OpEntryPoint must be 64-bit

- **VUID-vkCmdDrawIndexedIndirect-format-08937**
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and the scalar width associated with a `Location` decorated `Input` variable in the Vertex Execution Model OpEntryPoint is 64-bit, then the corresponding `VkVertexInputAttributeDescription2EXT::format` must have a 64-bit component

- **VUID-vkCmdDrawIndexedIndirect-None-09203**
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and `VkVertexInputAttributeDescription2EXT::format` has a 64-bit component, then all `Input` variables at the corresponding `Location` in the Vertex Execution Model OpEntryPoint must not use components that are not present in the format

- **VUID-vkCmdDrawIndexedIndirect-None-08882**
  If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetVertexInputEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-04875**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT` dynamic state enabled then `vkCmdSetPatchControlPointsEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-08883**
  If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetPatchControlPointsEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-None-04879**
  If the bound graphics pipeline state was created with the
**VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE** dynamic state enabled then

`vkCmdSetPrimitiveRestartEnable` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-rasterizerDiscardEnable-08884**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, `vkCmdSetPrimitiveRestartEnable` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirect-stage-06481**
  The bound graphics pipeline **must** not have been created with the `VkPipelineShaderStageCreateInfo::stage` member of an element of `VkGraphicsPipelineCreateInfo::pStages` set to `VK_SHADER_STAGE_TASK_BIT_EXT` or `VK_SHADER_STAGE_MESH_BIT_EXT`

- **VUID-vkCmdDrawIndexedIndirect-None-08885**
  There **must** be no shader object bound to either of the `VK_SHADER_STAGE_TASK_BIT_EXT` or `VK_SHADER_STAGE_MESH_BIT_EXT` stages

- **VUID-vkCmdDrawIndexedIndirect-buffer-02708**
  If `buffer` is non-sparse then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdDrawIndexedIndirect-buffer-02709**
  `buffer` **must** have been created with the `VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT` bit set

- **VUID-vkCmdDrawIndexedIndirect-offset-02710**
  `offset` **must** be a multiple of 4

- **VUID-vkCmdDrawIndexedIndirect-commandBuffer-02711**
  `commandBuffer` **must** not be a protected command buffer

- **VUID-vkCmdDrawIndexedIndirect-drawCount-02718**
  If the `multiDrawIndirect` feature is not enabled, `drawCount` **must** be 0 or 1

- **VUID-vkCmdDrawIndexedIndirect-drawCount-02719**
  `drawCount` **must** be less than or equal to `VkPhysicalDeviceLimits::maxDrawIndirectCount`

- **VUID-vkCmdDrawIndexedIndirect-None-07312**
  An index buffer **must** be bound

- **VUID-vkCmdDrawIndexedIndirect-robustBufferAccess2-07825**
  If `robustBufferAccess2` is not enabled, \((\text{indexSize} \times (\text{firstIndex} + \text{indexCount}) + \text{offset})\) **must** be less than or equal to the size of the bound index buffer, with `indexSize` being based on the type specified by `indexType`, where the index buffer, `indexType`, and `offset` are specified via `vkCmdBindIndexBuffer`

- **VUID-vkCmdDrawIndexedIndirect-drawCount-00528**
  If `drawCount` is greater than 1, `stride` **must** be a multiple of 4 and **must** be greater than or equal to `sizeof(VkDrawIndexedIndirectCommand)`

- **VUID-vkCmdDrawIndexedIndirect-drawCount-00539**
  If `drawCount` is equal to 1, \((\text{offset} + \text{sizeof(VkDrawIndexedIndirectCommand)})\) **must** be less than or equal to the size of the bound index buffer.
than or equal to the size of buffer

- VUID-vkCmdDrawIndexedIndirect-drawCount-00540
  If drawCount is greater than 1, \((\text{stride} \times (\text{drawCount} - 1) + \text{offset} + \text{sizeof} (\text{VkDrawIndexedIndirectCommand}))\) must be less than or equal to the size of buffer

---

**Valid Usage (Implicit)**

- VUID-vkCmdDrawIndexedIndirect-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdDrawIndexedIndirect-buffer-parameter
  buffer must be a valid VkBuffer handle

- VUID-vkCmdDrawIndexedIndirect-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdDrawIndexedIndirect-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdDrawIndexedIndirect-renderpass
  This command must only be called inside of a render pass instance

- VUID-vkCmdDrawIndexedIndirect-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdDrawIndexedIndirect-commonparent
  Both of buffer, and commandBuffer must have been created, allocated, or retrieved from the same VkDevice

---

**Host Synchronization**

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

---

**Command Properties**

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The VkDrawIndexedIndirectCommand structure is defined as:

```c
// Provided by VK_VERSION_1_0
```
typedef struct VkDrawIndexedIndirectCommand {
    uint32_t indexCount;
    uint32_t instanceCount;
    uint32_t firstIndex;
    int32_t vertexOffset;
    uint32_t firstInstance;
} VkDrawIndexedIndirectCommand;

• `indexCount` is the number of vertices to draw.
• `instanceCount` is the number of instances to draw.
• `firstIndex` is the base index within the index buffer.
• `vertexOffset` is the value added to the vertex index before indexing into the vertex buffer.
• `firstInstance` is the instance ID of the first instance to draw.

The members of `VkDrawIndexedIndirectCommand` have the same meaning as the similarly named parameters of `vkCmdDrawIndexed`.

### Valid Usage

- VUID-VkDrawIndexedIndirectCommand-robustBufferAccess2-08798
  If `robustBufferAccess2` is not enabled, `(indexSize × (firstIndex + indexCount) + offset)` must be less than or equal to the size of the bound index buffer, with `indexSize` being based on the type specified by `indexType`, where the index buffer, `indexType`, and `offset` are specified via `vkCmdBindIndexBuffer` or `vkCmdBindIndexBuffer2KHR`. If `vkCmdBindIndexBuffer2KHR` is used to bind the index buffer, the size of the bound index buffer is `vkCmdBindIndexBuffer2KHR::size`

- VUID-VkDrawIndexedIndirectCommand-None-00552
  For a given vertex buffer binding, any attribute data fetched must be entirely contained within the corresponding vertex buffer binding, as described in [Vertex Input Description](#).

- VUID-VkDrawIndexedIndirectCommand-firstInstance-00554
  If the `drawIndirectFirstInstance` feature is not enabled, `firstInstance` must be 0.

To record an indexed draw call with a draw call count sourced from a buffer, call:

```c
// Provided by VK_VERSION_1_2
void vkCmdDrawIndexedIndirectCount(
    VkCommandBuffer commandBuffer,
    VkBuffer buffer,
    VkDeviceSize offset,
    VkBuffer countBuffer,
    VkDeviceSize countBufferOffset,
    uint32_t maxDrawCount,
    uint32_t stride);
```
or the equivalent command

```c
// Provided by VK_KHR_draw_indirect_count
void vkCmdDrawIndexedIndirectCountKHR(
    VkCommandBuffer commandBuffer,  
    VkBuffer buffer,                
    VkDeviceSize offset,           
    VkBuffer countBuffer,          
    VkDeviceSize countBufferOffset, 
    uint32_t maxDrawCount,         
    uint32_t stride);
```

or the equivalent command

```c
// Provided by VK_AMD_draw_indirect_count
void vkCmdDrawIndexedIndirectCountAMD(  
    VkCommandBuffer commandBuffer,  
    VkBuffer buffer,                
    VkDeviceSize offset,           
    VkBuffer countBuffer,          
    VkDeviceSize countBufferOffset, 
    uint32_t maxDrawCount,         
    uint32_t stride);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `buffer` is the buffer containing draw parameters.
- `offset` is the byte offset into `buffer` where parameters begin.
- `countBuffer` is the buffer containing the draw count.
- `countBufferOffset` is the byte offset into `countBuffer` where the draw count begins.
- `maxDrawCount` specifies the maximum number of draws that will be executed. The actual number of executed draw calls is the minimum of the count specified in `countBuffer` and `maxDrawCount`.
- `stride` is the byte stride between successive sets of draw parameters.

`vkCmdDrawIndexedIndirectCount` behaves similarly to `vkCmdDrawIndexedIndirect` except that the draw count is read by the device from a buffer during execution. The command will read an unsigned 32-bit integer from `countBuffer` located at `countBufferOffset` and use this as the draw count.

### Valid Usage

- `VUID-vkCmdDrawIndexedIndirectCount-magFilter-04553`

  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`
• **VUID-vkCmdDrawIndexedIndirectCount-mipmapMode-04770**
  If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`.

• **VUID-vkCmdDrawIndexedIndirectCount-None-06479**
  If a `VkImageView` is sampled with `depth comparison`, the image view's `format features` must contain `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT`.

• **VUID-vkCmdDrawIndexedIndirectCount-None-02691**
  If a `VkImageView` is accessed using atomic operations as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT`.

• **VUID-vkCmdDrawIndexedIndirectCount-None-07888**
  If a `VkImageView` is accessed using atomic operations as a result of this command, then the storage texel buffer's `format features` must contain `VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT`.

• **VUID-vkCmdDrawIndexedIndirectCount-None-02692**
  If a `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`.

• **VUID-vkCmdDrawIndexedIndirectCount-filterCubic-02694**
  Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

• **VUID-vkCmdDrawIndexedIndirectCount-filterCubicMinmax-02695**
  Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` with a reduction mode of either `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering together with minmax filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

• **VUID-vkCmdDrawIndexedIndirectCount-cubicRangeClamp-09212**
  If the cubicRangeClamp feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must not have a `VkSamplerReductionModeCreateInfo` `reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`.

• **VUID-vkCmdDrawIndexedIndirectCount-reductionMode-09213**
  Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo` `reductionMode` of either `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX` as a result of this command must not have a `VkSamplerReductionModeCreateInfo` `reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`.

**Note:**
- `VK_SAMPLER_MIPMAP_MODE_LINEAR` refers to linear filtering for mipmaps.
- `VK_FALSE` indicates a disabled feature or parameter.
- `VK_FILTER_CUBIC_EXT` refers to cubic filtering.
- `red` indicates a feature or parameter setting.
- `vw` is used to denote various Vulkan commands and contexts.

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*This content is a natural language representation of the extracted text from the image.*
::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM as a result of this command must sample with VK_FILTER_CUBIC_EXT

- VUID-vkCmdDrawIndexedIndirectCount-selectableCubicWeights-09214
  If the selectableCubicWeights feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights equal to VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM

- VUID-vkCmdDrawIndexedIndirectCount-flags-02696
  Any VkImage created with a VkImageCreateInfo::flags containing VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV sampled as a result of this command must only be sampled using a VkSamplerAddressMode of VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE

- VUID-vkCmdDrawIndexedIndirectCount-OpTypeImage-07027
  For any VkImageView being written as a storage image where the image format field of the OpTypeImage is Unknown, the view's format features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

- VUID-vkCmdDrawIndexedIndirectCount-OpTypeImage-07028
  For any VkImageView being read as a storage image where the image format field of the OpTypeImage is Unknown, the view's format features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

- VUID-vkCmdDrawIndexedIndirectCount-OpTypeImage-07029
  For any VkBufferView being written as a storage texel buffer where the image format field of the OpTypeImage is Unknown, the view's buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

- VUID-vkCmdDrawIndexedIndirectCount-OpTypeImage-07030
  Any VkBufferView being read as a storage texel buffer where the image format field of the OpTypeImage is Unknown, then the view's buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

- VUID-vkCmdDrawIndexedIndirectCount-None-08600
  For each set n that is statically used by a bound shader, a descriptor set must have been bound to n at the same pipeline bind point, with a VkPipelineLayout that is compatible for set n, with the VkPipelineLayout or VkDescriptorSetLayout array that was used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawIndexedIndirectCount-None-08601
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawIndexedIndirectCount-maintenance4-08602
  If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility
Compatibility

- VUID-vkCmdDrawIndexedIndirectCount-None-08114
  Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, **must** be valid if they are statically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was not created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDrawIndexedIndirectCount-None-08115
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` **must** have been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDrawIndexedIndirectCount-None-08116
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, **must** be valid if they are dynamically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDrawIndexedIndirectCount-None-08604
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, **must** be valid if they are dynamically used by any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDrawIndexedIndirectCount-None-08117
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdSetDescriptorBufferOffsetsEXT`, the bound `VkPipeline` **must** have been created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDrawIndexedIndirectCount-None-08119
  If a descriptor is dynamically used with a `VkPipeline` created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory **must** be resident

- VUID-vkCmdDrawIndexedIndirectCount-None-08605
  If a descriptor is dynamically used with a `VkShaderEXT` created with a `VkDescriptorSetLayout` that was created with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory **must** be resident

- VUID-vkCmdDrawIndexedIndirectCount-None-08606
  If the `shaderObject` feature is not enabled, a valid pipeline **must** be bound to the pipeline bind point used by this command

- VUID-vkCmdDrawIndexedIndirectCount-None-08607
  If the `shaderObject` is enabled, either a valid pipeline **must** be bound to the pipeline bind point used by this command, or a valid combination of valid and `VK_NULL_HANDLE` shader objects **must** be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDrawIndexedIndirectCount-None-08608
  If a pipeline is bound to the pipeline bind point used by this command, there **must** not have been any calls to dynamic state setting commands for any state not specified as dynamic in the `VkPipeline` object bound to the pipeline bind point used by this command,
since that pipeline was bound

- **VUID-vkCmdDrawIndexedIndirectCount-None-08609**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler must not be used to sample from any `VkImage` with a `VkImageView` of the type `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, `VK_IMAGE_VIEW_TYPE_1D_ARRAY`, `VK_IMAGE_VIEW_TYPE_2D_ARRAY` or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`, in any shader stage

- **VUID-vkCmdDrawIndexedIndirectCount-None-08610**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V `OpImageSample*` or `OpImageSparseSample*` instructions with `ImplicitLod`, `Dref` or `Proj` in their name, in any shader stage

- **VUID-vkCmdDrawIndexedIndirectCount-None-08611**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V `OpImageSample*` or `OpImageSparseSample*` instructions that includes a LOD bias or any offset values, in any shader stage

- **VUID-vkCmdDrawIndexedIndirectCount-uniformBuffers-06935**
  If any stage of the `VkPipeline` object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT` or `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT` for `uniformBuffers`, and the `robustBufferAccess` feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawIndexedIndirectCount-None-08612**
  If the `robustBufferAccess` feature is not enabled, and any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawIndexedIndirectCount-storageBuffers-06936**
  If any stage of the `VkPipeline` object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT` or `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT` for `storageBuffers`, and the `robustBufferAccess` feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawIndexedIndirectCount-None-08613**
  If the `robustBufferAccess` feature is not enabled, and any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor
set bound to the same pipeline bind point

- VUID-vkCmdDrawIndexedIndirectCount-commandBuffer-02707
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, any resource accessed by `bound shaders` must not be a protected resource

- VUID-vkCmdDrawIndexedIndirectCount-None-06550
  If a `bound shader` accesses a `VkSampler` or `VkImageView` object that enables `sampler Y'C aC' conversion`, that object must only be used with `OpImageSample*` or `OpImageSparseSample*` instructions

- VUID-vkCmdDrawIndexedIndirectCount-ConstOffset-06551
  If a `bound shader` accesses a `VkSampler` or `VkImageView` object that enables `sampler Y'C aC' conversion`, that object must not use the `ConstOffset` and `Offset` operands

- VUID-vkCmdDrawIndexedIndirectCount-viewType-07752
  If a `VkImageView` is accessed as a result of this command, then the image view's `viewType` must match the `Dim` operand of the `OpTypeImage` as described in `Instruction/Sampler/Image View Validation`

- VUID-vkCmdDrawIndexedIndirectCount-format-07753
  If a `VkImageView` is accessed as a result of this command, then the numeric type of the image view's `format` and the `Sampled Type` operand of the `OpTypeImage` must match

- VUID-vkCmdDrawIndexedIndirectCount-OpImageWrite-08795
  If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have at least as many components as the image view's format

- VUID-vkCmdDrawIndexedIndirectCount-OpImageWrite-08796
  If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have four components

- VUID-vkCmdDrawIndexedIndirectCount-OpImageWrite-04469
  If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have at least as many components as the buffer view's format

- VUID-vkCmdDrawIndexedIndirectCount-SampledType-04470
  If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64

- VUID-vkCmdDrawIndexedIndirectCount-SampledType-04471
  If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 32

- VUID-vkCmdDrawIndexedIndirectCount-SampledType-04472
  If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64
If a `VkBufferView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 32

- VUID-vkCmdDrawIndexedIndirectCount-sparseImageInt64Atomics-04474
  If the `sparseImageInt64Atomics` feature is not enabled, `VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` flag **must** not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command

- VUID-vkCmdDrawIndexedIndirectCount-sparseImageInt64Atomics-04475
  If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag **must** not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command

- VUID-vkCmdDrawIndexedIndirectCount-OpImageWeightedSampleQCOM-06971
  If `OpImageWeightedSampleQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`

- VUID-vkCmdDrawIndexedIndirectCount-OpImageWeightedSampleQCOM-06972
  If `OpImageWeightedSampleQCOM` uses a `VkImageView` as a sample weight image as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`

- VUID-vkCmdDrawIndexedIndirectCount-OpImageBoxFilterQCOM-06973
  If `OpImageBoxFilterQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM`

- VUID-vkCmdDrawIndexedIndirectCount-OpImageBlockMatchSSDQCOM-06974
  If `OpImageBlockMatchSSDQCOM` is used to read from an `VkImageView` as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`

- VUID-vkCmdDrawIndexedIndirectCount-OpImageBlockMatchSADQCOM-06975
  If `OpImageBlockMatchSADQCOM` is used to read from an `VkImageView` as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`

- VUID-vkCmdDrawIndexedIndirectCount-OpImageBlockMatchSSDQCOM-06976
  If `OpImageBlockMatchSSDQCOM` or `OpImageBlockMatchSADQCOM` is used to read from a reference image as result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation

- VUID-vkCmdDrawIndexedIndirectCount-OpImageWeightedSampleQCOM-06977
  If `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler **must** have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`

- VUID-vkCmdDrawIndexedIndirectCount-OpImageWeightedSampleQCOM-06978
  If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, or `OpImageBlockMatchWindowSADQCOM`
OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, OpImageBlockMatchSSDQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this command, then the sampler must not have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM

- VUID-vkCmdDrawIndexedIndirectCount-OpImageBlockMatchWindow-09215
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdDrawIndexedIndirectCount-OpImageBlockMatchWindow-09216
  If a OpImageBlockMatchingWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view’s format must be a single-component format.

- VUID-vkCmdDrawIndexedIndirectCount-OpImageBlockMatchWindow-09217
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- VUID-vkCmdDrawIndexedIndirectCount-None-07288
  Any shader invocation executed by this command must terminate

- VUID-vkCmdDrawIndexedIndirectCount-renderPass-02684
  The current render pass must be compatible with the renderPass member of the VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdDrawIndexedIndirectCount-subpass-02685
  The subpass index of the current render pass must be equal to the subpass member of the VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdDrawIndexedIndirectCount-None-07748
  If any shader statically accesses an input attachment, a valid descriptor must be bound to the pipeline via a descriptor set

- VUID-vkCmdDrawIndexedIndirectCount-OpTypeImage-07468
  If any shader executed by this pipeline accesses an OpTypeImage variable with a Dim operand of SubpassData, it must be decorated with an InputAttachmentIndex that corresponds to a valid input attachment in the current subpass

- VUID-vkCmdDrawIndexedIndirectCount-None-07469
  Input attachment views accessed in a subpass must be created with the same VkFormat as the corresponding subpass definition, and be created with a VkImageView that is compatible with the attachment referenced by the subpass’ pInputAttachments [InputAttachmentIndex] in the currently bound VkFramebuffer as specified by Fragment Input Attachment Compatibility

- VUID-vkCmdDrawIndexedIndirectCount-None-06537
  Memory backing image subresources used as attachments in the current render pass must not be written in any way other than as an attachment by this command

- VUID-vkCmdDrawIndexedIndirectCount-None-09000
  Memory backing image subresources used as attachments in the current render pass must not be written in any way other than as an attachment by this command
If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:

- the VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
- the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_COLOR_BIT and
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawIndexedIndirectCount-None-09001
If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:

- the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
- the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_DEPTH_BIT and
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawIndexedIndirectCount-None-09002
If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:

- the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
- the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_STENCIL_BIT and
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawIndexedIndirectCount-None-09003
If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command

• VUID-vkCmdDrawIndexedIndirectCount-None-06539
If any previously recorded command in the current subpass accessed an image
subresource used as an attachment in this subpass in any way other than as an attachment, this command must not write to that image subresource as an attachment

• VUID-vkCmdDrawIndexedIndirectCount-None-06886
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, depth writes must be disabled

• VUID-vkCmdDrawIndexedIndirectCount-None-06887
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back writeMask are not zero, and stencil test is enabled, all stencil ops must be VK_STENCIL_OP_KEEP

• VUID-vkCmdDrawIndexedIndirectCount-None-07831
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT dynamic state enabled then vkCmdSetViewport must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-07832
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SCISSOR dynamic state enabled then vkCmdSetScissor must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-07833
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_WIDTH dynamic state enabled then vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-08617
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetPolygonModeEXT in the current command buffer set polygonMode to VK_POLYGON_MODE_LINE, vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-08618
  If a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, and the most recent call to vkCmdSetPrimitiveTopology in the current command buffer set primitiveTopology to any line topology, vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-08619
  If a shader object that outputs line primitives is bound to the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT stage, vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-07834
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BIAS dynamic state enabled then vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-08620
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to
vkCmdSetDepthBiasEnable in the current command buffer set depthBiasEnable to VK_TRUE, vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-07835
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_BLEND_CONSTANTS dynamic state enabled then vkCmdSetBlendConstants must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-08621
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetColorBlendEnableEXT in the current command buffer set any element of pColorBlendEnables to VK_TRUE, and the most recent call to vkCmdSetColorBlendEquationEXT in the current command buffer set the same element of pColorBlendEquations to a VkColorBlendEquationEXT structure with any VkBlendFactor member with a value of VK_BLEND_FACTOR_CONSTANT_COLOR, VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR, VK_BLEND_FACTOR_CONSTANT_ALPHA, or VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA, vkCmdSetBlendConstants must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-07836
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BOUNDS dynamic state enabled then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-08622
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDepthBoundsTestEnable in the current command buffer set depthBoundsTestEnable to VK_TRUE, then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-07837
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK dynamic state enabled then vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-08623
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-07838
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_WRITE_MASK dynamic state enabled then vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilWriteMask` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_REFERENCE` dynamic state enabled then `vkCmdSetStencilReference` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilReference` must have been called in the current command buffer prior to this drawing command.

If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to `VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex`.

If the bound graphics pipeline was created with `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` set to `VK_TRUE` and the current subpass has a depth/stencil attachment, then that attachment must have been created with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled, the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetSampleLocationsEnableEXT` in the current command buffer set `sampleLocationsEnable` to `VK_TRUE`, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_PER_PIXEL` dynamic state enabled then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to `VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_PER_PIXEL` state enabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with.
command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08627**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-07841**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08628**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-07843**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08629**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-07844**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` dynamic state enabled then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08630**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-07845**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP` dynamic state enabled then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08631**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to
vkCmdSetDepthTestEnable in the current command buffer set depthTestEnable to VK_TRUE, then vkCmdSetDepthCompareOp must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-07846
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE dynamic state enabled then vkCmdSetDepthBoundsTestEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-08632
  If a shader object is bound to any graphics stage, and the depthBounds feature is enabled, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then the vkCmdSetDepthBoundsTestEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-07847
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE dynamic state enabled then vkCmdSetStencilTestEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-08633
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetStencilTestEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-07848
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_OP dynamic state enabled then vkCmdSetStencilOp must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-08634
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, then vkCmdSetStencilOp must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-viewportCount-03417
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT dynamic state enabled, then vkCmdSetViewportWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must match the VkPipelineViewportStateCreateInfo::scissorCount of the pipeline

• VUID-vkCmdDrawIndexedIndirectCount-scissorCount-03418
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT dynamic state enabled, but not the
VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, then **vkCmdSetScissorWithCount** must have been called in the current command buffer prior to this drawing command, and the **scissorCount** parameter of **vkCmdSetScissorWithCount** must match the **VkPipelineViewportStateCreateInfo::viewportCount** of the pipeline.

- **VUID-vkCmdDrawIndexedIndirectCount-viewportCount-03419**
  - If the bound graphics pipeline state was created with both the **VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT** and **VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT** dynamic states enabled then both **vkCmdSetViewportWithCount** and **vkCmdSetScissorWithCount** must have been called in the current command buffer prior to this drawing command, and the **viewportCount** parameter of **vkCmdSetViewportWithCount** must match the **scissorCount** parameter of **vkCmdSetScissorWithCount**.

- **VUID-vkCmdDrawIndexedIndirectCount-viewportCount-04137**
  - If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT** dynamic state enabled, but not the **VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV** dynamic state enabled, then the bound graphics pipeline must have been created with **VkPipelineViewportWScalingStateCreateInfoNV::viewportCount** greater or equal to the **viewportCount** parameter in the last call to **vkCmdSetViewportWithCount**.

- **VUID-vkCmdDrawIndexedIndirectCount-viewportCount-04138**
  - If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT** and **VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV** dynamic states enabled then the **viewportCount** parameter in the last call to **vkCmdSetViewportWScalingNV** must be greater than or equal to the **viewportCount** parameter in the last call to **vkCmdSetViewportWithCount**.

- **VUID-vkCmdDrawIndexedIndirectCount-viewportCount-04139**
  - If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV** dynamic state enabled, but not the **VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV** dynamic state enabled, then the bound graphics pipeline must have been created with **VkPipelineViewportShadingRateImageStateCreateInfoNV::viewportCount** greater or equal...
to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`

- **VUID-vkCmdDrawIndexedIndirectCount-viewportCount-04140**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`

- **VUID-vkCmdDrawIndexedIndirectCount-shadingRateImage-09233**
  If the `shadingRateImage` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoarseSampleOrderNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-shadingRateImage-09234**
  If a shader object is bound to any graphics stage, and the `shadingRateImage` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetShadingRateImageEnableNV` in the current command buffer set `shadingRateImageEnable` to `VK_TRUE`, then `vkCmdSetViewportShadingRatePaletteNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08637**
  If a shader object is bound to any graphics stage, and the `shadingRateImage` feature is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`

- **VUID-vkCmdDrawIndexedIndirectCount-VkPipelineViewportCreateInfo-04141**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportSwizzleStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`

- **VUID-vkCmdDrawIndexedIndirectCount-VkPipelineViewportCreateInfo-04142**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportExclusiveScissorStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline must have been created with `VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`

- **VUID-vkCmdDrawIndexedIndirectCount-None-07878**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV` dynamic state enabled then `vkCmdSetExclusiveScissorEnableNV` must have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXCLUSIVE Scissor_NV` dynamic state enabled then `vkCmdSetExclusiveScissorNV` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the `exclusiveScissor` feature is enabled, then `vkCmdSetExclusiveScissorEnableNV` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetExclusiveScissorEnableNV` in the current command buffer set any element of `pExclusiveScissorEnables` to `VK_TRUE`, then `vkCmdSetExclusiveScissorNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE` dynamic state enabled then `vkCmdSetRasterizerDiscardEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, then `vkCmdSetRasterizerDiscardEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE` dynamic state enabled then `vkCmdSetDepthBiasEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthBiasEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LOGIC_OP_EXT` dynamic state enabled then `vkCmdSetLogicOpEXT` must have been called in the current command buffer prior to this drawing command and the `logicOp` must be a valid `VkLogicOp` value.

If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the `logicOp` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEXT` must have been called in the current command buffer prior to this drawing command and the `logicOp` must be a valid `VkLogicOp` value.
If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` **must** have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` **must** be 1.

If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, and any shader object bound to a graphics stage writes to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` **must** have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` **must** be 1.

If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view’s format features do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the `blendEnable` member of the corresponding element of the `pAttachments` member of `pColorBlendState` **must** be `VK_FALSE`.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then for each color attachment in the render pass, if the corresponding image view’s format features do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the corresponding member of `pColorBlendEnables` in the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer that affected that attachment index **must** have been `VK_FALSE`.

If rasterization is not disabled in the bound graphics pipeline, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then `rasterizationSamples` for the currently bound graphics pipeline **must** be the same as the current subpass color and/or depth/stencil attachments.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then the most recent call to `vkCmdSetRasterizationSamplesEXT` in the current command buffer **must** have set `rasterizationSamples` to be the same as the number of samples for the current render pass color and/or depth/stencil attachments.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then the most recent call to `vkCmdSetRasterizationSamplesEXT` in the current command buffer **must** have set `rasterizationSamples` to be the same as the number of samples for the current render pass color and/or depth/stencil attachments.
If a shader object is bound to any graphics stage, the current render pass instance must have been begun with `vkCmdBeginRendering`

- **VUID-vkCmdDrawIndexedIndirectCount-imageView-06172**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the layout member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment

- **VUID-vkCmdDrawIndexedIndirectCount-imageView-06173**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the layout member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment

- **VUID-vkCmdDrawIndexedIndirectCount-imageView-06174**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the layout member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, this command must not write any values to the depth attachment

- **VUID-vkCmdDrawIndexedIndirectCount-imageView-06175**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the layout member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment

- **VUID-vkCmdDrawIndexedIndirectCount-viewMask-06178**
  If the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo::viewMask` equal to `VkRenderingInfo::viewMask`

- **VUID-vkCmdDrawIndexedIndirectCount-colorAttachmentCount-06179**
  If the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo::colorAttachmentCount` equal to `VkRenderingInfo::colorAttachmentCount`

- **VUID-vkCmdDrawIndexedIndirectCount-dynamicRenderingUnusedAttachments-08910**
  If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo`
::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a VkFormat equal to the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the currently bound graphics pipeline

- VUID-vkCmdDrawIndexedIndirectCount-dynamicRenderingUnusedAttachments-08911
  If the dynamicRenderingUnusedAttachments feature is enabled, and the current render pass instance was begun with vkCmdBeginRendering and VkRenderingInfo ::colorAttachmentCount greater than 0, then each element of the VkRenderingInfo ::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a VkFormat equal to the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the currently bound graphics pipeline, or the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats, if it exists, must be VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawIndexedIndirectCount-dynamicRenderingUnusedAttachments-08912
  If the dynamicRenderingUnusedAttachments feature is not enabled, and the current render pass instance was begun with vkCmdBeginRendering and VkRenderingInfo ::colorAttachmentCount greater than 0, then each element of the VkRenderingInfo ::pColorAttachments array with a imageView equal to VK_NULL_HANDLE must have the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the currently bound pipeline equal to VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawIndexedIndirectCount-None-07749
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT dynamic state enabled then vkCmdSetColorWriteEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-08646
  If the colorWriteEnable feature is enabled on the device, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorWriteEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-attachmentCount-07750
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT dynamic state enabled then the attachmentCount parameter of vkCmdSetColorWriteEnableEXT must be greater than or equal to the VkPipelineColorBlendStateCreateInfo::attachmentCount of the currently bound graphics pipeline

- VUID-vkCmdDrawIndexedIndirectCount-None-08647
  If the colorWriteEnable feature is enabled on the device, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then the attachmentCount parameter of most recent call to vkCmdSetColorWriteEnableEXT in the current command buffer must be greater than or equal to the number of color attachments in the current render pass instance
If the bound graphics pipeline state was created with the
\texttt{VK_DYNAMIC\_STATE\_DISCARD\_RECTANGLE\_EXT} dynamic state enabled then
\texttt{vkCmdSetDiscardRectangleEXT} must have been called in the current command buffer
prior to this drawing command for each discard rectangle in
\texttt{VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount}

If the bound graphics pipeline state was created with the
\texttt{VK_DYNAMIC\_STATE\_DISCARD\_RECTANGLE\_ENABLE\_EXT} dynamic state enabled then
\texttt{vkCmdSetDiscardRectangleEnableEXT} must have been called in the current command buffer
prior to this drawing command

If the \texttt{VK\_EXT\_discard\_rectangles} extension is enabled, and a shader object is bound to any
graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the
current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, then
\texttt{vkCmdSetDiscardRectangleEXT} must have been called in the current command buffer
prior to this drawing command

If the \texttt{VK\_EXT\_discard\_rectangles} extension is enabled, and a shader object is bound to any
graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the
current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, and the most recent call
to \texttt{vkCmdSetDiscardRectangleEnableEXT} in the current command buffer set
\texttt{discardRectangleEnable} to \texttt{VK\_TRUE}, then \texttt{vkCmdSetDiscardRectangleModeEXT} must have
been called in the current command buffer prior to this drawing command

If the \texttt{VK\_EXT\_discard\_rectangles} extension is enabled, and a shader object is bound to any
graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the
current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, and the most recent call
to \texttt{vkCmdSetDiscardRectangleEnableEXT} in the current command buffer set
\texttt{discardRectangleEnable} to \texttt{VK\_TRUE}, then \texttt{vkCmdSetDiscardRectangleModeEXT} must have
been called in the current command buffer prior to this drawing command

If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the
\texttt{dynamicRenderingUnusedAttachments} feature is not enabled, and \texttt{VkRenderingInfo}
::\texttt{pDepthAttachment->imageView} was \texttt{VK\_NULL\_HANDLE}, the value of
\texttt{VkPipelineRenderingCreateInfo::depthAttachmentFormat} used to create the currently bound
graphics pipeline must be equal to \texttt{VK\_FORMAT\_UNDEFINED}

If current render pass instance was begun with \texttt{vkCmdBeginRendering}, the
\texttt{dynamicRenderingUnusedAttachments} feature is not enabled, and \texttt{VkRenderingInfo}
::\texttt{pDepthAttachment->imageView} was not \texttt{VK\_NULL\_HANDLE}, the value of
VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to the VkFormat used to create VkRenderingInfo::pDepthAttachment->imageView

- VUID-vkCmdDrawIndexedIndirectCount-dynamicRenderingUnusedAttachments-08915
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pDepthAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED.

- VUID-vkCmdDrawIndexedIndirectCount-dynamicRenderingUnusedAttachments-08916
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pStencilAttachment->imageView was VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline must be equal to VK_FORMAT_UNDEFINED.

- VUID-vkCmdDrawIndexedIndirectCount-dynamicRenderingUnusedAttachments-08917
  If current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline must be equal to the VkFormat used to create VkRenderingInfo::pStencilAttachment->imageView.

- VUID-vkCmdDrawIndexedIndirectCount-dynamicRenderingUnusedAttachments-08918
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pStencilAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED.

- VUID-vkCmdDrawIndexedIndirectCount-imageView-06183
  If the current render pass instance was begun with vkCmdBeginRendering and VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR.

- VUID-vkCmdDrawIndexedIndirectCount-imageView-06184
  If the current render pass instance was begun with vkCmdBeginRendering and VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT.

- VUID-vkCmdDrawIndexedIndirectCount-colorAttachmentCount-06185
  If the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments
array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the corresponding element of the `pColorAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline.

- **VUID-vkCmdDrawIndexedIndirectCount-pDepthAttachment-06186**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

- **VUID-vkCmdDrawIndexedIndirectCount-pStencilAttachment-06187**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

- **VUID-vkCmdDrawIndexedIndirectCount-multisampledRenderToSingleSampled-07285**
  If the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the value of `rasterizationSamples` for the currently bound graphics pipeline.

- **VUID-vkCmdDrawIndexedIndirectCount-multisampledRenderToSingleSampled-07286**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

- **VUID-vkCmdDrawIndexedIndirectCount-multisampledRenderToSingleSampled-07287**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.
• VUID-vkCmdDrawIndexedIndirectCount-pNext-07935
  If this command has been called inside a render pass instance started with
  vkCmdBeginRendering, and the pNext chain of VkRenderingInfo includes a
  VkMultisampledRenderToSingleSampledInfoEXT structure with
  multisampledRenderToSingleSampledEnable equal to VK_TRUE, then the value of
  rasterizationSamples for the currently bound graphics pipeline must be equal to
  VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples

• VUID-vkCmdDrawIndexedIndirectCount-renderPass-06198
  If the current render pass instance was begun with vkCmdBeginRendering, the currently
  bound pipeline must have been created with a VkGraphicsPipelineCreateInfo::renderPass
  equal to VK_NULL_HANDLE

• VUID-vkCmdDrawIndexedIndirectCount-pColorAttachments-08963
  If the current render pass instance was begun with vkCmdBeginRendering, there is a
  graphics pipeline bound with a fragment shader that statically writes to a color
  attachment, the color write mask is not zero, color writes are enabled, and the
  corresponding element of the VkRenderingInfo::pColorAttachments->imageView was not
  VK_NULL_HANDLE, then the corresponding element of VkPipelineRenderingCreateInfo
  ::pColorAttachmentFormats used to create the pipeline must not be VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawIndexedIndirectCount-pDepthAttachment-08964
  If the current render pass instance was begun with vkCmdBeginRendering, there is a
  graphics pipeline bound, depth test is enabled, depth write is enabled, and the
  VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, then the
  VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the pipeline must
  not be VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawIndexedIndirectCount-pStencilAttachment-08965
  If the current render pass instance was begun with vkCmdBeginRendering, there is a
  graphics pipeline bound, stencil test is enabled and the
  VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, then the
  VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the pipeline must
  not be VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawIndexedIndirectCount-primitivesGeneratedQueryWithRasterizerDiscard-06708
  If the primitivesGeneratedQueryWithRasterizerDiscard feature is not enabled and the
  VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, rasterization discard must not be
  enabled

• VUID-vkCmdDrawIndexedIndirectCount-primitivesGeneratedQueryWithNonZeroStreams-06709
  If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the
  VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, the bound graphics pipeline must
  not have been created with a non-zero value in
  VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream

• VUID-vkCmdDrawIndexedIndirectCount-None-07619
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT dynamic state enabled then
  vkCmdSetTessellationDomainOriginEXT must have been called in the current command
buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-07620
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-09237
  If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-08650
  If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-07621
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-08651
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-07622
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` dynamic state enabled then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-08652
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-07623
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` dynamic state enabled then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-08653
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled, and `alphaToCoverageEnable` was `VK_TRUE` in the last call to `vkCmdSetAlphaToCoverageEnableEXT`, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetAlphaToCoverageEnableEXT` in the current command buffer set `alphaToCoverageEnable` to `VK_TRUE`, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT` dynamic state enabled then `vkCmdSetAlphaToOneEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the alphaToOne feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetAlphaToOneEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the logicOp feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetLogicOpEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the logic feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEnableEXT` must have been called in the current command buffer prior to this drawing command.
vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08657**
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-07628**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT dynamic state enabled then vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08658**
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetColorBlendEnableEXT for any attachment set that attachment's value in pColorBlendEnables to VK_TRUE, then vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-07629**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT dynamic state enabled then vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08659**
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetColorWriteMaskEXT for any attachment set that attachment's value in pColorWriteMasks to VK_TRUE, then vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-07630**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT dynamic state enabled then vkCmdSetRasterizationStreamEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08660**
  If the geometryStreams feature is enabled, and a shader object is bound to the VK_SHADER_STAGE_GEOMETRY_BIT stage, then vkCmdSetRasterizationStreamEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-07631**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT dynamic state enabled then vkCmdSetConservativeRasterizationModeEXT must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08661**
If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-07632**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-08662**
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetConservativeRasterizationModeEXT` in the current command buffer set `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`, then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-07633**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-08663**
  If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-07634**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-08664**
  If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-07635**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-07636**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT` dynamic state enabled then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08665**
  If the `VK_EXT_provoking_vertex` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-07637**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08666**
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08667**
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08668**
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-07638**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` dynamic state enabled then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08669**
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndexedIndirectCount-None-08670**
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then
vkCmdSetLineStippleEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-08671
  If the VK_EXT_line_rasterization extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then vkCmdSetLineStippleEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-07849
  If the VK_EXT_line_rasterization extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then vkCmdSetLineStippleEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-08672
  If the VK_EXT_line_rasterization extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetLineStippleEnableEXT in the current command buffer set stippledLineEnable to VK_TRUE, then vkCmdSetLineStippleEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-07639
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_EXT dynamic state enabled then vkCmdSetLineStippleEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-08673
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT dynamic state enabled then vkCmdSetDepthClipNegativeOneToOneEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-07640
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV dynamic state enabled then vkCmdSetViewportWScalingEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-08674
  If the VK_NV_clip_space_w_scaling extension is enabled, and a shader object is bound to any graphics stage, then vkCmdSetViewportWScalingEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-07641
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic state enabled then vkCmdSetViewportSwizzleNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-08675
  If the VK_NV_viewport_swizzle extension is enabled, and a shader object is bound to any graphics stage, then vkCmdSetViewportSwizzleNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-07642
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-08676**
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-07643**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` dynamic state enabled then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-08677**
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set `coverageToColorEnable` to `VK_TRUE`, then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-07644**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-08678**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-07645**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndexedIndirectCount-None-08679**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationModeNV` in the current command buffer set `coverageModulationMode` to any value other than `VK_COVERAGE_MODULATION_MODE_NONE_NV`, then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationTableEnableNV` in the current command buffer set `coverageModulationTableEnable` to `VK_TRUE`, then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV` dynamic state enabled then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `pipelineFragmentShadingRate` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFragmentShadingRateKHR` must have been called in the current command buffer prior to this drawing command.

If the `shadingRateImage` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command.

If the `representativeFragmentTest` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command.
If the `coverageReductionMode` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` state enabled and the last call to `vkCmdSetColorBlendEnableEXT` set `pColorBlendEnables` for any attachment to `VK_TRUE`, then for those attachments in the subpass the corresponding image view's format features must contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must follow the rules for a zero-attachment subpass.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `VkPipelineMultisampleStateCreateInfo::rasterizationSamples` parameter used to create the bound graphics pipeline.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter in the last call to `vkCmdSetRasterizationSamplesEXT`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and neither the `VK_AMD_mixed_attachment_samples` nor the `VK_NV_framebuffer_mixed_samples` extensions are enabled, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the current subpass color and/or depth/stencil attachments.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the current subpass color and/or depth/stencil attachments.
rasterizationSamples member of that structure

• VUID-vkCmdDrawIndexedIndirectCount-firstAttachment-07476
If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then 
vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendEnableEXT calls must specify an enable for all active color attachments in the current subpass.

• VUID-vkCmdDrawIndexedIndirectCount-firstAttachment-07477
If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT dynamic state enabled then 
vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendEquationEXT calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled.

• VUID-vkCmdDrawIndexedIndirectCount-firstAttachment-07478
If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT dynamic state enabled then 
vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorWriteMaskEXT calls must specify the color write mask for all active color attachments in the current subpass.

• VUID-vkCmdDrawIndexedIndirectCount-firstAttachment-07479
If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT dynamic state enabled then 
vkCmdSetColorBlendAdvancedEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendAdvancedEXT calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled.

• VUID-vkCmdDrawIndexedIndirectCount-advancedBlendMaxColorAttachments-07480
If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT and 
VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic states enabled and the last calls to vkCmdSetColorBlendEnableEXT and vkCmdSetColorBlendAdvancedEXT have enabled advanced blending, then the number of active color attachments in the current subpass must not exceed advancedBlendMaxColorAttachments.

• VUID-vkCmdDrawIndexedIndirectCount-primitivesGeneratedQueryWithNonZeroStreams-07481
If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the 
VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, and the bound graphics pipeline was created with 
VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT state enabled, the last call to 
vkCmdSetRasterizationStreamEXT must have set the rasterizationStream to zero.

• VUID-vkCmdDrawIndexedIndirectCount-sampleLocationsPerPixel-07482
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with.

- **VUID-vkCmdDrawIndexedIndirectCount-sampleLocationsPerPixel-07483**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` parameter of the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawIndexedIndirectCount-sampleLocationsEnable-07484**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set.

- **VUID-vkCmdDrawIndexedIndirectCount-sampleLocationsEnable-07485**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, then the `sampleLocationsInfo.sampleLocationGridSize.width` in the last call to `vkCmdSetSampleLocationsEXT` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.width` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling `rasterizationSamples`.

- **VUID-vkCmdDrawIndexedIndirectCount-sampleLocationsEnable-07486**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, then the `sampleLocationsInfo.sampleLocationGridSize.height` in the last call to `vkCmdSetSampleLocationsEXT` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.height` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling `rasterizationSamples`.

- **VUID-vkCmdDrawIndexedIndirectCount-sampleLocationsEnable-07487**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, the fragment shader code must not statically use the extended instruction `InterpolateAtSample`. 

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If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.width` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.width` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling the value of `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.height` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.height` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling the value of `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationsPerPixel` must equal `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageModulationTableEnableNV` set `coverageModulationTableEnable` to `VK_TRUE`, then the `coverageModulationTableCount` parameter in the last call to `vkCmdSetCoverageModulationTableNV` must equal the current `rasterizationSamples` divided by the number of color samples in the current subpass.

If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current `rasterizationSamples` must be the same as the sample count of the depth/stencil attachment.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageToColorEnableNV` set the `coverageToColorEnable` to `VK_TRUE`, then the current subpass must have a color attachment at the location selected by the last call to `vkCmdSetCoverageToColorLocationNV` `coverageToColorLocation`, with a `VkFormat` of
VK_FORMAT_R8_UINT, VK_FORMAT_R8_SINT, VK_FORMAT_R16_UINT, VK_FORMAT_R16_SINT, VK_FORMAT_R32_UINT, or VK_FORMAT_R32_SINT

- **VUID-vkCmdDrawIndexedIndirectCount-coverageReductionMode-07491**
  
  If this `VK_NV_coverage_reduction_mode` extension is enabled, the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, the current coverage reduction mode `coverageReductionMode_EXT` states enabled, and the sample counts for the color and depth/stencil attachments (if the subpass has them) **must** be a valid combination returned by `vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV`.

- **VUID-vkCmdDrawIndexedIndirectCount-viewportCount-07492**
  
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled, then the bound graphics pipeline **must** have been created with `VkPipelineViewportSwizzleStateCreateInfoNV`::`viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexedIndirectCount-viewportCount-07493**
  
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportSwizzleNV` **must** be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawIndexedIndirectCount-rasterizationSamples-07494**
  
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if the current subpass has any color attachments and `rasterizationSamples` of the last call to `vkCmdSetRasterizationSamplesEXT` is greater than the number of color samples, then the pipeline `sampleShadingEnableEXT` **must** be `VK_FALSE`.

- **VUID-vkCmdDrawIndexedIndirectCount-stippledLineEnable-07495**
  
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT`, then the `stippledRectangularLines` feature **must** be enabled.

- **VUID-vkCmdDrawIndexedIndirectCount-stippledLineEnable-07496**
  
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT`, then the `stippledBresenhamLines` feature **must** be enabled.

- **VUID-vkCmdDrawIndexedIndirectCount-stippledLineEnable-07497**
  
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT`, then the `stippledBresenhamLines` feature **must** be enabled.
VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT, then the stippledSmoothLines feature must be enabled

• VUID-vkCmdDrawIndexedIndirectCount-stippledLineEnable-07498
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT, then the stippledRectangularLines feature must be enabled and VkPhysicalDeviceLimits::strictLines must be VK_TRUE

• VUID-vkCmdDrawIndexedIndirectCount-conservativePointAndLineRasterization-07499
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT dynamic state enabled, conservativePointAndLineRasterization is not supported, and the effective primitive topology output by the last pre-rasterization shader stage is a line or point, then the conservativeRasterizationMode set by the last call to vkCmdSetConservativeRasterizationModeEXT must be VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT

• VUID-vkCmdDrawIndexedIndirectCount-stage-07073
  If the currently bound pipeline was created with the VkPipelineShaderStageCreateInfo ::stage member of an element of VkGraphicsPipelineCreateInfo ::pStages set to VK_SHADER_STAGE_VERTEX_BIT, VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT, VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT, then Mesh Shader Queries must not be active

• VUID-vkCmdDrawIndexedIndirectCount-None-08877
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT dynamic state vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-07850
  If dynamic state was inherited from VkCommandBufferInheritanceViewportScissorInfoNV, it must be set in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndexedIndirectCount-None-08684
  If there is no bound graphics pipeline, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_VERTEX_BIT

• VUID-vkCmdDrawIndexedIndirectCount-None-08685
  If there is no bound graphics pipeline, and the tessellationShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT

• VUID-vkCmdDrawIndexedIndirectCount-None-08686
  If there is no bound graphics pipeline, and the tessellationShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT
• VUID-vkCmdDrawIndexedIndirectCount-None-08687
If there is no bound graphics pipeline, and the geometryShader feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_GEOMETRY_BIT`

• VUID-vkCmdDrawIndexedIndirectCount-None-08688
If there is no bound graphics pipeline, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_FRAGMENT_BIT`

• VUID-vkCmdDrawIndexedIndirectCount-None-08689
If there is no bound graphics pipeline, and the taskShader feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TASK_BIT_EXT`

• VUID-vkCmdDrawIndexedIndirectCount-None-08690
If there is no bound graphics pipeline, and the meshShader feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_MESH_BIT_EXT`

• VUID-vkCmdDrawIndexedIndirectCount-None-08693
If there is no bound graphics pipeline, and at least one of the taskShader and meshShader features is enabled, one of the `VK_SHADER_STAGE_VERTEX_BIT` or `VK_SHADER_STAGE_MESH_BIT_EXT` stages must have a valid `VkShaderEXT` bound, and the other must have no `VkShaderEXT` bound

• VUID-vkCmdDrawIndexedIndirectCount-None-08694
If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that `VkShaderEXT` was created without the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, a valid `VkShaderEXT` must be bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage

• VUID-vkCmdDrawIndexedIndirectCount-None-08695
If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that `VkShaderEXT` was created with the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, there must be no `VkShaderEXT` bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage

• VUID-vkCmdDrawIndexedIndirectCount-None-08696
If there is no bound graphics pipeline, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, there must be no `VkShaderEXT` bound to either the `VK_SHADER_STAGE_TASK_BIT_EXT` stage or the `VK_SHADER_STAGE_MESH_BIT_EXT` stage

• VUID-vkCmdDrawIndexedIndirectCount-None-08698
If any graphics shader is bound which was created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag, then all shaders created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag in the same `vkCreateShadersEXT` call must also be bound

• VUID-vkCmdDrawIndexedIndirectCount-None-08699
If any graphics shader is bound which was created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag, any stages in between stages whose shaders which did not create a shader with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag as part of
the same vkCreateShadersEXT call must not have any VkShaderEXT bound

- VUID-vkCmdDrawIndexedIndirectCount-None-08878
  All bound graphics shader objects must have been created with identical or identically defined push constant ranges

- VUID-vkCmdDrawIndexedIndirectCount-None-08879
  All bound graphics shader objects must have been created with identical or identically defined arrays of descriptor set layouts

- VUID-vkCmdDrawIndexedIndirectCount-None-08880
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage and the attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-pDynamicStates-08715
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable parameter in the last call to vkCmdSetDepthWriteEnable must be VK_FALSE

- VUID-vkCmdDrawIndexedIndirectCount-pDynamicStates-08716
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_STENCIL_WRITE_MASK set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpStencilAttachmentReadEXT, the writeMask parameter in the last call to vkCmdSetStencilWriteMask must be 0

- VUID-vkCmdDrawIndexedIndirectCount-None-09116
  If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT, and the format of any color attachment is VK_FORMAT_E5B9G9R9_UFLOAT_PACK32, the corresponding element of the pColorWriteMasks parameter of vkCmdSetColorWriteMaskEXT must either include all of VK_COLOR_COMPONENT_R_BIT, VK_COLOR_COMPONENT_G_BIT, and VK_COLOR_COMPONENT_B_BIT, or none of them

- VUID-vkCmdDrawIndexedIndirectCount-maxFragmentDualSrcAttachments-09239
  If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of Location for any output attachment statically used in the Fragment Execution Model executed by this command must be less than maxFragmentDualSrcAttachments

- VUID-vkCmdDrawIndexedIndirectCount-None-04007
  All vertex input bindings accessed via vertex input variables declared in the vertex shader entry point’s interface must have either valid or VK_NULL_HANDLE buffers bound

- VUID-vkCmdDrawIndexedIndirectCount-None-04008
  If the nullDescriptor feature is not enabled, all vertex input bindings accessed via vertex input variables declared in the vertex shader entry point’s interface must not be
For a given vertex buffer binding, any attribute data fetched must be entirely contained within the corresponding vertex buffer binding, as described in Vertex Input Description.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled then vkCmdSetPrimitiveTopology must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled and the dynamicPrimitiveTopologyUnrestricted is VK_FALSE, then the primitiveTopology parameter of vkCmdSetPrimitiveTopology must be of the same topology class as the pipeline VkPipelineInputAssemblyStateCreateInfo::topology state.

If the bound graphics pipeline was created with both the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT and VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT dynamic states enabled, then vkCmdSetVertexInputEXT must have been called in the current command buffer prior to this draw command.

If the bound graphics pipeline was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, then all variables with the Input storage class decorated with Location in the Vertex Execution Model OpEntryPoint must contain a location in VkVertexInputAttributeDescription2EXT::location.

If a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, then vkCmdSetPrimitiveTopology must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, then the numeric type associated with all Input variables of the corresponding Location in the Vertex Execution Model OpEntryPoint must be NULL.
Model OpEntryPoint must be the same as VkVertexInputAttributeDescription2EXT::format

- VUID-vkCmdDrawIndexedIndirectCount-format-08936
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, and VkVertexInputAttributeDescription2EXT::format has a 64-bit component, then the scalar width associated with all Input variables of the corresponding Location in the Vertex Execution Model OpEntryPoint must be 64-bit

- VUID-vkCmdDrawIndexedIndirectCount-format-08937
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT dynamic state enabled, and the scalar width associated with a Location decorated Input variable in the Vertex Execution Model OpEntryPoint is 64-bit, then the corresponding VkVertexInputAttributeDescription2EXT::format must have a 64-bit component

- VUID-vkCmdDrawIndexedIndirectCount-None-09203
  If a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, then vkCmdSetVertexInputEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-04875
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT dynamic state enabled then vkCmdSetPatchControlPointsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-None-04879
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE dynamic state enabled then vkCmdSetPrimitiveRestartEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-rasterizerDiscardEnable-08884
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, vkCmdSetPrimitiveRestartEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndexedIndirectCount-stage-06481
  The bound graphics pipeline must not have been created with the
VkPipelineShaderStageCreateInfo::stage member of an element of VkGraphicsPipelineCreateInfo::pStages set to VK_SHADER_STAGE_TASK_BIT_EXT or VK_SHADER_STAGE_MESH_BIT_EXT

• VUID-vkCmdDrawIndexedIndirectCount-None-08885
  There must be no shader object bound to either of the VK_SHADER_STAGE_TASK_BIT_EXT or VK_SHADER_STAGE_MESH_BIT_EXT stages

• VUID-vkCmdDrawIndexedIndirectCount-buffer-02708
  If buffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

• VUID-vkCmdDrawIndexedIndirectCount-buffer-02709
  buffer must have been created with the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT bit set

• VUID-vkCmdDrawIndexedIndirectCount-offset-02710
  offset must be a multiple of 4

• VUID-vkCmdDrawIndexedIndirectCount-commandBuffer-02711
  commandBuffer must not be a protected command buffer

• VUID-vkCmdDrawIndexedIndirectCount-countBuffer-02714
  If countBuffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

• VUID-vkCmdDrawIndexedIndirectCount-countBuffer-02715
  countBuffer must have been created with the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT bit set

• VUID-vkCmdDrawIndexedIndirectCount-countBufferOffset-02716
  countBufferOffset must be a multiple of 4

• VUID-vkCmdDrawIndexedIndirectCount-countBuffer-02717
  The count stored in countBuffer must be less than or equal to VkPhysicalDeviceLimits::maxDrawIndirectCount

• VUID-vkCmdDrawIndexedIndirectCount-countBufferOffset-04129
  (countBufferOffset + sizeof(uint32_t)) must be less than or equal to the size of countBuffer

• VUID-vkCmdDrawIndexedIndirectCount-None-04445
  If drawIndirectCount is not enabled this function must not be used

• VUID-vkCmdDrawIndexedIndirectCount-None-07312
  An index buffer must be bound

• VUID-vkCmdDrawIndexedIndirectCount-robustBufferAccess2-07825
  If robustBufferAccess2 is not enabled, (indexSize × (firstIndex + indexCount) + offset) must be less than or equal to the size of the bound index buffer, with indexSize being based on the type specified by indexType, where the index buffer, indexType, and offset are specified via vkCmdBindIndexBuffer

• VUID-vkCmdDrawIndexedIndirectCount-stride-03142
  stride must be a multiple of 4 and must be greater than or equal to sizeof(VkDrawIndexedIndirectCommand)

• VUID-vkCmdDrawIndexedIndirectCount-maxDrawCount-03143
  If maxDrawCount is greater than or equal to 1, (stride × (maxDrawCount - 1) + offset +
sizeof(VkDrawIndexedIndirectCommand)) must be less than or equal to the size of buffer

- VUID-vkCmdDrawIndexedIndirectCount-countBuffer-03153
  If count stored in countBuffer is equal to 1, \((\text{offset} + \text{sizeof}(\text{VkDrawIndexedIndirectCommand}))\) must be less than or equal to the size of buffer

- VUID-vkCmdDrawIndexedIndirectCount-countBuffer-03154
  If count stored in countBuffer is greater than 1, \((\text{stride} \times (\text{drawCount} - 1) + \text{offset} + \text{sizeof}(\text{VkDrawIndexedIndirectCommand}))\) must be less than or equal to the size of buffer

Valid Usage (Implicit)

- VUID-vkCmdDrawIndexedIndirectCount-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdDrawIndexedIndirectCount-buffer-parameter
  buffer must be a valid VkBuffer handle

- VUID-vkCmdDrawIndexedIndirectCount-countBuffer-parameter
  countBuffer must be a valid VkBuffer handle

- VUID-vkCmdDrawIndexedIndirectCount-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdDrawIndexedIndirectCount-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdDrawIndexedIndirectCount-renderpass
  This command must only be called inside of a render pass instance

- VUID-vkCmdDrawIndexedIndirectCount-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdDrawIndexedIndirectCount-commonparent
  Each of buffer, commandBuffer, and countBuffer must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
21.3.1. Drawing Transform Feedback

It is possible to draw vertex data that was previously captured during active transform feedback by binding one or more of the transform feedback buffers as vertex buffers. A pipeline barrier is required between using the buffers as transform feedback buffers and vertex buffers to ensure all writes to the transform feedback buffers are visible when the data is read as vertex attributes. The source access is `VK_ACCESS_TRANSFORM_FEEDBACK_WRITE_BIT_EXT` and the destination access is `VK_ACCESS_VERTEX_ATTRIBUTE_READ_BIT` for the pipeline stages `VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT` and `VK_PIPELINE_STAGE_VERTEX_INPUT_BIT` respectively. The value written to the counter buffer by `vkCmdEndTransformFeedbackEXT` can be used to determine the vertex count for the draw. A pipeline barrier is required between using the counter buffer for `vkCmdEndTransformFeedbackEXT` and `vkCmdDrawIndirectByteCountEXT` where the source access is `VK_ACCESS_TRANSFORM_FEEDBACK_COUNTER_WRITE_BIT_EXT` and the destination access is `VK_ACCESS_INDIRECT_COMMAND_READ_BIT` for the pipeline stages `VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT` and `VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT` respectively.

To record a non-indexed draw call, where the vertex count is based on a byte count read from a buffer and the passed in vertex stride parameter, call:

```c
// Provided by VK_EXT_transform_feedback
void vkCmdDrawIndirectByteCountEXT(
    VkCommandBuffer commandBuffer,
    uint32_t instanceCount,
    uint32_t firstInstance,
    VkBuffer counterBuffer,
    VkDeviceSize counterBufferOffset,
    uint32_t counterOffset,
    uint32_t vertexStride);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `instanceCount` is the number of instances to draw.
- `firstInstance` is the instance ID of the first instance to draw.
- `counterBuffer` is the buffer handle from where the byte count is read.
- `counterBufferOffset` is the offset into the buffer used to read the byte count, which is used to calculate the vertex count for this draw call.
- `counterOffset` is subtracted from the byte count read from the `counterBuffer` at the
counterBufferOffset

- vertexStride is the stride in bytes between each element of the vertex data that is used to calculate the vertex count from the counter value. This value is typically the same value that was used in the graphics pipeline state when the transform feedback was captured as the XfbStride.

When the command is executed, primitives are assembled in the same way as done with vkCmdDraw except the vertexCount is calculated based on the byte count read from counterBuffer at offset counterBufferOffset. The assembled primitives execute the bound graphics pipeline.

The effective vertexCount is calculated as follows:

```c
const uint32_t * counterBufferPtr = (const uint8_t *)counterBuffer.address + counterBufferOffset;
vertexCount = floor(max(0, (*counterBufferPtr - counterOffset)) / vertexStride);
```

The effective firstVertex is zero.

### Valid Usage

- VUID-vkCmdDrawIndirectByteCountEXT-magFilter-04553
  If a VkSampler created with magFilter or minFilter equal to VK_FILTER_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- VUID-vkCmdDrawIndirectByteCountEXT-mipmapMode-04770
  If a VkSampler created with mipmapMode equal to VK_SAMPLER_MIPMAP_MODE_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- VUID-vkCmdDrawIndirectByteCountEXT-None-06479
  If a VkImageView is sampled with depth comparison, the image view's format features must contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT

- VUID-vkCmdDrawIndirectByteCountEXT-None-02691
  If a VkImageView is accessed using atomic operations as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

- VUID-vkCmdDrawIndirectByteCountEXT-None-07888
  If a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

- VUID-vkCmdDrawIndirectByteCountEXT-None-02692
  If a VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT
If the \texttt{VK_EXT\_filter\_cubic} extension is not enabled and any \texttt{VkImageView} is sampled with \texttt{VK\_FILTER\_CUBIC\_EXT} as a result of this command, it \textbf{must} not have a \texttt{VkImageViewType} of \texttt{VK\_IMAGE\_VIEW\_TYPE\_3D}, \texttt{VK\_IMAGE\_VIEW\_TYPE\_CUBE}, or \texttt{VK\_IMAGE\_VIEW\_TYPE\_CUBE\_ARRAY}.

Any \texttt{VkImageView} being sampled with \texttt{VK\_FILTER\_CUBIC\_EXT} as a result of this command \textbf{must} have a \texttt{VkImageViewType} and format that supports cubic filtering, as specified by \texttt{VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic} returned by \texttt{vkGetPhysicalDeviceImageFormatProperties2}.

Any \texttt{VkImageView} being sampled with \texttt{VK\_FILTER\_CUBIC\_EXT} as a result of this command \textbf{must} have a \texttt{VkImageViewType} and format that supports cubic filtering together with minmax filtering, as specified by \texttt{VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax} returned by \texttt{vkGetPhysicalDeviceImageFormatProperties2}.

If the \texttt{cubicRangeClamp} feature is not enabled, then any \texttt{VkImageView} being sampled with \texttt{VK\_FILTER\_CUBIC\_EXT} as a result of this command \textbf{must not} have a \texttt{VkSamplerReductionModeCreateInfo} \begin{verbatim}reductionMode equal to VK\__SAMPLER\_REDUCTION\_MODE\_WEIGHTED\_AVERAGE\_RANGECLAMP\_QCOM\end{verbatim}.

Any \texttt{VkImageView} being sampled with a \texttt{VkSamplerReductionModeCreateInfo::reductionMode} equal to \texttt{VK\__SAMPLER\_REDUCTION\_MODE\_WEIGHTED\_AVERAGE\_RANGECLAMP\_QCOM} as a result of this command \textbf{must} sample with \texttt{VK\_FILTER\_CUBIC\_EXT}.

If the \texttt{selectableCubicWeights} feature is not enabled, then any \texttt{VkImageView} being sampled with \texttt{VK\_FILTER\_CUBIC\_EXT} as a result of this command \textbf{must} have \texttt{VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights} equal to \texttt{VK\_CUBIC\_FILTER\_WEIGHTS\_CATMULL\_ROM\_QCOM}.

Any \texttt{VkImage} created with a \texttt{VkImageCreateInfo::flags} containing \texttt{VK\_IMAGE\_CREATE\_CORNER\_SAMPLED\_BIT\_NV} sampled as a result of this command \textbf{must} only be sampled using a \texttt{VkSamplerAddressMode} of \texttt{VK\__SAMPLER\_ADDRESS\_MODE\_CLAMP\_TO\_EDGE}.

For any \texttt{VkImageView} being written as a storage image where the image format field of the \texttt{OpTypeImage} is \texttt{Unknown}, the view's format features \textbf{must} contain \texttt{VK\_FORMAT\_FEATURE\_2\_STORAGE\_WRITE\_WITHOUT\_FORMAT\_BIT}.

For any \texttt{VkImageView} being read as a storage image where the image format field of the \texttt{OpTypeImage} is \texttt{Unknown}, the view's format features \textbf{must} contain \texttt{VK\_FORMAT\_FEATURE\_2\_STORAGE\_READ\_WITHOUT\_FORMAT\_BIT}.\footnote{2026}
For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view’s `buffer features` must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`

- VUID-vkCmdDrawIndirectByteCountEXT-OpTypeImage-07030
  Any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown` then the view’s `buffer features` must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`

- VUID-vkCmdDrawIndirectByteCountEXT-None-08600
  For each set `n` that is statically used by a bound shader, a descriptor set must have been bound to `n` at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set `n`, with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawIndirectByteCountEXT-None-08601
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawIndirectByteCountEXT-maintenance4-08602
  If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawIndirectByteCountEXT-None-08114
  Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, must be valid if they are statically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was not created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDrawIndirectByteCountEXT-None-08115
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` must have been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDrawIndirectByteCountEXT-None-08116
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDrawIndirectByteCountEXT-None-08604
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command
If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdSetDescriptorBufferOffsetsEXT, the bound VkPipeline must have been created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT.

If a descriptor is dynamically used with a VkPipeline created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident.

If a descriptor is dynamically used with aVkShaderEXTcreated with a VkDescriptorSetLayout that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident.

If the shaderObject feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command.

If the shaderObject is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and VK_NULL_HANDLE shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command.

If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the VkPipeline object bound to the pipeline bind point used by this command, since that pipeline was bound.

If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used to sample from any VkImage with a VkImageView of the type VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY, VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage.

If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage.

If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage.
• VUID-vkCmdDrawIndirectByteCountEXT-uniformBuffers-06935
If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawIndirectByteCountEXT-None-08612
If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawIndirectByteCountEXT-storageBuffers-06936
If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawIndirectByteCountEXT-None-08613
If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawIndirectByteCountEXT-commandBuffer-02707
If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource

• VUID-vkCmdDrawIndirectByteCountEXT-None-06550
If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y’C₄C₈ conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions

• VUID-vkCmdDrawIndirectByteCountEXT-ConstOffset-06551
If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y’C₄C₈ conversion, that object must not use the ConstOffset and Offset operands

• VUID-vkCmdDrawIndirectByteCountEXT-viewType-07752
If a VkImageView is accessed as a result of this command, then the image view’s viewType must match the Dim operand of the OpTypeImage as described in Instruction/Sampler/Image View Validation

• VUID-vkCmdDrawIndirectByteCountEXT-format-07753
If a VkImageView is accessed as a result of this command, then the numeric type of the image view’s format and the Sampled Type operand of the OpTypeImage must match

• VUID-vkCmdDrawIndirectByteCountEXT-OpImageWrite-08795
If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the image view’s format.

- **VUID-vkCmdDrawIndirectByteCountEXT-OpImageWrite-08796**
  If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have four components.

- **VUID-vkCmdDrawIndirectByteCountEXT-OpImageWrite-04469**
  If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the buffer view’s format.

- **VUID-vkCmdDrawIndirectByteCountEXT-SampledType-04470**
  If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 64.

- **VUID-vkCmdDrawIndirectByteCountEXT-SampledType-04471**
  If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 32.

- **VUID-vkCmdDrawIndirectByteCountEXT-SampledType-04472**
  If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 64.

- **VUID-vkCmdDrawIndirectByteCountEXT-SampledType-04473**
  If a `VkBufferView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 32.

- **VUID-vkCmdDrawIndirectByteCountEXT-sparseImageInt64Atomics-04474**
  If the `sparseImageInt64Atomics` feature is not enabled, `VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` flag **must** not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

- **VUID-vkCmdDrawIndirectByteCountEXT-sparseImageInt64Atomics-04475**
  If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag **must** not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

- **VUID-vkCmdDrawIndirectByteCountEXT-OpImageWeightedSampleQCOM-06971**
  If `OpImageWeightedSampleQCOM` is used to sample a `VkImageView` as a result of this command, then the image view’s format features **must** contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`.

- **VUID-vkCmdDrawIndirectByteCountEXT-OpImageWeightedSampleQCOM-06972**
  If `OpImageWeightedSampleQCOM` uses a `VkImageView` as a sample weight image as a result of this command, then the image view’s format features **must** contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`.
• VUID-vkCmdDrawIndirectByteCountEXT-OpImageBoxFilterQCOM-06973
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM.

• VUID-vkCmdDrawIndirectByteCountEXT-OpImageBlockMatchSSDQCOM-06974
  If OpImageBlockMatchSSDQCOM is used to read from a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM.

• VUID-vkCmdDrawIndirectByteCountEXT-OpImageBlockMatchSADQCOM-06975
  If OpImageBlockMatchSADQCOM is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM.

• VUID-vkCmdDrawIndirectByteCountEXT-OpImageWeightedSampleQCOM-06977
  If OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, OpImageBlockMatchSSDQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this command, then the sampler must have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM.

• VUID-vkCmdDrawIndirectByteCountEXT-OpImageWeightedSampleQCOM-06978
  If any command other than OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, OpImageBlockMatchSSDQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this command, then the sampler must not have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM.

• VUID-vkCmdDrawIndirectByteCountEXT-OpImageBlockMatchWindow-09215
  If an OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM.

• VUID-vkCmdDrawIndirectByteCountEXT-OpImageBlockMatchWindow-09216
  If an OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view's format must be a single-component format.

• VUID-vkCmdDrawIndirectByteCountEXT-OpImageBlockMatchWindow-09217
  If an OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from a reference image as a result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.

• VUID-vkCmdDrawIndirectByteCountEXT-None-07288
  Any shader invocation executed by this command must terminate.

• VUID-vkCmdDrawIndirectByteCountEXT-renderPass-02684

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The current render pass must be compatible with the renderPass member of the VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdDrawIndirectByteCountEXT-subpass-02685
  The subpass index of the current render pass must be equal to the subpass member of the VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdDrawIndirectByteCountEXT-None-07748
  If any shader statically accesses an input attachment, a valid descriptor must be bound to the pipeline via a descriptor set

- VUID-vkCmdDrawIndirectByteCountEXT-OpTypeImage-07468
  If any shader executed by this pipeline accesses an OpTypeImage variable with a Dim operand of SubpassData, it must be decorated with an InputAttachmentIndex that corresponds to a valid input attachment in the current subpass

- VUID-vkCmdDrawIndirectByteCountEXT-None-07469
  Input attachment views accessed in a subpass must be created with the same VkFormat as the corresponding subpass definition, and be created with a VkImageView that is compatible with the attachment referenced by the subpass’ pInputAttachments [InputAttachmentIndex] in the currently bound VkFramebuffer as specified by Fragment Input Attachment Compatibility

- VUID-vkCmdDrawIndirectByteCountEXT-None-06537
  Memory backing image subresources used as attachments in the current render pass must not be written in any way other than as an attachment by this command

- VUID-vkCmdDrawIndirectByteCountEXT-None-09000
  If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:
  - the VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
  - the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_COLOR_BIT and
    - there is no currently bound graphics pipeline or
    - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawIndirectByteCountEXT-None-09001
  If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:
  - the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
  - the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_DEPTH_BIT and
• there is no currently bound graphics pipeline or
• the currently bound graphics pipeline was created with
  `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-09002**
  If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the
  `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:
  - the `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
  - the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_STENCIL_BIT`

- **VUID-vkCmdDrawIndirectByteCountEXT-None-09003**
  If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-06539**
  If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command must not write to that image subresource as an attachment

- **VUID-vkCmdDrawIndirectByteCountEXT-None-06886**
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, depth writes must be disabled

- **VUID-vkCmdDrawIndirectByteCountEXT-None-06887**
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back writeMask are not zero, and stencil test is enabled, all stencil ops must be `VK_STENCIL_OP_KEEP`

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07831**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT` dynamic state enabled then `vkCmdSetViewport` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07832**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SCISSOR` dynamic state enabled then `vkCmdSetScissor` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07833**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_WIDTH` dynamic state enabled then `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command.

If a shader object that outputs line primitives is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` or `VK_SHADER_STAGE_GEOMETRY_BIT` stage, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BIAS` dynamic state enabled then `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthBiasEnable` in the current command buffer set `depthBiasEnable` to `VK_TRUE`, `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_BLEND_CONSTANTS` dynamic state enabled then `vkCmdSetBlendConstants` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer set any element of `pColorBlendEnables` to `VK_TRUE`, and the most recent call to `vkCmdSetColorBlendEquationEXT` in the current command buffer set the same element of `pColorBlendEquations` to a `VkColorBlendEquationEXT` structure with any `VkBlendFactor` member with a value of `VK_BLEND_FACTOR_CONSTANT_COLOR`, `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR`, `VK_BLEND_FACTOR_CONSTANT_ALPHA`, or `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA`, `vkCmdSetBlendConstants` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS` dynamic state enabled then `vkCmdSetDepthBounds` must have been called in the current command buffer prior to this drawing command.
command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08622**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthBoundsTestEnable` in the current command buffer set `depthBoundsTestEnable` to `VK_TRUE`, then `vkCmdSetDepthBounds` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07837**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK` dynamic state enabled then `vkCmdSetStencilCompareMask` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08623**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilCompareMask` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07838**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_WRITE_MASK` dynamic state enabled then `vkCmdSetStencilWriteMask` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08624**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilWriteMask` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07839**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_REFERENCE` dynamic state enabled then `vkCmdSetStencilReference` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08625**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilReference` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-maxMultiviewInstanceIndex-02688**
  If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to `VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex`

- **VUID-vkCmdDrawIndirectByteCountEXT-sampleLocationsEnable-02689**
  If the bound graphics pipeline was created with...
VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable set to VK_TRUE and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set

- VUID-vkCmdDrawIndirectByteCountEXT-None-06666
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT dynamic state enabled then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-None-08626
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetSampleLocationsEnableEXT in the current command buffer set sampleLocationsEnable to VK_TRUE, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-sampleLocationsPerPixel-07934
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples member of the VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with

- VUID-vkCmdDrawIndirectByteCountEXT-None-07840
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CULL_MODE dynamic state enabled then vkCmdSetCullMode must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-None-08627
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCullMode must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-None-07841
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_FRONT_FACE dynamic state enabled then vkCmdSetFrontFace must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-None-08628
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetFrontFace must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-None-07843
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE dynamic state enabled then vkCmdSetDepthTestEnable must have been called in the current command buffer prior to this drawing command
• VUID-vkCmdDrawIndirectByteCountEXT-None-08629
If a shader object is bound to any graphics stage, and the most recent call to
\texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set
\texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, then \texttt{vkCmdSetDepthTestEnable} \textbf{must} have been
called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-07844
If the bound graphics pipeline state was created with the
\texttt{VK\_DYNAMIC\_STATE\_DEPTH\_WRITE\_ENABLE} dynamic state enabled then
\texttt{vkCmdSetDepthWriteEnable} \textbf{must} have been called in the current command buffer prior
to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-08630
If a shader object is bound to any graphics stage, and the most recent call to
\texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set
\texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, then \texttt{vkCmdSetDepthWriteEnable} \textbf{must} have been
called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-07845
If the bound graphics pipeline state was created with the
\texttt{VK\_DYNAMIC\_STATE\_DEPTH\_COMPARE\_OP} dynamic state enabled then
\texttt{vkCmdSetDepthCompareOp} \textbf{must} have been called in the current command buffer prior
to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-08631
If a shader object is bound to any graphics stage, and the most recent call to
\texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set
\texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, and the most recent call to
\texttt{vkCmdSetDepthTestEnable} in the current command buffer set \texttt{depthTestEnable} to \texttt{VK\_TRUE},
then \texttt{vkCmdSetDepthCompareOp} \textbf{must} have been called in the current command buffer prior
to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-07846
If the bound graphics pipeline state was created with the
\texttt{VK\_DYNAMIC\_STATE\_DEPTH\_BOUNDS\_TEST\_ENABLE} dynamic state enabled then
\texttt{vkCmdSetDepthBoundsTestEnable} \textbf{must} have been called in the current command buffer prior
to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-08632
If a shader object is bound to any graphics stage, and the \texttt{depthBounds} feature is enabled,
and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command
buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, then the \texttt{vkCmdSetDepthBoundsTestEnable}
\textbf{must} have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-07847
If the bound graphics pipeline state was created with the
\texttt{VK\_DYNAMIC\_STATE\_STENCIL\_TEST\_ENABLE} dynamic state enabled then
\texttt{vkCmdSetStencilTestEnable} \textbf{must} have been called in the current command buffer prior
to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-08633
If a shader object is bound to any graphics stage, and the most recent call to
\texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetStencilTestEnable must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndirectByteCountEXT-None-07848
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_OP dynamic state enabled then vkCmdSetStencilOp must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndirectByteCountEXT-None-08634
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, then vkCmdSetStencilOp must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawIndirectByteCountEXT-viewportCount-03417
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT dynamic state enabled, then vkCmdSetViewportWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must match the VkPipelineViewportStateCreateInfo::scissorCount of the pipeline.

• VUID-vkCmdDrawIndirectByteCountEXT-scissorCount-03418
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, then vkCmdSetScissorWithCount must have been called in the current command buffer prior to this drawing command, and the scissorCount parameter of vkCmdSetScissorWithCount must match the VkPipelineViewportStateCreateInfo::viewportCount of the pipeline.

• VUID-vkCmdDrawIndirectByteCountEXT-viewportCount-03419
  If the bound graphics pipeline state was created with both the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic states enabled then both vkCmdSetViewportWithCount and vkCmdSetScissorWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must match the scissorCount parameter of vkCmdSetScissorWithCount.

• VUID-vkCmdDrawIndirectByteCountEXT-None-08635
  If a shader object is bound to any graphics stage, then both vkCmdSetViewportWithCount and vkCmdSetScissorWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must match the scissorCount parameter of vkCmdSetScissorWithCount.

• VUID-vkCmdDrawIndirectByteCountEXT-viewportCount-04137
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV dynamic state enabled, then the bound graphics
pipeline must have been created with \texttt{VkPipelineViewportWScalingStateCreateInfoNV} ::\texttt{viewportCount} greater or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- VUID-vkCmdDrawIndirectByteCountEXT-viewportCount-04138
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} and \texttt{VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV} dynamic states enabled then the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWScalingNV} must be greater than or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- VUID-vkCmdDrawIndirectByteCountEXT-None-09232
  If a shader object is bound to any graphics stage, and the \texttt{VK_NV_clip_space_w_scaling} extension is enabled on the device, then \texttt{vkCmdSetViewportWScalingNV} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-None-08636
  If a shader object is bound to any graphics stage, and the \texttt{VK_NV_clip_space_w_scaling} extension is enabled on the device, then the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWScalingNV} must be greater than or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- VUID-vkCmdDrawIndirectByteCountEXT-viewportCount-04139
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} dynamic state enabled, but not the \texttt{VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV} dynamic state enabled, then the bound graphics pipeline must have been created with \texttt{VkPipelineViewportShadingRateImageStateCreateInfoNV} ::\texttt{viewportCount} greater or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- VUID-vkCmdDrawIndirectByteCountEXT-viewportCount-04140
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} and \texttt{VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV} dynamic states enabled then the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportShadingRatePaletteNV} must be greater than or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- VUID-vkCmdDrawIndirectByteCountEXT-shadingRateImage-09233
  If the \texttt{shadingRateImage} feature is enabled, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetCoarseSampleOrderNV} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-shadingRateImage-09234
  If a shader object is bound to any graphics stage, and the \texttt{shadingRateImage} feature is enabled on the device, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, and the most recent call to \texttt{vkCmdSetShadingRateImageEnableNV} in the current command buffer set \texttt{shadingRateImageEnable} to \texttt{VK_TRUE}, then \texttt{vkCmdSetViewportShadingRatePaletteNV} must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-None-08637
If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, then the viewportCount parameter in the last call to vkCmdSetViewportShadingRatePaletteNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount.

- VUID-vkCmdDrawIndirectByteCountEXT-VkPipelineViewportCreateInfo-04141
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled and a VkPipelineViewportSwizzleStateCreateInfoNV structure chained from VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have been created with VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount.

- VUID-vkCmdDrawIndirectByteCountEXT-VkPipelineViewportCreateInfo-04142
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled and a VkPipelineViewportExclusiveScissorStateCreateInfoNV structure chained from VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have been created with VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount.

- VUID-vkCmdDrawIndirectByteCountEXT-None-07878
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV dynamic state enabled then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectByteCountEXT-None-07879
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV dynamic state enabled then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectByteCountEXT-exclusiveScissor-09235
  If a shader object is bound to any graphics stage, and the exclusiveScissor feature is enabled, then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectByteCountEXT-None-08638
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetExclusiveScissorEnableNV in the current command buffer set any element of pExclusiveScissorEnables to VK_TRUE, then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectByteCountEXT-None-08639
  If a shader object is bound to any graphics stage, then vkCmdSetRasterizerDiscardEnable.
**must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-04877**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE` dynamic state enabled then `vkCmdSetDepthBiasEnable` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08640**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthBiasEnable` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-logicOp-04878**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LOGIC_OP_EXT` dynamic state enabled then `vkCmdSetLogicOpEXT` **must** have been called in the current command buffer prior to this drawing command and the `logicOp` **must** be a valid `VkLogicOp` value

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08641**
  If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the `logicOp` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEXT` **must** have been called in the current command buffer prior to this drawing command and the `logicOp` **must** be a valid `VkLogicOp` value

- **VUID-vkCmdDrawIndirectByteCountEXT-primitiveFragmentShadingRateWithMultipleViewports-04552**
  If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` **must** have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` **must** be 1

- **VUID-vkCmdDrawIndirectByteCountEXT-primitiveFragmentShadingRateWithMultipleViewports-08642**
  If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, and any shader object bound to a graphics stage writes to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` **must** have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` **must** be 1

- **VUID-vkCmdDrawIndirectByteCountEXT-blendEnable-04727**
  If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view's format features do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the `blendEnable` member of the corresponding element of the `pAttachments` member of `pColorBlendState` **must** be `VK_FALSE`

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08643**
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then for each color attachment in the render pass, if the corresponding image view’s format features do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the corresponding member of `pColorBlendEnables` in the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer that affected that attachment index must have been `VK_FALSE`.

- **VUID-vkCmdDrawIndirectByteCountEXT-multisampledRenderToSingleSampled-07284**
  If rasterization is not disabled in the bound graphics pipeline, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then `rasterizationSamples` for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08644**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then the most recent call to `vkCmdSetRasterizationSamplesEXT` in the current command buffer must have set `rasterizationSamples` to be the same as the number of samples for the current render pass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08876**
  If a shader object is bound to any graphics stage, the current render pass instance must have been begun with `vkCmdBeginRendering`.

- **VUID-vkCmdDrawIndirectByteCountEXT-imageView-06172**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment.

- **VUID-vkCmdDrawIndirectByteCountEXT-imageView-06173**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment.

- **VUID-vkCmdDrawIndirectByteCountEXT-imageView-06174**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment.

- **VUID-vkCmdDrawIndirectByteCountEXT-imageView-06175**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment.
If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo`::`viewMask` equal to `VkRenderingInfo`::`viewMask`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo`::`colorAttachmentCount` equal to `VkRenderingInfo`::`colorAttachmentCount`.

If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo`::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo`::`pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo`::`pColorAttachmentFormats` used to create the currently bound graphics pipeline.

If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo`::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo`::`pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` must have the corresponding element of `VkPipelineRenderingCreateInfo`::`pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`.

If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo`::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo`::`pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo`::`pColorAttachmentFormats` used to create the currently bound graphics pipeline, or the corresponding element of `VkPipelineRenderingCreateInfo`::`pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`.

If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo`::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo`::`pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` must have the corresponding element of `VkPipelineRenderingCreateInfo`::`pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`.

If the bound graphics pipeline state was created with the
- **VUID-vkCmdDrawIndirectByteCountEXT-None-08646**
  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteEnableEXT` **must** have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectByteCountEXT-attachmentCount-07750**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then the `attachmentCount` parameter of `vkCmdSetColorWriteEnableEXT` **must** be greater than or equal to the `VkPipelineColorBlendStateCreateInfo::attachmentCount` of the currently bound graphics pipeline.

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08647**
  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `attachmentCount` parameter of most recent call to `vkCmdSetColorWriteEnableEXT` in the current command buffer **must** be greater than or equal to the number of color attachments in the current render pass instance.

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08648**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` dynamic state enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDiscardRectangleEnableEXT` **must** have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07880**
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDiscardRectangleEnableEXT` **must** have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawIndirectByteCountEXT-rasterizerDiscardEnable-09236**
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDiscardRectangleEnableEXT` **must** have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT dynamic state enabled then 
vkCmdSetDiscardRectangleModeEXT must have been called in the current command 
buffer prior to this drawing command.

If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any 
graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the 
current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to 
vkCmdSetDiscardRectangleEnableEXT in the current command buffer set 
discardRectangleEnable to VK_TRUE, then vkCmdSetDiscardRectangleModeEXT must have 
been called in the current command buffer prior to this drawing command.

If the current render pass instance was begun with vkCmdBeginRendering, the 
dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo 
::pDepthAttachment->imageView was VK_NULL_HANDLE, the value of 
VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound 
graphics pipeline must be equal to VK_FORMAT_UNDEFINED.

If current render pass instance was begun with vkCmdBeginRendering, the 
dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo 
::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of 
VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound 
graphics pipeline must be equal to the VkFormat used to create VkRenderingInfo 
::pDepthAttachment->imageView.

If the current render pass instance was begun with vkCmdBeginRendering, the 
dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo 
::pDepthAttachment->imageView was not VK_NULL_HANDLE, and the value of 
VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound 
graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo 
::pDepthAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED.

If the current render pass instance was begun with vkCmdBeginRendering, the 
dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo 
::pStencilAttachment->imageView was VK_NULL_HANDLE, the value of 
VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound 
graphics pipeline must be equal to VK_FORMAT_UNDEFINED.

If current render pass instance was begun with vkCmdBeginRendering, the 
dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo 
::pStencilAttachment->imageView was not VK_NULL_HANDLE, the value of 
VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound 
graphics pipeline must be equal to the VkFormat used to create VkRenderingInfo 
::pStencilAttachment->imageView.
If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo::pStencilAttachment->imageView`, the value of the format must be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView` was not `VK_NULL_HANDLE`, the currently bound graphics pipeline must have been created with `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`.

If the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView` was not `VK_NULL_HANDLE`, the currently bound graphics pipeline must have been created with `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT`.

If the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the corresponding element of the `pColorAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline.

If the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and...
the `multisampledRenderToSingleSampled` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the value of `rasterizationSamples` for the currently bound graphics pipeline.

- **VUID-vkCmdDrawIndirectByteCountEXT-multisampledRenderToSingleSampled-07286**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

- **VUID-vkCmdDrawIndirectByteCountEXT-multisampledRenderToSingleSampled-07287**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

- **VUID-vkCmdDrawIndirectByteCountEXT-pNext-07935**
  If this command has been called inside a render pass instance started with `vkCmdBeginRendering`, and the `pNext` chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to `VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples`.

- **VUID-vkCmdDrawIndirectByteCountEXT-renderPass-06198**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline must have been created with a `VkGraphicsPipelineCreateInfo::renderPass` equal to `VK_NULL_HANDLE`.

- **VUID-vkCmdDrawIndirectByteCountEXT-pColorAttachments-08963**
  If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the `VkRenderingInfo::pColorAttachments->imageView` was not `VK_NULL_HANDLE`, then the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

- **VUID-vkCmdDrawIndirectByteCountEXT-pDepthAttachment-08964**
  If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the pipeline must
If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, stencil test is enabled and the `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

If the `primitivesGeneratedQueryWithRasterizerDiscard` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES/generated_EXT` query is active, rasterization discard must not be enabled.

If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES/generated_EXT` query is active, the bound graphics pipeline must not have been created with a non-zero value in `VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT` dynamic state enabled then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command.

If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetPolygonModeEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectByteCountEXT-None-07622
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT dynamic state enabled then vkCmdSetRasterizationSamplesEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectByteCountEXT-None-08652
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetRasterizationSamplesEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectByteCountEXT-None-07623
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_MASK_EXT dynamic state enabled then vkCmdSetSampleMaskEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectByteCountEXT-None-08653
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleMaskEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectByteCountEXT-None-07624
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled then vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectByteCountEXT-alphaToCoverageEnable-08919
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled, and alphaToCoverageEnable was VK_TRUE in the last call to vkCmdSetAlphaToCoverageEnableEXT, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0.

- VUID-vkCmdDrawIndirectByteCountEXT-None-08654
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectByteCountEXT-alphaToCoverageEnable-08920
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetAlphaToCoverageEnableEXT in the current command buffer set alphaToCoverageEnable to VK_TRUE, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0.

- VUID-vkCmdDrawIndirectByteCountEXT-None-07625
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT` dynamic state enabled then `vkCmdSetAlphaToOneEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08655**
  If the `alphaToOne` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetAlphaToOneEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07626**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT` dynamic state enabled then `vkCmdSetLogicOpEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08656**
  If the `logicOp` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07627**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08657**
  If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` for any attachment set that attachment's value in `pColorBlendEnables` to `VK_TRUE`, then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08658**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07628**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` for any attachment set that attachment's value in `pColorBlendEnables` to `VK_TRUE`, then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07629**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then
**vkCmdSetColorWriteMaskEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08659**
  If a shader object is bound to the **VK_SHADER_STAGE_FRAGMENT_BIT** stage, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set **rasterizerDiscardEnable** to **VK_FALSE**, then **vkCmdSetColorWriteMaskEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07630**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT** dynamic state enabled then **vkCmdSetRasterizationStreamEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07631**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT** dynamic state enabled then **vkCmdSetConservativeRasterizationModeEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07632**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT** dynamic state enabled then **vkCmdSetExtraPrimitiveOverestimationSizeEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07633**
  If the **VK_EXT_conservative_rasterization** extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set **rasterizerDiscardEnable** to **VK_FALSE**, and the most recent call to **vkCmdSetConservativeRasterizationModeEXT** in the current command buffer set **conservativeRasterizationMode** to **VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT**, then **vkCmdSetExtraPrimitiveOverestimationSizeEXT** must have been called in the current command buffer prior to this drawing command
prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-08663
  If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics
  stage, then `vkCmdSetDepthClipEnableEXT` must have been called in the current
  command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-07634
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then
  `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command
  buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-08664
  If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any
  graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the
  current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then
  `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command
  buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-07635
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then
  `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command
  buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-08665
  If the `VK_EXT_provoking_vertex` extension is enabled, and a shader object is bound to the
  `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetProvokingVertexModeEXT` must have
  been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-07637
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic state enabled then
  `vkCmdSetLineRasterizationModeEXT` must have been called in the current command
  buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-08666
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any
  graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current
  command buffer set `polygonMode` to `VK_POLYGON MODE LINE`, then
  `vkCmdSetLineRasterizationModeEXT` must have been called in the current command
  buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-08667
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the
  vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current
command buffer set **primitiveTopology** to any line topology, then **vkCmdSetLineRasterizationModeEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08668**
  If the **VK_EXT_line_rasterization** extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then **vkCmdSetLineRasterizationModeEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07638**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT** dynamic state enabled then **vkCmdSetLineStippleEnableEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08669**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT** dynamic state enabled then **vkCmdSetLineStippleEnableEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08670**
  If the **VK_EXT_line_rasterization** extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetPolygonModeEXT** in the current command buffer set **polygonMode** to **VK_POLYGON_MODE_LINE**, then **vkCmdSetLineStippleEnableEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08671**
  If the **VK_EXT_line_rasterization** extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetPolygonModeEXT** in the current command buffer set **polygonMode** to **VK_POLYGON_MODE_LINE**, then **vkCmdSetLineStippleEnableEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07849**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_LINE_STIPPLE_EXT** dynamic state enabled then **vkCmdSetLineStippleEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-08672**
  If the **VK_EXT_line_rasterization** extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetLineStippleEnableEXT** in the current command buffer set **stippledLineEnable** to **VK_TRUE**, then **vkCmdSetLineStippleEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawIndirectByteCountEXT-None-07639**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT** dynamic state enabled then **vkCmdSetDepthClipNegativeOneToOneEXT** must have been called in the current command buffer prior to this drawing command
If the `depthClipControl` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV` dynamic state enabled then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_clip_space_w_scaling` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_viewport_swizzle` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` dynamic state enabled then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set `coverageToColorEnable` to `VK_TRUE`, then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV` dynamic state enabled then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `pipelineFragmentShadingRate` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set rasterizerDiscardEnable to `VK_FALSE`, then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetFragmentShadingRateKHR must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-08681
If the shadingRateImage feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetShadingRateImageEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-07648
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV dynamic state enabled then vkCmdSetRepresentativeFragmentTestEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-08682
If the representativeFragmentTest feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetRepresentativeFragmentTestEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-07649
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV dynamic state enabled then vkCmdSetCoverageReductionModeNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-None-08683
If the coverageReductionMode feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCoverageReductionModeNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawIndirectByteCountEXT-pColorBlendEnables-07470
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT state enabled and the last call to vkCmdSetColorBlendEnableEXT set pColorBlendEnables for any attachment to VK_TRUE, then for those attachments in the subpass the corresponding image view’s format features must contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT

• VUID-vkCmdDrawIndirectByteCountEXT-rasterizationSamples-07471
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT must follow the rules for a zero-attachment subpass

• VUID-vkCmdDrawIndirectByteCountEXT-samples-07472
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_MASK_EXT state enabled and the
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state disabled, then the samples parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `VkPipelineMultisampleStateCreateInfo::rasterizationSamples` parameter used to create the bound graphics pipeline

- **VUID-vkCmdDrawIndirectByteCountEXT-samples-07473**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, then the samples parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter in the last call to `vkCmdSetRasterizationSamplesEXT`

- **VUID-vkCmdDrawIndirectByteCountEXT-rasterizationSamples-07474**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and neither the `VK_AMD_mixed_attachment_samples` nor the `VK_NV_framebuffer_mixed_samples` extensions are enabled, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the current subpass color and/or depth/stencil attachments

- **VUID-vkCmdDrawIndirectByteCountEXT-None-09211**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the `rasterizationSamples` member of that structure

- **VUID-vkCmdDrawIndirectByteCountEXT-firstAttachment-07476**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEnableEXT` calls must specify an enable for all active color attachments in the current subpass

- **VUID-vkCmdDrawIndirectByteCountEXT-firstAttachment-07477**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEquationEXT` calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled

- **VUID-vkCmdDrawIndirectByteCountEXT-firstAttachment-07478**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and
attachmentCount parameters of `vkCmdSetColorWriteMaskEXT` calls must specify the color write mask for all active color attachments in the current subpass

- **VUID-vkCmdDrawIndirectByteCountEXT-firstAttachment-07479**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendAdvancedEXT` calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled

- **VUID-vkCmdDrawIndirectByteCountEXT-advancedBlendMaxColorAttachments-07480**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` and `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic states enabled and the last calls to `vkCmdSetColorBlendEnableEXT` and `vkCmdSetColorBlendAdvancedEXT` have enabled advanced blending, then the number of active color attachments in the current subpass must not exceed `advancedBlendMaxColorAttachments`

- **VUID-vkCmdDrawIndirectByteCountEXT-primitivesGeneratedQueryWithNonZeroStreams-07481**
  If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, and the bound graphics pipeline was created with `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` state enabled, the last call to `vkCmdSetRasterizationStreamEXT` must have set the `rasterizationStream` to zero

- **VUID-vkCmdDrawIndirectByteCountEXT-sampleLocationsPerPixel-07482**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with

- **VUID-vkCmdDrawIndirectByteCountEXT-sampleLocationsEnable-07483**
  If the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set

- **VUID-vkCmdDrawIndirectByteCountEXT-sampleLocationsEnable-07484**
  If the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable
was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the
sampleLocationsInfo.sampleLocationGridSize.width in the last call to
vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT
::sampleLocationGridSize.width as returned by
vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling
rasterizationSamples

• VUID-vkCmdDrawIndirectByteCountEXT-sampleLocationsEnable-07486
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable
was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the
sampleLocationsInfo.sampleLocationGridSize.height in the last call to
vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT
::sampleLocationGridSize.height as returned by
vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling
rasterizationSamples

• VUID-vkCmdDrawIndirectByteCountEXT-sampleLocationsEnable-07487
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_Enable_EXT state enabled, and if sampleLocationsEnable
was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, the fragment shader
code must not statically use the extended instruction InterpolateAtSample

• VUID-vkCmdDrawIndirectByteCountEXT-sampleLocationsEnable-07936
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable
member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the
bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state
enabled, then, sampleLocationsInfo.sampleLocationGridSize.width must evenly divide
VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by
vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the
value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

• VUID-vkCmdDrawIndirectByteCountEXT-sampleLocationsEnable-07937
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable
member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the
bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state
enabled, then, sampleLocationsInfo.sampleLocationGridSize.height must evenly divide
VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by
vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the
value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

• VUID-vkCmdDrawIndirectByteCountEXT-sampleLocationsEnable-07938
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationsPerPixel must equal rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawIndirectByteCountEXT-coverageModulationTableEnable-07488
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV state enabled and the last call to vkCmdSetCoverageModulationTableEnableNV set coverageModulationTableEnable to VK_TRUE, then the coverageModulationTableCount parameter in the last call to vkCmdSetCoverageModulationTableNV must equal the current rasterizationSamples divided by the number of color samples in the current subpass

- VUID-vkCmdDrawIndirectByteCountEXT-rasterizationSamples-07489
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current rasterizationSamples must be the same as the sample count of the depth/stencil attachment

- VUID-vkCmdDrawIndirectByteCountEXT-coverageToColorEnable-07490
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV state enabled and the last call to vkCmdSetCoverageToColorEnableNV set the coverageToColorEnable to VK_TRUE, then the current subpass must have a color attachment at the location selected by the last call to vkCmdSetCoverageToColorLocationNV coverageToColorLocation, with a VkFormat of VK_FORMAT_R8_UINT, VK_FORMAT_R8_SINT, VK_FORMAT_R16_UINT, VK_FORMAT_R16_SINT, VK_FORMAT_R32_UINT, or VK_FORMAT_R32_SINT

- VUID-vkCmdDrawIndirectByteCountEXT-coverageReductionMode-07491
  If this VK_NV_coverage_reduction_mode extension is enabled, the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV and VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT states enabled, the current coverage reduction mode coverageReductionMode, then the current rasterizationSamples, and the sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV

- VUID-vkCmdDrawIndirectByteCountEXT-viewportCount-07492
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic state enabled, then the bound graphics pipeline must have been created with VkPipelineViewportSwizzleStateCreateInfoNV ::viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

- VUID-vkCmdDrawIndirectByteCountEXT-viewportCount-07493
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic states enabled then the viewportCount parameter in the last call to
vkCmdSetViewportSwizzleNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

- VUID-vkCmdDrawIndirectByteCountEXT-rasterizationSamples-07494
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and if the current subpass has any color attachments and rasterizationSamples of the last call to vkCmdSetRasterizationSamplesEXT is greater than the number of color samples, then the pipeline sampleShadingEnable must be VK_FALSE

- VUID-vkCmdDrawIndirectByteCountEXT-stippledLineEnable-07495
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT, then the stippledRectangularLines feature must be enabled

- VUID-vkCmdDrawIndirectByteCountEXT-stippledLineEnable-07496
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT, then the stippledBresenhamLines feature must be enabled

- VUID-vkCmdDrawIndirectByteCountEXT-stippledLineEnable-07497
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT, then the stippledSmoothLines feature must be enabled

- VUID-vkCmdDrawIndirectByteCountEXT-stippledLineEnable-07498
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT, then the stippledRectangularLines feature must be enabled and VkPhysicalDeviceLimits::strictLines must be VK_TRUE

- VUID-vkCmdDrawIndirectByteCountEXT-conservativePointAndLineRasterization-07499
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT dynamic state enabled, conservativePointAndLineRasterization is not supported, and the effective primitive topology output by the last pre-rasterization shader stage is a line or point, then the conservativeRasterizationMode set by the last call to vkCmdSetConservativeRasterizationModeEXT must be VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT

- VUID-vkCmdDrawIndirectByteCountEXT-stage-07073
  If the currently bound pipeline was created with the VkPipelineShaderStageCreateInfo::
::stage member of an element of VkGraphicsPipelineCreateInfo::pStages set to VK_SHADER_STAGE_VERTEX_BIT, VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT, VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT, then Mesh Shader Queries must not be active

- VUID-vkCmdDrawIndirectByteCountEXT-None-08877
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT dynamic state
  vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current
  command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-None-07850
  If dynamic state was inherited from
  VkCommandBufferInheritanceViewportScissorInfoNV, it must be set in the current
  command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-None-08684
  If there is no bound graphics pipeline, vkCmdBindShadersEXT must have been called in the
  current command buffer with pStages with an element of VK_SHADER_STAGE_VERTEX_BIT

- VUID-vkCmdDrawIndirectByteCountEXT-None-08685
  If there is no bound graphics pipeline, and the tessellationShader feature is enabled,
  vkCmdBindShadersEXT must have been called in the current command buffer with pStages
  with an element of VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT

- VUID-vkCmdDrawIndirectByteCountEXT-None-08686
  If there is no bound graphics pipeline, and the tessellationShader feature is enabled,
  vkCmdBindShadersEXT must have been called in the current command buffer with pStages
  with an element of VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT

- VUID-vkCmdDrawIndirectByteCountEXT-None-08687
  If there is no bound graphics pipeline, and the geometryShader feature is enabled,
  vkCmdBindShadersEXT must have been called in the current command buffer with pStages
  with an element of VK_SHADER_STAGE_GEOMETRY_BIT

- VUID-vkCmdDrawIndirectByteCountEXT-None-08688
  If there is no bound graphics pipeline, vkCmdBindShadersEXT must have been called in the
  current command buffer with pStages with an element of VK_SHADER_STAGE_FRAGMENT_BIT

- VUID-vkCmdDrawIndirectByteCountEXT-None-08689
  If there is no bound graphics pipeline, and the taskShader feature is enabled,
  vkCmdBindShadersEXT must have been called in the current command buffer with pStages
  with an element of VK_SHADER_STAGE_TASK_BIT_EXT

- VUID-vkCmdDrawIndirectByteCountEXT-None-08690
  If there is no bound graphics pipeline, and the meshShader feature is enabled,
  vkCmdBindShadersEXT must have been called in the current command buffer with pStages
  with an element of VK_SHADER_STAGE_MESH_BIT_EXT

- VUID-vkCmdDrawIndirectByteCountEXT-None-08693
  If there is no bound graphics pipeline, and at least one of the taskShader and meshShader
  features is enabled, one of the VK_SHADER_STAGE_VERTEX_BIT or
  VK_SHADER_STAGE_MESH_BIT_EXT stages must have a valid VkShaderEXT bound, and the other
  must have no VkShaderEXT bound
If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_MESH_BIT_EXT stage, and that VkShaderEXT was created without the VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT flag, a valid VkShaderEXT must be bound to the VK_SHADER_STAGE_TASK_BIT_EXT stage.

If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_MESH_BIT_EXT stage, and that VkShaderEXT was created with the VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT flag, there must be no VkShaderEXT bound to the VK_SHADER_STAGE_TASK_BIT_EXT stage.

If there is no bound graphics pipeline, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, there must be no VkShaderEXT bound to either the VK_SHADER_STAGE_TASK_BIT_EXT stage or the VK_SHADER_STAGE_MESH_BIT_EXT stage.

If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, then all shaders created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag in the same vkCreateShadersEXT call must also be bound.

All bound graphics shader objects must have been created with identical or identically defined push constant ranges.

All bound graphics shader objects must have been created with identical or identically defined arrays of descriptor set layouts.

If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage and the attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable parameter in the last call to vkCmdSetDepthWriteEnable must be VK_FALSE.
If the bound graphics pipeline state includes a fragment shader stage, was created with `VK_DYNAMIC_STATE_STENCIL_WRITE_MASK` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`, and the fragment shader declares the `EarlyFragmentTests` execution mode and uses `OpStencilAttachmentReadEXT`, the `writeMask` parameter in the last call to `vkCmdSetStencilWriteMask` must be 0.

- VUID-vkCmdDrawIndirectByteCountEXT-None-09116
  If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT`, and the format of any color attachment is `VK_FORMAT_E5B9G9R9_UFLOAT_PACK32`, the corresponding element of the `pColorWriteMasks` parameter of `vkCmdSetColorWriteMaskEXT` must either include all of `VK_COLOR_COMPONENT_R_BIT`, `VK_COLOR_COMPONENT_G_BIT`, and `VK_COLOR_COMPONENT_B_BIT`, or none of them.

- VUID-vkCmdDrawIndirectByteCountEXT-maxFragmentDualSrcAttachments-09239
  If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of `Location` for any output attachment statically used in the Fragment Execution Model executed by this command must be less than `maxFragmentDualSrcAttachments`.

- VUID-vkCmdDrawIndirectByteCountEXT-None-04007
  All vertex input bindings accessed via vertex input variables declared in the vertex shader entry point's interface must have either valid or `VK_NULL_HANDLE` buffers bound.

- VUID-vkCmdDrawIndirectByteCountEXT-None-04008
  If the `nullDescriptor` feature is not enabled, all vertex input bindings accessed via vertex input variables declared in the vertex shader entry point's interface must not be `VK_NULL_HANDLE`.

- VUID-vkCmdDrawIndirectByteCountEXT-None-02721
  For a given vertex buffer binding, any attribute data fetched must be entirely contained within the corresponding vertex buffer binding, as described in Vertex Input Description.

- VUID-vkCmdDrawIndirectByteCountEXT-None-07842
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY` dynamic state enabled then `vkCmdSetPrimitiveTopology` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawIndirectByteCountEXT-dynamicPrimitiveTopologyUnrestricted-07500
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY` dynamic state enabled and the `dynamicPrimitiveTopologyUnrestricted` is `VK_FALSE`, then the `primitiveTopology` parameter of `vkCmdSetPrimitiveTopology` must be of the same topology class as the pipeline `VkPipelineInputAssemblyStateCreateInfo::topology` state.

- VUID-vkCmdDrawIndirectByteCountEXT-None-04912
  If the bound graphics pipeline was created with both the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` and `VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT` dynamic states enabled, then `vkCmdSetVertexInputEXT` must have been called in the current command buffer prior to this draw command.
If the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then `vkCmdBindVertexBuffers2EXT` must have been called in the current command buffer prior to this draw command, and the `pStrides` parameter of `vkCmdBindVertexBuffers2EXT` must not be NULL.

If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetPrimitiveTopology` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then `vkCmdSetVertexInputEXT` must have been called in the current command buffer prior to this draw command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then all variables with the `Input` storage class decorated with `Location` in the `Vertex Execution Model OpEntryPoint` must contain a location in `VkVertexInputAttributeDescription2EXT::location`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then the numeric type associated with all `Input` variables of the corresponding `Location` in the `Vertex Execution Model OpEntryPoint` must be the same as `VkVertexInputAttributeDescription2EXT::format`.

If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and `VkVertexInputAttributeDescription2EXT::format` has a 64-bit component, then the scalar width associated with all `Input` variables of the corresponding `Location` in the `Vertex Execution Model OpEntryPoint` must be 64-bit.

If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and the scalar width associated with a `Location` decorated `Input` variable in the `Vertex Execution Model OpEntryPoint` is 64-bit, then the corresponding `VkVertexInputAttributeDescription2EXT::format` must have a 64-bit component.

If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and `VkVertexInputAttributeDescription2EXT::format` has a 64-bit component, then all `Input` variables at the corresponding `Location` in the `Vertex Execution Model OpEntryPoint` must not use components that are not present in the format.

If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then...
vkCmdSetVertexInputEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-None-04875
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT dynamic state enabled then vkCmdSetPatchControlPointsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-None-08883
  If a shader object is bound to the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT stage, then vkCmdSetPatchControlPointsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-None-04879
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE dynamic state enabled then vkCmdSetPrimitiveRestartEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-rasterizerDiscardEnable-08884
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, vkCmdSetPrimitiveRestartEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawIndirectByteCountEXT-stage-06481
  The bound graphics pipeline must not have been created with the VkPipelineShaderStageCreateInfo::stage member of an element of VkGraphicsPipelineCreateInfo::pStages set to VK_SHADER_STAGE_TASK_BIT_EXT or VK_SHADER_STAGE_MESH_BIT_EXT

- VUID-vkCmdDrawIndirectByteCountEXT-None-08885
  There must be no shader object bound to either of the VK_SHADER_STAGE_TASK_BIT_EXT or VK_SHADER_STAGE_MESH_BIT_EXT stages

- VUID-vkCmdDrawIndirectByteCountEXT-transformFeedback-02287
  VkPhysicalDeviceTransformFeedbackFeaturesEXT::transformFeedback must be enabled

- VUID-vkCmdDrawIndirectByteCountEXT-transformFeedbackDraw-02288
  The implementation must support VkPhysicalDeviceTransformFeedbackPropertiesEXT::transformFeedbackDraw

- VUID-vkCmdDrawIndirectByteCountEXT-vertexStride-02289
  vertexStride must be greater than 0 and less than or equal to VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackBufferDataStride

- VUID-vkCmdDrawIndirectByteCountEXT-counterBuffer-04567
  If counterBuffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdDrawIndirectByteCountEXT-counterBuffer-02290
  counterBuffer must have been created with the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT bit set
• VUID-vkCmdDrawIndirectByteCountEXT-counterBufferOffset-04568
  counterBufferOffset must be a multiple of 4
• VUID-vkCmdDrawIndirectByteCountEXT-commandBuffer-02646
  commandBuffer must not be a protected command buffer

Valid Usage (Implicit)

• VUID-vkCmdDrawIndirectByteCountEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle
• VUID-vkCmdDrawIndirectByteCountEXT-counterBuffer-parameter
  counterBuffer must be a valid VkBuffer handle
• VUID-vkCmdDrawIndirectByteCountEXT-commandBuffer-recording
  commandBuffer must be in the recording state
• VUID-vkCmdDrawIndirectByteCountEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations
• VUID-vkCmdDrawIndirectByteCountEXT-renderpass
  This command must only be called inside of a render pass instance
• VUID-vkCmdDrawIndirectByteCountEXT-videocoding
  This command must only be called outside of a video coding scope
• VUID-vkCmdDrawIndirectByteCountEXT-commonparent
  Both of commandBuffer, and counterBuffer must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

• Host access to commandBuffer must be externally synchronized
• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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21.4. Conditional Rendering

Certain rendering commands can be executed conditionally based on a value in buffer memory. These rendering commands are limited to drawing commands, dispatching commands, and clearing attachments with `vkCmdClearAttachments` within a conditional rendering block which is defined by commands `vkCmdBeginConditionalRenderingEXT` and `vkCmdEndConditionalRenderingEXT`. Other rendering commands remain unaffected by conditional rendering.

After beginning conditional rendering, it is considered active within the command buffer it was called until it is ended with `vkCmdEndConditionalRenderingEXT`.

Conditional rendering must begin and end in the same command buffer. When conditional rendering is active, a primary command buffer can execute secondary command buffers if the inheritedConditionalRendering feature is enabled. For a secondary command buffer to be executed while conditional rendering is active in the primary command buffer, it must set the conditionalRenderingEnable flag of `VkCommandBufferInheritanceConditionalRenderingInfoEXT`, as described in the Command Buffer Recording section.

Conditional rendering must also either begin and end inside the same subpass of a render pass instance, or must both begin and end outside of a render pass instance (i.e. contain entire render pass instances).

To begin conditional rendering, call:

```c
// Provided by VK_EXT_conditional_rendering
void vkCmdBeginConditionalRenderingEXT(
    VkCommandBuffer commandBuffer,
    const VkConditionalRenderingBeginInfoEXT* pConditionalRenderingBegin);
```

- `commandBuffer` is the command buffer into which this command will be recorded.
- `pConditionalRenderingBegin` is a pointer to a `VkConditionalRenderingBeginInfoEXT` structure specifying parameters of conditional rendering.

### Valid Usage

- VUID-vkCmdBeginConditionalRenderingEXT-None-01980
  Conditional rendering must not already be active

### Valid Usage (Implicit)

- VUID-vkCmdBeginConditionalRenderingEXT-commandBuffer-parameter
  commandBuffer must be a valid `VkCommandBuffer` handle

- VUID-vkCmdBeginConditionalRenderingEXT-pConditionalRenderingBegin-parameter
  `pConditionalRenderingBegin` must be a valid pointer to a valid
The `VkConditionalRenderingBeginInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_conditional_rendering
typedef struct VkConditionalRenderingBeginInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkBuffer buffer;
    VkDeviceSize offset;
    VkConditionalRenderingFlagsEXT flags;
} VkConditionalRenderingBeginInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `buffer` is a buffer containing the predicate for conditional rendering.
- `offset` is the byte offset into `buffer` where the predicate is located.
- `flags` is a bitmask of `VkConditionalRenderingFlagsEXT` specifying the behavior of conditional rendering.

If the 32-bit value at `offset` in `buffer` memory is zero, then the rendering commands are discarded.
otherwise they are executed as normal. If the value of the predicate in buffer memory changes while conditional rendering is active, the rendering commands may be discarded in an implementation-dependent way. Some implementations may latch the value of the predicate upon beginning conditional rendering while others may read it before every rendering command.

### Valid Usage

- **VUID-VkConditionalRenderingBeginInfoEXT-buffer-01981**
  If buffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object.

- **VUID-VkConditionalRenderingBeginInfoEXT-buffer-01982**
  buffer must have been created with the VK_BUFFER_USAGE_CONDITIONAL_RENDERING_BIT_EXT bit set.

- **VUID-VkConditionalRenderingBeginInfoEXT-offset-01983**
  offset must be less than the size of buffer by at least 32 bits.

- **VUID-VkConditionalRenderingBeginInfoEXT-offset-01984**
  offset must be a multiple of 4.

### Valid Usage (Implicit)

- **VUID-VkConditionalRenderingBeginInfoEXT-sType-sType**
  sType must be VK_STRUCTURE_TYPE_CONDITIONAL_RENDERING_BEGIN_INFO_EXT.

- **VUID-VkConditionalRenderingBeginInfoEXT-pNext-pNext**
  pNext must be NULL.

- **VUID-VkConditionalRenderingBeginInfoEXT-buffer-parameter**
  buffer must be a valid VkBuffer handle.

- **VUID-VkConditionalRenderingBeginInfoEXT-flags-parameter**
  flags must be a valid combination of VkConditionalRenderingFlagBitsEXT values.

Bits which can be set in vkCmdBeginConditionalRenderingEXT::flags, specifying the behavior of conditional rendering, are:

```c
// Provided by VK_EXT_conditional_rendering
typedef enum VkConditionalRenderingFlagBitsEXT {
  VK_CONDITIONAL_RENDERING_INVERTED_BIT_EXT = 0x00000001,
} VkConditionalRenderingFlagBitsEXT;
```

- **VK_CONDITIONAL_RENDERING_INVERTED_BIT_EXT** specifies the condition used to determine whether to discard rendering commands or not. That is, if the 32-bit predicate read from buffer memory at offset is zero, the rendering commands are not discarded, and if non zero, then they are discarded.
```c
// Provided by VK_EXT_conditional_rendering
typedef VkFlags VkConditionalRenderingFlagsEXT;
```

`VkConditionalRenderingFlagsEXT` is a bitmask type for setting a mask of zero or more `VkConditionalRenderingFlagBitsEXT`.

To end conditional rendering, call:

```c
// Provided by VK_EXT_conditional_rendering
void vkCmdEndConditionalRenderingEXT(
    VkCommandBuffer commandBuffer);
```

- `commandBuffer` is the command buffer into which this command will be recorded.

Once ended, conditional rendering becomes inactive.

**Valid Usage**

- VUID-vkCmdEndConditionalRenderingEXT-None-01985
  Conditional rendering **must** be **active**

- VUID-vkCmdEndConditionalRenderingEXT-None-01986
  If conditional rendering was made **active** outside of a render pass instance, it **must** not be ended inside a render pass instance

- VUID-vkCmdEndConditionalRenderingEXT-None-01987
  If conditional rendering was made **active** within a subpass it **must** be ended in the same subpass

**Valid Usage (Implicit)**

- VUID-vkCmdEndConditionalRenderingEXT-commandBuffer-parameter
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- VUID-vkCmdEndConditionalRenderingEXT-commandBuffer-recording
  `commandBuffer` **must** be in the recording state

- VUID-vkCmdEndConditionalRenderingEXT-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics, or compute operations

- VUID-vkCmdEndConditionalRenderingEXT-videocoding
  This command **must** only be called outside of a video coding scope

**Host Synchronization**

- Host access to `commandBuffer` **must** be externally synchronized
Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

### Command Properties

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### 21.5. Programmable Mesh Shading

In this drawing approach, primitives are assembled by the mesh shader stage. Mesh shading operates similarly to dispatching compute as the shaders make use of workgroups.

To record a mesh tasks drawing command, call:

```c
// Provided by VK_NV_mesh_shader
void vkCmdDrawMeshTasksNV(
    VkCommandBuffer commandBuffer,     
    uint32_t taskCount,                
    uint32_t firstTask);               
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `taskCount` is the number of local workgroups to dispatch in the X dimension. Y and Z dimension are implicitly set to one.
- `firstTask` is the X component of the first workgroup ID.

When the command is executed, a global workgroup consisting of `taskCount` local workgroups is assembled.

### Valid Usage

- **VUID-vkCmdDrawMeshTasksNV-magFilter-04553**
  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`.

- **VUID-vkCmdDrawMeshTasksNV-mipmapMode-04770**
  If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`.
If a `VkImageView` is sampled with depth comparison, the image view’s format features must contain `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT`.

If a `VkImageView` is accessed using atomic operations as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT`.

If a `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`.

If the `VK_EXT_filter_cubic` extension is not enabled and any `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, it must not have a `VkImageViewType` of `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`.

If a `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`.

If the `VK_EXT_filter_cubic` extension is not enabled and any `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, it must not have a `VkImageViewType` of `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`.

Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` with a reduction mode of either `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering together with minmax filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

If the `cubicRangeClamp` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must not have a `VkSamplerReductionModeCreateInfo` `reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`.

Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo` `reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have...
VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights equal to VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM

- VUID-vkCmdDrawMeshTasksNV-flags-02696
  Any VkImage created with a VkImageCreateInfo::flags containing VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV sampled as a result of this command must only be sampled using a VkSamplerAddressMode of VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE

- VUID-vkCmdDrawMeshTasksNV-OpTypeImage-07027
  For any VkImageView being written as a storage image where the image format field of the OpTypeImage is Unknown, the view’s format features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

- VUID-vkCmdDrawMeshTasksNV-OpTypeImage-07028
  For any VkImageView being read as a storage image where the image format field of the OpTypeImage is Unknown, the view’s format features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

- VUID-vkCmdDrawMeshTasksNV-OpTypeImage-07029
  For any VkBufferView being written as a storage texel buffer where the image format field of the OpTypeImage is Unknown, the view’s buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

- VUID-vkCmdDrawMeshTasksNV-OpTypeImage-07030
  Any VkBufferView being read as a storage texel buffer where the image format field of the OpTypeImage is Unknown then the view’s buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

- VUID-vkCmdDrawMeshTasksNV-None-08600
  For each set n that is statically used by a bound shader, a descriptor set must have been bound to n at the same pipeline bind point, with a VkPipelineLayout that is compatible for set n, with the VkPipelineLayout or VkDescriptorSetLayout array that was used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMeshTasksNV-None-08601
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMeshTasksNV-maintenance4-08602
  If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMeshTasksNV-None-08114
  Descriptors in each bound descriptor set, specified via vkCmdBindDescriptorSets, must be valid if they are statically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was not created with
VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMeshTasksNV-None-08115
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdBindDescriptorSets, the bound VkPipeline must have been created without VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMeshTasksNV-None-08116
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMeshTasksNV-None-08604
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDrawMeshTasksNV-None-08117
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdSetDescriptorBufferOffsetsEXT, the bound VkPipeline must have been created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMeshTasksNV-None-08119
  If a descriptor is dynamically used with a VkPipeline created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdDrawMeshTasksNV-None-08605
  If a descriptor is dynamically used with a VkShaderEXT created with a VkDescriptorSetLayout that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdDrawMeshTasksNV-None-08606
  If the shaderObject feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command

- VUID-vkCmdDrawMeshTasksNV-None-08607
  If the shaderObject is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and VK_NULL_HANDLE shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDrawMeshTasksNV-None-08608
  If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the VkPipeline object bound to the pipeline bind point used by this command, since that pipeline was bound

- VUID-vkCmdDrawMeshTasksNV-None-08609
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler
must not be used to sample from any VkImage with a VkImageView of the type VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY, VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage.

- **VUID-vkCmdDrawMeshTasksNV-None-08610**
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage.

- **VUID-vkCmdDrawMeshTasksNV-None-08611**
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage.

- **VUID-vkCmdDrawMeshTasksNV-uniformBuffers-06935**
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdDrawMeshTasksNV-None-08612**
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdDrawMeshTasksNV-storageBuffers-06936**
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdDrawMeshTasksNV-None-08613**
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdDrawMeshTasksNV-commandBuffer-02707**
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource.

- **VUID-vkCmdDrawMeshTasksNV-None-06550**

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If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y’C aCr conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions.

- **VUID-vkCmdDrawMeshTasksNV-ConstOffset-06551**
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y’C aCr conversion, that object must not use the ConstOffset and Offset operands.

- **VUID-vkCmdDrawMeshTasksNV-viewType-07752**
  If a VkImageView is accessed as a result of this command, then the image view’s viewType must match the Dim operand of the OpTypeImage as described in Instruction/Sampler/Image View Validation.

- **VUID-vkCmdDrawMeshTasksNV-format-07753**
  If a VkImageView is accessed as a result of this command, then the numeric type of the image view’s format and the Sampled Type operand of the OpTypeImage must match.

- **VUID-vkCmdDrawMeshTasksNV-OpImageWrite-08795**
  If a VkImageView created with a format other than VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the image view’s format.

- **VUID-vkCmdDrawMeshTasksNV-OpImageWrite-08796**
  If a VkImageView created with the format VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have four components.

- **VUID-vkCmdDrawMeshTasksNV-OpImageWrite-04469**
  If a VkBufferView is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the buffer view’s format.

- **VUID-vkCmdDrawMeshTasksNV-SampledType-04470**
  If a VkImageView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64.

- **VUID-vkCmdDrawMeshTasksNV-SampledType-04471**
  If a VkImageView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32.

- **VUID-vkCmdDrawMeshTasksNV-SampledType-04472**
  If a VkBufferView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64.

- **VUID-vkCmdDrawMeshTasksNV-SampledType-04473**
  If a VkBufferView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32.

- **VUID-vkCmdDrawMeshTasksNV-sparseImageInt64Atomics-04474**
  If the sparseImageInt64Atomics feature is not enabled, VkImage objects created with the
VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command.

- VUID-vkCmdDrawMeshTasksNV-sparseImageInt64Atomics-04475
  If the sparseImageInt64Atomics feature is not enabled, VkBuffer objects created with the VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command.

- VUID-vkCmdDrawMeshTasksNV-OpImageWeightedSampleQCOM-06971
  If OpImageWeightedSampleQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM.

- VUID-vkCmdDrawMeshTasksNV-OpImageWeightedSampleQCOM-06972
  If OpImageWeightedSampleQCOM uses a VkImageView as a sample weight image as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM.

- VUID-vkCmdDrawMeshTasksNV-OpImageBoxFilterQCOM-06973
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMATFEATURE_2_BOX_FILTER_SAMPLED_IMAGE_BIT_QCOM.

- VUID-vkCmdDrawMeshTasksNV-OpImageBlockMatchSSDQCOM-06974
  If OpImageBlockMatchSSDQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMATFEATURE_2_BLOCK_MATCHING_SAMPLED_IMAGE_BIT_QCOM.

- VUID-vkCmdDrawMeshTasksNV-OpImageBlockMatchSADQCOM-06975
  If OpImageBlockMatchSADQCOM is used to read from an VkImageView as a result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.

- VUID-vkCmdDrawMeshTasksNV-OpImageWeightedSampleQCOM-06977
  If any command other than OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, OpImageBlockMatchSSDQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this command, then the sampler must have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM.

- VUID-vkCmdDrawMeshTasksNV-OpImageWeightedSampleQCOM-06978
  If any command other than OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, OpImageBlockMatchSSDQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this command, then the sampler must not have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM.

- VUID-vkCmdDrawMeshTasksNV-OpImageBlockMatchWindow-09215
If an `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

- VUID-vkCmdDrawMeshTasksNV-OpImageBlockMatchWindow-09216
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from a `VkImageView` as a result of this command, then the image view’s format must be a single-component format.

- VUID-vkCmdDrawMeshTasksNV-OpImageBlockMatchWindow-09217
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.

- VUID-vkCmdDrawMeshTasksNV-None-07288
  Any shader invocation executed by this command must terminate.

- VUID-vkCmdDrawMeshTasksNV-renderPass-02684
  The current render pass must be compatible with the `renderPass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

- VUID-vkCmdDrawMeshTasksNV-subpass-02685
  The subpass index of the current render pass must be equal to the `subpass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

- VUID-vkCmdDrawMeshTasksNV-None-07748
  If any shader statically accesses an input attachment, a valid descriptor must be bound to the pipeline via a descriptor set.

- VUID-vkCmdDrawMeshTasksNV-OpTypeImage-07468
  If any shader executed by this pipeline accesses an `OpTypeImage` variable with a `Dim` operand of `SubpassData`, it must be decorated with an `InputAttachmentIndex` that corresponds to a valid input attachment in the current subpass.

- VUID-vkCmdDrawMeshTasksNV-None-07469
  Input attachment views accessed in a subpass must be created with the same `VkFormat` as the corresponding subpass definition, and be created with a `VkImageView` that is compatible with the attachment referenced by the subpass’ `pInputAttachments[InputAttachmentIndex]` in the currently bound `VkFramebuffer` as specified by Fragment Input Attachment Compatibility.

- VUID-vkCmdDrawMeshTasksNV-None-06537
  Memory backing image subresources used as attachments in the current render pass must not be written in any way other than as an attachment by this command.

- VUID-vkCmdDrawMeshTasksNV-None-09000
  If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:
  
  - the `VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_COLOR_BIT` and

- there is no currently bound graphics pipeline or
- the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

- **VUID-vkCmdDrawMeshTasksNV-None-09001**
  If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:
  - the `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
  - the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_DEPTH_BIT` and
    - there is no currently bound graphics pipeline or
    - the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

- **VUID-vkCmdDrawMeshTasksNV-None-09002**
  If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:
  - the `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
  - the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_STENCIL_BIT` and
    - there is no currently bound graphics pipeline or
    - the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

- **VUID-vkCmdDrawMeshTasksNV-None-09003**
  If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command

- **VUID-vkCmdDrawMeshTasksNV-None-06539**
  If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command must not write to that image subresource as an attachment

- **VUID-vkCmdDrawMeshTasksNV-None-06886**
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, depth writes must be disabled
If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back writeMask are not zero, and stencil test is enabled, all stencil ops must be VK_STENCIL_OP_KEEP.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT dynamic state enabled then vkCmdSetViewport must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SCISSOR dynamic state enabled then vkCmdSetScissor must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_WIDTH dynamic state enabled then vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetPolygonModeEXT in the current command buffer set polygonMode to VK_POLYGON_MODE_LINE, vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, and the most recent call to vkCmdSetPrimitiveTopology in the current command buffer set primitiveTopology to any line topology, vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command.

If a shader object that outputs line primitives is bound to the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT stage, vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BIAS dynamic state enabled then vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDepthBiasEnable in the current command buffer set depthBiasEnable to VK_TRUE, vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_BLEND_CONSTANTS dynamic state enabled then vkCmdSetBlendConstants must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08621
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetColorBlendEnableEXT in the current command buffer set any element of pColorBlendEnables to VK_TRUE, and the most recent call to vkCmdSetColorBlendEquationEXT in the current command buffer set the same element of pColorBlendEquations to a VkColorBlendEquationEXT structure with any VkBlendFactor member with a value of VK_BLEND_FACTOR_CONSTANT_COLOR, VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR, VK_BLEND_FACTOR_CONSTANT_ALPHA, or VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA, vkCmdSetBlendConstants must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07836
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BOUNDS dynamic state enabled then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08622
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDepthBoundsTestEnable in the current command buffer set depthBoundsTestEnable to VK_TRUE, then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07837
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK dynamic state enabled then vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08623
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07838
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_WRITE_MASK dynamic state enabled then vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08624
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_REFERENCE` dynamic state enabled then `vkCmdSetStencilReference` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilReference` must have been called in the current command buffer prior to this drawing command.

If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to `VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex`.

If the bound graphics pipeline was created with `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` set to `VK_TRUE` and the current subpass has a depth/stencil attachment, then that attachment must have been created with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetSampleLocationsEnableEXT` in the current command buffer set `sampleLocationsEnable` to `VK_TRUE`, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CULL_MODE` dynamic state enabled then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCullMode` must have been called in
the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07841
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08628
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07843
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08629
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07844
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` dynamic state enabled then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08630
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07845
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP` dynamic state enabled then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08631
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthTestEnable` in the current command buffer set `depthTestEnable` to `VK_TRUE`, then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07846
  If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE dynamic state enabled then
vkCmdSetDepthBoundsTestEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08632
  If a shader object is bound to any graphics stage, and the depthBounds feature is enabled, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then the vkCmdSetDepthBoundsTestEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07847
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE dynamic state enabled then
  vkCmdSetStencilTestEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08633
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then the vkCmdSetStencilTestEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08634
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, then
  vkCmdSetStencilOp must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-viewportCount-03417
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT dynamic state enabled, then
  vkCmdSetViewportWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of
  vkCmdSetViewportWithCount must match the VkPipelineViewportStateCreateInfo::viewportCount of the pipeline

- VUID-vkCmdDrawMeshTasksNV-scissorCount-03418
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT dynamic state enabled, but not the
  VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, then
  vkCmdSetScissorWithCount must have been called in the current command buffer prior to this drawing command, and the scissorCount parameter of
  vkCmdSetScissorWithCount must match the VkPipelineViewportStateCreateInfo::viewportCount of the pipeline

- VUID-vkCmdDrawMeshTasksNV-viewportCount-03419
If the bound graphics pipeline state was created with both the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic states enabled, then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- VUID-vkCmdDrawMeshTasksNV-None-08635
  If a shader object is bound to any graphics stage, then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- VUID-vkCmdDrawMeshTasksNV-viewportCount-04137
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportWScalingStateCreateInfoNV`::`viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- VUID-vkCmdDrawMeshTasksNV-viewportCount-04138
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic states enabled, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- VUID-vkCmdDrawMeshTasksNV-None-09232
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then `vkCmdSetViewportWScalingNV` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksNV-None-08636
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- VUID-vkCmdDrawMeshTasksNV-viewportCount-04139
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportShadingRateImageStateCreateInfoNV`::`viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- VUID-vkCmdDrawMeshTasksNV-viewportCount-04140
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic states enabled, then the
viewportCount parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksNV-shadingRateImage-09233**
  If the `shadingRateImage` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoarseSampleOrderNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-shadingRateImage-09234**
  If a shader object is bound to any graphics stage, and the `shadingRateImage` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetShadingRateImageEnableNV` in the current command buffer set `shadingRateImageEnable` to `VK_TRUE`, then `vkCmdSetViewportShadingRatePaletteNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-08637**
  If a shader object is bound to any graphics stage, and the `shadingRateImage` feature is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksNV-VkPipelineViewportCreateInfo-04141**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportSwizzleStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksNV-VkPipelineViewportCreateInfo-04142**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportExclusiveScissorStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline must have been created with `VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksNV-None-07878**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV` dynamic state enabled then `vkCmdSetExclusiveScissorEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-07879**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV` dynamic state enabled then `vkCmdSetExclusiveScissorNV` must have been called in the current command buffer prior to this drawing command.
• **VUID-vkCmdDrawMeshTasksNV-exclusiveScissor-09235**
  If a shader object is bound to any graphics stage, and the `exclusiveScissor` feature is enabled, then `vkCmdSetExclusiveScissorEnableNV` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawMeshTasksNV-None-08638**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetExclusiveScissorEnableNV` in the current command buffer set any element of `pExclusiveScissorEnables` to `VK_TRUE`, then `vkCmdSetExclusiveScissorNV` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawMeshTasksNV-None-04876**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE` dynamic state enabled then `vkCmdSetRasterizerDiscardEnable` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawMeshTasksNV-None-08639**
  If a shader object is bound to any graphics stage, then `vkCmdSetRasterizerDiscardEnable` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawMeshTasksNV-None-04877**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE` dynamic state enabled then `vkCmdSetDepthBiasEnable` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawMeshTasksNV-None-08640**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthBiasEnable` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawMeshTasksNV-logicOp-04878**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LOGIC_OP_EXT` dynamic state enabled then `vkCmdSetLogicOpEXT` must have been called in the current command buffer prior to this drawing command and the `logicOp` must be a valid `VkLogicOp` value.

• **VUID-vkCmdDrawMeshTasksNV-None-08641**
  If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the `logicOp` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEXT` must have been called in the current command buffer prior to this drawing command and the `logicOp` must be a valid `VkLogicOp` value.

• **VUID-vkCmdDrawMeshTasksNV-primitiveFragmentShadingRateWithMultipleViewports-04552**
  If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` must have
been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must be 1

- **VUID-vkCmdDrawMeshTasksNV-primitiveFragmentShadingRateWithMultipleViewports-08642**
  If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, and any shader object bound to a graphics stage writes to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must be 1

- **VUID-vkCmdDrawMeshTasksNV-blendEnable-04727**
  If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view’s `format features` do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the `blendEnable` member of the corresponding element of the `pAttachments` member of `pColorBlendState` must be `VK_FALSE`

- **VUID-vkCmdDrawMeshTasksNV-None-08643**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then for each color attachment in the render pass, if the corresponding image view’s `format features` do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the corresponding member of `pColorBlendEnables` in the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer that affected that attachment index must have been `VK_FALSE`

- **VUID-vkCmdDrawMeshTasksNV-multisampledRenderToSingleSampled-07284**
  If rasterization is not disabled in the bound graphics pipeline, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then `rasterizationSamples` for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments

- **VUID-vkCmdDrawMeshTasksNV-None-08644**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then the most recent call to `vkCmdSetRasterizationSamplesEXT` in the current command buffer must have set `rasterizationSamples` to be the same as the number of samples for the current render pass color and/or depth/stencil attachments

- **VUID-vkCmdDrawMeshTasksNV-None-08876**
  If a shader object is bound to any graphics stage, the current render pass instance must have been begun with `vkCmdBeginRendering`

- **VUID-vkCmdDrawMeshTasksNV-imageView-06172**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepth Attachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must
not write any values to the depth attachment

- VUID-vkCmdDrawMeshTasksNV-imageView-06173
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment

- VUID-vkCmdDrawMeshTasksNV-imageView-06174
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, this command must not write any values to the depth attachment

- VUID-vkCmdDrawMeshTasksNV-imageView-06175
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment

- VUID-vkCmdDrawMeshTasksNV-imageView-06176
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment

- VUID-vkCmdDrawMeshTasksNV-viewMask-06178
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo`::`viewMask` equal to `VkRenderingInfo`::`viewMask`

- VUID-vkCmdDrawMeshTasksNV-colorAttachmentCount-06179
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo`::`colorAttachmentCount` equal to `VkRenderingInfo`::`colorAttachmentCount`

- VUID-vkCmdDrawMeshTasksNV-dynamicRenderingUnusedAttachments-08910
  If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo`::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo`::`pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo`::`pColorAttachmentFormats` used to create the currently bound graphics pipeline

- VUID-vkCmdDrawMeshTasksNV-dynamicRenderingUnusedAttachments-08911
  If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo`::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo`::`pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo`::`pColorAttachmentFormats` used to create the currently bound graphics pipeline
instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline, or the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`

- VUID-vkCmdDrawMeshTasksNV-dynamicRenderingUnusedAttachments-08912
  If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` must have the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`

- VUID-vkCmdDrawMeshTasksNV-None-07749
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08646
  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-attachmentCount-07750
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then the `attachmentCount` parameter of `vkCmdSetColorWriteEnableEXT` must be greater than or equal to the `VkPipelineColorBlendStateCreateInfo::attachmentCount` of the currently bound graphics pipeline

- VUID-vkCmdDrawMeshTasksNV-None-08647
  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `attachmentCount` parameter of most recent call to `vkCmdSetColorWriteEnableEXT` in the current command buffer must be greater than or equal to the number of color attachments in the current render pass instance

- VUID-vkCmdDrawMeshTasksNV-attachmentCount-07751
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEXT` must have been called in the current command buffer for each discard rectangle in `VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount`
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDiscardRectangleEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDiscardRectangleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleModeEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDiscardRectangleEnableEXT` in the current command buffer set `discardRectangleEnable` to `VK_TRUE`, then `vkCmdSetDiscardRectangleModeEXT` must have been called in the current command buffer prior to this drawing command.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo` ::pDepthAttachment->imageView was `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo`::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to `VK_FORMAT_UNDEFINED`.

If current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo` ::pDepthAttachment->imageView was not `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo`::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to the `VkFormat` used to create `VkRenderingInfo` ::pDepthAttachment->imageView.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo`
::pDepthAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo ::pDepthAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED

- **VUID-vkCmdDrawMeshTasksNV-dynamicRenderingUnusedAttachments-08916**
If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo ::pDepthAttachment->imageView was VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to VK_FORMAT_UNDEFINED

- **VUID-vkCmdDrawMeshTasksNV-dynamicRenderingUnusedAttachments-08917**
If current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo ::pStencilAttachment->imageView was not VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline must be equal to the VkFormat used to create VkRenderingInfo ::pStencilAttachment->imageView

- **VUID-vkCmdDrawMeshTasksNV-dynamicRenderingUnusedAttachments-08918**
If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo ::pStencilAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo ::pStencilAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED

- **VUID-vkCmdDrawMeshTasksNV-imageView-06183**
If the current render pass instance was begun with vkCmdBeginRendering and VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

- **VUID-vkCmdDrawMeshTasksNV-imageView-06184**
If the current render pass instance was begun with vkCmdBeginRendering and VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT

- **VUID-vkCmdDrawMeshTasksNV-colorAttachmentCount-06185**
If the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a sample count equal to the corresponding element of the pColorAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline

- **VUID-vkCmdDrawMeshTasksNV-pDepthAttachment-06186**
If the current render pass instance was begun with vkCmdBeginRendering, the currently
bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`

- **VUID-vkCmdDrawMeshTasksNV-pStencilAttachment-06187**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`

- **VUID-vkCmdDrawMeshTasksNV-multisampledRenderToSingleSampled-07285**
  If the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the value of `rasterizationSamples` for the currently bound graphics pipeline

- **VUID-vkCmdDrawMeshTasksNV-multisampledRenderToSingleSampled-07286**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`

- **VUID-vkCmdDrawMeshTasksNV-multisampledRenderToSingleSampled-07287**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`

- **VUID-vkCmdDrawMeshTasksNV-pNext-07935**
  If this command has been called inside a render pass instance started with `vkCmdBeginRendering`, and the `pNext` chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to `VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples`
If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline must have been created with a `VkGraphicsPipelineCreateInfo::renderPass` equal to `VK_NULL_HANDLE`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the `VkRenderingInfo::pColorAttachments->imageView` was not `VK_NULL_HANDLE`, then the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, stencil test is enabled and the `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

If the `primitivesGeneratedQueryWithRasterizerDiscard` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, rasterization discard must not be enabled.

If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, the bound graphics pipeline must not have been created with a non-zero value in `VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream`.

If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command.
buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksNV-None-08650**
  If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-07621**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-08651**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-07622**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` dynamic state enabled then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-08652**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-07623**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` dynamic state enabled then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-08653**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-07624**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-alphaToCoverageEnable-08919**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled, and `alphaToCoverageEnable` was `VK_TRUE` in the last call to
vkCmdSetAlphaToCoverageEnableEXT, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0

- VUID-vkCmdDrawMeshTasksNV-None-08654
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-alphaToCoverageEnable-08920
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetAlphaToCoverageEnableEXT in the current command buffer set alphaToCoverageEnable to VK_TRUE, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0

- VUID-vkCmdDrawMeshTasksNV-None-07625
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT dynamic state enabled then vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08655
  If the alphaToOne feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07626
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT dynamic state enabled then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08656
  If the logicOp feature is enabled, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07627
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08657
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07628
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-08658**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` for any attachment set that attachment's value in `pColorBlendEnables` to `VK_TRUE`, then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-07629**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-08659**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorWriteMaskEXT` for any attachment set that attachment's value in `pColorWriteEnables` to `VK_TRUE`, then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-07630**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` dynamic state enabled then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-08660**
  If the `geometryStreams` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_GEOMETRY_BIT` stage, then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-07631**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-08661**
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksNV-None-07632**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.
command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08662
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetConservativeRasterizationModeEXT` in the current command buffer set `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`, then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07633
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08663
  If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07634
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08664
  If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07635
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07636
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT` dynamic state enabled then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08665
  If the `VK_EXT_provoking_vertex` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the
`VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic state enabled then
`vkCmdSetLineRasterizationModeEXT` must have been called in the current command
buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any
graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current
command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then
`vkCmdSetLineRasterizationModeEXT` must have been called in the current command
buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the
vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current
command buffer set `primitiveTopology` to any line topology, then
`vkCmdSetLineRasterizationModeEXT` must have been called in the current command
buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs
line primitives is bound to the tessellation evaluation or geometry stage, then
`vkCmdSetLineRasterizationModeEXT` must have been called in the current command
buffer prior to this drawing command.

If the bound graphics pipeline state was created with the
`VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` dynamic state enabled then
`vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer
prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any
graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current
command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then
`vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer
prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the
vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current
command buffer set `primitiveTopology` to any line topology, then
`vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer
prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs
line primitives is bound to the tessellation evaluation or geometry stage, then
`vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer
prior to this drawing command.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_EXT` dynamic state enabled then `vkCmdSetLineStippleEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08672
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetLineStippleEnableEXT` in the current command buffer set `stippledLineEnable` to `VK_TRUE`, then `vkCmdSetLineStippleEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07639
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT` dynamic state enabled then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08673
  If the `depthClipControl` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07640
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV` dynamic state enabled then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08674
  If the `VK_NV_clip_space_w_scaling` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07641
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08675
  If the `VK_NV_viewport_swizzle` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07642
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08676
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCoverageToColorEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07643
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV dynamic state enabled then vkCmdSetCoverageToColorLocationNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08677
  If the VK_NV_fragment_coverage_to_color extension is enabled, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetCoverageToColorEnableNV in the current command buffer set coverageToColorEnable to VK_TRUE, then vkCmdSetCoverageToColorLocationNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07644
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV dynamic state enabled then vkCmdSetCoverageModulationModeNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08678
  If the VK_NV_fragment_coverage_to_color extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetCoverageModulationModeNV in the current command buffer set coverageModulationMode to any value other than VK_COVERAGE_MODULATION_MODE_NONE_NV, then vkCmdSetCoverageModulationTableEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08679
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV dynamic state enabled then vkCmdSetCoverageModulationTableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-07645
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV dynamic state enabled then vkCmdSetCoverageModulationTableEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08674
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCoverageModulationTableEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08670
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV dynamic state enabled then vkCmdSetCoverageModulationTableEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08674
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set coverageModulationMode to any value other than VK_COVERAGE_MODULATION_MODE_NONE_NV, then vkCmdSetCoverageModulationTableEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08670
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV dynamic state enabled then vkCmdSetCoverageModulationTableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksNV-None-08680
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the
current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationTableEnableNV` in the current command buffer set `coverageModulationTableEnable` to `VK_TRUE`, then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksNV-None-07647**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV` dynamic state enabled then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksNV-pipelineFragmentShadingRate-09238**
  If the `pipelineFragmentShadingRate` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFragmentShadingRateKHR` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksNV-None-08681**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV` dynamic state enabled then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksNV-None-08682**
  If the `representativeFragmentTest` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksNV-None-07649**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksNV-None-08683**
  If the `coverageReductionMode` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksNV-pColorBlendEnables-07470**
  If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT state enabled and the last call to 
vkCmdSetColorBlendEnableEXT set pColorBlendEnables for any attachment to VK_TRUE, 
then for those attachments in the subpass the corresponding image view’s format features 
**must** contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT

- VUID-vkCmdDrawMeshTasksNV-rasterizationSamples-07471
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, and the current subpass does 
  not use any color and/or depth/stencil attachments, then the **rasterizationSamples** in the 
  last call to vkCmdSetRasterizationSamplesEXT **must** follow the rules for a zero-attachment subpass

- VUID-vkCmdDrawMeshTasksNV-samples-07472
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_SAMPLE_MASK_EXT state enabled and the 
  VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state disabled, then the **samples** parameter in 
  the last call to vkCmdSetSampleMaskEXT **must** be greater or equal to the 
  VkPipelineMultisampleStateCreateInfo::rasterizationSamples parameter used to create 
  the bound graphics pipeline

- VUID-vkCmdDrawMeshTasksNV-samples-07473
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_SAMPLE_MASK_EXT state and 
  VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT states enabled, then the **samples** parameter in the last call to 
  vkCmdSetSampleMaskEXT **must** be greater or equal to the **rasterizationSamples** parameter in the last call to 
  vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawMeshTasksNV-rasterizationSamples-07474
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, and neither the 
  VK_AMD_mixed_attachment_samples nor the VK_NV_framebuffer_mixed_samples extensions are 
  enabled, then the **rasterizationSamples** in the last call to 
  vkCmdSetRasterizationSamplesEXT **must** be the same as the current subpass color and/or 
  depth/stencil attachments

- VUID-vkCmdDrawMeshTasksNV-None-09211
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, or a shader object is bound to 
  any graphics stage, and the current render pass instance includes a 
  VkMultisampledRenderToSingleSampledInfoEXT structure with 
  multisampledRenderToSingleSampledEnable equal to VK_TRUE, then the **rasterizationSamples** 
  in the last call to vkCmdSetRasterizationSamplesEXT **must** be the same as the 
  rasterizationSamples member of that structure

- VUID-vkCmdDrawMeshTasksNV-firstAttachment-07476
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then 
  vkCmdSetColorBlendEnableEXT **must** have been called in the current command buffer 
  prior to this drawing command, and the attachments specified by the firstAttachment and 
  attachmentCount parameters of vkCmdSetColorBlendEnableEXT calls **must** specify an enable 
  for all active color attachments in the current subpass
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEquationEXT` calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorWriteMaskEXT` calls must specify the color write mask for all active color attachments in the current subpass.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendAdvancedEXT` calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` and `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic states enabled and the last calls to `vkCmdSetColorBlendEnableEXT` and `vkCmdSetColorBlendAdvancedEXT` have enabled advanced blending, then the number of active color attachments in the current subpass must not exceed `advancedBlendMaxColorAttachments`.

If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, and the bound graphics pipeline was created with `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` state enabled, the last call to `vkCmdSetRasterizationStreamEXT` must have set the `rasterizationStream` to zero.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with.

If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, then the
cSampleLocationsPerPixel member of pSampleLocationsInfo in the last call to
vkCmdSetSampleLocationsEXT must equal the rasterizationSamples parameter of the last
call to vkCmdSetRasterizationSamplesEXT

• VUID-vkCmdDrawMeshTasksNV-sampleLocationsEnable-07484
  If the bound graphics pipeline was created with the
  VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and sampleLocationsEnable
  was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, and the current
  subpass has a depth/stencil attachment, then that attachment must have been created
  with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set

• VUID-vkCmdDrawMeshTasksNV-sampleLocationsEnable-07485
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the
  VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable
  was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the
  sampleLocationsInfo.sampleLocationGridSize.width in the last call to
  vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT
  ::sampleLocationGridSize.width as returned by
  vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling
  rasterizationSamples

• VUID-vkCmdDrawMeshTasksNV-sampleLocationsEnable-07486
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the
  VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable
  was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the
  sampleLocationsInfo.sampleLocationGridSize.height in the last call to
  vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT
  ::sampleLocationGridSize.height as returned by
  vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling
  rasterizationSamples

• VUID-vkCmdDrawMeshTasksNV-sampleLocationsEnable-07487
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable
  was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, the fragment shader
  code must not statically use the extended instruction InterpolateAtSample

• VUID-vkCmdDrawMeshTasksNV-sampleLocationsEnable-07936
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the
  VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable
  member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the
  bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state
  enabled, then, sampleLocationsInfo.sampleLocationGridSize.width must evenly divide
  VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by
  vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the
  value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.height` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.height` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling the value of `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationsPerPixel` must equal `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageModulationTableEnableNV` set `coverageModulationTableEnable` to `VK_TRUE`, then the `coverageModulationTableCount` parameter in the last call to `vkCmdSetCoverageModulationTableNV` must equal the current `rasterizationSamples` divided by the number of color samples in the current subpass.

If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current `rasterizationSamples` must be the same as the sample count of the depth/stencil attachment.

If this `VK_NV_coverage_reduction_mode` extension is enabled, the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, the current coverage reduction mode `coverageReductionMode`, then the current `rasterizationSamples`, and the sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by `vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV`.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled, then the bound graphics pipeline **must** have been created with `VkPipelineViewportSwizzleStateCreateInfoNV`::`viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportSwizzleNV` **must** be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if the current subpass has any color attachments and `rasterizationSamples` of the last call to `vkCmdSetRasterizationSamplesEXT` is greater than the number of color samples, then the pipeline `sampleShadingEnable` **must** be `VK_FALSE`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT`, then the `stippledRectangularLines` feature **must** be enabled.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT`, then the `stippledBresenhamLines` feature **must** be enabled.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT`, then the `stippledSmoothLines` feature **must** be enabled.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT`, then the `stippledRectangularLines` feature **must** be enabled.
be enabled and \texttt{VkPhysicalDeviceLimits::strictLines} must be \texttt{VK_TRUE}

- **VUID-vkCmdDrawMeshTasksNV-conservativePointAndLineRasterization-07499**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT} dynamic state enabled, \texttt{conservativePointAndLineRasterization} is not supported, and the effective primitive topology output by the last pre-rasterization shader stage is a line or point, then \texttt{vkCmdSetConservativeRasterizationModeEXT} must be \texttt{VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT}

- **VUID-vkCmdDrawMeshTasksNV-stage-07073**
  If the currently bound pipeline was created with the \texttt{VkPipelineShaderStageCreateInfo::stage} member of an element of \texttt{VkGraphicsPipelineCreateInfo::pStages} set to \texttt{VK_SHADER_STAGE_VERTEX_BIT}, \texttt{VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT}, \texttt{VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT} or \texttt{VK_SHADER_STAGE_GEOMETRY_BIT}, then \texttt{Mesh Shader Queries} must not be active

- **VUID-vkCmdDrawMeshTasksNV-None-08877**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT} dynamic state \texttt{vkCmdSetAttachmentFeedbackLoopEnableEXT} must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksNV-None-07850**
  If dynamic state was inherited from \texttt{VkCommandBufferInheritanceViewportScissorInfoNV}, it must be set in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksNV-None-08684**
  If there is no bound graphics pipeline, \texttt{vkCmdBindShadersEXT} must have been called in the current command buffer with \texttt{pStages} with an element of \texttt{VK_SHADER_STAGE_VERTEX_BIT}

- **VUID-vkCmdDrawMeshTasksNV-None-08685**
  If there is no bound graphics pipeline, and the \texttt{tessellationShader} feature is enabled, \texttt{vkCmdBindShadersEXT} must have been called in the current command buffer with \texttt{pStages} with an element of \texttt{VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT}

- **VUID-vkCmdDrawMeshTasksNV-None-08686**
  If there is no bound graphics pipeline, and the \texttt{tessellationShader} feature is enabled, \texttt{vkCmdBindShadersEXT} must have been called in the current command buffer with \texttt{pStages} with an element of \texttt{VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT}

- **VUID-vkCmdDrawMeshTasksNV-None-08687**
  If there is no bound graphics pipeline, and the \texttt{geometryShader} feature is enabled, \texttt{vkCmdBindShadersEXT} must have been called in the current command buffer with \texttt{pStages} with an element of \texttt{VK_SHADER_STAGE_GEOMETRY_BIT}

- **VUID-vkCmdDrawMeshTasksNV-None-08688**
  If there is no bound graphics pipeline, \texttt{vkCmdBindShadersEXT} must have been called in the current command buffer with \texttt{pStages} with an element of \texttt{VK_SHADER_STAGE_FRAGMENT_BIT}

- **VUID-vkCmdDrawMeshTasksNV-None-08689**
  If there is no bound graphics pipeline, and the \texttt{taskShader} feature is enabled,
`vkCmdBindShadersEXT` **must** have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TASK_BIT_EXT`

- **VUID-vkCmdDrawMeshTasksNV-None-08690**
  If there is no bound graphics pipeline, and the `meshShader` feature is enabled, `vkCmdBindShadersEXT` **must** have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_MESH_BIT_EXT`

- **VUID-vkCmdDrawMeshTasksNV-None-08693**
  If there is no bound graphics pipeline, and at least one of the `taskShader` and `meshShader` features is enabled, one of the `VK_SHADER_STAGE_VERTEX_BIT` or `VK_SHADER_STAGE_MESH_BIT_EXT` stages **must** have a valid `VkShaderEXT` bound, and the other **must** have no `VkShaderEXT` bound

- **VUID-vkCmdDrawMeshTasksNV-None-08694**
  If there is no bound graphics pipeline, and both the `taskShader` and `meshShader` features are enabled, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that `VkShaderEXT` was created without the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, a valid `VkShaderEXT` **must** be bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage

- **VUID-vkCmdDrawMeshTasksNV-None-08695**
  If there is no bound graphics pipeline, and both the `taskShader` and `meshShader` features are enabled, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that `VkShaderEXT` was created with the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, there **must** be no `VkShaderEXT` bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage

- **VUID-vkCmdDrawMeshTasksNV-None-08696**
  If there is no bound graphics pipeline, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, there **must** be no `VkShaderEXT` bound to either the `VK_SHADER_STAGE_TASK_BIT_EXT` stage or the `VK_SHADER_STAGE_MESH_BIT_EXT` stage

- **VUID-vkCmdDrawMeshTasksNV-None-08698**
  If any graphics shader is bound which was created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag, then all shaders created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag in the same `vkCreateShadersEXT` call **must** also be bound

- **VUID-vkCmdDrawMeshTasksNV-None-08699**
  If any graphics shader is bound which was created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag, any stages in between stages whose shaders which did not create a shader with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag as part of the same `vkCreateShadersEXT` call **must** not have any `VkShaderEXT` bound

- **VUID-vkCmdDrawMeshTasksNV-None-08878**
  All bound graphics shader objects **must** have been created with identical or identically defined push constant ranges

- **VUID-vkCmdDrawMeshTasksNV-None-08879**
  All bound graphics shader objects **must** have been created with identical or identically defined arrays of descriptor set layouts

- **VUID-vkCmdDrawMeshTasksNV-None-08880**
  If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage and the
attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksNV-pDynamicStates-08715
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable parameter in the last call to vkCmdSetDepthWriteEnable must be VK_FALSE

• VUID-vkCmdDrawMeshTasksNV-pDynamicStates-08716
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_STENCIL_WRITE_MASK set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpStencilAttachmentReadEXT, the writeMask parameter in the last call to vkCmdSetStencilWriteMask must be 0

• VUID-vkCmdDrawMeshTasksNV-None-09116
  If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT, and the format of any color attachment is VK_FORMAT_E5B9G9R9_UFLOAT_PACK32, the corresponding element of the pColorWriteMasks parameter of vkCmdSetColorWriteMaskEXT must either include all of VK_COLOR_COMPONENT_R_BIT, VK_COLOR_COMPONENT_G_BIT, and VK_COLOR_COMPONENT_B_BIT, or none of them

• VUID-vkCmdDrawMeshTasksNV-maxFragmentDualSrcAttachments-09239
  If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of Location for any output attachment statically used in the Fragment Execution Model executed by this command must be less than maxFragmentDualSrcAttachments

• VUID-vkCmdDrawMeshTasksNV-stage-06480
  The bound graphics pipeline must not have been created with the VkPipelineShaderStageCreateInfo::stage member of an element of VkGraphicsPipelineCreateInfo::pStages set to VK_SHADER_STAGE_VERTEX_BIT, VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT, VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT

• VUID-vkCmdDrawMeshTasksNV-None-07074
  Transform Feedback Queries must not be active

• VUID-vkCmdDrawMeshTasksNV-None-07075
  Primitives Generated Queries must not be active

• VUID-vkCmdDrawMeshTasksNV-pipelineStatistics-07076
  The pipelineStatistics member used to create any active Pipeline Statistics Query must not contain VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_VERTICES_BIT, VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_PRIMITIVES_BIT, VK_QUERY_PIPELINE_STATISTIC_VERTEX_SHADER_INVOCATIONS_BIT, VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_INVOCATIONS_BIT,
VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_PRIMITIVES_BIT, VK_QUERY_PIPELINE_STATISTIC_CLIPPING_INVOCATIONS_BIT, VK_QUERY_PIPELINE_STATISTIC_CLIPPING_PRIMITIVES_BIT, VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_CONTROL_SHADER_PATCHES_BIT, or VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_EVALUATION_SHADER_INVOCATIONS_BIT

- VUID-vkCmdDrawMeshTasksNV-taskCount-02119
taskCount must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesNV::maxDrawMeshTasksCount

- VUID-vkCmdDrawMeshTasksNV-MeshNV-07080
The current pipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS must contain a shader stage using the MeshNV Execution Model

Valid Usage (Implicit)

- VUID-vkCmdDrawMeshTasksNV-commandBuffer-parameter
commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdDrawMeshTasksNV-commandBuffer-recording
commandBuffer must be in the recording state

- VUID-vkCmdDrawMeshTasksNV-commandBuffer-cmdpool
The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdDrawMeshTasksNV-renderpass
This command must only be called inside of a render pass instance

- VUID-vkCmdDrawMeshTasksNV-videocoding
This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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To record an indirect mesh tasks drawing command, call:
void vkCmdDrawMeshTasksIndirectNV(
    VkCommandBuffer commandBuffer,
    VkBuffer buffer,
    VkDeviceSize offset,
    uint32_t drawCount,
    uint32_t stride);

• **commandBuffer** is the command buffer into which the command is recorded.
• **buffer** is the buffer containing draw parameters.
• **offset** is the byte offset into buffer where parameters begin.
• **drawCount** is the number of draws to execute, and **can** be zero.
• **stride** is the byte stride between successive sets of draw parameters.

*vkCmdDrawMeshTasksIndirectNV* behaves similarly to *vkCmdDrawMeshTasksNV* except that the parameters are read by the device from a buffer during execution. *drawCount* draws are executed by the command, with parameters taken from *buffer* starting at *offset* and increasing by *stride* bytes for each successive draw. The parameters of each draw are encoded in an array of *VkDrawMeshTasksIndirectCommandNV* structures. If *drawCount* is less than or equal to one, *stride* is ignored.

### Valid Usage

- **VUID-vkCmdDrawMeshTasksIndirectNV-magFilter-04553**
  If a *VkSampler* created with **magFilter** or **minFilter** equal to **VK_FILTER_LINEAR** and **compareEnable** equal to **VK_FALSE** is used to sample a *VkImageView* as a result of this command, then the image view's format features must contain **VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT**

- **VUID-vkCmdDrawMeshTasksIndirectNV-mipmapMode-04770**
  If a *VkSampler* created with **mipmapMode** equal to **VK_SAMPLER_MIPMAP_MODE_LINEAR** and **compareEnable** equal to **VK_FALSE** is used to sample a *VkImageView* as a result of this command, then the image view's format features must contain **VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT**

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-06479**
  If a *VkImageView* is sampled with depth comparison, the image view's format features must contain **VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT**

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-02691**
  If a *VkImageView* is accessed using atomic operations as a result of this command, then the image view's format features must contain **VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT**

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-07888**
  If a **VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER** descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain **VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT**
If a `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`.

If the `VK_EXT_filter_cubic` extension is not enabled and any `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, it must not have a `VkImageViewType` of `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`.

Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` with a reduction mode of either `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering together with minmax filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

If the `cubicRangeClamp` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must not have a `VkSamplerReductionModeCreateInfo` `reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`.

Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo` `reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`.

Any `VkImage` created with a `VkImageCreateInfo` `flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

For any `VkImageView` being written as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view’s format features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

For any `VkImageView` being written as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view’s format features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.
For any `VkImageView` being read as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view's `format features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`

- VUID-vkCmdDrawMeshTasksIndirectNV-OpTypeImage-07029
  For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view's `buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`

- VUID-vkCmdDrawMeshTasksIndirectNV-OpTypeImage-07030
  Any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown` then the view's `buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08600
  For each set `n` that is statically used by a bound shader, a descriptor set must have been bound to `n` at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set `n`, with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08601
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMeshTasksIndirectNV-maintenance4-08602
  If the `maintenance4` feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08114
  Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, must be valid if they are statically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was not created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08115
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` must have been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08116
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08604
Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08117**
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdSetDescriptorBufferOffsetsEXT`, the bound `VkPipeline` must have been created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08119**
  If a descriptor is dynamically used with a `VkPipeline` created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory must be resident.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08605**
  If a descriptor is dynamically used with a `VkShaderEXT` created with a `VkDescriptorSetLayout` that was created with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory must be resident.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08606**
  If the `shaderObject` feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08607**
  If the `shaderObject` is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and `VK_NULL_HANDLE` shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08608**
  If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the `VkPipeline` object bound to the pipeline bind point used by this command, since that pipeline was bound.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08609**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler must not be used to sample from any `VkImage` with a `VkImageView` of the type `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, `VK_IMAGE_VIEW_TYPE_1D_ARRAY`, `VK_IMAGE_VIEW_TYPE_2D_ARRAY` or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`, in any shader stage.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08610**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V `OpImageSample*` or `OpImageSparseSample*` instructions with `ImplicitLod`, `Dref` or `Proj` in their name, in any shader stage.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08611**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any
VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage.

- VUID-vkCmdDrawMeshTasksIndirectNV-uniformBuffers-06935
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08612
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- VUID-vkCmdDrawMeshTasksIndirectNV-storageBuffers-06936
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08613
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- VUID-vkCmdDrawMeshTasksIndirectNV-commandBuffer-02707
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource.

- VUID-vkCmdDrawMeshTasksIndirectNV-None-06550
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y’C₉₉₉₉ conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions.

- VUID-vkCmdDrawMeshTasksIndirectNV-ConstOffset-06551
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y’C₉₉₉₉ conversion, that object must not use the ConstOffset and Offset operands.

- VUID-vkCmdDrawMeshTasksIndirectNV-viewType-07752
  If a VkImageView is accessed as a result of this command, then the image view’s viewType must match the Dim operand of the OpTypeImage as described in Instruction/Sampler/Image View Validation.
If a `VkImageView` is accessed as a result of this command, then the numeric type of the image view's format and the Sampled Type operand of the `OpTypeImage` must match.

If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the image view's format.

If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the Type of the Texel operand of that instruction must have four components.

If a `VkImageView` is accessed using `OpImageWrite` as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the buffer view's format.

If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the SampledType of the `OpTypeImage` operand of that instruction must have a Width of 64.

If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the `OpTypeImage` operand of that instruction must have a Width of 32.

If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the SampledType of the `OpTypeImage` operand of that instruction must have a Width of 64.

If a `VkBufferView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the `OpTypeImage` operand of that instruction must have a Width of 32.

If the `sparseImageInt64Atomics` feature is not enabled, `VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a SampledType with a Width of 64 by this command.

If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a SampledType with a Width of 64 by this command.

If `OpImageWeightedSampleQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`.
- VUID-vkCmdDrawMeshTasksIndirectNV-OpImageWeightedSampleQCOM-06972
  If `OpImageWeightedSampleQCOM` uses a `VkImageView` as a sample weight image as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`

- VUID-vkCmdDrawMeshTasksIndirectNV-OpImageBoxFilterQCOM-06973
  If `OpImageBoxFilterQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM`

- VUID-vkCmdDrawMeshTasksIndirectNV-OpImageBlockMatchSSDQCOM-06974
  If `OpImageBlockMatchSSDQCOM` is used to read from an `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`

- VUID-vkCmdDrawMeshTasksIndirectNV-OpImageBlockMatchSADQCOM-06975
  If `OpImageBlockMatchSADQCOM` is used to read from an `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`

- VUID-vkCmdDrawMeshTasksIndirectNV-OpImageWeightedSampleQCOM-06976
  If `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`

- VUID-vkCmdDrawMeshTasksIndirectNV-OpImageWeightedSampleQCOM-06977
  If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must not have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`

- VUID-vkCmdDrawMeshTasksIndirectNV-OpImageBlockMatchWindow-09215
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format must be a single-component format.

- VUID-vkCmdDrawMeshTasksIndirectNV-OpImageBlockMatchWindow-09216
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format must be a single-component format.

- VUID-vkCmdDrawMeshTasksIndirectNV-OpImageBlockMatchWindow-09217
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.
integer texel coordinate validation

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07288
  Any shader invocation executed by this command must terminate

- VUID-vkCmdDrawMeshTasksIndirectNV-renderPass-02684
  The current render pass must be compatible with the renderPass member of the VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdDrawMeshTasksIndirectNV-subpass-02685
  The subpass index of the current render pass must be equal to the subpass member of the VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07748
  If any shader statically accesses an input attachment, a valid descriptor must be bound to the pipeline via a descriptor set

- VUID-vkCmdDrawMeshTasksIndirectNV-OpTypeImage-07468
  If any shader executed by this pipeline accesses an OpTypeImage variable with a Dim operand of SubpassData, it must be decorated with an InputAttachmentIndex that corresponds to a valid input attachment in the current subpass

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07469
  Input attachment views accessed in a subpass must be created with the same VkFormat as the corresponding subpass definition, and be created with a VkImageView that is compatible with the attachment referenced by the subpass’ pInputAttachments [InputAttachmentIndex] in the currently bound VkFramebuffer as specified by Fragment Input Attachment Compatibility

- VUID-vkCmdDrawMeshTasksIndirectNV-None-06537
  Memory backing image subresources used as attachments in the current render pass must not be written in any way other than as an attachment by this command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-09000
  If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:
  - the VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
  - the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_COLOR_BIT and
    - there is no currently bound graphics pipeline or
    - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-09001
  If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:
• the \texttt{VK\_PIPELINE\_CREATE\_DEPTH\_STENCIL\_ATTACHMENT\_FEEDBACK\_LOOP\_BIT\_EXT} is set on the currently bound pipeline or
• the last call to \texttt{vkCmdSetAttachmentFeedbackLoopEnableEXT} included \texttt{VK\_IMAGE\_ASPECT\_DEPTH\_BIT} and
  ▪ there is no currently bound graphics pipeline or
  ▪ the currently bound graphics pipeline was created with \texttt{VK\_DYNAMIC\_STATE\_ATTACHMENT\_FEEDBACK\_LOOP\_ENABLE\_EXT} it must not be accessed in any way other than as an attachment by this command

VUID-vkCmdDrawMeshTasksIndirectNV-None-09002
If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the \texttt{VK\_IMAGE\_LAYOUT\_ATTACHMENT\_FEEDBACK\_LOOP\_OPTIMAL\_EXT} image layout, and either:
• the \texttt{VK\_PIPELINE\_CREATE\_DEPTH\_STENCIL\_ATTACHMENT\_FEEDBACK\_LOOP\_BIT\_EXT} is set on the currently bound pipeline or
• the last call to \texttt{vkCmdSetAttachmentFeedbackLoopEnableEXT} included \texttt{VK\_IMAGE\_ASPECT\_STENCIL\_BIT} and
  ▪ there is no currently bound graphics pipeline or
  ▪ the currently bound graphics pipeline was created with \texttt{VK\_DYNAMIC\_STATE\_ATTACHMENT\_FEEDBACK\_LOOP\_ENABLE\_EXT} it must not be accessed in any way other than as an attachment by this command

VUID-vkCmdDrawMeshTasksIndirectNV-None-09003
If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command

VUID-vkCmdDrawMeshTasksIndirectNV-None-06539
If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command must not write to that image subresource as an attachment

VUID-vkCmdDrawMeshTasksIndirectNV-None-06886
If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, depth writes must be disabled

VUID-vkCmdDrawMeshTasksIndirectNV-None-06887
If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back writeMask are not zero, and stencil test is enabled, all stencil ops must be \texttt{VK\_STENCIL\_OP\_KEEP}

VUID-vkCmdDrawMeshTasksIndirectNV-None-07831
If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_VIEWPORT} dynamic state enabled then \texttt{vkCmdSetViewport} must have been called in the current command buffer prior to this drawing command

VUID-vkCmdDrawMeshTasksIndirectNV-None-07832
If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_SCISSOR} dynamic state enabled then \texttt{vkCmdSetScissor} must have been called in the current
command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-07833
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_WIDTH` dynamic state enabled then `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-08617
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-08618
  If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-08619
  If a shader object that outputs line primitives is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` or `VK_SHADER_STAGE_GEOMETRY_BIT` stage, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-07834
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BIAS` dynamic state enabled then `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-08620
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthBiasEnable` in the current command buffer set `depthBiasEnable` to `VK_TRUE`, `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-07835
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_BLEND_CONSTANTS` dynamic state enabled then `vkCmdSetBlendConstants` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-08621
  If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer set any element of `pColorBlendEnables` to `VK_TRUE`, and the most recent call to `vkCmdSetColorBlendEquationEXT` in the current command buffer set the same element of `pColorBlendEquations` to a `VkColorBlendEquationEXT` structure with any `VkBlendFactor` member with a value of `VK_BLEND_FACTOR_CONSTANT_COLOR`, `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR`, `VK_BLEND_FACTOR_CONSTANT_ALPHA`, or
**VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA**, **vkCmdSetBlendConstants** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-07836**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_DEPTH_BOUNDS** dynamic state enabled then **vkCmdSetDepthBounds** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08622**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set `rasterizerDiscardEnable` to **VK_FALSE**, and the most recent call to **vkCmdSetDepthBoundsTestEnable** in the current command buffer set `depthBoundsTestEnable` to **VK_TRUE**, then **vkCmdSetDepthBounds** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-07837**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK** dynamic state enabled then **vkCmdSetStencilCompareMask** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08623**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetStencilTestEnable** in the current command buffer set `stencilTestEnable` to **VK_TRUE**, **vkCmdSetStencilCompareMask** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-07838**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_STENCIL_WRITE_MASK** dynamic state enabled then **vkCmdSetStencilWriteMask** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08624**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetStencilTestEnable** in the current command buffer set `stencilTestEnable` to **VK_TRUE**, **vkCmdSetStencilWriteMask** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-07839**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_STENCIL_REFERENCE** dynamic state enabled then **vkCmdSetStencilReference** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08625**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetStencilTestEnable** in the current command buffer set `stencilTestEnable` to **VK_TRUE**, **vkCmdSetStencilReference** must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-maxMultiviewInstanceIndex-02688**
If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex

- VUID-vkCmdDrawMeshTasksIndirectNV-sampleLocationsEnable-02689
  If the bound graphics pipeline was created with VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable set to VK_TRUE and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set

- VUID-vkCmdDrawMeshTasksIndirectNV-None-06666
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT dynamic state enabled then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08626
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetSampleLocationsEnableEXT in the current command buffer set sampleLocationsEnable to VK_TRUE, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-sampleLocationsPerPixel-07934
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples member of the VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07840
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CULL_MODE dynamic state enabled then vkCmdSetCullMode must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08627
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCullMode must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07841
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_FRONT_FACE dynamic state enabled then vkCmdSetFrontFace must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08628
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetFrontFace must have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` dynamic state enabled then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP` dynamic state enabled then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthTestEnable` in the current command buffer set `depthTestEnable` to `VK_TRUE`, then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the `depthBounds` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE` dynamic state enabled then
vkCmdSetStencilTestEnable **must** have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08633**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetStencilTestEnable` **must** have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-07848**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_OP` dynamic state enabled then `vkCmdSetStencilOp` **must** have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08634**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, then `vkCmdSetStencilOp` **must** have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-viewportCount-03417**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, then `vkCmdSetViewportWithCount` **must** have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` **must** match the `VkPipelineViewportStateCreateInfo`:::scissorCount of the pipeline.

- **VUID-vkCmdDrawMeshTasksIndirectNV-scissorCount-03418**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, then `vkCmdSetScissorWithCount` **must** have been called in the current command buffer prior to this drawing command, and the `scissorCount` parameter of `vkCmdSetScissorWithCount` **must** match the `VkPipelineViewportStateCreateInfo`:::viewportCount of the pipeline.

- **VUID-vkCmdDrawMeshTasksIndirectNV-viewportCount-03419**
  If the bound graphics pipeline state was created with both the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic states enabled then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` **must** have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` **must** match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08635**
  If a shader object is bound to any graphics stage, then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` **must** have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` **must** match the `scissorCount` parameter of
vkCmdSetScissorWithCount

- VUID-vkCmdDrawMeshTasksIndirectNV-viewportCount-04137
  If the bound graphics pipeline state was created with the 
  `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the 
  `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic state enabled, then the bound graphics 
  pipeline must have been created with `VkPipelineViewportWScalingStateCreateInfoNV` 
  `viewportCount` greater or equal to the `viewportCount` parameter in the last call to 
  `vkCmdSetViewportWithCount`

- VUID-vkCmdDrawMeshTasksIndirectNV-viewportCount-04138
  If the bound graphics pipeline state was created with the 
  `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` 
  dynamic states enabled then the `viewportCount` parameter in the last call to 
  `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` 
  parameter in the last call to `vkCmdSetViewportWithCount`

- VUID-vkCmdDrawMeshTasksIndirectNV-viewportCount-04139
  If the bound graphics pipeline state was created with the 
  `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` 
  dynamic states enabled then the `viewportCount` parameter in the last call to 
  `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` 
  parameter in the last call to `vkCmdSetViewportWithCount`

- VUID-vkCmdDrawMeshTasksIndirectNV-shadingRateImage-09233
  If the shadingRateImage feature is enabled, and the most recent call to 
  `vkCmdSetRasterizerDiscardEnable` in the current command buffer set 
  rasterizerDiscardEnable to `VK_FALSE`, then `vkCmdSetCoarseSampleOrderNV` must have 
  been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-shadingRateImage-09234
  If a shader object is bound to any graphics stage, and the shadingRateImage feature is 
  enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in
the current command buffer set rasterizerDiscardEnable to \textsc{vk\_false}, and the most recent call to 
\texttt{vkCmdSetShadingRateImageEnableNV} in the current command buffer set shadingRateImageEnable to \textsc{vk\_true}, then \texttt{vkCmdSetViewportShadingRatePaletteNV} must have been called in the current command buffer prior to this drawing command

- \textbf{VUID-vkCmdDrawMeshTasksIndirectNV-None-08637}
  If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, then the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportShadingRatePaletteNV} must be greater than or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- \textbf{VUID-vkCmdDrawMeshTasksIndirectNV-VkPipelineViewportCreateInfo-04141}
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_VIEWPORT\_WITH\_COUNT} dynamic state enabled and a \texttt{VkPipelineViewportSwizzleStateCreateInfoNV} structure chained from \texttt{VkPipelineViewportStateCreateInfo}, then the bound graphics pipeline must have been created with \texttt{VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount} greater or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- \textbf{VUID-vkCmdDrawMeshTasksIndirectNV-VkPipelineViewportCreateInfo-04142}
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_VIEWPORT\_WITH\_COUNT} dynamic state enabled and a \texttt{VkPipelineViewportExclusiveScissorStateCreateInfoNV} structure chained from \texttt{VkPipelineViewportStateCreateInfo}, then the bound graphics pipeline must have been created with \texttt{VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount} greater or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- \textbf{VUID-vkCmdDrawMeshTasksIndirectNV-None-07878}
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_EXCLUSIVE\_SCISSOR\_ENABLE\_NV} dynamic state enabled then \texttt{vkCmdSetExclusiveScissorEnableNV} must have been called in the current command buffer prior to this drawing command

- \textbf{VUID-vkCmdDrawMeshTasksIndirectNV-None-07879}
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_EXCLUSIVE\_SCISSOR\_NV} dynamic state enabled then \texttt{vkCmdSetExclusiveScissorNV} must have been called in the current command buffer prior to this drawing command

- \textbf{VUID-vkCmdDrawMeshTasksIndirectNV-exclusiveScissor-09235}
  If a shader object is bound to any graphics stage, and the exclusiveScissor feature is enabled, then \texttt{vkCmdSetExclusiveScissorEnableNV} must have been called in the current command buffer prior to this drawing command

- \textbf{VUID-vkCmdDrawMeshTasksIndirectNV-None-08638}
  If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetExclusiveScissorEnableNV} in the current command buffer set any element of \texttt{pExclusiveScissorEnables} to \textsc{vk\_true}, then \texttt{vkCmdSetExclusiveScissorNV} must have been called in the current command buffer prior to this drawing command

- \textbf{VUID-vkCmdDrawMeshTasksIndirectNV-None-04876}
  If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE
dynamic state enabled then
vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08639
  If a shader object is bound to any graphics stage, then vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-04877
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE dynamic state enabled then vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08640
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-logicOp-04878
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_EXT dynamic state enabled then vkCmdSetLogicOpEXT must have been called in the current command buffer prior to this drawing command and the logicOp must be a valid VkLogicOp value

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08641
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the logicOp feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEXT must have been called in the current command buffer prior to this drawing command and the logicOp must be a valid VkLogicOp value

- VUID-vkCmdDrawMeshTasksIndirectNV-primitiveFragmentShadingRateWithMultipleViewports-04552
  If the primitiveFragmentShadingRateWithMultipleViewports limit is not supported, the bound graphics pipeline was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the PrimitiveShadingRateKHR built-in, then vkCmdSetViewportWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must be 1

- VUID-vkCmdDrawMeshTasksIndirectNV-primitiveFragmentShadingRateWithMultipleViewports-08642
  If the primitiveFragmentShadingRateWithMultipleViewports limit is not supported, and any shader object bound to a graphics stage writes to the PrimitiveShadingRateKHR built-in, then vkCmdSetViewportWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must be 1

- VUID-vkCmdDrawMeshTasksIndirectNV-blendEnable-04727
  If rasterization is not disabled in the bound graphics pipeline, then for each color
attachment in the subpass, if the corresponding image view’s `format features` do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the `blendEnable` member of the corresponding element of the `pAttachments` member of `pColorBlendState` must be `VK_FALSE`.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08643**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then for each color attachment in the render pass, if the corresponding image view’s `format features` do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the corresponding member of `pColorBlendEnables` in the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer that affected that attachment index must have been `VK_FALSE`.

- **VUID-vkCmdDrawMeshTasksIndirectNV-multisampledRenderToSingleSampled-07284**
  If rasterization is not disabled in the bound graphics pipeline, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then `rasterizationSamples` for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08876**
  If a shader object is bound to any graphics stage, the current render pass instance must have been begun with `vkCmdBeginRendering`.

- **VUID-vkCmdDrawMeshTasksIndirectNV-imageView-06172**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment.

- **VUID-vkCmdDrawMeshTasksIndirectNV-imageView-06173**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment.

- **VUID-vkCmdDrawMeshTasksIndirectNV-imageView-06174**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, this command must not write any values to the depth attachment.
If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo::viewMask` equal to `VkRenderingInfo::viewMask`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo::colorAttachmentCount` equal to `VkRenderingInfo::colorAttachmentCount`.

If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with an `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline.

If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with an `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`.

If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with an `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`.
::pColorAttachments array with a imageView equal to VK_NULL_HANDLE must have the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the currently bound pipeline equal to VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07749
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT dynamic state enabled then vkCmdSetColorWriteEnableEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08646
  If the colorWriteEnable feature is enabled on the device, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorWriteEnableEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksIndirectNV-attachmentCount-07750
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT dynamic state enabled then the attachmentCount parameter of vkCmdSetColorWriteEnableEXT must be greater than or equal to the VkPipelineColorBlendStateCreateInfo::attachmentCount of the currently bound graphics pipeline.

- VUID-vkCmdDrawMeshTasksIndirectNV-attachmentCount-08647
  If the colorWriteEnable feature is enabled on the device, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then the attachmentCount parameter of most recent call to vkCmdSetColorWriteEnableEXT in the current command buffer must be greater than or equal to the number of color attachments in the current render pass instance.

- VUID-vkCmdDrawMeshTasksIndirectNV-attachmentCount-07751
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT dynamic state enabled then vkCmdSetDiscardRectangleEXT must have been called in the current command buffer prior to this drawing command for each discard rectangle in VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount.

- VUID-vkCmdDrawMeshTasksIndirectNV-attachmentCount-08648
  If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDiscardRectangleEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksIndirectNV-attachmentCount-07880
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT dynamic state enabled then vkCmdSetDiscardRectangleEnableEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksIndirectNV-rasterizerDiscardEnable-09236
  If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDiscardRectangleEXT must have been called in the current command buffer prior to this drawing command.
If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDiscardRectangleEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-07881**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08649**
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDiscardRectangleEnableEXT` in the current command buffer set `discardRectangleEnable` to `VK_TRUE`, then `vkCmdSetDiscardRectangleModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-dynamicRenderingUnusedAttachments-08913**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline must be equal to `VK_FORMAT_UNDEFINED`.

- **VUID-vkCmdDrawMeshTasksIndirectNV-dynamicRenderingUnusedAttachments-08914**
  If current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline must be equal to the `VkFormat` used to create `VkRenderingInfo::pDepthAttachment->imageView`.

- **VUID-vkCmdDrawMeshTasksIndirectNV-dynamicRenderingUnusedAttachments-08915**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo::pDepthAttachment->imageView`, the value of the format must be `VK_FORMAT_UNDEFINED`.

- **VUID-vkCmdDrawMeshTasksIndirectNV-dynamicRenderingUnusedAttachments-08916**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to `VK_FORMAT_UNDEFINED`.

- **VUID-vkCmdDrawMeshTasksIndirectNV-dynamicRenderingUnusedAttachments-08917**
  If current render pass instance was begun with `vkCmdBeginRendering`, the
If the current render pass instance was begun with vkCmdBeginRendering and
VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView was not
VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with
VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

If the current render pass instance was begun with vkCmdBeginRendering and
VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView was not
VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with
VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT

If the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD
or VkAttachmentSampleCountInfoNV structure, and the current render pass instance was
begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount
parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments
array with a imageView not equal to VK_NULL_HANDLE must have been created with a
sample count equal to the corresponding element of the pColorAttachmentSamples member
of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to
create the currently bound graphics pipeline

If the current render pass instance was begun with vkCmdBeginRendering, the currently
bound pipeline was created with a VkAttachmentSampleCountInfoAMD or
VkAttachmentSampleCountInfoNV structure, and VkRenderingInfo::pDepthAttachment->imageView was not
VK_NULL_HANDLE, the value of the depthStencilAttachmentSamples member of
VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline must be equal to the sample count
used to create VkRenderingInfo::pDepthAttachment->imageView

If the current render pass instance was begun with vkCmdBeginRendering, the currently
bound pipeline was created with a VkAttachmentSampleCountInfoAMD or
VkAttachmentSampleCountInfoNV structure, and VkRenderingInfo::pStencilAttachment->imageView was not
VK_NULL_HANDLE, the value of the depthStencilAttachmentSamples member of
VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline must be equal to the sample count
used to create VkRenderingInfo::pStencilAttachment->imageView

If the current render pass instance was begun with vkCmdBeginRendering and
VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView was not
VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with
VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

If the current render pass instance was begun with vkCmdBeginRendering and
VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView was not
VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with
VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT

If the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD
or VkAttachmentSampleCountInfoNV structure, and the current render pass instance was
begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount
parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments
array with a imageView not equal to VK_NULL_HANDLE must have been created with a
sample count equal to the corresponding element of the pColorAttachmentSamples member
of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to
create the currently bound graphics pipeline

If the current render pass instance was begun with vkCmdBeginRendering, the currently
bound pipeline was created with a VkAttachmentSampleCountInfoAMD or
VkAttachmentSampleCountInfoNV structure, and VkRenderingInfo::pDepthAttachment->imageView was not
VK_NULL_HANDLE, the value of the depthStencilAttachmentSamples member of
VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline must be equal to the sample count
used to create VkRenderingInfo::pDepthAttachment->imageView

If the current render pass instance was begun with vkCmdBeginRendering, the currently
bound pipeline was created with a VkAttachmentSampleCountInfoAMD or
VkAttachmentSampleCountInfoNV structure, and VkRenderingInfo::pStencilAttachment->imageView was not
VK_NULL_HANDLE, the value of the depthStencilAttachmentSamples member of
VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline must be equal to the sample count
used to create VkRenderingInfo::pStencilAttachment->imageView
used to create the currently bound graphics pipeline must be equal to the sample count used to create VkRenderingInfo::pStencilAttachment->imageView

- VUID-vkCmdDrawMeshTasksIndirectNV-multisampledRenderToSingleSampled-07285
  If the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled feature is not enabled, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a sample count equal to the value of rasterizationSamples for the currently bound graphics pipeline

- VUID-vkCmdDrawMeshTasksIndirectNV-multisampledRenderToSingleSampled-07286
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of rasterizationSamples for the currently bound graphics pipeline must be equal to the sample count used to create VkRenderingInfo::pDepthAttachment->imageView

- VUID-vkCmdDrawMeshTasksIndirectNV-multisampledRenderToSingleSampled-07287
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled feature is not enabled, and VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, the value of rasterizationSamples for the currently bound graphics pipeline must be equal to the sample count used to create VkRenderingInfo::pStencilAttachment->imageView

- VUID-vkCmdDrawMeshTasksIndirectNV-pNext-07935
  If this command has been called inside a render pass instance started with vkCmdBeginRendering, and the pNext chain of VkRenderingInfo includes a VkMultisampledRenderToSingleSampledInfoEXT structure with multisampledRenderToSingleSampledEnable equal to VK_TRUE, then the value of rasterizationSamples for the currently bound graphics pipeline must be equal to VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples

- VUID-vkCmdDrawMeshTasksIndirectNV-renderPass-06198
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline must have been created with a VkGraphicsPipelineCreateInfo::renderPass equal to VK_NULL_HANDLE

- VUID-vkCmdDrawMeshTasksIndirectNV-pColorAttachments-08963
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the VkRenderingInfo::pColorAttachments->imageView was not VK_NULL_HANDLE, then the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the pipeline must not be VK_FORMAT_UNDEFINED
• VUID-vkCmdDrawMeshTasksIndirectNV-pDepthAttachment-08964
If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

• VUID-vkCmdDrawMeshTasksIndirectNV-pStencilAttachment-08965
If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, stencil test is enabled and the `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

• VUID-vkCmdDrawMeshTasksIndirectNV-primitivesGeneratedQueryWithRasterizerDiscard-06708
If the `primitivesGeneratedQueryWithRasterizerDiscard` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, rasterization discard must not be enabled.

• VUID-vkCmdDrawMeshTasksIndirectNV-primitivesGeneratedQueryWithNonZeroStreams-06709
If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, the bound graphics pipeline must not have been created with a non-zero value in `VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream`.

• VUID-vkCmdDrawMeshTasksIndirectNV-None-07619
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT` dynamic state enabled then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectNV-None-07620
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectNV-None-09237
If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectNV-None-08650
If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectNV-None-07621
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then
\texttt{vkCmdSetPolygonModeEXT} must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08651**
  If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetPolygonModeEXT} must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-07622**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT} dynamic state enabled then \texttt{vkCmdSetRasterizationSamplesEXT} must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08652**
  If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetRasterizationSamplesEXT} must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-07623**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_SAMPLE_MASK_EXT} dynamic state enabled then \texttt{vkCmdSetSampleMaskEXT} must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08653**
  If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetSampleMaskEXT} must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-07624**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT} dynamic state enabled then \texttt{vkCmdSetAlphaToCoverageEnableEXT} must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-alphaToCoverageEnable-08919**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT} dynamic state enabled, and \texttt{alphaToCoverageEnable} was \texttt{VK_TRUE} in the last call to \texttt{vkCmdSetAlphaToCoverageEnableEXT}, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-08654**
  If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetAlphaToCoverageEnableEXT} must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectNV-alphaToCoverageEnable-08920**
  If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetAlphaToCoverageEnableEXT in the current command buffer set alphaToCoverageEnable to VK_TRUE, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0

• VUID-vkCmdDrawMeshTasksIndirectNV-None-07625
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT dynamic state enabled then vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-08655
  If the alphaToOne feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-07626
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT dynamic state enabled then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-08656
  If the logicOp feature is enabled, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-07627
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-08657
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetColorBlendEnableEXT for any attachment set that attachment's value in pColorBlendEnables to VK_TRUE, then vkCmdSetColorBlendEquationEXT must have been
• VUID-vkCmdDrawMeshTasksIndirectNV-None-07629
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then
  `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-08659
  If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent
  call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
  `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteMaskEXT` must have been
  called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-07630
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` dynamic state enabled then
  `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-08660
  If the `geometryStreams` feature is enabled, and a shader object is bound to the
  `VK_SHADER_STAGE_GEOMETRY_BIT` stage, then `vkCmdSetRasterizationStreamEXT` must have
  been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-07631
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled then
  `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current
  command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-08661
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is
  bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable`
  in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetConservativeRasterizationModeEXT`
  must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-07632
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then
  `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current
  command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectNV-None-08662
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is
  bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable`
  in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to
  `vkCmdSetConservativeRasterizationModeEXT` in the current command buffer set
  `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`,
  then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the
  current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT` dynamic state enabled then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_provoking_vertex` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.
If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` dynamic state enabled then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` dynamic state enabled then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.
vkCmdSetDepthClipNegativeOneToOneEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08673
  If the `depthClipControl` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07640
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV` dynamic state enabled then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08674
  If the `VK_NV_clip_space_w_scaling` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07641
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08675
  If the `VK_NV_viewport_swizzle` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07642
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08676
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07643
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` dynamic state enabled then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08677
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set
coverageToColorEnable to VK_TRUE, then vkCmdSetCoverageToColorLocationNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07644
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV dynamic state enabled then vkCmdSetCoverageModulationModeNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08678
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCoverageModulationModeNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07645
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV dynamic state enabled then vkCmdSetCoverageModulationTableEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08679
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetCoverageModulationModeNV in the current command buffer set coverageModulationMode to any value other than VK_COVERAGE_MODULATION_MODE_NONE_NV, then vkCmdSetCoverageModulationTableEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07646
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV dynamic state enabled then vkCmdSetShadingRateImageEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08680
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetCoverageModulationTableEnableNV in the current command buffer set coverageModulationTableEnable to VK_TRUE, then vkCmdSetCoverageModulationTableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07647
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV dynamic state enabled then vkCmdSetShadingRateImageEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-pipelineFragmentShadingRate-09238
  If the pipelineFragmentShadingRate feature is enabled, and a shader object is bound to the
VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to 
vkCmdSetRasterizerDiscardEnable in the current command buffer set 
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetFragmentShadingRateKHR must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08681
  If the shadingRateImage feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetFragmentShadingRateImageEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07648
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV dynamic state enabled then 
vkCmdSetRepresentativeFragmentTestEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08682
  If the representativeFragmentTest feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then 
vkCmdSetRepresentativeFragmentTestEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-07649
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV dynamic state enabled then 
vkCmdSetCoverageReductionModeNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08683
  If the coverageReductionMode feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then 
vkCmdSetCoverageReductionModeNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectNV-pColorBlendEnables-07470
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT state enabled and the last call to 
vkCmdSetColorBlendEnableEXT set pColorBlendEnables for any attachment to VK_TRUE, 
then for those attachments in the subpass the corresponding image view's format features must contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT

- VUID-vkCmdDrawMeshTasksIndirectNV-rasterizationSamples-07471
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the rasterizationSamples in the last call to 
vkCmdSetRasterizationSamplesEXT must follow the rules for a zero-attachment subpass

- VUID-vkCmdDrawMeshTasksIndirectNV-samples-07472
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `VkPipelineMultisampleStateCreateInfo::rasterizationSamples` parameter used to create the bound graphics pipeline.

- **VUID-vkCmdDrawMeshTasksIndirectNV-samples-07473**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawMeshTasksIndirectNV-rasterizationSamples-07474**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and neither the `VK_AMD_mixed_attachment_samples` nor the `VK_NV_framebuffer_mixed_samples` extensions are enabled, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-09211**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the `rasterizationSamples` member of that structure.

- **VUID-vkCmdDrawMeshTasksIndirectNV-firstAttachment-07476**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEnableEXT` calls must specify an enable for all active color attachments in the current subpass.

- **VUID-vkCmdDrawMeshTasksIndirectNV-firstAttachment-07477**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEquationEXT` calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled.

- **VUID-vkCmdDrawMeshTasksIndirectNV-firstAttachment-07478**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then
vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorWriteMaskEXT calls must specify the color write mask for all active color attachments in the current subpass.

- VUID-vkCmdDrawMeshTasksIndirectNV-firstAttachment-07479
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT dynamic state enabled then vkCmdSetColorBlendAdvancedEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendAdvancedEXT calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled.

- VUID-vkCmdDrawMeshTasksIndirectNV-advancedBlendMaxColorAttachments-07480
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT and VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic states enabled and the last calls to vkCmdSetColorBlendEnableEXT and vkCmdSetColorBlendAdvancedEXT have enabled advanced blending, then the number of active color attachments in the current subpass must not exceed advancedBlendMaxColorAttachments.

- VUID-vkCmdDrawMeshTasksIndirectNV-primitivesGeneratedQueryWithNonZeroStreams-07481
  If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, and the bound graphics pipeline was created with VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT state enabled, the last call to vkCmdSetRasterizationStreamEXT must have set the rasterizationStream to zero.

- VUID-vkCmdDrawMeshTasksIndirectNV-sampleLocationsPerPixel-07482
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state disabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples member of the VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with.

- VUID-vkCmdDrawMeshTasksIndirectNV-sampleLocationsEnable-07484
  If the bound graphics pipeline was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, and the current subpass has a depth/stencil attachment, then that attachment must have been created.
with the \texttt{VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT} bit set

- **VUID-vkCmdDrawMeshTasksIndirectNV-sampleLocationsEnable-07485**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT} state enabled and the \texttt{VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT} state enabled, and if \texttt{sampleLocationsEnable} was \texttt{VK_TRUE} in the last call to \texttt{vkCmdSetSampleLocationsEnableEXT}, then the \texttt{sampleLocationsInfo.sampleLocationGridSize.width} in the last call to \texttt{vkCmdSetSampleLocationsEXT} must evenly divide \texttt{VkMultisamplePropertiesEXT::sampleLocationGridSize.width} as returned by \texttt{vkGetPhysicalDeviceMultisamplePropertiesEXT} with a \texttt{samples} parameter equaling \texttt{rasterizationSamples}

- **VUID-vkCmdDrawMeshTasksIndirectNV-sampleLocationsEnable-07486**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT} state enabled and the \texttt{VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT} state enabled, and if \texttt{sampleLocationsEnable} was \texttt{VK_TRUE} in the last call to \texttt{vkCmdSetSampleLocationsEnableEXT}, then the \texttt{sampleLocationsInfo.sampleLocationGridSize.height} in the last call to \texttt{vkCmdSetSampleLocationsEXT} must evenly divide \texttt{VkMultisamplePropertiesEXT::sampleLocationGridSize.height} as returned by \texttt{vkGetPhysicalDeviceMultisamplePropertiesEXT} with a \texttt{samples} parameter equaling \texttt{rasterizationSamples}

- **VUID-vkCmdDrawMeshTasksIndirectNV-sampleLocationsEnable-07487**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT} state disabled and the \texttt{VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT} state enabled, the \texttt{sampleLocationsEnable} member of a \texttt{VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable} in the bound graphics pipeline is \texttt{VK_TRUE} or \texttt{VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT} state enabled, then, \texttt{sampleLocationsInfo.sampleLocationGridSize.width} must evenly divide \texttt{VkMultisamplePropertiesEXT::sampleLocationGridSize.width} as returned by \texttt{vkGetPhysicalDeviceMultisamplePropertiesEXT} with a \texttt{samples} parameter equaling the value of \texttt{rasterizationSamples} in the last call to \texttt{vkCmdSetRasterizationSamplesEXT}

- **VUID-vkCmdDrawMeshTasksIndirectNV-sampleLocationsEnable-07937**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT} state disabled and the \texttt{VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT} state enabled, the \texttt{sampleLocationsEnable} member of a \texttt{VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable} in the bound graphics pipeline is \texttt{VK_TRUE} or \texttt{VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT} state enabled, then, \texttt{sampleLocationsInfo.sampleLocationGridSize.height} must evenly divide \texttt{VkMultisamplePropertiesEXT::sampleLocationGridSize.height} as returned by \texttt{vkGetPhysicalDeviceMultisamplePropertiesEXT} with a \texttt{samples} parameter equaling the value of \texttt{rasterizationSamples} in the last call to \texttt{vkCmdSetRasterizationSamplesEXT}
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationsPerPixel must equal rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT.

If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV state enabled and the last call to vkCmdSetCoverageModulationTableEnableNV set coverageModulationTableEnable to VK_TRUE, then the coverageModulationTableCount parameter in the last call to vkCmdSetCoverageModulationTableNV must equal the current rasterizationSamples divided by the number of color samples in the current subpass.

If the VK_NV_framebuffer_mixed_samples extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current rasterizationSamples must be the same as the sample count of the depth/stencil attachment.

If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV state enabled and the last call to vkCmdSetCoverageToColorEnableNV set the coverageToColorEnable to VK_TRUE, then the current subpass must have a color attachment at the location selected by the last call to vkCmdSetCoverageToColorLocationNV coverageToColorLocation, with a VkFormat of VK_FORMAT_R8_UINT, VK_FORMAT_R8_SINT, VK_FORMAT_R16_UINT, VK_FORMAT_R16_SINT, VK_FORMAT_R32_UINT, or VK_FORMAT_R32_SINT.

If this VK_NV_coverage_reduction_mode extension is enabled, the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV and VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT states enabled, the current coverage reduction mode coverageReductionMode, then the current rasterizationSamples, and the sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV.

If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic state enabled, then the bound graphics pipeline must have been created with VkPipelineViewportSwizzleStateCreateInfoNV viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount.

If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic states enabled then the viewportCount parameter in the last call to vkCmdSetViewportWithCountSwizzleNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount.

- VUID-vkCmdDrawMeshTasksIndirectNV-rasterizationSamples-07494
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and if the current subpass has any color attachments and rasterizationSamples of the last call to vkCmdSetRasterizationSamplesEXT is greater than the number of color samples, then the pipeline sampleShadingEnable must be VK_FALSE.

- VUID-vkCmdDrawMeshTasksIndirectNV-stippledLineEnable-07495
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT, then the stippledRectangularLines feature must be enabled.

- VUID-vkCmdDrawMeshTasksIndirectNV-stippledLineEnable-07496
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT, then the stippledBresenhamLines feature must be enabled.

- VUID-vkCmdDrawMeshTasksIndirectNV-stippledLineEnable-07497
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT, then the stippledSmoothLines feature must be enabled.

- VUID-vkCmdDrawMeshTasksIndirectNV-stippledLineEnable-07498
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT, then the stippledRectangularLines feature must be enabled and VkPhysicalDeviceLimits::strictLines must be VK_TRUE.

- VUID-vkCmdDrawMeshTasksIndirectNV-conservativePointAndLineRasterization-07499
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT dynamic state enabled, conservativePointAndLineRasterization is not supported, and the effective primitive topology output by the last pre-rasterization shader stage is a line or point, then the conservativeRasterizationMode set by the last call to vkCmdSetConservativeRasterizationModeEXT must be VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT.
If the currently bound pipeline was created with the `VkPipelineShaderStageCreateInfo` `::stage` member of an element of `VkGraphicsPipelineCreateInfo::pStages` set to `VK_SHADER_STAGE_VERTEX_BIT`, `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`, `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` or `VK_SHADER_STAGE_GEOMETRY_BIT`, then Mesh Shader Queries must not be active.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` dynamic state `vkCmdSetAttachmentFeedbackLoopEnableEXT` must have been called in the current command buffer prior to this drawing command.

If dynamic state was inherited from `VkCommandBufferInheritanceViewportScissorInfoNV`, it must be set in the current command buffer prior to this drawing command.

If there is no bound graphics pipeline, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_VERTEX_BIT`.

If there is no bound graphics pipeline, and the tessellationShader feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`.

If there is no bound graphics pipeline, and the tessellationShader feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`.

If there is no bound graphics pipeline, and the geometryShader feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_GEOMETRY_BIT`.

If there is no bound graphics pipeline, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_FRAGMENT_BIT`.

If there is no bound graphics pipeline, and the taskShader feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TASK_BIT_EXT`.

If there is no bound graphics pipeline, and the meshShader feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_MESH_BIT_EXT`.

If there is no bound graphics pipeline, and at least one of the taskShader and meshShader features is enabled, one of the `VK_SHADER_STAGE_VERTEX_BIT` or
VK_SHADER_STAGE_MESH_BIT_EXT stages **must** have a valid VkShaderEXT bound, and the other **must** have no VkShaderEXT bound.

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08694
  If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound the to the VK_SHADER_STAGE_MESH_BIT_EXT stage, and that VkShaderEXT was created without the VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT flag, a valid VkShaderEXT **must** be bound to the VK_SHADER_STAGE_TASK_BIT_EXT stage.

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08695
  If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound the to the VK_SHADER_STAGE_MESH_BIT_EXT stage, and that VkShaderEXT was created with the VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT flag, there **must** be no VkShaderEXT bound to the VK_SHADER_STAGE_TASK_BIT_EXT stage.

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08696
  If there is no bound graphics pipeline, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, there **must** be no VkShaderEXT bound to either the VK_SHADER_STAGE_TASK_BIT_EXT stage or the VK_SHADER_STAGE_MESH_BIT_EXT stage.

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08698
  If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, then all shaders created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag in the same vkCreateShadersEXT call **must** also be bound.

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08699
  If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, any stages in between stages whose shaders which did not create a shader with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag as part of the same vkCreateShadersEXT call **must** not have any VkShaderEXT bound.

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08878
  All bound graphics shader objects **must** have been created with identical or identically defined push constant ranges.

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08879
  All bound graphics shader objects **must** have been created with identical or identically defined arrays of descriptor set layouts.

- VUID-vkCmdDrawMeshTasksIndirectNV-None-08880
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage and the attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE vkCmdSetAttachmentFeedbackLoopEnableEXT **must** have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksIndirectNV-pDynamicStates-08715
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable parameter in the last call...
to `vkCmdSetDepthWriteEnable` **must** be `VK_FALSE`

- **VUID-vkCmdDrawMeshTasksIndirectNV-pDynamicStates-08716**
  If the bound graphics pipeline state includes a fragment shader stage, was created with `VkPipelineDynamicStateCreateInfo::pDynamicStates` set, and the fragment shader declares the `EarlyFragmentTests` execution mode and uses `OpStencilAttachmentReadEXT`, the `writeMask` parameter in the last call to `vkCmdSetStencilWriteMask` **must** be `0`

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-09116**
  If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` and the format of any color attachment is `VK_FORMAT_E5B9G9R9_UFLOAT_PACK32`, the corresponding element of the `pColorWriteMasks` parameter of `vkCmdSetColorWriteMaskEXT` **must** either include all of `VK_COLOR_COMPONENT_R_BIT`, `VK_COLOR_COMPONENT_G_BIT`, and `VK_COLOR_COMPONENT_B_BIT`, or none of them

- **VUID-vkCmdDrawMeshTasksIndirectNV-maxFragmentDualSrcAttachments-09239**
  If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of `Location` for any output attachment statically used in the Fragment Execution Model executed by this command **must** be less than `maxFragmentDualSrcAttachments`

- **VUID-vkCmdDrawMeshTasksIndirectNV-stage-06480**
  The bound graphics pipeline **must** not have been created with the `VkPipelineShaderStageCreateInfo::stage` member of an element of `VkGraphicsPipelineCreateInfo::pStages` set to `VK_SHADER_STAGE_VERTEX_BIT`, `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`, `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` or `VK_SHADER_STAGE_GEOMETRY_BIT`

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-07074**
  Transform Feedback Queries **must** not be active

- **VUID-vkCmdDrawMeshTasksIndirectNV-None-07075**
  Primitives Generated Queries **must** not be active

- **VUID-vkCmdDrawMeshTasksIndirectNV-pipelineStatistics-07076**
  The `pipelineStatistics` member used to create any active Pipeline Statistics Query **must** not contain `VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_VERTICES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_PRIMITIVES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_VERTEX_SHADER_INVOCATIONS_BIT`, `VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_INVOCATIONS_BIT`, `VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_PRIMITIVES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_CLIPPING_INVOCATIONS_BIT`, `VK_QUERY_PIPELINE_STATISTIC_CLIPPING_PRIMITIVES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_CONTROL_SHADER_PATCHES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_EVALUATION_SHADER_INVOCATIONS_BIT`

- **VUID-vkCmdDrawMeshTasksIndirectNV-buffer-02708**
  If `buffer` is non-sparse then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object
• **VUID-vkCmdDrawMeshTasksIndirectNV-buffer-02709**
  buffer must have been created with the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT bit set

• **VUID-vkCmdDrawMeshTasksIndirectNV-offset-02710**
  offset must be a multiple of 4

• **VUID-vkCmdDrawMeshTasksIndirectNV-commandBuffer-02711**
  commandBuffer must not be a protected command buffer

• **VUID-vkCmdDrawMeshTasksIndirectNV-drawCount-02718**
  If the multiDrawIndirect feature is not enabled, drawCount must be 0 or 1

• **VUID-vkCmdDrawMeshTasksIndirectNV-drawCount-02719**
  drawCount must be less than or equal to VkPhysicalDeviceLimits::maxDrawIndirectCount

• **VUID-vkCmdDrawMeshTasksIndirectNV-drawCount-02146**
  If drawCount is greater than 1, stride must be a multiple of 4 and must be greater than or equal to sizeof(VkDrawMeshTasksIndirectCommandNV)

• **VUID-vkCmdDrawMeshTasksIndirectNV-drawCount-02156**
  If drawCount is equal to 1, (offset + sizeof(VkDrawMeshTasksIndirectCommandNV)) must be less than or equal to the size of buffer

• **VUID-vkCmdDrawMeshTasksIndirectNV-drawCount-02157**
  If drawCount is greater than 1, (stride × (drawCount - 1) + offset + sizeof(VkDrawMeshTasksIndirectCommandNV)) must be less than or equal to the size of buffer

• **VUID-vkCmdDrawMeshTasksIndirectNV-MeshNV-07081**
  The current pipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS must contain a shader stage using the MeshNV Execution Model

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**Valid Usage (Implicit)**

• **VUID-vkCmdDrawMeshTasksIndirectNV-commandBuffer-parameter**
  commandBuffer must be a valid VkCommandBuffer handle

• **VUID-vkCmdDrawMeshTasksIndirectNV-buffer-parameter**
  buffer must be a valid VkBuffer handle

• **VUID-vkCmdDrawMeshTasksIndirectNV-commandBuffer-recording**
  commandBuffer must be in the recording state

• **VUID-vkCmdDrawMeshTasksIndirectNV-commandBuffer-cmdpool**
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

• **VUID-vkCmdDrawMeshTasksIndirectNV-renderpass**
  This command must only be called inside of a render pass instance

• **VUID-vkCmdDrawMeshTasksIndirectNV-videocoding**
  This command must only be called outside of a video coding scope

• **VUID-vkCmdDrawMeshTasksIndirectNV-commonparent**
  Both of buffer, and commandBuffer must have been created, allocated, or retrieved from the same VkDevice
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

Command Properties

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<tr>
<td>Primary</td>
<td>Inside</td>
<td>Outside</td>
<td>Graphics</td>
<td>Action</td>
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<tr>
<td>Secondary</td>
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The `VkDrawMeshTasksIndirectCommandNV` structure is defined as:

```c
// Provided by VK_NV_mesh_shader
typedef struct VkDrawMeshTasksIndirectCommandNV {
    uint32_t taskCount;
    uint32_t firstTask;
} VkDrawMeshTasksIndirectCommandNV;
```

- `taskCount` is the number of local workgroups to dispatch in the X dimension. Y and Z dimension are implicitly set to one.
- `firstTask` is the X component of the first workgroup ID.

The members of `VkDrawMeshTasksIndirectCommandNV` have the same meaning as the similarly named parameters of `vkCmdDrawMeshTasksNV`.

Valid Usage

- VUID-VkDrawMeshTasksIndirectCommandNV-taskCount-02175
  
  `taskCount must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesNV::maxDrawMeshTasksCount`

To record an indirect mesh tasks drawing command with the draw count sourced from a buffer, call:

```c
// Provided by VK_NV_mesh_shader
void vkCmdDrawMeshTasksIndirectCountNV(
    VkCommandBuffer commandBuffer,
    VkBuffer buffer,
    VkDeviceSize offset,
    VkBuffer countBuffer,
```
VkDeviceSize countBufferOffset,
uint32_t maxDrawCount,
uint32_t stride);

• commandBuffer is the command buffer into which the command is recorded.
• buffer is the buffer containing draw parameters.
• offset is the byte offset into buffer where parameters begin.
• countBuffer is the buffer containing the draw count.
• countBufferOffset is the byte offset into countBuffer where the draw count begins.
• maxDrawCount specifies the maximum number of draws that will be executed. The actual number of executed draw calls is the minimum of the count specified in countBuffer and maxDrawCount.
• stride is the byte stride between successive sets of draw parameters.

vkCmdDrawMeshTasksIndirectCountNV behaves similarly to vkCmdDrawMeshTasksIndirectNV except that the draw count is read by the device from a buffer during execution. The command will read an unsigned 32-bit integer from countBuffer located at countBufferOffset and use this as the draw count.

Valid Usage

• VUID-vkCmdDrawMeshTasksIndirectCountNV-magFilter-04553
  If a VkSampler created with magFilter or minFilter equal to VK_FILTER_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-mipmapMode-04770
  If a VkSampler created with.mipmapMode equal to VK_SAMPLER_MIPMAP_MODE_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-06479
  If a VkImageView is sampled with depth comparison, the image view's format features must contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-02691
  If a VkImageView is accessed using atomic operations as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07888
  If a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-02692
  If a VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, then
the image view’s format features must contain
VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-02693
If the VK_EXT_filter_cubic extension is not enabled and any VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, it must not have a VkImageViewType of VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

• VUID-vkCmdDrawMeshTasksIndirectCountNV-filterCubic-02694
Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2

• VUID-vkCmdDrawMeshTasksIndirectCountNV-filterCubicMinmax-02695
Any VkImageView being sampled with VK_FILTER_CUBIC_EXT with a reduction mode of either VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX as a result of this command must have a VkImageViewType and format that supports cubic filtering together with minmax filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax returned by vkGetPhysicalDeviceImageFormatProperties2

• VUID-vkCmdDrawMeshTasksIndirectCountNV-cubicRangeClamp-09212
If the cubicRangeClamp feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must not have a VkSamplerReductionModeCreateInfo::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM

• VUID-vkCmdDrawMeshTasksIndirectCountNV-reductionMode-09213
Any VkImageView being sampled with a VkSamplerReductionModeCreateInfo::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM as a result of this command must sample with VK_FILTER_CUBIC_EXT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-selectableCubicWeights-09214
If the selectableCubicWeights feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights equal to VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM

• VUID-vkCmdDrawMeshTasksIndirectCountNV-flags-02696
Any VkImage created with a VkImageCreateInfo::flags containing VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV sampled as a result of this command must only be sampled using a VkSamplerAddressMode of VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE

• VUID-vkCmdDrawMeshTasksIndirectCountNV-OpTypeImage-07027
For any VkImageView being written as a storage image where the image format field of the OpTypeImage is Unknown, the view’s format features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-OpTypeImage-07028
For any VkImageView being read as a storage image where the image format field of the OpTypeImage is Unknown, the view’s format features must contain
VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-OpTypeImage-07029
  For any VkBufferView being written as a storage texel buffer where the image format field of the OpTypeImage is Unknown, the view's buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-OpTypeImage-07030
  Any VkBufferView being read as a storage texel buffer where the image format field of the OpTypeImage is Unknown then the view's buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08600
  For each set n that is statically used by a bound shader, a descriptor set must have been bound to n at the same pipeline bind point, with a VkPipelineLayout that is compatible for set n, with the VkPipelineLayout or VkDescriptorSetLayout array that was used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08601
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

• VUID-vkCmdDrawMeshTasksIndirectCountNV-maintenance4-08602
  If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08114
  Descriptors in each bound descriptor set, specified via vkCmdBindDescriptorSets, must be valid if they are statically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was not created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08115
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdBindDescriptorSets, the bound VkPipeline must have been created without VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08116
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08604
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by any
**VkShaderEXT** bound to a stage corresponding to the pipeline bind point used by this command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08117**
  If the descriptors used by the **VkPipeline** bound to the pipeline bind point were specified via `vkCmdSetDescriptorBufferOffsetsEXT`, the bound **VkPipeline** must have been created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08119**
  If a descriptor is dynamically used with a **VkPipeline** created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory must be resident

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08605**
  If a descriptor is dynamically used with a **VkShaderEXT** created with a **VkDescriptorSetLayout** that was created with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory must be resident

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08606**
  If the `shaderObject` feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08607**
  If the `shaderObject` is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and `VK_NULL_HANDLE` shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08608**
  If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the **VkPipeline** object bound to the pipeline bind point used by this command, since that pipeline was bound

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08609**
  If the **VkPipeline** object bound to the pipeline bind point used by this command or any **VkShaderEXT** bound to a stage corresponding to the pipeline bind point used by this command accesses a **VkSampler** object that uses unnormalized coordinates, that sampler must not be used to sample from any **VkImage** with a **VkImageView** of the type `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, `VK_IMAGE_VIEW_TYPE_1D_ARRAY`, `VK_IMAGE_VIEW_TYPE_2D_ARRAY` or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`, in any shader stage

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08610**
  If the **VkPipeline** object bound to the pipeline bind point used by this command or any **VkShaderEXT** bound to a stage corresponding to the pipeline bind point used by this command accesses a **VkSampler** object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V `OpImageSample*` or `OpImageSparseSample*` instructions with `ImplicitLod`, `Dref` or `Proj` in their name, in any shader stage

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08611**
  If the **VkPipeline** object bound to the pipeline bind point used by this command or any **VkShaderEXT** bound to a stage corresponding to the pipeline bind point used by this command accesses a **VkSampler** object that uses unnormalized coordinates, that sampler
must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage

- VUID-vkCmdDrawMeshTasksIndirectCountNV-uniformBuffers-06935
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08612
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDrawMeshTasksIndirectCountNV-storageBuffers-06936
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08613
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDrawMeshTasksIndirectCountNV-commandBuffer-02707
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource

- VUID-vkCmdDrawMeshTasksIndirectCountNV-None-06550
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y′C bC r conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions

- VUID-vkCmdDrawMeshTasksIndirectCountNV-ConstOffset-06551
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y′C bC r conversion, that object must not use the ConstOffset and Offset operands

- VUID-vkCmdDrawMeshTasksIndirectCountNV-viewType-07752
  If a VkImageView is accessed as a result of this command, then the image view’s viewType must match the Dim operand of the OpTypeImage as described in Instruction/Sampler/Image View Validation

- VUID-vkCmdDrawMeshTasksIndirectCountNV-format-07753
  If a VkImageView is accessed as a result of this command, then the numeric type of the
image view’s format and the Sampled Type operand of the OpTypeImage must match

• VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageWrite-08795

If a VkImageView created with a format other than VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the image view’s format

• VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageWrite-08796

If a VkImageView created with the format VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have four components

• VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageWrite-04469

If a VkBufferView is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the buffer view’s format

• VUID-vkCmdDrawMeshTasksIndirectCountNV-SampledType-04470

If a VkImageView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64

• VUID-vkCmdDrawMeshTasksIndirectCountNV-SampledType-04471

If a VkImageView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

• VUID-vkCmdDrawMeshTasksIndirectCountNV-SampledType-04472

If a VkBufferView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64

• VUID-vkCmdDrawMeshTasksIndirectCountNV-SampledType-04473

If a VkBufferView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

• VUID-vkCmdDrawMeshTasksIndirectCountNV-sparseImageInt64Atomics-04474

If the sparseImageInt64Atomics feature is not enabled, VkImage objects created with the VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-sparseImageInt64Atomics-04475

If the sparseImageInt64Atomics feature is not enabled, VkBuffer objects created with the VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageWeightedSampleQCOM-06971

If OpImageWeightedSampleQCOM is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM

• VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageWeightedSampleQCOM-06972

If OpImageWeightedSampleQCOM uses a VkImageView as a sample weight image as a result of
this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM

- VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageBoxFilterQCOM-06973
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM

- VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageBlockMatchSSDQCOM-06974
  If OpImageBlockMatchSSDQCOM is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageBlockMatchSADQCOM-06975
  If OpImageBlockMatchSADQCOM is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageBoxFilterQCOM-06973
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM

- VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageBlockMatchSSDQCOM-06974
  If OpImageBlockMatchSSDQCOM is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageBlockMatchSADQCOM-06975
  If OpImageBlockMatchSADQCOM is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageWeightedSampleQCOM-06977
  If OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, OpImageBlockMatchSSDQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this command, then the sampler must have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM

- VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageWeightedSampleQCOM-06978
  If any command other than OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, OpImageBlockMatchSSDQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this command, then the sampler must not have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM

- VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageBlockMatchWindow-09215
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageBlockMatchWindow-09216
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view's format must be a single-component format.

- VUID-vkCmdDrawMeshTasksIndirectCountNV-OpImageBlockMatchWindow-09217
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07288
Any shader invocation executed by this command **must** terminate

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-renderPass-02684**
  The current render pass **must** be compatible with the `renderPass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-subpass-02685**
  The subpass index of the current render pass **must** be equal to the `subpass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07748**
  If any shader statically accesses an input attachment, a valid descriptor **must** be bound to the pipeline via a descriptor set

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-OpTypeImage-07468**
  If any shader executed by this pipeline accesses an `OpTypeImage` variable with a `Dim` operand of `SubpassData`, it **must** be decorated with an `InputAttachmentIndex` that corresponds to a valid input attachment in the current subpass

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07469**
  Input attachment views accessed in a subpass **must** be created with the same `VkFormat` as the corresponding subpass definition, and be created with a `VkImageView` that is compatible with the attachment referenced by the subpass' `pInputAttachments[InputAttachmentIndex]` in the currently bound `VkFramebuffer` as specified by Fragment Input Attachment Compatibility

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-06537**
  Memory backing image subresources used as attachments in the current render pass **must** not be written in any way other than as an attachment by this command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-09000**
  If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:
  - the `VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
  - the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_COLOR_BIT` and
    - there is no currently bound graphics pipeline or
    - the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it **must** not be accessed in any way other than as an attachment by this command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-09001**
  If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:
  - the `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
• the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_DEPTH_BIT` and
  • there is no currently bound graphics pipeline or
  • the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-09002
  If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:
  ◦ the `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
  ◦ the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_STENCIL_BIT` and
    • there is no currently bound graphics pipeline or
    • the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-09003
  If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-06539
  If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command must not write to that image subresource as an attachment

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-06886
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, depth writes must be disabled

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-06887
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back writeMask are not zero, and stencil test is enabled, all stencil ops must be `VK_STENCIL_OP_KEEP`

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07831
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT` dynamic state enabled then `vkCmdSetViewport` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07832
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SCISSOR` dynamic state enabled then `vkCmdSetScissor` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07833
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_WIDTH` dynamic state enabled then `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08617**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08618**
  If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08619**
  If a shader object that outputs line primitives is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` or `VK_SHADER_STAGE_GEOMETRY_BIT` stage, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07834**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BIAS` dynamic state enabled then `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08620**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthBiasEnable` in the current command buffer set `depthBiasEnable` to `VK_TRUE`, `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07835**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_BLEND_CONSTANTS` dynamic state enabled then `vkCmdSetBlendConstants` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08621**
  If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer set any element of `pColorBlendEnables` to `VK_TRUE`, and the most recent call to `vkCmdSetColorBlendEquationEXT` in the current command buffer set the same element of `pColorBlendEquations` to a `VkColorBlendEquationEXT` structure with any `VkBlendFactor` member with a value of `VK_BLEND_FACTOR_CONSTANT_COLOR`, `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR`, `VK_BLEND_FACTOR_CONSTANT_ALPHA`, or `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA`, `vkCmdSetBlendConstants` must have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS` dynamic state enabled then `vkCmdSetDepthBounds` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthBoundsTestEnable` in the current command buffer set `depthBoundsTestEnable` to `VK_TRUE`, then `vkCmdSetDepthBounds` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK` dynamic state enabled then `vkCmdSetStencilCompareMask` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilCompareMask` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_WRITE_MASK` dynamic state enabled then `vkCmdSetStencilWriteMask` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilWriteMask` must have been called in the current command buffer prior to this drawing command.

If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to `VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex`.
If the bound graphics pipeline was created with
`VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` set to `VK_TRUE` and
the current subpass has a depth/stencil attachment, then that attachment must have been
created with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` dynamic state enabled
then `vkCmdSetSampleLocationsEXT` must have been called in the current command buffer prior to this drawing command

If a shader object is bound to any graphics stage, and the most recent call to
`vkCmdSetSampleLocationsEnableEXT` in the current command buffer set
`sampleLocationsEnable` to `VK_TRUE`, and the most recent call to
`vkCmdSetRasterizerDiscardEnable` in the current command buffer set
`rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEXT` must have been
called in the current command buffer prior to this drawing command

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled, then the
`samplingLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must
equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CULL_MODE` dynamic state enabled then
`vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command

If a shader object is bound to any graphics stage, and the most recent call to
`vkCmdSetRasterizerDiscardEnable` in the current command buffer set
`rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCullMode` must have been called in
the current command buffer prior to this drawing command

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled then
`vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command

If a shader object is bound to any graphics stage, and the most recent call to
`vkCmdSetRasterizerDiscardEnable` in the current command buffer set
`rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFrontFace` must have been called in
the current command buffer prior to this drawing command

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` dynamic state enabled then
`vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to
this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08629**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable must` have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07844**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` dynamic state enabled then `vkCmdSetDepthWriteEnable must` have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08630**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthWriteEnable must` have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07845**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP` dynamic state enabled then `vkCmdSetDepthCompareOp must` have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08631**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthTestEnable` in the current command buffer set `depthTestEnable` to `VK_TRUE`, then `vkCmdSetDepthCompareOp must` have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07846**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthBoundsTestEnable must` have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08632**
  If a shader object is bound to any graphics stage, and the `depthBounds` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthBoundsTestEnable must` have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07847**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE` dynamic state enabled then `vkCmdSetStencilTestEnable must` have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08633**
  If a shader object is bound to any graphics stage, and the `depthBounds` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetStencilTestEnable must` have been called in the current command buffer prior to this drawing command.
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07848**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_OP` dynamic state enabled then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08634**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-viewportCount-03417**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `VkPipelineViewportStateCreateInfo::viewportCount` of the pipeline.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-scissorCount-03418**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, then `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `scissorCount` parameter of `vkCmdSetScissorWithCount` must match the `VkPipelineViewportStateCreateInfo::viewportCount` of the pipeline.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-viewportCount-03419**
  If the bound graphics pipeline state was created with both the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic states enabled then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08635**
  If a shader object is bound to any graphics stage, then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-viewportCount-04137**
  If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the
VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV dynamic state enabled, then the bound graphics pipeline must have been created with VkPipelineViewportWScalingStateCreateInfoNV :
viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawMeshTasksIndirectCountNV-viewportCount-04138
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV dynamic states enabled then the viewportCount parameter in the last call to vkCmdSetViewportWScalingNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-09232
If a shader object is bound to any graphics stage, and the VK_NV_clip_space_w_scaling extension is enabled on the device, then vkCmdSetViewportWScalingNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08636
If a shader object is bound to any graphics stage, and the VK_NV_clip_space_w_scaling extension is enabled on the device, then the viewportCount parameter in the last call to vkCmdSetViewportWScalingNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawMeshTasksIndirectCountNV-viewportCount-04139
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV dynamic state enabled, then the bound graphics pipeline must have been created with VkPipelineViewportShadingRateImageStateCreateInfoNV :
viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawMeshTasksIndirectCountNV-viewportCount-04140
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV dynamic states enabled then the viewportCount parameter in the last call to vkCmdSetViewportShadingRatePaletteNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawMeshTasksIndirectCountNV-shadingRateImage-09233
If the shadingRateImage feature is enabled, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCoarseSampleOrderNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-shadingRateImage-09234
If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetShadingRateImageEnableNV in the current command buffer set shadingRateImageEnable to VK_TRUE, then vkCmdSetViewportShadingRatePaletteNV must
have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08637
If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, then the viewportCount parameter in the last call to vkCmdSetViewportShadingRatePaletteNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawMeshTasksIndirectCountNV-VkPipelineVieportCreateInfo-04141
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled and a VkPipelineViewportSwizzleStateCreateInfoNV structure chained from VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have been created with VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07878
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV dynamic state enabled then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07879
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV dynamic state enabled then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-exclusiveScissor-09235
If a shader object is bound to any graphics stage, and the exclusiveScissor feature is enabled, then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08638
If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetExclusiveScissorEnableNV in the current command buffer set any element of pExclusiveScissorEnables to VK_TRUE, then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-04876
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE dynamic state enabled then vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command
• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08639
If a shader object is bound to any graphics stage, then \texttt{vkCmdSetRasterizerDiscardEnable} \textbf{must} have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-04877
If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE} dynamic state enabled then \texttt{vkCmdSetDepthBiasEnable} \textbf{must} have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08640
If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetDepthBiasEnable} \textbf{must} have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-logicOp-04878
If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LOGIC_OP_EXT} dynamic state enabled then \texttt{vkCmdSetLogicOpEXT} \textbf{must} have been called in the current command buffer prior to this drawing command and the \texttt{logicOp} \textbf{must} be a valid \texttt{VkLogicOp} value

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08641
If a shader object is bound to the \texttt{VK_SHADER_STAGE_FRAGMENT_BIT} stage, and the \texttt{logicOp} feature is enabled on the device, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetLogicOpEXT} \textbf{must} have been called in the current command buffer prior to this drawing command and the \texttt{logicOp} \textbf{must} be a valid \texttt{VkLogicOp} value

• VUID-vkCmdDrawMeshTasksIndirectCountNV-primitiveFragmentShadingRateWithMultipleViewports-04552
If the \texttt{primitiveFragmentShadingRateWithMultipleViewports} limit is not supported, the bound graphics pipeline was created with the \texttt{VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT} dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the \texttt{PrimitiveShadingRateKHR} built-in, then \texttt{vkCmdSetViewportWithCount} \textbf{must} have been called in the current command buffer prior to this drawing command, and the \texttt{viewportCount} parameter of \texttt{vkCmdSetViewportWithCount} \textbf{must} be $1$

• VUID-vkCmdDrawMeshTasksIndirectCountNV-primitiveFragmentShadingRateWithMultipleViewports-08642
If the \texttt{primitiveFragmentShadingRateWithMultipleViewports} limit is not supported, and any shader object bound to a graphics stage writes to the \texttt{PrimitiveShadingRateKHR} built-in, then \texttt{vkCmdSetViewportWithCount} \textbf{must} have been called in the current command buffer prior to this drawing command, and the \texttt{viewportCount} parameter of \texttt{vkCmdSetViewportWithCount} \textbf{must} be $1$

• VUID-vkCmdDrawMeshTasksIndirectCountNV-blendEnable-04727
If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view's \texttt{format features} do not contain \texttt{VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT}, then the \texttt{blendEnable} member of the corresponding element of the \texttt{pAttachments} member of \texttt{pColorBlendState} \textbf{must} be
VK_FALSE

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08643**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to VK_FALSE, then for each color attachment in the render pass, if the corresponding image view’s format features do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the corresponding member of `pColorBlendEnables` in the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer that affected that attachment index must have been VK_FALSE.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-multisampledRenderToSingleSampled-07284**
  If rasterization is not disabled in the bound graphics pipeline, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the multisampledRenderToSingleSampled feature is enabled, then `rasterizationSamples` for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08644**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to VK_FALSE, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the multisampledRenderToSingleSampled feature is enabled, then the most recent call to `vkCmdSetRasterizationSamplesEXT` in the current command buffer must have set `rasterizationSamples` to be the same as the number of samples for the current render pass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08876**
  If a shader object is bound to any graphics stage, the current render pass instance must have been begun with `vkCmdBeginRendering`.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-imageView-06172**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-imageView-06173**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-imageView-06174**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, this command must not write any values to the depth attachment.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-imageView-06175**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, this command must not write any values to the depth attachment.
member of pStencilAttachment is not VK_NULL_HANDLE, and the layout member of pStencilAttachment is VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL, this command must not write any values to the stencil attachment

- VUID-vkCmdDrawMeshTasksIndirectCountNV-imageView-06176
  If the current render pass instance was begun with vkCmdBeginRendering, the imageView member of pDepthAttachment is not VK_NULL_HANDLE, and the layout member of pDepthAttachment is VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL, this command must not write any values to the depth attachment

- VUID-vkCmdDrawMeshTasksIndirectCountNV-imageView-06177
  If the current render pass instance was begun with vkCmdBeginRendering, the imageView member of pStencilAttachment is not VK_NULL_HANDLE, and the layout member of pStencilAttachment is VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL, this command must not write any values to the stencil attachment

- VUID-vkCmdDrawMeshTasksIndirectCountNV-viewMask-06178
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound graphics pipeline must have been created with a VkPipelineRenderingCreateInfo::viewMask equal to VkRenderingInfo::viewMask

- VUID-vkCmdDrawMeshTasksIndirectCountNV-colorAttachmentCount-06179
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound graphics pipeline must have been created with a VkPipelineRenderingCreateInfo::viewMask equal to VkRenderingInfo::viewMask

- VUID-vkCmdDrawMeshTasksIndirectCountNV-dynamicRenderingUnusedAttachments-08910
  If the dynamicRenderingUnusedAttachments feature is not enabled, and the current render pass instance was begun with vkCmdBeginRendering and VkRenderingInfo::colorAttachmentCount greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a VkFormat equal to the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the currently bound graphics pipeline

- VUID-vkCmdDrawMeshTasksIndirectCountNV-dynamicRenderingUnusedAttachments-08911
  If the dynamicRenderingUnusedAttachments feature is enabled, and the current render pass instance was begun with vkCmdBeginRendering and VkRenderingInfo::colorAttachmentCount greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a VkFormat equal to the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the currently bound graphics pipeline, or the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats, if it exists, must be VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawMeshTasksIndirectCountNV-dynamicRenderingUnusedAttachments-08912
  If the dynamicRenderingUnusedAttachments feature is not enabled, and the current render pass instance was begun with vkCmdBeginRendering and VkRenderingInfo::colorAttachmentCount greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a VkFormat equal to the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the currently bound graphics pipeline, or the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats, if it exists, must be VK_FORMAT_UNDEFINED
::colorAttachmentCount greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView equal to VK_NULL_HANDLE must have the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the currently bound pipeline equal to VK_FORMAT_UNDEFINED

• **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07749**

  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT dynamic state enabled then **vkCmdSetColorWriteEnableEXT must** have been called in the current command buffer prior to this drawing command

• **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08646**

  If the colorWriteEnable feature is enabled on the device, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then **vkCmdSetColorWriteEnableEXT must** have been called in the current command buffer prior to this drawing command

• **VUID-vkCmdDrawMeshTasksIndirectCountNV-attachmentCount-07750**

  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT dynamic state enabled then the attachmentCount parameter of **vkCmdSetColorWriteEnableEXT must** be greater than or equal to the VkPipelineColorBlendStateCreateInfo::attachmentCount of the currently bound graphics pipeline

• **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08647**

  If the colorWriteEnable feature is enabled on the device, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then the attachmentCount parameter of most recent call to **vkCmdSetColorWriteEnableEXT in the current command buffer must be greater than or equal to the number of color attachments in the current render pass instance**

• **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07751**

  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT dynamic state enabled then **vkCmdSetDiscardRectangleEXT must** have been called in the current command buffer prior to this drawing command for each discard rectangle in VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount

• **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07880**

  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT dynamic state enabled then **vkCmdSetDiscardRectangleEnableEXT must** have been called in the current command buffer prior to this drawing command

• **VUID-vkCmdDrawMeshTasksIndirectCountNV-rasterizerDiscardEnable-09236**

  If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then **vkCmdSetDiscardRectangleEXT must** have been called in the current command buffer prior to this drawing command
If the **VK_EXT_discard_rectangles** extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to **VK_FALSE**, then `vkCmdSetDiscardRectangleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT** dynamic state enabled then `vkCmdSetDiscardRectangleModeEXT` must have been called in the current command buffer prior to this drawing command.

If the **VK_EXT_discard_rectangles** extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to **VK_FALSE**, and the most recent call to `vkCmdSetDiscardRectangleEnableEXT` in the current command buffer set `discardRectangleEnable` to **VK_TRUE**, then `vkCmdSetDiscardRectangleModeEXT` must have been called in the current command buffer prior to this drawing command.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was **VK_NULL_HANDLE**, the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline must be equal to **VK_FORMAT_UNDEFINED**.

If current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not **VK_NULL_HANDLE**, the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline must be equal to the `VkFormat` used to create `VkRenderingInfo::pDepthAttachment->imageView`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pDepthAttachment->imageView` was not **VK_NULL_HANDLE**, and the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo::pDepthAttachment->imageView`, the value of the format must be **VK_FORMAT_UNDEFINED**.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not **VK_NULL_HANDLE**, the value of the format must be **VK_FORMAT_UNDEFINED**.
::pStencilAttachment->imageView was VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline must be equal to VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawMeshTasksIndirectCountNV-dynamicRenderingUnusedAttachments-08917
If current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo ::pStencilAttachment->imageView was not VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline must be equal to the VkFormat used to create VkRenderingInfo ::pStencilAttachment->imageView

• VUID-vkCmdDrawMeshTasksIndirectCountNV-dynamicRenderingUnusedAttachments-08918
If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo ::pStencilAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo ::pStencilAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawMeshTasksIndirectCountNV-imageView-06183
If the current render pass instance was begun with vkCmdBeginRendering and VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

• VUID-vkCmdDrawMeshTasksIndirectCountNV-imageView-06184
If the current render pass instance was begun with vkCmdBeginRendering and VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-colorAttachmentCount-06185
If the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a sample count equal to the corresponding element of the pColorAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline

• VUID-vkCmdDrawMeshTasksIndirectCountNV-pDepthAttachment-06186
If the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of the depthStencilAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline must be equal to the sample count
used to create VkRenderingInfo::pDepthAttachment->imageView

• VUID-vkCmdDrawMeshTasksIndirectCountNV-pStencilAttachment-06187
  If the current render pass instance was begun with vkCmdBeginRendering, the currently
  bound pipeline was created with a VkAttachmentSampleCountInfoAMD or
  VkAttachmentSampleCountInfoNV structure, and VkRenderingInfo::pStencilAttachment-
  >imageView was not VK_NULL_HANDLE, the value of the depthStencilAttachmentSamples
  member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV
  used to create the currently bound graphics pipeline must be equal to the sample count
  used to create VkRenderingInfo::pStencilAttachment->imageView

• VUID-vkCmdDrawMeshTasksIndirectCountNV-multisampledRenderToSingleSampled-
  07285
  If the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or
  VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled
  feature is not enabled, and the current render pass instance was begun with vkCmdBeginRendering
  with a VkRenderingInfo ::colorAttachmentCount parameter greater than 0, then each element of the
  VkRenderingInfo::pColorAttachments array with a imageView not equal to
  VK_NULL_HANDLE must have been created with a sample count equal to the value of
  rasterizationSamples for the currently bound graphics pipeline

• VUID-vkCmdDrawMeshTasksIndirectCountNV-multisampledRenderToSingleSampled-
  07286
  If the current render pass instance was begun with vkCmdBeginRendering, the currently
  bound pipeline was created without a VkAttachmentSampleCountInfoAMD or
  VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled
  feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was not
  VK_NULL_HANDLE, the value of rasterizationSamples for the currently bound graphics
  pipeline must be equal to the sample count used to create VkRenderingInfo
  ::pDepthAttachment->imageView

• VUID-vkCmdDrawMeshTasksIndirectCountNV-multisampledRenderToSingleSampled-
  07287
  If the current render pass instance was begun with vkCmdBeginRendering, the currently
  bound pipeline was created without a VkAttachmentSampleCountInfoAMD or
  VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled
  feature is not enabled, and VkRenderingInfo::pStencilAttachment->imageView was not
  VK_NULL_HANDLE, the value of rasterizationSamples for the currently bound graphics
  pipeline must be equal to the sample count used to create VkRenderingInfo
  ::pStencilAttachment->imageView

• VUID-vkCmdDrawMeshTasksIndirectCountNV-pNext-07935
  If this command has been called inside a render pass instance started with
  vkCmdBeginRendering, and the pNext chain of VkRenderingInfo includes a
  VkMultisampledRenderToSingleSampledInfoEXT structure with
  multisampledRenderToSingleSampledEnable equal to VK_TRUE, then the value of
  rasterizationSamples for the currently bound graphics pipeline must be equal to
  VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples

• VUID-vkCmdDrawMeshTasksIndirectCountNV-renderPass-06198
If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline must have been created with a `VkGraphicsPipelineCreateInfo::renderPass` equal to `VK_NULL_HANDLE`

• VUID-vkCmdDrawMeshTasksIndirectCountNV-pColorAttachments-08963
  If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the `VkRenderingInfo::pColorAttachments->imageView` was not `VK_NULL_HANDLE`, then the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`

• VUID-vkCmdDrawMeshTasksIndirectCountNV-pDepthAttachment-08964
  If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`

• VUID-vkCmdDrawMeshTasksIndirectCountNV-pStencilAttachment-08965
  If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, stencil test is enabled and the `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`

• VUID-vkCmdDrawMeshTasksIndirectCountNV-primitivesGeneratedQueryWithRasterizerDiscard-06708
  If the `primitivesGeneratedQueryWithRasterizerDiscard` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, rasterization discard must not be enabled

• VUID-vkCmdDrawMeshTasksIndirectCountNV-primitivesGeneratedQueryWithNonZeroStreams-06709
  If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, the bound graphics pipeline must not have been created with a non-zero value in `VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream`

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07619
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT` dynamic state enabled then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07620
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-09237
  If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then
**vkCmdSetTessellationDomainOriginEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08650**
  If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07621**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07622**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` dynamic state enabled then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07623**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` dynamic state enabled then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07624**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-alphaToCoverageEnable-08919**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled, and
alphaToCoverageEnable was VK_TRUE in the last call to 
vkCmdSetAlphaToCoverageEnableEXT, then the Fragment Output Interface must contain 
a variable for the alpha Component word in Location 0 at Index 0

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08654
  If a shader object is bound to any graphics stage, and the most recent call to 
vkCmdSetRasterizerDiscardEnable in the current command buffer set 
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToCoverageEnableEXT must 
have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-alphaToCoverageEnable-08920
  If a shader object is bound to any graphics stage, and the most recent call to 
vkCmdSetAlphaToCoverageEnableEXT in the current command buffer set 
alphaToCoverageEnable to VK_TRUE, then the Fragment Output Interface must contain a 
variable for the alpha Component word in Location 0 at Index 0

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07625
  If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT dynamic state enabled then 
vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer 
prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08655
  If the alphaToOne feature is enabled, and a shader object is bound to any graphics stage, 
and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command 
buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToOneEnableEXT must 
have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07626
  If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT dynamic state enabled then 
vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior 
to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08656
  If the logicOp feature is enabled, and a shader object is bound to the 
VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to 
vkCmdSetRasterizerDiscardEnable in the current command buffer set 
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEnableEXT must have 
been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07627
  If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then 
vkCmdSetColorBlendEnableEXT must have been called in the current command buffer 
prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08657
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most 
recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set 
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorBlendEnableEXT must have 
been called in the current command buffer prior to this drawing command
• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07628
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08658
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` for any attachment set that attachment’s value in `pColorBlendEnables` to `VK_TRUE`, then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07629
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08659
If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07630
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` dynamic state enabled then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08660
If the `geometryStreams` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_GEOMETRY_BIT` stage, then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07631
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08661
If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07632
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then
vkCmdSetExtraPrimitiveOverestimationSizeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08662
  If the VK_EXT_conservative_rasterization extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetConservativeRasterizationModeEXT in the current command buffer set conservativeRasterizationMode to VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT, then vkCmdSetExtraPrimitiveOverestimationSizeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07633
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT dynamic state enabled then vkCmdSetDepthClipEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08663
  If the depthClipEnable feature is enabled, and a shader object is bound to any graphics stage, then vkCmdSetDepthClipEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07634
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT dynamic state enabled then vkCmdSetSampleLocationsEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08664
  If the VK_EXT_sample_locations extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleLocationsEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07635
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT dynamic state enabled then vkCmdSetColorBlendAdvancedEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07636
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT dynamic state enabled then vkCmdSetProvokingVertexModeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08665
  If the VK_EXT_provoking_vertex extension is enabled, and a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, then vkCmdSetProvokingVertexModeEXT must have been called in the current command buffer prior to this drawing command
• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07637
If the bound graphics pipeline state was created with the
`VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic state enabled then
`vkCmdSetLineRasterizationModeEXT` must have been called in the current command
buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08666
If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any
graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current
command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then
`vkCmdSetLineRasterizationModeEXT` must have been called in the current command
buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08667
If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the
vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current
command buffer set `primitiveTopology` to any line topology, then
`vkCmdSetLineRasterizationModeEXT` must have been called in the current command
buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08668
If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs
line primitives is bound to the tessellation evaluation or geometry stage, then
`vkCmdSetLineRasterizationModeEXT` must have been called in the current command
buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07638
If the bound graphics pipeline state was created with the
`VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` dynamic state enabled then
`vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer
prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08669
If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any
graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current
command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then
`vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer
prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08670
If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the
vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current
command buffer set `primitiveTopology` to any line topology, then
`vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer
prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08671
If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs
line primitives is bound to the tessellation evaluation or geometry stage, then
`vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer
prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07849
If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_LINE_STIPPLE_EXT** dynamic state enabled then **vkCmdSetLineStippleEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08672**
  If the **VK_EXT_line_rasterization** extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetLineStippleEnableEXT** in the current command buffer set **stippledLineEnable** to **VK_TRUE**, then **vkCmdSetLineStippleEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07639**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT** dynamic state enabled then **vkCmdSetDepthClipNegativeOneToOneEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08673**
  If the **depthClipControl** feature is enabled, and a shader object is bound to any graphics stage, then **vkCmdSetDepthClipNegativeOneToOneEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07640**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV** dynamic state enabled then **vkCmdSetViewportWScalingEnableNV** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08674**
  If the **VK_NV_clip_space_w_scaling** extension is enabled, and a shader object is bound to any graphics stage, then **vkCmdSetViewportWScalingEnableNV** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07641**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV** dynamic state enabled then **vkCmdSetViewportSwizzleNV** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08675**
  If the **VK_NV_viewport_swizzle** extension is enabled, and a shader object is bound to any graphics stage, then **vkCmdSetViewportSwizzleNV** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07642**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV** dynamic state enabled then **vkCmdSetCoverageToColorEnableNV** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08676**
  If the **VK_NV_fragment_coverage_to_color** extension is enabled, and a shader object is bound to the **VK_SHADER_STAGE_FRAGMENT_BIT** stage, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCoverageToColorEnableNV must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07643**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV dynamic state enabled then vkCmdSetCoverageToColorLocationNV must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08677**
  If the VK_NV_fragment_coverage_to_color extension is enabled, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetCoverageToColorEnableNV in the current command buffer set coverageToColorEnable to VK_TRUE, then vkCmdSetCoverageToColorLocationNV must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07644**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV dynamic state enabled then vkCmdSetCoverageModulationModeNV must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08678**
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCoverageModulationModeNV must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07645**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV dynamic state enabled then vkCmdSetCoverageModulationTableEnableNV must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08679**
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set coverageModulationMode to any value other than VK_COVERAGE_MODULATION_MODE_NONE_NV, then vkCmdSetCoverageModulationTableEnableNV must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07646**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV dynamic state enabled then vkCmdSetCoverageModulationTableNV must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08680**
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then...
current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to
`vkCmdSetCoverageModulationTableEnableNV` in the current command buffer set
`coverageModulationTableEnable` to `VK_TRUE`, then `vkCmdSetCoverageModulationTableNV`
**must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07647**
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV` dynamic state enabled then
  `vkCmdSetShadingRateImageEnableNV` **must** have been called in the current command
  buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-pipelineFragmentShadingRate-09238**
  If the `pipelineFragmentShadingRate` feature is enabled, and a shader object is bound to the
  `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to
  `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
  `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFragmentShadingRateKHR` must have
  been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08681**
  If the `shadingRateImage` feature is enabled, and a shader object is bound to any graphics
  stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current
  command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetShadingRateImageEnableNV` **must** have been called in the current command
  buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07648**
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV` dynamic state enabled then
  `vkCmdSetRepresentativeFragmentTestEnableNV` **must** have been called in the current command
  buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08682**
  If the `representativeFragmentTest` feature is enabled, and a shader object is bound to any
  graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current
  command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRepresentativeFragmentTestEnableNV` **must** have been called in the current command
  buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07649**
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV` dynamic state enabled then
  `vkCmdSetCoverageReductionModeNV` **must** have been called in the current command
  buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08683**
  If the `coverageReductionMode` feature is enabled, and a shader object is bound to any graphics
  stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current
  command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageReductionModeNV` **must** have been called in the current command
  buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-pColorBlendEnables-07470**
  If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT state enabled and the last call to vkCmdSetColorBlendEnableEXT set pColorBlendEnables for any attachment to VK_TRUE, then for those attachments in the subpass the corresponding image view’s format features must contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-rasterizationSamples-07471
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT must follow the rules for a zero-attachment subpass

• VUID-vkCmdDrawMeshTasksIndirectCountNV-samples-07472
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_MASK_EXT state enabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state disabled, then the samples parameter in the last call to vkCmdSetSampleMaskEXT must be greater or equal to the VkPipelineMultisampleStateCreateInfo::rasterizationSamples parameter used to create the bound graphics pipeline

• VUID-vkCmdDrawMeshTasksIndirectCountNV-samples-07473
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_MASK_EXT state and VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT states enabled, then the samples parameter in the last call to vkCmdSetSampleMaskEXT must be greater or equal to the rasterizationSamples parameter in the last call to vkCmdSetRasterizationSamplesEXT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-rasterizationSamples-07474
  If the bound graphics pipeline state was created with the VK_AMD_mixed_attachment_samples or the VK_NV_framebuffer_mixed_samples extensions are enabled, then the rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT must be the same as the current subpass color and/or depth/stencil attachments

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-09211
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a VkMultisampledRenderToSingleSampledInfoEXT structure with multisampledRenderToSingleSampledEnable equal to VK_TRUE, then the rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT must be the same as the rasterizationSamples member of that structure

• VUID-vkCmdDrawMeshTasksIndirectCountNV-firstAttachment-07476
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendEnableEXT calls must specify an enable for all active color attachments in the current subpass
• VUID-vkCmdDrawMeshTasksIndirectCountNV-firstAttachment-07477
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEquationEXT` calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-firstAttachment-07478
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorWriteMaskEXT` calls must specify the color write mask for all active color attachments in the current subpass.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-firstAttachment-07479
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendAdvancedEXT` calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-advancedBlendMaxColorAttachments-07480
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` and `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic states enabled and the last calls to `vkCmdSetColorBlendEnableEXT` and `vkCmdSetColorBlendAdvancedEXT` have enabled advanced blending, then the number of active color attachments in the current subpass must not exceed `advancedBlendMaxColorAttachments`.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-primitivesGeneratedQueryWithNonZeroStreams-07481
If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, and the bound graphics pipeline was created with `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` state enabled, the last call to `vkCmdSetRasterizationStreamEXT` must have set the `rasterizationStream` to zero.

• VUID-vkCmdDrawMeshTasksIndirectCountNV-sampleLocationsPerPixel-07482
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` parameter of the last call to `vkCmdSetRasterizationSamplesEXT`.

If the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and `sampleLocationsEnable was VK_TRUE in the last call to `vkCmdSetSampleLocationsEnableEXT`, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable was VK_TRUE in the last call to `vkCmdSetSampleLocationsEnableEXT`, then the `sampleLocationsInfo.sampleLocationGridSize.width` in the last call to `vkCmdSetSampleLocationsEXT` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.width` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling `rasterizationSamples`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable was VK_TRUE in the last call to `vkCmdSetSampleLocationsEnableEXT`, then the `sampleLocationsInfo.sampleLocationGridSize.height` in the last call to `vkCmdSetSampleLocationsEXT` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.height` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling `rasterizationSamples`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable was VK_TRUE in the last call to `vkCmdSetSampleLocationsEnableEXT`, the fragment shader code must not statically use the extended instruction `InterpolateAtSample`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.width` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.width` as returned by...
vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawMeshTasksIndirectCountNV-sampleLocationsEnable-07937
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.height must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawMeshTasksIndirectCountNV-sampleLocationsEnable-07938
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationsPerPixel must equal rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawMeshTasksIndirectCountNV-coverageModulationTableEnable-07488
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV state enabled and the last call to vkCmdSetCoverageModulationTableEnableNV set coverageModulationTableEnable to VK_TRUE, then the current subpass must equal the current rasterizationSamples divided by the number of color samples in the current subpass

- VUID-vkCmdDrawMeshTasksIndirectCountNV-rasterizationSamples-07489
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current rasterizationSamples must be the same as the sample count of the depth/stencil attachment

- VUID-vkCmdDrawMeshTasksIndirectCountNV-coverageToColorEnable-07490
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV state enabled and the last call to vkCmdSetCoverageToColorEnableNV set the coverageToColorEnable to VK_TRUE, then the current subpass must have a color attachment at the location selected by the last call to vkCmdSetCoverageToColorLocationNV coverageToColorLocation, with a VkFormat of VK_FORMAT_R8_UINT, VK_FORMAT_R8_SINT, VK_FORMAT_R16_UINT, VK_FORMAT_R16_SINT, VK_FORMAT_R32_UINT, or VK_FORMAT_R32_SINT

- VUID-vkCmdDrawMeshTasksIndirectCountNV-coverageReductionMode-07491
  If this VK_NV_coverage_reduction_mode extension is enabled, the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV and VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT states enabled, the current coverage reduction mode coverageReductionMode, then the current rasterizationSamples, and the
sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-viewportCount-07492**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic state enabled, then the bound graphics pipeline must have been created with VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-viewportCount-07493**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic states enabled then the viewportCount parameter in the last call to vkCmdSetViewportSwizzleNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-rasterizationSamples-07494**
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and if the current subpass has any color attachments and rasterizationSamples of the last call to vkCmdSetRasterizationSamplesEXT is greater than the number of color samples, then the pipeline sampleShadingEnable must be VK_FALSE

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-stippledLineEnable-07495**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT, then the stippledRectangularLines feature must be enabled

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-stippledLineEnable-07496**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT, then the stippledBresenhamLines feature must be enabled

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-stippledLineEnable-07497**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT, then the stippledSmoothLines feature must be enabled

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-stippledLineEnable-07498**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_BRESENHAM_SMOOTH_EXT, then the stippledBresenhamSmoothLines feature must be enabled
VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT, then the stippledRectangularLines feature must be enabled and VkPhysicalDeviceLimits::strictLines must be VK_TRUE

• VUID-vkCmdDrawMeshTasksIndirectCountNV-conservativePointAndLineRasterization-07499
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT dynamic state enabled, conservativePointAndLineRasterization is not supported, and the effective primitive topology output by the last pre-rasterization shader stage is a line or point, then the conservativeRasterizationMode set by the last call to vkCmdSetConservativeRasterizationModeModeEXT must be VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-stage-07073
  If the currently bound pipeline was created with the VkPipelineShaderStageCreateInfo::stage member of an element of VkGraphicsPipelineCreateInfo::pStages set to VK_SHADER_STAGE_VERTEX_BIT, VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT, VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT, then Mesh Shader Queries must not be active

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08877
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT dynamic state vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07850
  If dynamic state was inherited from VkCommandBufferInheritanceViewportScissorInfoNV, it must be set in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08684
  If there is no bound graphics pipeline, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_VERTEX_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08685
  If there is no bound graphics pipeline, and the tessellationShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08686
  If there is no bound graphics pipeline, and the tessellationShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08687
  If there is no bound graphics pipeline, and the geometryShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_GEOMETRY_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08688
If there is no bound graphics pipeline, \texttt{vkCmdBindShadersEXT} \textbf{must} have been called in the current command buffer with \texttt{pStages} with an element of \texttt{VK_SHADER_STAGE_FRAGMENT_BIT}

- \textbf{VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08689}
  If there is no bound graphics pipeline, and the \texttt{taskShader} feature is enabled, \texttt{vkCmdBindShadersEXT} \textbf{must} have been called in the current command buffer with \texttt{pStages} with an element of \texttt{VK_SHADER_STAGE_TASK_BIT_EXT}

- \textbf{VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08690}
  If there is no bound graphics pipeline, and the \texttt{meshShader} feature is enabled, \texttt{vkCmdBindShadersEXT} \textbf{must} have been called in the current command buffer with \texttt{pStages} with an element of \texttt{VK_SHADER_STAGE_MESH_BIT_EXT}

- \textbf{VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08693}
  If there is no bound graphics pipeline, and at least one of the \texttt{taskShader} and \texttt{meshShader} features is enabled, one of the \texttt{VK_SHADER_STAGE_VERTEX_BIT} or \texttt{VK_SHADER_STAGE_MESH_BIT_EXT} stages \textbf{must} have a valid \texttt{VkShaderEXT} bound, and the other \textbf{must} have no \texttt{VkShaderEXT} bound

- \textbf{VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08694}
  If there is no bound graphics pipeline, and both the \texttt{taskShader} and \texttt{meshShader} features are enabled, and a valid \texttt{VkShaderEXT} is bound to the \texttt{VK_SHADER_STAGE_MESH_BIT_EXT} stage, and that \texttt{VkShaderEXT} was created without the \texttt{VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT} flag, a valid \texttt{VkShaderEXT} \textbf{must} be bound to the \texttt{VK_SHADER_STAGE_TASK_BIT_EXT} stage

- \textbf{VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08695}
  If there is no bound graphics pipeline, and both the \texttt{taskShader} and \texttt{meshShader} features are enabled, and a valid \texttt{VkShaderEXT} is bound to the \texttt{VK_SHADER_STAGE_MESH_BIT_EXT} stage, and that \texttt{VkShaderEXT} was created with the \texttt{VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT} flag, there \textbf{must} be no \texttt{VkShaderEXT} bound to the \texttt{VK_SHADER_STAGE_TASK_BIT_EXT} stage

- \textbf{VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08696}
  If there is no bound graphics pipeline, and a valid \texttt{VkShaderEXT} is bound to the \texttt{VK_SHADER_STAGE_VERTEX_BIT} stage, there \textbf{must} be no \texttt{VkShaderEXT} bound to either the \texttt{VK_SHADER_STAGE_TASK_BIT_EXT} stage or the \texttt{VK_SHADER_STAGE_MESH_BIT_EXT} stage

- \textbf{VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08698}
  If any graphics shader is bound which was created with the \texttt{VK_SHADER_CREATE_LINK_STAGE_BIT_EXT} flag, then all shaders created with the \texttt{VK_SHADER_CREATE_LINK_STAGE_BIT_EXT} flag in the same \texttt{vkCreateShadersEXT} call \textbf{must} also be bound

- \textbf{VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08699}
  If any graphics shader is bound which was created with the \texttt{VK_SHADER_CREATE_LINK_STAGE_BIT_EXT} flag, any stages in between stages whose shaders which did not create a shader with the \texttt{VK_SHADER_CREATE_LINK_STAGE_BIT_EXT} flag as part of the same \texttt{vkCreateShadersEXT} call \textbf{must} not have any \texttt{VkShaderEXT} bound

- \textbf{VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08878}
  All bound graphics shader objects \textbf{must} have been created with identical or identically defined push constant ranges

- \textbf{VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08879}
All bound graphics shader objects must have been created with identical or identically defined arrays of descriptor set layouts

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-08880**
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage and the attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-pDynamicStates-08715**
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable parameter in the last call to vkCmdSetDepthWriteEnable must be VK_FALSE.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-pDynamicStates-08716**
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_STENCIL_WRITE_MASK set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpStencilAttachmentReadEXT, the writeMask parameter in the last call to vkCmdSetStencilWriteMask must be 0.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-09116**
  If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT, and the format of any color attachment is VK_FORMAT_E5B9G9R9_UFLOAT_PACK32, the corresponding element of the pColorWriteMasks parameter of vkCmdSetColorWriteMaskEXT must either include all of VK_COLOR_COMPONENT_R_BIT, VK_COLOR_COMPONENT_G_BIT, and VK_COLOR_COMPONENT_B_BIT, or none of them.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-maxFragmentDualSrcAttachments-09239**
  If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of Location for any output attachment statically used in the Fragment Execution Model executed by this command must be less than maxFragmentDualSrcAttachments.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-stage-06480**
  The bound graphics pipeline must not have been created with the VkPipelineShaderStageCreateInfo::stage member of an element of VkGraphicsPipelineCreateInfo::pStages set to VK_SHADER_STAGE_VERTEX_BIT, VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT, VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07074**
  Transform Feedback Queries must not be active.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-None-07075**
  Primitives Generated Queries must not be active.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-pipelineStatistics-07076**
  The pipelineStatistics member used to create any active Pipeline Statistics Query must
not contain
VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_VERTICES_BIT,
VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_PRIMITIVES_BIT,
VK_QUERY_PIPELINE_STATISTIC_VERTEX_SHADER_INVOCATIONS_BIT,
VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_INVOCATIONS_BIT,
VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_PRIMITIVES_BIT,
VK_QUERY_PIPELINE_STATISTIC_CLIPPING_INVOCATIONS_BIT,
VK_QUERY_PIPELINE_STATISTIC_CLIPPING_PRIMITIVES_BIT,
VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_CONTROL_SHADER_PATCHES_BIT,
or
VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_EVALUATION_SHADER_INVOCATIONS_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountNV-buffer-02708
  If buffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

• VUID-vkCmdDrawMeshTasksIndirectCountNV-buffer-02709
  buffer must have been created with the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT bit set

• VUID-vkCmdDrawMeshTasksIndirectCountNV-offset-02710
  offset must be a multiple of 4

• VUID-vkCmdDrawMeshTasksIndirectCountNV-commandBuffer-02711
  commandBuffer must not be a protected command buffer

• VUID-vkCmdDrawMeshTasksIndirectCountNV-countBuffer-02714
  If countBuffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

• VUID-vkCmdDrawMeshTasksIndirectCountNV-countBuffer-02715
  countBuffer must have been created with the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT bit set

• VUID-vkCmdDrawMeshTasksIndirectCountNV-countBufferOffset-02716
  countBufferOffset must be a multiple of 4

• VUID-vkCmdDrawMeshTasksIndirectCountNV-countBuffer-02717
  The count stored in countBuffer must be less than or equal to VkPhysicalDeviceLimits::maxDrawIndirectCount

• VUID-vkCmdDrawMeshTasksIndirectCountNV-countBufferOffset-04129
  (countBufferOffset + sizeof(uint32_t)) must be less than or equal to the size of countBuffer

• VUID-vkCmdDrawMeshTasksIndirectCountNV-None-04445
  If drawIndirectCount is not enabled this function must not be used

• VUID-vkCmdDrawMeshTasksIndirectCountNV-stride-02182
  stride must be a multiple of 4 and must be greater than or equal to sizeof(VkDrawMeshTasksIndirectCommandNV)

• VUID-vkCmdDrawMeshTasksIndirectCountNV-maxDrawCount-02183
  If maxDrawCount is greater than or equal to 1, (stride \times (maxDrawCount - 1) + offset + sizeof(VkDrawMeshTasksIndirectCommandNV)) must be less than or equal to the size of buffer

• VUID-vkCmdDrawMeshTasksIndirectCountNV-countBuffer-02191
  If the count stored in countBuffer is equal to 1, (offset + sizeof(VkDrawMeshTasksIndirectCommandNV)) must be less than or equal to the size of buffer
If the count stored in `countBuffer` is greater than 1, \((\text{stride} \times (\text{drawCount} - 1) + \text{offset} + \text{sizeof}(\text{VkDrawMeshTasksIndirectCommandNV}))\) must be less than or equal to the size of `buffer`.

The current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` must contain a shader stage using the `MeshNV Execution Model`.

### Valid Usage (Implicit)

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-commandBuffer-parameter**
  - `commandBuffer` must be a valid `VkCommandBuffer` handle.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-buffer-parameter**
  - `buffer` must be a valid `VkBuffer` handle.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-countBuffer-parameter**
  - `countBuffer` must be a valid `VkBuffer` handle.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-commandBuffer-recording**
  - `commandBuffer` must be in the recording state.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-renderpass**
  - The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-videocoding**
  - This command must only be called inside of a render pass instance.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-videoencoding**
  - This command must only be called outside of a video coding scope.

- **VUID-vkCmdDrawMeshTasksIndirectCountNV-commonparent**
  - Each of `buffer`, `commandBuffer`, and `countBuffer` must have been created, allocated, or retrieved from the same `VkDevice`.

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

### Command Properties

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To record a mesh tasks drawing command, call:

```c
// Provided by VK_EXT_mesh_shader
void vkCmdDrawMeshTasksEXT(
    VkCommandBuffer commandBuffer,
    uint32_t groupCountX,
    uint32_t groupCountY,
    uint32_t groupCountZ);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `groupCountX` is the number of local workgroups to dispatch in the X dimension.
- `groupCountY` is the number of local workgroups to dispatch in the Y dimension.
- `groupCountZ` is the number of local workgroups to dispatch in the Z dimension.

When the command is executed, a global workgroup consisting of `groupCountX × groupCountY × groupCountZ` local workgroups is assembled.

### Valid Usage

- **VUID-vkCmdDrawMeshTasksEXT-magFilter-04553**
  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`.

- **VUID-vkCmdDrawMeshTasksEXT-mipmapMode-04770**
  If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`.

- **VUID-vkCmdDrawMeshTasksEXT-None-06479**
  If a `VkImageView` is sampled with depth comparison, the image view's format features must contain `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT`.

- **VUID-vkCmdDrawMeshTasksEXT-None-02691**
  If a `VkImageView` is accessed using atomic operations as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT`.

- **VUID-vkCmdDrawMeshTasksEXT-None-07888**
  If a `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER` descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain `VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT`.

- **VUID-vkCmdDrawMeshTasksEXT-None-02692**
  If a `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`.
If the `VK_EXT_filter_cubic` extension is not enabled and any `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, it must not have a `VkImageViewType` of `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`.

Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` and a reduction mode of either `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering together with minmax filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

If the `cubicRangeClamp` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must not have a `VkSamplerReductionModeCreateInfo reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`.

Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`.

Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

For any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command, the view’s format features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

For any `VkImage` being written as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view’s format features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

For any `VkImage` being read as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view’s format features must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`.

If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`.
For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view's buffer features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`

- VUID-vkCmdDrawMeshTasksEXT-OpTypeImage-07030
  Any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown` then the view's buffer features must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`

- VUID-vkCmdDrawMeshTasksEXT-None-08600
  For each set `n` that is statically used by a bound shader, a descriptor set must have been bound to `n` at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set `n`, with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMeshTasksEXT-None-08601
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMeshTasksEXT-maintenance4-08602
  If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMeshTasksEXT-None-08114
  Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, must be valid if they are statically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was not created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDrawMeshTasksEXT-None-08115
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` must have been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDrawMeshTasksEXT-None-08116
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDrawMeshTasksEXT-None-08604
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command
• VUID-vkCmdDrawMeshTasksEXT-None-08117
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdSetDescriptorBufferOffsetsEXT, the bound VkPipeline must have been created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT.

• VUID-vkCmdDrawMeshTasksEXT-None-08119
  If a descriptor is dynamically used with a VkPipeline created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident.

• VUID-vkCmdDrawMeshTasksEXT-None-08605
  If a descriptor is dynamically used with a VkShaderEXT created with a VkDescriptorSetLayout that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident.

• VUID-vkCmdDrawMeshTasksEXT-None-08606
  If the shaderObject feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command.

• VUID-vkCmdDrawMeshTasksEXT-None-08607
  If the shaderObject is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and VK_NULL_HANDLE shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command.

• VUID-vkCmdDrawMeshTasksEXT-None-08608
  If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the VkPipeline object bound to the pipeline bind point used by this command, since that pipeline was bound.

• VUID-vkCmdDrawMeshTasksEXT-None-08609
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used to sample from any VkImage with a VkImageView of the type VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY, VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage.

• VUID-vkCmdDrawMeshTasksEXT-None-08610
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage.

• VUID-vkCmdDrawMeshTasksEXT-None-08611
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage.
If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource.

If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y′C′ aCr conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions.

If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y′C′ aCr conversion, that object must not use the ConstOffset and Offset operands.

If a VkImageView is accessed as a result of this command, then the image view's viewType must match the Dim operand of the OpTypeImage as described in Instruction/Sampler/Image View Validation.

If a VkImageView is accessed as a result of this command, then the numeric type of the image view's format and the Sampled Type operand of the OpTypeImage must match.
If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have at least as many components as the image view’s format.

- **VUID-vkCmdDrawMeshTasksEXT-OpImageWrite-08796**
  If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have four components.

- **VUID-vkCmdDrawMeshTasksEXT-OpImageWrite-04469**
  If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have at least as many components as the buffer view’s format.

- **VUID-vkCmdDrawMeshTasksEXT-SampledType-04470**
  If a `VkImage` view with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64.

- **VUID-vkCmdDrawMeshTasksEXT-SampledType-04471**
  If a `VkImage` view with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 32.

- **VUID-vkCmdDrawMeshTasksEXT-SampledType-04472**
  If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64.

- **VUID-vkCmdDrawMeshTasksEXT-SampledType-04473**
  If a `VkBufferView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 32.

- **VUID-vkCmdDrawMeshTasksEXT-sparseImageInt64Atomics-04474**
  If the `sparseImageInt64Atomics` feature is not enabled, `VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

- **VUID-vkCmdDrawMeshTasksEXT-sparseImageInt64Atomics-04475**
  If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

- **VUID-vkCmdDrawMeshTasksEXT-OpImageWeightedSampleQCOM-06971**
  If `OpImageWeightedSampleQCOM` is used to sample a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`.

- **VUID-vkCmdDrawMeshTasksEXT-OpImageWeightedSampleQCOM-06972**
  If `OpImageWeightedSampleQCOM` uses a `VkImageView` as a sample weight image as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`. 
If `OpImageBoxFilterQCOM` is used to sample a `VkImageView` as a result of this command, then the image view’s format features **must** contain `VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM`.

If `OpImageBlockMatchSSDQCOM` is used to read from an `VkImageView` as a result of this command, then the image view’s format features **must** contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

If `OpImageBlockMatchSADQCOM` is used to read from an `VkImageView` as a result of this command, then the image view’s format features **must** contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

If `OpImageBlockMatchSSDQCOM` or `OpImageBlockMatchSADQCOM` is used to read from a reference image as result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation.

If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler **must** have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSADQCOM`, or `OpImageBlockMatchSSDQCOM` uses a `VkSampler` as a result of this command, then the sampler **must** not have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

If an `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view’s format **must** contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

If an `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view’s format **must** be a single-component format.

If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from a reference image as result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation.

Any shader invocation executed by this command **must** terminate.
The current render pass must be compatible with the renderPass member of the VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdDrawMeshTasksEXT-subpass-02685
  The subpass index of the current render pass must be equal to the subpass member of the VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdDrawMeshTasksEXT-None-07748
  If any shader statically accesses an input attachment, a valid descriptor must be bound to the pipeline via a descriptor set

- VUID-vkCmdDrawMeshTasksEXT-OpTypeImage-07468
  If any shader executed by this pipeline accesses an OpTypeImage variable with a Dim operand of SubpassData, it must be decorated with an InputAttachmentIndex that corresponds to a valid input attachment in the current subpass

- VUID-vkCmdDrawMeshTasksEXT-None-07469
  Input attachment views accessed in a subpass must be created with the same VkFormat as the corresponding subpass definition, and be created with a VkImageView that is compatible with the attachment referenced by the subpass' pInputAttachments [InputAttachmentIndex] in the currently bound VkFramebuffer as specified by Fragment Input Attachment Compatibility

- VUID-vkCmdDrawMeshTasksEXT-None-06537
  Memory backing image subresources used as attachments in the current render pass must not be written in any way other than as an attachment by this command

- VUID-vkCmdDrawMeshTasksEXT-None-09000
  If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:
  - the VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
  - the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_COLOR_BIT and
    - there is no currently bound graphics pipeline or
    - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawMeshTasksEXT-None-09001
  If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:
  - the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
  - the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_DEPTH_BIT and
There is no currently bound graphics pipeline or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` feature. It must not be accessed in any way other than as an attachment by this command.

**VUID-vkCmdDrawMeshTasksEXT-None-09002**

If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:

- the `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
- the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_STENCIL_BIT` and
  - there is no currently bound graphics pipeline or
  - the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` feature. It must not be accessed in any way other than as an attachment by this command.

**VUID-vkCmdDrawMeshTasksEXT-None-09003**

If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command.

**VUID-vkCmdDrawMeshTasksEXT-None-06539**

If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command must not write to that image subresource as an attachment.

**VUID-vkCmdDrawMeshTasksEXT-None-06886**

If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, depth writes must be disabled.

**VUID-vkCmdDrawMeshTasksEXT-None-06887**

If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back writeMask are not zero, and stencil test is enabled, all stencil ops must be `VK_STENCIL_OP_KEEP`.

**VUID-vkCmdDrawMeshTasksEXT-None-07831**

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT` dynamic state enabled then `vkCmdSetViewport` must have been called in the current command buffer prior to this drawing command.

**VUID-vkCmdDrawMeshTasksEXT-None-07832**

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SCISSOR` dynamic state enabled then `vkCmdSetScissor` must have been called in the current command buffer prior to this drawing command.

**VUID-vkCmdDrawMeshTasksEXT-None-07833**

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_WIDTH` dynamic state enabled then `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command.
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command.

If a shader object that outputs line primitives is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` or `VK_SHADER_STAGE_GEOMETRY_BIT` stage, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BIAS` dynamic state enabled then `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthBiasEnable` in the current command buffer set `depthBiasEnable` to `VK_TRUE`, `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_BLEND_CONSTANTS` dynamic state enabled then `vkCmdSetBlendConstants` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer set any element of `pColorBlendEnables` to `VK_TRUE`, and the most recent call to `vkCmdSetColorBlendEquationEXT` in the current command buffer set the same element of `pColorBlendEquations` to a `VkColorBlendEquationEXT` structure with any `VkBlendFactor` member with a value of `VK_BLEND_FACTOR_CONSTANT_COLOR`, `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR`, `VK_BLEND_FACTOR_CONSTANT_ALPHA`, or `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA`, `vkCmdSetBlendConstants` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS` dynamic state enabled then `vkCmdSetDepthBounds` must have been called in the current command buffer prior to this drawing command.
• VUID-vkCmdDrawMeshTasksEXT-None-08622
  If a shader object is bound to any graphics stage, and the most recent call to
  `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
  `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to
  `vkCmdSetDepthBoundsTestEnable` in the current command buffer set
  `depthBoundsTestEnable` to `VK_TRUE`, then `vkCmdSetDepthBounds` must have been called in
  the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksEXT-None-07837
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK` dynamic state enabled then
  `vkCmdSetStencilCompareMask` must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdDrawMeshTasksEXT-None-08623
  If a shader object is bound to any graphics stage, and the most recent call to
  `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to
  `VK_TRUE`, `vkCmdSetStencilCompareMask` must have been called in the current command
  buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksEXT-None-07838
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_STENCIL_WRITE_MASK` dynamic state enabled then
  `vkCmdSetStencilWriteMask` must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdDrawMeshTasksEXT-None-08624
  If a shader object is bound to any graphics stage, and the most recent call to
  `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to
  `VK_TRUE`, `vkCmdSetStencilWriteMask` must have been called in the current command
  buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksEXT-None-07839
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_STENCIL_REFERENCE` dynamic state enabled then
  `vkCmdSetStencilReference` must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdDrawMeshTasksEXT-None-08625
  If a shader object is bound to any graphics stage, and the most recent call to
  `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to
  `VK_TRUE`, `vkCmdSetStencilReference` must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdDrawMeshTasksEXT-maxMultiviewInstanceIndex-02688
  If the draw is recorded in a render pass instance with multiview enabled, the maximum
  instance index must be less than or equal to `VkPhysicalDeviceMultiviewProperties`
  `::maxMultiviewInstanceIndex`

• VUID-vkCmdDrawMeshTasksEXT-sampleLocationsEnable-02689
  If the bound graphics pipeline was created with
 VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable set to VK_TRUE and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set

- VUID-vkCmdDrawMeshTasksEXT-None-06666
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT dynamic state enabled then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-None-08626
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetSampleLocationsEnableEXT in the current command buffer set sampleLocationsEnable to VK_TRUE, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-None-07934
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples member of the VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with

- VUID-vkCmdDrawMeshTasksEXT-None-07840
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CULL_MODE dynamic state enabled then vkCmdSetCullMode must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-None-08627
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCullMode must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-None-07841
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_FRONT_FACE dynamic state enabled then vkCmdSetFrontFace must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-None-08628
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetFrontFace must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-None-07843
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE dynamic state enabled then vkCmdSetDepthTestEnable must have been called in the current command buffer prior to this drawing command
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` dynamic state enabled then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP` dynamic state enabled then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthTestEnable` in the current command buffer set `depthTestEnable` to `VK_TRUE`, then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the `depthBounds` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE` dynamic state enabled then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_OP` dynamic state enabled then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `VkPipelineViewportStateCreateInfo`::`viewportCount` of the pipeline.

If the bound graphics pipeline state was created with both the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic states enabled then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `viewportCount` parameter of `vkCmdSetScissorWithCount`.

If a shader object is bound to any graphics stage, then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `viewportCount` parameter of `vkCmdSetScissorWithCount`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic state enabled, then the bound graphics
pipeline **must** have been created with `VkPipelineViewportWScalingStateCreateInfoNV` `viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksEXT-viewportCount-04138**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` **must** be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksEXT-None-08636**
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then `vkCmdSetViewportWScalingNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksEXT-None-08636**
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` **must** be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksEXT-viewportCount-04139**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic state enabled, then the bound graphics pipeline **must** have been created with `VkPipelineViewportShadingRateImageStateCreateInfoNV` `viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksEXT-viewportCount-04140**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` **must** be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksEXT-shadingRateImage-09233**
  If the `shadingRateImage` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoarseSampleOrderNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksEXT-shadingRateImage-09234**
  If a shader object is bound to any graphics stage, and the `shadingRateImage` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetShadingRateImageEnableNV` in the current command buffer set `shadingRateImageEnable` to `VK_TRUE`, then `vkCmdSetViewportShadingRatePaletteNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksEXT-None-08637**
If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, then the viewportCount parameter in the last call to vkCmdSetViewportShadingRatePaletteNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

- VUID-vkCmdDrawMeshTasksEXT-VkPipelineViewportCreateInfo-04141
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled and a VkPipelineViewportSwizzleStateCreateInfoNV structure chained from VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have been created with VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

- VUID-vkCmdDrawMeshTasksEXT-VkPipelineViewportCreateInfo-04142
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled and a VkPipelineViewportExclusiveScissorStateCreateInfoNV structure chained from VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have been created with VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

- VUID-vkCmdDrawMeshTasksEXT-None-07878
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV dynamic state enabled then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-None-07879
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV dynamic state enabled then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-exclusiveScissor-09235
  If a shader object is bound to any graphics stage, and the exclusiveScissor feature is enabled, then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-None-08638
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetExclusiveScissorEnableNV in the current command buffer set any element of pExclusiveScissorEnables to VK_TRUE, then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-None-04876
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE dynamic state enabled then vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-None-08639
  If a shader object is bound to any graphics stage, then vkCmdSetRasterizerDiscardEnable
must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-None-04877
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE dynamic state enabled then vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-None-08640
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-logicOp-04878
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_EXT dynamic state enabled then vkCmdSetLogicOpEXT must have been called in the current command buffer prior to this drawing command and the logicOp must be a valid VkLogicOp value

- VUID-vkCmdDrawMeshTasksEXT-None-08641
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the logicOp feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEXT must have been called in the current command buffer prior to this drawing command and the logicOp must be a valid VkLogicOp value

- VUID-vkCmdDrawMeshTasksEXT-primitiveFragmentShadingRateWithMultipleViewports-04552
  If the primitiveFragmentShadingRateWithMultipleViewports limit is not supported, the bound graphics pipeline was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the PrimitiveShadingRateKHR built-in, then vkCmdSetViewportWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must be 1

- VUID-vkCmdDrawMeshTasksEXT-primitiveFragmentShadingRateWithMultipleViewports-08642
  If the primitiveFragmentShadingRateWithMultipleViewports limit is not supported, and any shader object bound to a graphics stage writes to the PrimitiveShadingRateKHR built-in, then vkCmdSetViewportWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must be 1

- VUID-vkCmdDrawMeshTasksEXT-blendEnable-04727
  If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view’s format features do not contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT, then the blendEnable member of the corresponding element of the pAttachments member of pColorBlendState must be VK_FALSE

- VUID-vkCmdDrawMeshTasksEXT-None-08643
If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then for each color attachment in the render pass, if the corresponding image view’s \textit{format features} do not contain \texttt{VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT}, then the corresponding member of \texttt{pColorBlendEnables} in the most recent call to \texttt{vkCmdSetColorBlendEnableEXT} in the current command buffer that affected that attachment index \textbf{must} have been \texttt{VK_FALSE}.

- **VUID-vkCmdDrawMeshTasksEXT-multisampledRenderToSingleSampled-07284**
  If rasterization is not disabled in the bound graphics pipeline, and none of the \texttt{VK_AMD_mixed_attachment_samples} extension, the \texttt{VK_NV_framebuffer_mixed_samples} extension, or the \texttt{multisampledRenderToSingleSampled} feature is enabled, then \texttt{rasterizationSamples} for the currently bound graphics pipeline \textbf{must} be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawMeshTasksEXT-None-08644**
  If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, and none of the \texttt{VK_AMD_mixed_attachment_samples} extension, the \texttt{VK_NV_framebuffer_mixed_samples} extension, or the \texttt{multisampledRenderToSingleSampled} feature is enabled, then the most recent call to \texttt{vkCmdSetRasterizationSamplesEXT} in the current command buffer \textbf{must} have set \texttt{rasterizationSamples} to be the same as the number of samples for the current render pass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawMeshTasksEXT-None-08876**
  If a shader object is bound to any graphics stage, the current render pass instance \textbf{must} have been begun with \texttt{vkCmdBeginRendering}.

- **VUID-vkCmdDrawMeshTasksEXT-imageView-06172**
  If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{imageView} member of \texttt{pDepthAttachment} is not \texttt{VK_NULL_HANDLE}, and the \texttt{layout} member of \texttt{pDepthAttachment} is \texttt{VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL}, this command \textbf{must} not write any values to the depth attachment.

- **VUID-vkCmdDrawMeshTasksEXT-imageView-06173**
  If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{imageView} member of \texttt{pStencilAttachment} is not \texttt{VK_NULL_HANDLE}, and the \texttt{layout} member of \texttt{pStencilAttachment} is \texttt{VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL}, this command \textbf{must} not write any values to the stencil attachment.

- **VUID-vkCmdDrawMeshTasksEXT-imageView-06174**
  If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{imageView} member of \texttt{pDepthAttachment} is not \texttt{VK_NULL_HANDLE}, and the \texttt{layout} member of \texttt{pDepthAttachment} is \texttt{VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL}, this command \textbf{must} not write any values to the depth attachment.

- **VUID-vkCmdDrawMeshTasksEXT-imageView-06175**
  If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{imageView} member of \texttt{pStencilAttachment} is not \texttt{VK_NULL_HANDLE}, and the \texttt{layout} member of \texttt{pStencilAttachment} is \texttt{VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL}, this command \textbf{must} not write any values to the stencil attachment.
If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo::viewMask` equal to `VkRenderingInfo::viewMask`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo::colorAttachmentCount` equal to `VkRenderingInfo::colorAttachmentCount`.

If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline.

If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`.

If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` must have the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`.

If the bound graphics pipeline state was created with the...
• VUID-vkCmdDrawMeshTasksEXT-None-08646
If the colorWriteEnable feature is enabled on the device, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorWriteEnableEXT must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksEXT-attachmentCount-07750
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT dynamic state enabled then the attachmentCount parameter of vkCmdSetColorWriteEnableEXT must be greater than or equal to the VkPipelineColorBlendStateCreateInfo::attachmentCount of the currently bound graphics pipeline.

• VUID-vkCmdDrawMeshTasksEXT-None-08647
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT dynamic state enabled then the attachmentCount parameter of most recent call to vkCmdSetColorWriteEnableEXT in the current command buffer must be greater than or equal to the number of color attachments in the current render pass instance.

• VUID-vkCmdDrawMeshTasksEXT-None-07751
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT dynamic state enabled then vkCmdSetDiscardRectangleEXT must have been called in the current command buffer prior to this drawing command for each discard rectangle in VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount.

• VUID-vkCmdDrawMeshTasksEXT-None-07880
If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDiscardRectangleEXT must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksEXT-rasterizerDiscardEnable-09236
If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDiscardRectangleEnableEXT must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksEXT-None-08648
If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDiscardRectangleEnableEXT must have been called in the current command buffer prior to this drawing command.
• VUID-vkCmdDrawMeshTasksEXT-None-07881
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleModeEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksEXT-None-08649
If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDiscardRectangleEnableEXT` in the current command buffer set `discardRectangleEnable` to `VK_TRUE`, then `vkCmdSetDiscardRectangleModeEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksEXT-dynamicRenderingUnusedAttachments-08913
If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline must be equal to `VK_FORMAT_UNDEFINED`

• VUID-vkCmdDrawMeshTasksEXT-dynamicRenderingUnusedAttachments-08914
If current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline must be equal to the `VkFormat` used to create `VkRenderingInfo::pDepthAttachment->imageView`

• VUID-vkCmdDrawMeshTasksEXT-dynamicRenderingUnusedAttachments-08915
If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo::pDepthAttachment->imageView`, the value of the format must be `VK_FORMAT_UNDEFINED`

• VUID-vkCmdDrawMeshTasksEXT-dynamicRenderingUnusedAttachments-08916
If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to `VK_FORMAT_UNDEFINED`

• VUID-vkCmdDrawMeshTasksEXT-dynamicRenderingUnusedAttachments-08917
If current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to the `VkFormat` used to create `VkRenderingInfo::pStencilAttachment->imageView`
If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pStencilAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED.

If the current render pass instance was begun with vkCmdBeginRendering and VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR.

If the current render pass instance was begun with vkCmdBeginRendering and VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT.

If the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a sample count equal to the corresponding element of the pColorAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline.

If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of the depthStencilAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline must be equal to the sample count used to create VkRenderingInfo::pDepthAttachment->imageView.

If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, the value of the depthStencilAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline must be equal to the sample count used to create VkRenderingInfo::pStencilAttachment->imageView.

If the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and...
the multisampledRenderToSingleSampled feature is not enabled, and the current render pass instance was begun with vkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a sample count equal to the value of rasterizationSamples for the currently bound graphics pipeline.

- VUID-vkCmdDrawMeshTasksEXT-multisampledRenderToSingleSampled-07286
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of rasterizationSamples for the currently bound graphics pipeline must be equal to the sample count used to create VkRenderingInfo::pDepthAttachment->imageView.

- VUID-vkCmdDrawMeshTasksEXT-multisampledRenderToSingleSampled-07287
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled feature is not enabled, and VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, the value of rasterizationSamples for the currently bound graphics pipeline must be equal to the sample count used to create VkRenderingInfo::pStencilAttachment->imageView.

- VUID-vkCmdDrawMeshTasksEXT-pNext-07935
  If this command has been called inside a render pass instance started with vkCmdBeginRendering, and the pNext chain of VkRenderingInfo includes a VkMultisampledRenderToSingleSampledInfoEXT structure with multisampledRenderToSingleSampledEnable equal to VK_TRUE, then the value of rasterizationSamples for the currently bound graphics pipeline must be equal to VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples.

- VUID-vkCmdDrawMeshTasksEXT-renderPass-06198
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline must have been created with a VkGraphicsPipelineCreateInfo::renderPass equal to VK_NULL_HANDLE.

- VUID-vkCmdDrawMeshTasksEXT-pColorAttachments-08963
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the VkRenderingInfo::pColorAttachments->imageView was not VK_NULL_HANDLE, then the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the pipeline must not be VK_FORMAT_UNDEFINED.

- VUID-vkCmdDrawMeshTasksEXT-pDepthAttachment-08964
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, then the VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the pipeline must
not be VK_FORMAT_UNDEFINED

- **VUID-vkCmdDrawMeshTasksEXT-pStencilAttachment-08965**
  If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, stencil test is enabled and the `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the pipeline must not be VK_FORMAT_UNDEFINED

- **VUID-vkCmdDrawMeshTasksEXT-primitivesGeneratedQueryWithRasterizerDiscard-06708**
  If the `primitivesGeneratedQueryWithRasterizerDiscard` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, rasterization discard must not be enabled

- **VUID-vkCmdDrawMeshTasksEXT-primitivesGeneratedQueryWithNonZeroStreams-06709**
  If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, the bound graphics pipeline must not have been created with a non-zero value in `VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream`

- **VUID-vkCmdDrawMeshTasksEXT-None-07619**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT` dynamic state enabled then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-07620**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-09237**
  If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-08650**
  If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-07621**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-08651**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetPolygonModeEXT` must have been
called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-07622**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` dynamic state enabled then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-08652**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-07623**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` dynamic state enabled then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-08653**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-07624**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-alphaToCoverageEnable-08919**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled, and `alphaToCoverageEnable` was `VK_TRUE` in the last call to `vkCmdSetAlphaToCoverageEnableEXT`, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0

- **VUID-vkCmdDrawMeshTasksEXT-None-08654**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-alphaToCoverageEnable-08920**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetAlphaToCoverageEnableEXT` in the current command buffer set `alphaToCoverageEnable` to `VK_TRUE`, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0

- **VUID-vkCmdDrawMeshTasksEXT-None-07625**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT` dynamic state enabled then
vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksEXT-None-08655
  If the alphaToOne feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksEXT-None-07626
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT dynamic state enabled then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksEXT-None-08656
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksEXT-None-07627
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT dynamic state enabled then vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksEXT-None-08657
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksEXT-None-07628
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT dynamic state enabled then vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command.
If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` dynamic state enabled then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

If the `geometryStreams` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_GEOMETRY_BIT` stage, then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetConservativeRasterizationModeEXT` in the current command buffer set `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`, then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.
If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-07634**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-08664**
  If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-07635**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-07636**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT` dynamic state enabled then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-08665**
  If the `VK_EXT_provoking_vertex` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-07637**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-08666**
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksEXT-None-08667**
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command
If the VK_EXT_line_rasterization extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT dynamic state enabled then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the VK_EXT_line_rasterization extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to VK_POLYGON_MODE_LINE, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the VK_EXT_line_rasterization extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_EXT dynamic state enabled then `vkCmdSetLineStippleEXT` must have been called in the current command buffer prior to this drawing command.

If the VK_EXT_line_rasterization extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetLineStippleEnableEXT` in the current command buffer set `stippledLineEnable` to VK_TRUE, then `vkCmdSetLineStippleEXT` must have been called in the current command buffer prior to this drawing command.

If the depthClipControl feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV` dynamic state enabled then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_clip_space_w_scaling` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_viewport_swizzle` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set `coverageToColorEnable` to `VK_TRUE`, then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.
• **VUID-vkCmdDrawMeshTasksEXT-None-08678**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawMeshTasksEXT-None-07645**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawMeshTasksEXT-None-08679**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationModeNV` in the current command buffer set `coverageModulationMode` to any value other than `VK_COVERAGE_MODULATION_MODE_NONE_NV`, then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawMeshTasksEXT-None-07646**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawMeshTasksEXT-None-08680**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationTableEnableNV` in the current command buffer set `coverageModulationTableEnable` to `VK_TRUE`, then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawMeshTasksEXT-None-08681**
  If the `shadingRateImage` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current
command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksEXT-None-07648
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV` dynamic state enabled then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksEXT-None-08682
  If the `representativeFragmentTest` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksEXT-None-07649
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksEXT-None-08683
  If the `coverageReductionMode` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksEXT-pColorBlendEnables-07470
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` state enabled and the last call to `vkCmdSetColorBlendEnableEXT` set `pNextColorBlendEnables` for any attachment to `VK_TRUE`, then for those attachments in the subpass the corresponding image view's format features must contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`.

- VUID-vkCmdDrawMeshTasksEXT-rasterizationSamples-07471
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must follow the rules for a zero-attachment subpass.

- VUID-vkCmdDrawMeshTasksEXT-samples-07472
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `VkPipelineMultisampleStateCreateInfo::rasterizationSamples` parameter used to create the bound graphics pipeline.

- VUID-vkCmdDrawMeshTasksEXT-samples-07473
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawMeshTasksEXT-rasterizationSamples-07474**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and neither the `VK_AMD_mixed_attachment_samples` nor the `VK_NV_framebuffer_mixed_samples` extensions are enabled, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawMeshTasksEXT-None-09211**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the `rasterizationSamples` member of that structure.

- **VUID-vkCmdDrawMeshTasksEXT-firstAttachment-07476**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEnableEXT` calls must specify an enable for all active color attachments in the current subpass.

- **VUID-vkCmdDrawMeshTasksEXT-firstAttachment-07477**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEquationEXT` calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled.

- **VUID-vkCmdDrawMeshTasksEXT-firstAttachment-07478**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorWriteMaskEXT` calls must specify the color write mask for all active color attachments in the current subpass.

- **VUID-vkCmdDrawMeshTasksEXT-firstAttachment-07479**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then
vkCmdSetColorBlendAdvancedEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendAdvancedEXT calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled.

- **VUID-vkCmdDrawMeshTasksEXT-advancedBlendMaxColorAttachments-07480**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT and VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic states enabled and the last calls to vkCmdSetColorBlendEnableEXT and vkCmdSetColorBlendAdvancedEXT have enabled advanced blending, then the number of active color attachments in the current subpass must not exceed advancedBlendMaxColorAttachments.

- **VUID-vkCmdDrawMeshTasksEXT-primitivesGeneratedQueryWithNonZeroStreams-07481**
  If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, and the bound graphics pipeline was created with VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT state enabled, the last call to vkCmdSetRasterizationStreamEXT must have set the rasterizationStream to zero.

- **VUID-vkCmdDrawMeshTasksEXT-sampleLocationsPerPixel-07482**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state disabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples member of the VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with.

- **VUID-vkCmdDrawMeshTasksEXT-sampleLocationsEnable-07483**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set.

- **VUID-vkCmdDrawMeshTasksEXT-sampleLocationsEnable-07484**
  If the bound graphics pipeline was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set.

- **VUID-vkCmdDrawMeshTasksEXT-sampleLocationsEnable-07485**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the sampleLocationsInfo.sampleLocationGridSize.width in the last call to vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT.
sampleLocationGridSize.width as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples

- VUID-vkCmdDrawMeshTasksEXT-sampleLocationsEnable-07486
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the sampleLocationsInfo.sampleLocationGridSize.height in the last call to vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples

- VUID-vkCmdDrawMeshTasksEXT-sampleLocationsEnable-07487
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, the fragment shader code must not statically use the extended instruction InterpolateAtSample

- VUID-vkCmdDrawMeshTasksEXT-sampleLocationsEnable-07936
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.width must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawMeshTasksEXT-sampleLocationsEnable-07937
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.height must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawMeshTasksEXT-sampleLocationsEnable-07938
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationsPerPixel must equal rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageModulationTableEnableNV` set `coverageModulationTableEnable` to `VK_TRUE`, then the `coverageModulationTableCount` parameter in the last call to `vkCmdSetCoverageModulationTableNV` must equal the current `rasterizationSamples` divided by the number of color samples in the current subpass.

If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current `rasterizationSamples` must be the same as the sample count of the depth/stencil attachment.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageToColorEnableNV` set the `coverageToColorEnable` to `VK_TRUE`, then the current subpass must have a color attachment at the location selected by the last call to `vkCmdSetCoverageToColorLocationNV` `coverageToColorLocation`, with a `VkFormat` of `VK_FORMAT_R8_UINT`, `VK_FORMAT_R8_SINT`, `VK_FORMAT_R16_UINT`, `VK_FORMAT_R16_SINT`, `VK_FORMAT_R32_UINT`, or `VK_FORMAT_R32_SINT`.

If this `VK_NV_coverage_reduction_mode` extension is enabled, the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, the current coverage reduction mode `coverageReductionMode`, then the current `rasterizationSamples`, and the sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by `vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV` `viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportSwizzleNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if the current subpass has any color attachments and `rasterizationSamples` of the last call to `vkCmdSetRasterizationSamplesEXT` is greater than the number of color samples, then the
pipeline sampleShadingEnable must be VK_FALSE

- VUID-vkCmdDrawMeshTasksEXT-stippledLineEnable-07495
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT, then the stippledRectangularLines feature must be enabled.

- VUID-vkCmdDrawMeshTasksEXT-stippledLineEnable-07496
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT, then the stippledBresenhamLines feature must be enabled.

- VUID-vkCmdDrawMeshTasksEXT-stippledLineEnable-07497
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT, then the stippledSmoothLines feature must be enabled.

- VUID-vkCmdDrawMeshTasksEXT-stippledLineEnable-07498
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT, then the stippledRectangularLines feature must be enabled and VkPhysicalDeviceLimits::strictLines must be VK_TRUE.

- VUID-vkCmdDrawMeshTasksEXT-conservativePointAndLineRasterization-07499
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT dynamic state enabled, conservativePointAndLineRasterization is not supported, and the effective primitive topology output by the last pre-rasterization shader stage is a line or point, then the conservativeRasterizationMode set by the last call to vkCmdSetConservativeRasterizationModeEXT must be VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT.

- VUID-vkCmdDrawMeshTasksEXT-stage-07073
  If the currently bound pipeline was created with the VkPipelineShaderStageCreateInfo ::stage member of an element of VkGraphicsPipelineCreateInfo::pStages set to VK_SHADER_STAGE_VERTEX_BIT, VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT, VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT, then Mesh Shader Queries must not be active.

- VUID-vkCmdDrawMeshTasksEXT-None-08877
  If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT dynamic state
vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksEXT-None-07850
If dynamic state was inherited from VkCommandBufferInheritanceViewportScissorInfoNV, it must be set in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksEXT-None-08684
If there is no bound graphics pipeline, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_VERTEX_BIT

• VUID-vkCmdDrawMeshTasksEXT-None-08685
If there is no bound graphics pipeline, and the tessellationShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT

• VUID-vkCmdDrawMeshTasksEXT-None-08686
If there is no bound graphics pipeline, and the tessellationShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT

• VUID-vkCmdDrawMeshTasksEXT-None-08687
If there is no bound graphics pipeline, and the geometryShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_GEOMETRY_BIT

• VUID-vkCmdDrawMeshTasksEXT-None-08688
If there is no bound graphics pipeline, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_FRAGMENT_BIT

• VUID-vkCmdDrawMeshTasksEXT-None-08689
If there is no bound graphics pipeline, and the taskShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TASK_BIT_EXT

• VUID-vkCmdDrawMeshTasksEXT-None-08690
If there is no bound graphics pipeline, and the meshShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_MESH_BIT_EXT

• VUID-vkCmdDrawMeshTasksEXT-None-08693
If there is no bound graphics pipeline, and at least one of the taskShader and meshShader features is enabled, one of the VK_SHADER_STAGE_VERTEX_BIT or VK_SHADER_STAGE_MESH_BIT_EXT stages must have a valid VkShaderEXT bound, and the other must have no VkShaderEXT bound

• VUID-vkCmdDrawMeshTasksEXT-None-08694
If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_MESH_BIT_EXT stage, and that VkShaderEXT was created without the VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT flag, a valid VkShaderEXT must be bound to the VK_SHADER_STAGE_TASK_BIT_EXT stage
If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_MESH_BIT_EXT stage, and that VkShaderEXT was created with the VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT flag, there **must** be no VkShaderEXT bound to the VK_SHADER_STAGE_TASK_BIT_EXT stage.

If there is no bound graphics pipeline, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, there **must** be no VkShaderEXT bound to either the VK_SHADER_STAGE_TASK_BIT_EXT stage or the VK_SHADER_STAGE_MESH_BIT_EXT stage.

If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, any stages in between stages whose shaders which did not create a shader with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag as part of the same vkCreateShadersEXT call **must** not have any VkShaderEXT bound.

All bound graphics shader objects **must** have been created with identical or identically defined push constant ranges.

All bound graphics shader objects **must** have been created with identical or identically defined arrays of descriptor set layouts.

If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage and the attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set rasterizerDiscardEnable to VK_FALSE `vkCmdSetAttachmentFeedbackLoopEnableEXT` **must** have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable parameter in the last call to `vkCmdSetDepthWriteEnable` **must** be VK_FALSE.

If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_STENCIL_WRITE_MASK set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpStencilAttachmentReadEXT, the writeMask parameter in the last call to `vkCmdSetStencilWriteMask` **must** be 0.

All bound graphics shader objects **must** have been created with identical or identically defined push constant ranges.

All bound graphics shader objects **must** have been created with identical or identically defined arrays of descriptor set layouts.
If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT`, and the format of any color attachment is `VK_FORMAT_E5B9G9R9_UFLOAT_PACK32`, the corresponding element of the `pColorWriteMasks` parameter of `vkCmdSetColorWriteMaskEXT` must either include all of `VK_COLOR_COMPONENT_R_BIT`, `VK_COLOR_COMPONENT_G_BIT`, and `VK_COLOR_COMPONENT_B_BIT`, or none of them.

- **VUID-vkCmdDrawMeshTasksEXT-maxFragmentDualSrcAttachments-09239**
  If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of Location for any output attachment statically used in the Fragment Execution Model executed by this command must be less than `maxFragmentDualSrcAttachments`.

- **VUID-vkCmdDrawMeshTasksEXT-stage-06480**
  The bound graphics pipeline must not have been created with the `VkPipelineShaderStageCreateInfo::stage` member of an element of `VkGraphicsPipelineCreateInfo::pStages` set to `VK_SHADER_STAGE_VERTEX_BIT`, `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`, `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` or `VK_SHADER_STAGE_GEOMETRY_BIT`.

- **VUID-vkCmdDrawMeshTasksEXT-None-07074**
  Transform Feedback Queries must not be active.

- **VUID-vkCmdDrawMeshTasksEXT-None-07075**
  Primitives Generated Queries must not be active.

- **VUID-vkCmdDrawMeshTasksEXT-pipelineStatistics-07076**
  The `pipelineStatistics` member used to create any active Pipeline Statistics Query must not contain `VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_VERTICES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_PRIMITIVES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_VERTEX_SHADER_INVOCATIONS_BIT`, `VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_INVOCATIONS_BIT`, `VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_PRIMITIVES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_CLIPPING_INVOCATIONS_BIT`, `VK_QUERY_PIPELINE_STATISTIC_CLIPPING_PRIMITIVES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_CONTROL_SHADER_PATCHES_BIT`, or `VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_EVALUATION_SHADER_INVOCATIONS_BIT`.

- **VUID-vkCmdDrawMeshTasksEXT-TaskEXT-07322**
  If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` contains a shader using the TaskEXT Execution Model, `groupCountX` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxTaskWorkGroupCount[0].`

- **VUID-vkCmdDrawMeshTasksEXT-TaskEXT-07323**
  If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` contains a shader using the TaskEXT Execution Model, `groupCountY` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxTaskWorkGroupCount[1].`

- **VUID-vkCmdDrawMeshTasksEXT-TaskEXT-07324**
  If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` contains a shader using the TaskEXT Execution Model, `groupCountZ` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxTaskWorkGroupCount[2].`
If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` contains a shader using the TaskEXT Execution Model, the product of `groupCountX`, `groupCountY` and `groupCountZ` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxTaskWorkGroupTotalCount`

If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` does not contain a shader using the TaskEXT Execution Model, `groupCountX` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupCount[0]`

If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` does not contain a shader using the TaskEXT Execution Model, `groupCountY` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupCount[1]`

If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` does not contain a shader using the TaskEXT Execution Model, `groupCountZ` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupCount[2]`

If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` does not contain a shader using the TaskEXT Execution Model, the product of `groupCountX`, `groupCountY` and `groupCountZ` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupTotalCount`

The current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` must contain a shader stage using the MeshEXT Execution Model

Valid Usage (Implicit)

- `commandBuffer` must be a valid `VkCommandBuffer` handle
- `commandBuffer` must be in the recording state
- The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations
- This command must only be called inside of a render pass instance
- This command must only be called outside of a video coding scope
Host Synchronization

- Host access to commandBuffer must be externally synchronized.
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized.

Command Properties

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To record an indirect mesh tasks drawing command, call:

```c
// Provided by VK_EXT_mesh_shader
void vkCmdDrawMeshTasksIndirectEXT(
    VkCommandBuffer commandBuffer,       commandBuffer,
    VkBuffer buffer,                     buffer,
    VkDeviceSize offset,                 offset,
    uint32_t drawCount,                  drawCount,
    uint32_t stride);                    stride);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `buffer` is the buffer containing draw parameters.
- `offset` is the byte offset into `buffer` where parameters begin.
- `drawCount` is the number of draws to execute, and can be zero.
- `stride` is the byte stride between successive sets of draw parameters.

`vkCmdDrawMeshTasksIndirectEXT` behaves similarly to `vkCmdDrawMeshTasksEXT` except that the parameters are read by the device from a buffer during execution. `drawCount` draws are executed by the command, with parameters taken from `buffer` starting at `offset` and increasing by `stride` bytes for each successive draw. The parameters of each draw are encoded in an array of `VkDrawMeshTasksIndirectCommandEXT` structures. If `drawCount` is less than or equal to one, `stride` is ignored.

Valid Usage

- VUID-vkCmdDrawMeshTasksIndirectEXT-magFilter-04553
  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's `format features` must contain
If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`.

If a `VkImageView` is sampled with depth comparison, the image view's format features **must** contain `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT`.

If a `VkImageView` is accessed using atomic operations as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT`.

If a `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER` descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features **must** contain `VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT`.

If a `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`.

If the `VK_EXT_filter_cubic` extension is not enabled and any `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, it **must** not have a `VkImageViewType` of `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`.

Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command **must** have a `VkImageViewType` and format that supports cubic filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` with a reduction mode of either `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX` as a result of this command **must** have a `VkImageViewType` and format that supports cubic filtering together with minmax filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

If the `cubicRangeClamp` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command **must not** have a `VkSamplerReductionModeCreateInfo::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`.
Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`.

Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

For any `VkImageView` being written as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view’s format features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view’s buffer features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

For each set `n` that is statically used by a bound shader, a descriptor set must have been bound to `n` at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set `n`, with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

If the `maintenance4` feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the
VK_PIPELINE or VK_DESCRIPTOR_SET_LAYOUT and VK_PUSH_CONSTANT_RANGE arrays used to create the current VK_PIPELINE or VK_SHADEREXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08114
  Descriptors in each bound descriptor set, specified via vkCmdBindDescriptorSets, must be valid if they are statically used by the VK_PIPELINE bound to the pipeline bind point used by this command and the bound VK_PIPELINE was not created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08115
  If the descriptors used by the VK_PIPELINE bound to the pipeline bind point were specified via vkCmdBindDescriptorSets, the bound VK_PIPELINE must have been created without VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08116
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by the VK_PIPELINE bound to the pipeline bind point used by this command and the bound VK_PIPELINE was created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08604
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by any VK_SHADEREXT bound to a stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08117
  If the descriptors used by the VK_PIPELINE bound to the pipeline bind point were specified via vkCmdSetDescriptorBufferOffsetsEXT, the bound VK_PIPELINE must have been created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08119
  If a descriptor is dynamically used with a VK_PIPELINE created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08605
  If a descriptor is dynamically used with a VK_SHADEREXT created with a VK_DESCRIPTOR_SET_LAYOUT that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08606
  If the shaderObject feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08607
  If the shaderObject is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and VK_NULL_HANDLE shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08608
  If a pipeline is bound to the pipeline bind point used by this command, there must not
have been any calls to dynamic state setting commands for any state not specified as dynamic in the VkPipeline object bound to the pipeline bind point used by this command, since that pipeline was bound

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08609
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used to sample from any VkImage with a VkImageView of the type VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY, VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08610
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08611
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage

- VUID-vkCmdDrawMeshTasksIndirectEXT-uniformBuffers-06935
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08612
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDrawMeshTasksIndirectEXT-storageBuffers-06936
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08613
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage
corresponding to the pipeline bind point used by this command accesses a storage buffer, it **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDrawMeshTasksIndirectEXT-commandBuffer-02707**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, any resource accessed by `bound shaders` **must** not be a protected resource

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-06550**
  If a `bound shader` accesses a `VkSampler` or `VkImageView` object that enables sampler Y’C_aC_b conversion, that object **must** only be used with `OpImageSample*` or `OpImageSparseSample*` instructions

- **VUID-vkCmdDrawMeshTasksIndirectEXT-ConstOffset-06551**
  If a `bound shader` accesses a `VkSampler` or `VkImageView` object that enables sampler Y’C_aC_b conversion, that object **must** not use the `ConstOffset` and `Offset` operands

- **VUID-vkCmdDrawMeshTasksIndirectEXT-viewType-07752**
  If a `VkImageView` is accessed as a result of this command, then the image view’s `viewType` **must** match the `Dim` operand of the `OpTypeImage` as described in Instruction/Sampler/Image View Validation

- **VUID-vkCmdDrawMeshTasksIndirectEXT-format-07753**
  If a `VkImageView` is accessed as a result of this command, then the numeric type of the image view’s `format` and the `Sampled Type` operand of the `OpTypeImage` **must** match

- **VUID-vkCmdDrawMeshTasksIndirectEXT-OpImageWrite-08795**
  If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the image view’s format

- **VUID-vkCmdDrawMeshTasksIndirectEXT-OpImageWrite-08796**
  If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have four components

- **VUID-vkCmdDrawMeshTasksIndirectEXT-OpImageWrite-04469**
  If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the buffer view’s format

- **VUID-vkCmdDrawMeshTasksIndirectEXT-SampledType-04470**
  If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 64

- **VUID-vkCmdDrawMeshTasksIndirectEXT-SampledType-04471**
  If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 32

- **VUID-vkCmdDrawMeshTasksIndirectEXT-SampledType-04472**
  If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction
must have a Width of 64

- VUID-vkCmdDrawMeshTasksIndirectEXT-SampledType-04473
  If a VkBufferView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

- VUID-vkCmdDrawMeshTasksIndirectEXT-sparseImageInt64Atomics-04474
  If the sparseImageInt64Atomics feature is not enabled, VkImage objects created with the VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- VUID-vkCmdDrawMeshTasksIndirectEXT-sparseImageInt64Atomics-04475
  If the sparseImageInt64Atomics feature is not enabled, VkBuffer objects created with the VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- VUID-vkCmdDrawMeshTasksIndirectEXT-OpImageWeightedSampleQCOM-06971
  If OpImageWeightedSampleQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM

- VUID-vkCmdDrawMeshTasksIndirectEXT-OpImageWeightedSampleQCOM-06972
  If OpImageWeightedSampleQCOM uses a VkImageView as a sample weight image as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM

- VUID-vkCmdDrawMeshTasksIndirectEXT-OpImageBoxFilterQCOM-06973
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM

- VUID-vkCmdDrawMeshTasksIndirectEXT-OpImageBlockMatchSSDQCOM-06974
  If OpImageBlockMatchSSDQCOM is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdDrawMeshTasksIndirectEXT-OpImageBlockMatchSADQCOM-06975
  If OpImageBlockMatchSADQCOM is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- VUID-vkCmdDrawMeshTasksIndirectEXT-OpImageWeightedSampleQCOM-06977
  If OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, OpImageBlockMatchSSDQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this command, then the sampler must have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM
• VUID-vkCmdDrawMeshTasksIndirectEXT-OpImageWeightedSampleQCOM-06978
If any command other than OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this command, then the sampler must not have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM

• VUID-vkCmdDrawMeshTasksIndirectEXT-OpImageBlockMatchWindow-09215
If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

• VUID-vkCmdDrawMeshTasksIndirectEXT-OpImageBlockMatchWindow-09216
If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view’s format must be a single-component format.

• VUID-vkCmdDrawMeshTasksIndirectEXT-OpImageBlockMatchWindow-09217
If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07288
Any shader invocation executed by this command must terminate

• VUID-vkCmdDrawMeshTasksIndirectEXT-renderPass-02684
The current render pass must be compatible with the renderPass member of the VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS

• VUID-vkCmdDrawMeshTasksIndirectEXT-subpass-02685
The subpass index of the current render pass must be equal to the subpass member of the VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to VK_PIPELINE_BIND_POINT_GRAPHICS

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07748
If any shader statically accesses an input attachment, a valid descriptor must be bound to the pipeline via a descriptor set

• VUID-vkCmdDrawMeshTasksIndirectEXT-OpTypeImage-07468
If any shader executed by this pipeline accesses an OpTypeImage variable with a Dim operand of SubpassData, it must be decorated with an InputAttachmentIndex that corresponds to a valid input attachment in the current subpass

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07469
Input attachment views accessed in a subpass must be created with the same VkFormat as the corresponding subpass definition, and be created with a VkImageView that is compatible with the attachment referenced by the subpass’ pInputAttachments [InputAttachmentIndex] in the currently bound VkFramebuffer as specified by Fragment Input Attachment Compatibility

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-06537
Memory backing image subresources used as attachments in the current render pass
must not be written in any way other than as an attachment by this command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-09000
If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:
  ◦ the `VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
  ◦ the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_COLOR_BIT` and
    ▪ there is no currently bound graphics pipeline or
    ▪ the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-09001
If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:
  ◦ the `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
  ◦ the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_DEPTH_BIT` and
    ▪ there is no currently bound graphics pipeline or
    ▪ the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-09002
If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:
  ◦ the `VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
  ◦ the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included `VK_IMAGE_ASPECT_STENCIL_BIT` and
    ▪ there is no currently bound graphics pipeline or
    ▪ the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-09003
If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command
If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command must not write to that image subresource as an attachment.

If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, depth writes must be disabled.

If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back writeMask are not zero, and stencil test is enabled, all stencil ops must be VK_STENCIL_OP_KEEP.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT dynamic state enabled then vkCmdSetViewport must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SCISSOR dynamic state enabled then vkCmdSetScissor must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_WIDTH dynamic state enabled then vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetPolygonModeEXT in the current command buffer set polygonMode to VK_POLYGON_MODE_LINE, vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, and the most recent call to vkCmdSetPrimitiveTopology in the current command buffer set primitiveTopology to any line topology, vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command.

If a shader object that outputs line primitives is bound to the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT stage, vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BIAS dynamic state enabled then vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDepthBiasEnable in the current command buffer set depthBiasEnable to VK_TRUE, vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07835
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_BLEND_CONSTANTS dynamic state enabled then vkCmdSetBlendConstants must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08621
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetColorBlendEnableEXT in the current command buffer set any element of pColorBlendEnables to VK_TRUE, and the most recent call to vkCmdSetColorBlendEquationEXT in the current command buffer set the same element of pColorBlendEquations to a VkColorBlendEquationEXT structure with any VkBlendFactor member with a value of VK_BLEND_FACTOR_CONSTANT_COLOR, VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR, VK_BLEND_FACTOR_CONSTANT_ALPHA, or VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA, vkCmdSetBlendConstants must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07836
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BOUNDS dynamic state enabled then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08622
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDepthBoundsTestEnable in the current command buffer set depthBoundsTestEnable to VK_TRUE, then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07837
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK dynamic state enabled then vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08623
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07838
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_WRITE_MASK dynamic state enabled then
vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08624
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07839
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_REFERENCE dynamic state enabled then vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08625
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-maxMultiviewInstanceIndex-02688
  If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex

- VUID-vkCmdDrawMeshTasksIndirectEXT-sampleLocationsEnable-02689
  If the bound graphics pipeline was created with VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable set to VK_TRUE and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-06666
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT dynamic state enabled then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08626
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetSampleLocationsEnableEXT in the current command buffer set sampleLocationsEnable to VK_TRUE, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-sampleLocationsPerPixel-07934
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples member of the VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with
• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07840
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CULL_MODE` dynamic state enabled then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08627
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07841
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08628
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07843
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08629
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07844
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` dynamic state enabled then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08630
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07845
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP` dynamic state enabled then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08631
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthTestEnable` in the current command buffer set `depthTestEnable` to `VK_TRUE`, then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07846
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08632
If a shader object is bound to any graphics stage, and the `depthBounds` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07847
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE` dynamic state enabled then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08633
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07848
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_OP` dynamic state enabled then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08634
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-viewportCount-03417
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `VkPipelineViewportStateCreateInfo`::`scissorCount` of the pipeline

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If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, then `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `scissorCount` parameter of `vkCmdSetScissorWithCount` must match the `VkPipelineViewportStateCreateInfo::viewportCount` of the pipeline.

If the bound graphics pipeline state was created with both the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic states enabled then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

If a shader object is bound to any graphics stage, then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportWScalingStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then `vkCmdSetViewportWScalingNV` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, then

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VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV dynamic state enabled, then the bound graphics pipeline must have been created with VkPipelineViewportShadingRateImageStateCreateInfoNV::viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawMeshTasksIndirectEXT-viewportCount-04140
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORTsWithCount and VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV dynamic states enabled then the viewportCount parameter in the last call to vkCmdSetViewportShadingRatePaletteNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawMeshTasksIndirectEXT-shadingRateImage-09233
If the shadingRateImage feature is enabled, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCoarseSampleOrderNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-shadingRateImage-09234
If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetShadingRateImageEnableNV in the current command buffer set shadingRateImageEnable to VK_TRUE, then vkCmdSetViewportShadingRatePaletteNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08637
If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, then the viewportCount parameter in the last call to vkCmdSetViewportShadingRatePaletteNV must be greater than or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawMeshTasksIndirectEXT-VkPipelineViewportCreateInfo-04141
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORTsWithCount dynamic state enabled and a VkPipelineViewportSwizzleStateCreateInfoNV structure chained from VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have been created with VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawMeshTasksIndirectEXT-VkPipelineViewportCreateInfo-04142
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORTsWithCount dynamic state enabled and a VkPipelineViewportExclusiveScissorStateCreateInfoNV structure chained from VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have been created with VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07878
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV dynamic state enabled then 
vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07879
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV dynamic state enabled then
  vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-exclusiveScissor-09235
  If a shader object is bound to any graphics stage, and the exclusiveScissor feature is enabled, then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08638
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetExclusiveScissorEnableNV in the current command buffer set any element of pExclusiveScissorEnables to VK_TRUE, then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-04876
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE dynamic state enabled then
  vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08639
  If a shader object is bound to any graphics stage, then vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-04877
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE dynamic state enabled then
  vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08640
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-logicOp-04878
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_EXT dynamic state enabled then vkCmdSetLogicOpEXT must have been called in the current command buffer prior to this drawing command and the logicOp must be a valid VkLogicOp value

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08641
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the logicOp feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set
- **rasterizerDiscardEnable** to **VK_FALSE**, then **vkCmdSetLogicOpEXT** must have been called in the current command buffer prior to this drawing command and the **logicOp** must be a valid **VkLogicOp** value.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-primitiveFragmentShadingRateWithMultipleViewports-04552**
  If the **primitiveFragmentShadingRateWithMultipleViewports** limit is not supported, the bound graphics pipeline was created with the **VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT** dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the **PrimitiveShadingRateKHR** built-in, then **vkCmdSetViewportWithCount** must have been called in the current command buffer prior to this drawing command and the **viewportCount** parameter of **vkCmdSetViewportWithCount** must be 1.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-primitiveFragmentShadingRateWithMultipleViewports-08642**
  If the **primitiveFragmentShadingRateWithMultipleViewports** limit is not supported, and any shader object bound to a graphics stage writes to the **PrimitiveShadingRateKHR** built-in, then **vkCmdSetViewportWithCount** must have been called in the current command buffer prior to this drawing command, and the **viewportCount** parameter of **vkCmdSetViewportWithCount** must be 1.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-blendEnable-04727**
  If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view's **format features** do not contain **VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT**, then the **blendEnable** member of the corresponding element of the **pAttachments** member of **pColorBlendState** must be **VK_FALSE**.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08643**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set **rasterizerDiscardEnable** to **VK_FALSE**, then for each color attachment in the render pass, if the corresponding image view's **format features** do not contain **VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT**, then the corresponding member of **pColorBlendEnable** in the most recent call to **vkCmdSetColorBlendEnableEXT** in the current command buffer that affected that attachment index must have been **VK_FALSE**.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-multisampledRenderToSingleSampled-07284**
  If rasterization is not disabled in the bound graphics pipeline, and none of the **VK_AMD_mixed_attachment_samples** extension, the **VK_NV_framebuffer_mixed_samples** extension, or the **multisampledRenderToSingleSampled** feature is enabled, then **rasterizationSamples** for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08644**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set **rasterizerDiscardEnable** to **VK_FALSE**, and none of the **VK_AMD_mixed_attachment_samples** extension, the **VK_NV_framebuffer_mixed_samples** extension, or the **multisampledRenderToSingleSampled** feature is enabled, then the most recent call to **vkCmdSetRasterizationSamplesEXT** in the current command buffer must have set **2255**.
rasterizationSamples to be the same as the number of samples for the current render pass color and/or depth/stencil attachments

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08876
  If a shader object is bound to any graphics stage, the current render pass instance **must** have been begun with `vkCmdBeginRendering`

• VUID-vkCmdDrawMeshTasksIndirectEXT-imageView-06172
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the depth attachment

• VUID-vkCmdDrawMeshTasksIndirectEXT-imageView-06173
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the stencil attachment

• VUID-vkCmdDrawMeshTasksIndirectEXT-imageView-06174
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the depth attachment

• VUID-vkCmdDrawMeshTasksIndirectEXT-imageView-06175
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the stencil attachment

• VUID-vkCmdDrawMeshTasksIndirectEXT-imageView-06176
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, this command **must** not write any values to the depth attachment

• VUID-vkCmdDrawMeshTasksIndirectEXT-imageView-06177
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the stencil attachment

• VUID-vkCmdDrawMeshTasksIndirectEXT-viewMask-06178
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline **must** have been created with a `VkPipelineRenderingCreateInfo` ::`viewMask` equal to `VkRenderingInfo` ::`viewMask`

• VUID-vkCmdDrawMeshTasksIndirectEXT-colorAttachmentCount-06179
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline **must** have been created with a `VkPipelineRenderingCreateInfo` ::`colorAttachmentCount` equal to `VkRenderingInfo` ::`colorAttachmentCount`

• VUID-vkCmdDrawMeshTasksIndirectEXT-dynamicRenderingUnusedAttachments-08910
If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-dynamicRenderingUnusedAttachments-08911**
  If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline, or the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-dynamicRenderingUnusedAttachments-08912**
  If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` must have the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07749**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08646**
  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-attachmentCount-07750**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then the `attachmentCount` parameter of `vkCmdSetColorWriteEnableEXT` must be greater than or equal to the `VkPipelineColorBlendStateCreateInfo::attachmentCount` of the currently bound graphics pipeline.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08647**
  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then the attachmentCount parameter of most recent call to vkCmdSetColorWriteEnableEXT in the current command buffer must be greater than or equal to the number of color attachments in the current render pass instance

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07751
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT dynamic state enabled then vkCmdSetDiscardRectangleEXT must have been called in the current command buffer prior to this drawing command for each discard rectangle in VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07880
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT dynamic state enabled then vkCmdSetDiscardRectangleEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07881
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT dynamic state enabled then vkCmdSetDiscardRectangleModeEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07882
  If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDiscardRectangleEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08648
  If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDiscardRectangleEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-07881
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT dynamic state enabled then vkCmdSetDiscardRectangleModeEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08649
  If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDiscardRectangleEnableEXT in the current command buffer set discardRectangleEnable to VK_TRUE, then vkCmdSetDiscardRectangleModeEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectEXT-dynamicRenderingUnusedAttachments-08913
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawMeshTasksIndirectEXT-dynamicRenderingUnusedAttachments-08914
If current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo`::`pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo`::`depthAttachmentFormat` used to create the currently bound graphics pipeline must be equal to the `VkFormat` used to create `VkRenderingInfo`::`pDepthAttachment->imageView`.

- VUID-vkCmdDrawMeshTasksIndirectEXT-dynamicRenderingUnusedAttachments-08915
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo`::`pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo`::`depthAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo`::`pDepthAttachment->imageView`, the value of the format must be `VK_FORMAT_UNDEFINED`.

- VUID-vkCmdDrawMeshTasksIndirectEXT-dynamicRenderingUnusedAttachments-08916
  If current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo`::`pStencilAttachment->imageView` was `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo`::`stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to `VK_FORMAT_UNDEFINED`.

- VUID-vkCmdDrawMeshTasksIndirectEXT-dynamicRenderingUnusedAttachments-08917
  If current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo`::`pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo`::`stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to the `VkFormat` used to create `VkRenderingInfo`::`pStencilAttachment->imageView`.

- VUID-vkCmdDrawMeshTasksIndirectEXT-dynamicRenderingUnusedAttachments-08918
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo`::`pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo`::`stencilAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo`::`pStencilAttachment->imageView`, the value of the format must be `VK_FORMAT_UNDEFINED`.

- VUID-vkCmdDrawMeshTasksIndirectEXT-imageView-06183
  If the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingFragmentShadingRateAttachmentInfoKHR`::`imageView` was not `VK_NULL_HANDLE`, the currently bound graphics pipeline must have been created with `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`.

- VUID-vkCmdDrawMeshTasksIndirectEXT-imageView-06184
  If the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingFragmentDensityMapAttachmentInfoEXT`::`imageView` was not `VK_NULL_HANDLE`, the currently bound graphics pipeline must have been created with `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT`.

- VUID-vkCmdDrawMeshTasksIndirectEXT-colorAttachmentCount-06185
  If the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD`...
or `VkAttachmentSampleCountInfoNV` structure, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the corresponding element of the `pColorAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-pDepthAttachment-06186**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-pStencilAttachment-06187**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-multisampledRenderToSingleSampled-07285**
  If the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the value of `rasterizationSamples` for the currently bound graphics pipeline.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-multisampledRenderToSingleSampled-07286**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-multisampledRenderToSingleSampled-07287**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

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pipeline **must** be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`

- **VUID-vkCmdDrawMeshTasksIndirectEXT-pNext-07935**
  If this command has been called inside a render pass instance started with `vkCmdBeginRendering`, and the **pNext** chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the value of `rasterizationSamples` for the currently bound graphics pipeline **must** be equal to `VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples`

- **VUID-vkCmdDrawMeshTasksIndirectEXT-renderPass-06198**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline **must** have been created with a `VkGraphicsPipelineCreateInfo::renderPass` equal to `VK_NULL_HANDLE`

- **VUID-vkCmdDrawMeshTasksIndirectEXT-pColorAttachments-08963**
  If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the `VkRenderingInfo::pColorAttachments->imageView` was not `VK_NULL_HANDLE`, then the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the pipeline **must** not be `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdDrawMeshTasksIndirectEXT-pDepthAttachment-08964**
  If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the pipeline **must** not be `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdDrawMeshTasksIndirectEXT-pStencilAttachment-08965**
  If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, stencil test is enabled and the `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the pipeline **must** not be `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdDrawMeshTasksIndirectEXT-primitivesGeneratedQueryWithRasterizerDiscard-06708**
  If the `primitivesGeneratedQueryWithRasterizerDiscard` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, **rasterization discar**d **must** not be enabled

- **VUID-vkCmdDrawMeshTasksIndirectEXT-primitivesGeneratedQueryWithNonZeroStreams-06709**
  If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, the bound graphics pipeline **must** not have been created with a non-zero value in `VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream`

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07619**
  If the bound graphics pipeline state was created with the
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_TESSellation_DOMAIN_ORIGIN_EXT` dynamic state enabled then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07620**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-09237**
  If a shader object is bound to the `VK_SHADER_STAGE_TESSellation_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08650**
  If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07621**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08651**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07622**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` dynamic state enabled then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08652**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07623**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` dynamic state enabled then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08653**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set...
rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleMaskEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07624
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled then vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-alphaToCoverageEnable-08919
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled, and alphaToCoverageEnable was VK_TRUE in the last call to vkCmdSetAlphaToCoverageEnableEXT, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08654
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-alphaToCoverageEnable-08920
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetAlphaToCoverageEnableEXT in the current command buffer set alphaToCoverageEnable to VK_TRUE, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07625
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT dynamic state enabled then vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08655
  If the alphaToOne feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07626
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT dynamic state enabled then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08656
  If the logicOp feature is enabled, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` for any attachment set that attachment's value in `pColorBlendEnables` to `VK_TRUE`, then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

If the `geometryStreams` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_GEOMETRY_BIT` stage, then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` dynamic state enabled then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

If the `geometryStreams` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_GEOMETRY_BIT` stage, then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.
command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08661**
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07632**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08662**
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetConservativeRasterizationModeEXT` in the current command buffer set `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`, then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07633**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08663**
  If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07634**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08664**
  If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07635**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer
prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07636
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT` dynamic state enabled then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08665
  If the `VK_EXT_provoking_vertex` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07637
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08666
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08667
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08668
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07638
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` dynamic state enabled then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08669
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08670
If the VK_EXT_line_rasterization extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to vkCmdSetPrimitiveTopology in the current command buffer set primitiveTopology to any line topology, then vkCmdSetLineStippleEnableEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08671
  If the VK_EXT_line_rasterization extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then vkCmdSetLineStippleEnableEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07849
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_STIPPLE_EXT dynamic state enabled then vkCmdSetLineStippleEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08672
  If the VK_EXT_line_rasterization extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetLineStippleEnableEXT in the current command buffer set stippledLineEnable to VK_TRUE, then vkCmdSetLineStippleEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07639
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT dynamic state enabled then vkCmdSetDepthClipNegativeOneToOneEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08673
  If the depthClipControl feature is enabled, and a shader object is bound to any graphics stage, then vkCmdSetDepthClipNegativeOneToOneEXT must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07640
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV dynamic state enabled then vkCmdSetViewportWScalingEnableNV must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08674
  If the VK_NV_clip_space_w_scaling extension is enabled, and a shader object is bound to any graphics stage, then vkCmdSetViewportWScalingEnableNV must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07641
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic state enabled then vkCmdSetViewportSwizzleNV must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08675
  If the VK_NV_viewport_swizzle extension is enabled, and a shader object is bound to any
graphics stage, then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07642**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08676**
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07643**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` dynamic state enabled then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08677**
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set `coverageToColorEnable` to `VK_TRUE`, then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07644**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08678**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07645**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08679**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationModeNV` in the current command buffer set
coverageModulationMode to any value other than \texttt{VK\_COVERAGE\_MODULATION\_MODE\_NONE\_NV}, then \texttt{vkCmdSetCoverageModulationTableEnableNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07646
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_COVERAGE\_MODULATION\_TABLE\_NV} dynamic state enabled then \texttt{vkCmdSetCoverageModulationTableNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08680
  If the \texttt{VK\_NV\_framebuffer\_mixed\_samples} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, and the most recent call to \texttt{vkCmdSetCoverageModulationTableEnableNV} in the current command buffer set \texttt{coverageModulationTableEnable} to \texttt{VK\_TRUE}, then \texttt{vkCmdSetCoverageModulationTableNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07647
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_SHADING\_RATE\_IMAGE\_ENABLE\_NV} dynamic state enabled then \texttt{vkCmdSetShadingRateImageEnableNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-pipelineFragmentShadingRate-09238
  If the \texttt{pipelineFragmentShadingRate} feature is enabled, and a shader object is bound to the \texttt{VK\_SHADER\_STAGE\_FRAGMENT\_BIT} stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, then \texttt{vkCmdSetFragmentShadingRateKHR} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08681
  If the \texttt{shadingRateImage} feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, then \texttt{vkCmdSetShadingRateImageEnableNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07648
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_REPRESENTATIVE\_FRAGMENT\_TEST\_ENABLE\_NV} dynamic state enabled then \texttt{vkCmdSetRepresentativeFragmentTestEnableNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-08682
  If the \texttt{representativeFragmentTest} feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, then \texttt{vkCmdSetRepresentativeFragmentTestEnableNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07649
  If the bound graphics pipeline state was created with the
**VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV**  
dynamic state enabled then  
`vkCmdSetCoverageReductionModeNV` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08683**  
  If the `coverageReductionMode` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageReductionModeNV` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-pColorBlendEnables-07470**  
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` state enabled and the last call to `vkCmdSetColorBlendEnableEXT` set `pColorBlendEnables` for any attachment to `VK_TRUE`, then for those attachments in the subpass the corresponding image view’s format features **must** contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`

- **VUID-vkCmdDrawMeshTasksIndirectEXT-rasterizationSamples-07471**  
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` **must** follow the rules for a zero-attachment subpass

- **VUID-vkCmdDrawMeshTasksIndirectEXT-samples-07472**  
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` **must** be greater or equal to the `VkPipelineMultisampleStateCreateInfo::rasterizationSamples` parameter used to create the bound graphics pipeline

- **VUID-vkCmdDrawMeshTasksIndirectEXT-samples-07473**  
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` **must** be greater or equal to the `rasterizationSamples` parameter in the last call to `vkCmdSetRasterizationSamplesEXT`

- **VUID-vkCmdDrawMeshTasksIndirectEXT-rasterizationSamples-07474**  
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and neither the `VK_AMD_mixed_attachment_samples` nor the `VK_NV_framebuffer_mixed_samples` extensions are enabled, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` **must** be the same as the current subpass color and/or depth/stencil attachments

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-09211**  
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a
VkMultisampledRenderToSingleSampledInfoEXT structure with multisampledRenderToSingleSampledEnable equal to VK_TRUE, then the rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT must be the same as the rasterizationSamples member of that structure.

- VUID-vkCmdDrawMeshTasksIndirectEXT-firstAttachment-07476
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendEnableEXT calls must specify an enable for all active color attachments in the current subpass.

- VUID-vkCmdDrawMeshTasksIndirectEXT-firstAttachment-07477
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT dynamic state enabled then vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendEquationEXT calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled.

- VUID-vkCmdDrawMeshTasksIndirectEXT-firstAttachment-07478
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT dynamic state enabled then vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorWriteMaskEXT calls must specify the color write mask for all active color attachments in the current subpass.

- VUID-vkCmdDrawMeshTasksIndirectEXT-firstAttachment-07479
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT dynamic state enabled then vkCmdSetColorBlendAdvancedEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendAdvancedEXT calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled.

- VUID-vkCmdDrawMeshTasksIndirectEXT-advancedBlendMaxColorAttachments-07480
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT and VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic states enabled and the last calls to vkCmdSetColorBlendEnableEXT and vkCmdSetColorBlendAdvancedEXT have enabled advanced blending, then the number of active color attachments in the current subpass must not exceed advancedBlendMaxColorAttachments.

- VUID-vkCmdDrawMeshTasksIndirectEXT-primitivesGeneratedQueryWithNonZeroStreams-07481
  If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, and the bound graphics pipeline
was created with \texttt{VK\_DYNAMIC\_STATE\_RASTERIZATION\_STREAM\_EXT} state enabled, the last call to \texttt{vkCmdSetRasterizationStreamEXT} must have set the \texttt{rasterizationStream} to zero.

- \textbf{VUID-vkCmdDrawMeshTasksIndirectEXT-sampleLocationsPerPixel-07482}
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_SAMPLE\_LOCATIONS\_EXT} state enabled and the \texttt{VK\_DYNAMIC\_STATE\_RASTERIZATION\_SAMPLES\_EXT} state disabled, then the \texttt{sampleLocationsPerPixel} member of \texttt{pSampleLocationsInfo} in the last call to \texttt{vkCmdSetSampleLocationsEXT} must equal the \texttt{rasterizationSamples} member of the \texttt{VkPipelineMultisampleStateCreateInfo} structure the bound graphics pipeline has been created with.

- \textbf{VUID-vkCmdDrawMeshTasksIndirectEXT-sampleLocationsPerPixel-07483}
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_SAMPLE\_LOCATIONS\_EXT} state enabled and the \texttt{VK\_DYNAMIC\_STATE\_RASTERIZATION\_SAMPLES\_EXT} state disabled, then the \texttt{sampleLocationsPerPixel} member of \texttt{pSampleLocationsInfo} in the last call to \texttt{vkCmdSetSampleLocationsEXT} must equal the \texttt{rasterizationSamples} member of the last call to \texttt{vkCmdSetRasterizationSamplesEXT}.

- \textbf{VUID-vkCmdDrawMeshTasksIndirectEXT-sampleLocationsEnable-07484}
  If the bound graphics pipeline was created with the \texttt{VK\_DYNAMIC\_STATE\_SAMPLE\_LOCATIONS\_ENABLE\_EXT} state enabled, and \texttt{sampleLocationsEnable} was \texttt{VK\_TRUE} in the last call to \texttt{vkCmdSetSampleLocationsEnableEXT}, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the \texttt{VK\_IMAGE\_CREATE\_SAMPLE\_LOCATIONS\_COMPATIBLE\_DEPTH\_BIT\_EXT} bit set.

- \textbf{VUID-vkCmdDrawMeshTasksIndirectEXT-sampleLocationsEnable-07485}
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_SAMPLE\_LOCATIONS\_ENABLE\_EXT} state enabled and the \texttt{VK\_DYNAMIC\_STATE\_SAMPLE\_LOCATIONS\_ENABLE\_EXT} state enabled, and if \texttt{sampleLocationsEnable} was \texttt{VK\_TRUE} in the last call to \texttt{vkCmdSetSampleLocationsEnableEXT}, then the \texttt{sampleLocationsInfo.sampleLocationGridSize.width} in the last call to \texttt{vkCmdSetSampleLocationsEXT} must evenly divide \texttt{VkMultisamplePropertiesEXT::sampleLocationGridSize.width} as returned by \texttt{vkGetPhysicalDeviceMultisamplePropertiesEXT} with a \texttt{samples} parameter equaling \texttt{rasterizationSamples}.

- \textbf{VUID-vkCmdDrawMeshTasksIndirectEXT-sampleLocationsEnable-07486}
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_SAMPLE\_LOCATIONS\_ENABLE\_EXT} state enabled and the \texttt{VK\_DYNAMIC\_STATE\_SAMPLE\_LOCATIONS\_ENABLE\_EXT} state enabled, and if \texttt{sampleLocationsEnable} was \texttt{VK\_TRUE} in the last call to \texttt{vkCmdSetSampleLocationsEnableEXT}, then the \texttt{sampleLocationsInfo.sampleLocationGridSize.height} in the last call to \texttt{vkCmdSetSampleLocationsEXT} must evenly divide \texttt{VkMultisamplePropertiesEXT::sampleLocationGridSize.height} as returned by \texttt{vkGetPhysicalDeviceMultisamplePropertiesEXT} with a \texttt{samples} parameter equaling \texttt{rasterizationSamples}.

- \textbf{VUID-vkCmdDrawMeshTasksIndirectEXT-sampleLocationsEnable-07487}
  If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, the fragment shader code must not statically use the extended instruction InterpolateAtSample

- VUID-vkCmdDrawMeshTasksIndirectEXT-sampleLocationsEnable-07936
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.width must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawMeshTasksIndirectEXT-sampleLocationsEnable-07937
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.height must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawMeshTasksIndirectEXT-sampleLocationsEnable-07938
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationsPerPixel must equal rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawMeshTasksIndirectEXT-coverageModulationTableEnable-07488
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV state enabled and the last call to vkCmdSetCoverageModulationTableEnableNV set coverageModulationTableEnable to VK_TRUE, then the coverageModulationTableCount parameter in the last call to vkCmdSetCoverageModulationTableNV must equal the current rasterizationSamples divided by the number of color samples in the current subpass

- VUID-vkCmdDrawMeshTasksIndirectEXT-rasterizationSamples-07489
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current rasterizationSamples must be the same as the sample count of the depth/stencil attachment

- VUID-vkCmdDrawMeshTasksIndirectEXT-coverageToColorEnable-07490
  If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV state enabled and the last call to 
vkCmdSetCoverageToColorEnableNV set the coverageToColorEnable to VK_TRUE, then the 
current subpass must have a color attachment at the location selected by the last call to 
vkCmdSetCoverageToColorLocationNV coverageToColorLocation, with a VkFormat of 
VK_FORMAT_R8_UINT, VK_FORMAT_R8_SINT, VK_FORMAT_R16_UINT, VK_FORMAT_R16_SINT, 
VK_FORMAT_R32_UINT, or VK_FORMAT_R32_SINT

• VUID-vkCmdDrawMeshTasksIndirectEXT-coverageReductionMode-07491
  If this VK_NV_coverage_reduction_mode extension is enabled, the bound graphics pipeline 
  state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV and 
  VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT states enabled, the current coverage 
  reduction mode coverageReductionMode, then the current rasterizationSamples, and the 
  sample counts for the color and depth/stencil attachments (if the subpass has them) must 
  be a valid combination returned by 
vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV

• VUID-vkCmdDrawMeshTasksIndirectEXT-viewportCount-07492
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the 
  VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic state enabled, then the bound graphics 
  pipeline must have been created with VkPipelineViewportSwizzleStateCreateInfoNV ::viewportCount greater or equal to the viewportCount parameter in the last call to 
vkCmdSetViewportWithCount

• VUID-vkCmdDrawMeshTasksIndirectEXT-viewportCount-07493
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic 
  states enabled then the viewportCount parameter in the last call to 
vkCmdSetViewportSwizzleNV must be greater than or equal to the viewportCount parameter in the last call to 
vkCmdSetViewportWithCount

• VUID-vkCmdDrawMeshTasksIndirectEXT-rasterizationSamples-07494
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and if the current subpass 
  has any color attachments and rasterizationSamples of the last call to 
vkCmdSetRasterizationSamplesEXT is greater than the number of color samples, then the 
  pipeline sampleShadingEnable must be VK_FALSE

• VUID-vkCmdDrawMeshTasksIndirectEXT-stippledLineEnable-07495
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or 
  VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current 
  stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is 
  VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT, then the stippledRectangularLines feature 
  must be enabled

• VUID-vkCmdDrawMeshTasksIndirectEXT-stippledLineEnable-07496
  If the bound graphics pipeline state was created with the 
  VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or 
  VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current 
  stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is 
  VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT, then the stippledBresenhamLines feature must
be enabled

- **VUID-vkCmdDrawMeshTasksIndirectEXT-stippledLineEnable-07497**
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or
  `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current
  `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is
  `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT`, then the `stippledSmoothLines` feature
  must be enabled

- **VUID-vkCmdDrawMeshTasksIndirectEXT-stippledLineEnable-07498**
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or
  `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current
  `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is
  `VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT`, then the `stippledRectangularLines` feature must
  be enabled and `VkPhysicalDeviceLimits::strictLines` must be `VK_TRUE`

- **VUID-vkCmdDrawMeshTasksIndirectEXT-conservativePointAndLineRasterization-07499**
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled,
  `conservativePointAndLineRasterization` is not supported, and the effective primitive
  topology output by the last pre-rasterization shader stage is a line or point, then the
  `conservativeRasterizationMode` set by the last call to
  `vkCmdSetConservativeRasterizationModeEXT` must be
  `VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT`

- **VUID-vkCmdDrawMeshTasksIndirectEXT-stage-07073**
  If the currently bound pipeline was created with the `VkPipelineShaderStageCreateInfo` ::`stage` member of an element of `VkGraphicsPipelineCreateInfo` ::`pStages` set to
  `VK_SHADER_STAGE_VERTEX_BIT`, `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`,
  `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` or `VK_SHADER_STAGE_GEOMETRY_BIT`, then `Mesh Shader Queries` must not be active

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08877**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` dynamic state
  `vkCmdSetAttachmentFeedbackLoopEnableEXT` must have been called in the current
  command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-07850**
  If dynamic state was inherited from `VkCommandBufferInheritanceViewportScissorInfoNV`, it must be set in the current
  command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08684**
  If there is no bound graphics pipeline, `vkCmdBindShadersEXT` must have been called in the
  current command buffer with `pStages` with an element of `VK_SHADER_STAGE_VERTEX_BIT`

- **VUID-vkCmdDrawMeshTasksIndirectEXT-None-08685**
  If there is no bound graphics pipeline, and the `tessellationShader` feature is enabled,
  `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages`
  with an element of `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`
If there is no bound graphics pipeline, and the **tessellationShader** feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`

If there is no bound graphics pipeline, and the **geometryShader** feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_GEOMETRY_BIT`

If there is no bound graphics pipeline, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_FRAGMENT_BIT`

If there is no bound graphics pipeline, and the **taskShader** feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TASK_BIT_EXT`

If there is no bound graphics pipeline, and the **meshShader** feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_MESH_BIT_EXT`

If there is no bound graphics pipeline, and at least one of the **taskShader** and **meshShader** features is enabled, one of the `VK_SHADER_STAGE_VERTEX_BIT` or `VK_SHADER_STAGE_MESH_BIT_EXT` stages must have a valid `VkShaderEXT` bound, and the other must have no `VkShaderEXT` bound.

If there is no bound graphics pipeline, and both the **taskShader** and **meshShader** features are enabled, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that `VkShaderEXT` was created without the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, there must be no `VkShaderEXT` bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage.

If there is no bound graphics pipeline, and both the **taskShader** and **meshShader** features are enabled, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that `VkShaderEXT` was created with the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, there must be no `VkShaderEXT` bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage.

If any graphics shader is bound which was created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag, then all shaders created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag in the same `vkCreateShadersEXT` call must also be bound.
• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08699
If any graphics shader is bound which was created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag, any stages in between stages whose shaders did not create a shader with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag as part of the same `vkCreateShadersEXT` call must not have any VkShaderEXT bound.

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08878
All bound graphics shader objects must have been created with identical or identically defined push constant ranges.

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08879
All bound graphics shader objects must have been created with identical or identically defined arrays of descriptor set layouts.

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-08880
If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage and the `attachmentFeedbackLoopDynamicState` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE` `vkCmdSetAttachmentFeedbackLoopEnableEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectEXT-pDynamicStates-08715
If the bound graphics pipeline state includes a fragment shader stage, was created with `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`, and the fragment shader declares the `EarlyFragmentTests` execution mode and uses `OpDepthAttachmentReadEXT`, the `depthWriteEnable` parameter in the last call to `vkCmdSetDepthWriteEnable` must be `VK_FALSE`.

• VUID-vkCmdDrawMeshTasksIndirectEXT-pDynamicStates-08716
If the bound graphics pipeline state includes a fragment shader stage, was created with `VK_DYNAMIC_STATE_STENCIL_WRITE_MASK` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`, and the fragment shader declares the `EarlyFragmentTests` execution mode and uses `OpStencilAttachmentReadEXT`, the `writeMask` parameter in the last call to `vkCmdSetStencilWriteMask` must be 0.

• VUID-vkCmdDrawMeshTasksIndirectEXT-None-09116
If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT`, and the format of any color attachment is `VK_FORMAT_E5B9G9R9_UFLOAT_PACK32`, the corresponding element of the `pColorWriteMasks` parameter of `vkCmdSetColorWriteMaskEXT` must either include all of `VK_COLOR_COMPONENT_R_BIT`, `VK_COLOR_COMPONENT_G_BIT`, and `VK_COLOR_COMPONENT_B_BIT`, or none of them.

• VUID-vkCmdDrawMeshTasksIndirectEXT-maxFragmentDualSrcAttachments-09239
If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of `Location` for any output attachment statically used in the Fragment Execution Model executed by this command must be less than `maxFragmentDualSrcAttachments`.

• VUID-vkCmdDrawMeshTasksIndirectEXT-stage-06480
The bound graphics pipeline must not have been created with the `VkPipelineShaderStageCreateInfo::stage` member of an element of
VkGraphicsPipelineCreateInfo::pStages set to VK_SHADER_STAGE_VERTEX_BIT, VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT, VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07074
  Transform Feedback Queries must not be active

- VUID-vkCmdDrawMeshTasksIndirectEXT-None-07075
  Primitives Generated Queries must not be active

- VUID-vkCmdDrawMeshTasksIndirectEXT-pipelineStatistics-07076
  The pipelineStatistics member used to create any active Pipeline Statistics Query must not contain VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_VERTICES_BIT, VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_PRIMITIVES_BIT, VK_QUERY_PIPELINE_STATISTIC_VERTEX_SHADER_INVOCATIONS_BIT, VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_INVOCATIONS_BIT, VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_PRIMITIVES_BIT, VK_QUERY_PIPELINE_STATISTIC_CLIPPING_INVOCATIONS_BIT, VK_QUERY_PIPELINE_STATISTIC_CLIPPING_PRIMITIVES_BIT, VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_CONTROL_SHADER_PATCHES_BIT, or VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_EVALUATION_SHADER_INVOCATIONS_BIT

- VUID-vkCmdDrawMeshTasksIndirectEXT-buffer-02708
  If buffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdDrawMeshTasksIndirectEXT-buffer-02709
  buffer must have been created with the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT bit set

- VUID-vkCmdDrawMeshTasksIndirectEXT-offset-02710
  offset must be a multiple of 4

- VUID-vkCmdDrawMeshTasksIndirectEXT-commandBuffer-02711
  commandBuffer must not be a protected command buffer

- VUID-vkCmdDrawMeshTasksIndirectEXT-drawCount-02718
  If the multiDrawIndirect feature is not enabled, drawCount must be 0 or 1

- VUID-vkCmdDrawMeshTasksIndirectEXT-drawCount-02719
  drawCount must be less than or equal to VkPhysicalDeviceLimits::maxDrawIndirectCount

- VUID-vkCmdDrawMeshTasksIndirectEXT-drawCount-07088
  If drawCount is greater than 1, stride must be a multiple of 4 and must be greater than or equal to sizeof(VkDrawMeshTasksIndirectCommandEXT)

- VUID-vkCmdDrawMeshTasksIndirectEXT-drawCount-07089
  If drawCount is equal to 1, (offset + sizeof(VkDrawMeshTasksIndirectCommandEXT)) must be less than or equal to the size of buffer

- VUID-vkCmdDrawMeshTasksIndirectEXT-drawCount-07090
  If drawCount is greater than 1, (stride × (drawCount - 1) + offset + sizeof(VkDrawMeshTasksIndirectCommandEXT)) must be less than or equal to the size of buffer

- VUID-vkCmdDrawMeshTasksIndirectEXT-MeshEXT-07091
The current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` must contain a shader stage using the MeshEXT Execution Model

### Valid Usage (Implicit)

- VUID-vkCmdDrawMeshTasksIndirectEXT-commandBuffer-parameter
  - `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdDrawMeshTasksIndirectEXT-buffer-parameter
  - `buffer` must be a valid `VkBuffer` handle
- VUID-vkCmdDrawMeshTasksIndirectEXT-commandBuffer-recording
  - `commandBuffer` must be in the recording state
- VUID-vkCmdDrawMeshTasksIndirectEXT-commandBuffer-cmdpool
  - The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations
- VUID-vkCmdDrawMeshTasksIndirectEXT-renderpass
  - This command must only be called inside of a render pass instance
- VUID-vkCmdDrawMeshTasksIndirectEXT-videocoding
  - This command must only be called outside of a video coding scope
- VUID-vkCmdDrawMeshTasksIndirectEXT-commonparent
  - Both of `buffer`, and `commandBuffer` must have been created, allocated, or retrieved from the same `VkDevice`

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

### Command Properties

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The `VkDrawMeshTasksIndirectCommandEXT` structure is defined as:

```c
// Provided by VK_EXT_mesh_shader
typedef struct VkDrawMeshTasksIndirectCommandEXT {
    uint32_t groupCountX;
}
```
uint32_t groupCountY;
uint32_t groupCountZ;
} VkDrawMeshTasksIndirectCommandEXT;

- `groupCountX` is the number of local workgroups to dispatch in the X dimension.
- `groupCountY` is the number of local workgroups to dispatch in the Y dimension.
- `groupCountZ` is the number of local workgroups to dispatch in the Z dimension.

The members of `VkDrawMeshTasksIndirectCommandEXT` have the same meaning as the similarly named parameters of `vkCmdDrawMeshTasksEXT`.

### Valid Usage

- **VUID-VkDrawMeshTasksIndirectCommandEXT-TaskEXT-07322**
  If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` contains a shader using the `TaskEXT` Execution Model, `groupCountX` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxTaskWorkGroupCount[0]`

- **VUID-VkDrawMeshTasksIndirectCommandEXT-TaskEXT-07323**
  If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` contains a shader using the `TaskEXT` Execution Model, `groupCountY` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxTaskWorkGroupCount[1]`

- **VUID-VkDrawMeshTasksIndirectCommandEXT-TaskEXT-07324**
  If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` contains a shader using the `TaskEXT` Execution Model, `groupCountZ` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxTaskWorkGroupCount[2]`

- **VUID-VkDrawMeshTasksIndirectCommandEXT-TaskEXT-07325**
  If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` contains a shader using the `TaskEXT` Execution Model, the product of `groupCountX`, `groupCountY` and `groupCountZ` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxTaskWorkGroupTotalCount`

- **VUID-VkDrawMeshTasksIndirectCommandEXT-TaskEXT-07326**
  If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` does not contain a shader using the `TaskEXT` Execution Model, `groupCountX` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupCount[0]`

- **VUID-VkDrawMeshTasksIndirectCommandEXT-TaskEXT-07327**
  If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` does not contain a shader using the `TaskEXT` Execution Model, `groupCountY` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupCount[1]`

- **VUID-VkDrawMeshTasksIndirectCommandEXT-TaskEXT-07328**
  If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` does not contain a shader using the `TaskEXT` Execution Model, `groupCountZ` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupCount[2]`

- **VUID-VkDrawMeshTasksIndirectCommandEXT-TaskEXT-07329**
  If the current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` does not contain a...
shader using the TaskEXT Execution Model. The product of `groupCountX`, `groupCountY` and `groupCountZ` must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupTotalCount`

To record an indirect mesh tasks drawing command with the draw count sourced from a buffer, call:

```c
void vkCmdDrawMeshTasksIndirectCountEXT(
    VkCommandBuffer commandBuffer,
    VkBuffer buffer,
    VkDeviceSize offset,
    VkBuffer countBuffer,
    VkDeviceSize countBufferOffset,
    uint32_t maxDrawCount,
    uint32_t stride);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `buffer` is the buffer containing draw parameters.
- `offset` is the byte offset into `buffer` where parameters begin.
- `countBuffer` is the buffer containing the draw count.
- `countBufferOffset` is the byte offset into `countBuffer` where the draw count begins.
- `maxDrawCount` specifies the maximum number of draws that will be executed. The actual number of executed draw calls is the minimum of the count specified in `countBuffer` and `maxDrawCount`.
- `stride` is the byte stride between successive sets of draw parameters.

`vkCmdDrawMeshTasksIndirectCountEXT` behaves similarly to `vkCmdDrawMeshTasksIndirectEXT` except that the draw count is read by the device from a buffer during execution. The command will read an unsigned 32-bit integer from `countBuffer` located at `countBufferOffset` and use this as the draw count.

**Valid Usage**

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-magFilter-04553
  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's `format` features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-mipmapMode-04770
  If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's `format` features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-06479

If a `VkImageView` is sampled with depth comparison, the image view's format features must contain `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-02691**
  If a `VkImageView` is accessed using atomic operations as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07888**
  If a `VkImageView` is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain `VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-02692**
  If a `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER` descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain `VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-02693**
  If a `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-filterCubic-02694**
  Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-filterCubicMinmax-02695**
  Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` with a reduction mode of either `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering together with minmax filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-cubicRangeClamp-09212**
  If the `cubicRangeClamp` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must not have a `VkSamplerReductionModeCreateInfo` reductionMode equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-reductionMode-09213**
  Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo`::reductionMode equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-selectableCubicWeights-09214**
  If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to
- VUID-vkCmdDrawMeshTasksIndirectCountEXT-flags-02696
  Any \texttt{VkImage} created with a \texttt{VkImageCreateInfo::flags} containing \texttt{VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV} sampled as a result of this command \textbf{must} only be sampled using a \texttt{VkSamplerAddressMode} of \texttt{VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE}

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpTypeImage-07027
  For any \texttt{VkImageView} being written as a storage image where the image format field of the \texttt{OpTypeImage} is \textit{Unknown}, the view's format features \textbf{must} contain \texttt{VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT}

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpTypeImage-07028
  For any \texttt{VkImageView} being read as a storage image where the image format field of the \texttt{OpTypeImage} is \textit{Unknown}, the view's format features \textbf{must} contain \texttt{VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT}

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpTypeImage-07029
  For any \texttt{VkBufferView} being written as a storage texel buffer where the image format field of the \texttt{OpTypeImage} is \textit{Unknown}, the view's buffer features \textbf{must} contain \texttt{VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT}

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpTypeImage-07030
  Any \texttt{VkBufferView} being read as a storage texel buffer where the image format field of the \texttt{OpTypeImage} is \textit{Unknown} then the view's buffer features \textbf{must} contain \texttt{VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT}

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08600
  For each set \(n\) that is statically used by a bound shader, a descriptor set \textbf{must} have been bound to \(n\) at the same pipeline bind point, with a \texttt{VkPipelineLayout} that is compatible for set \(n\), with the \texttt{VkPipelineLayout} or \texttt{VkDescriptorSetLayout} array that was used to create the current \texttt{VkPipeline} or \texttt{VkShaderEXT}, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08601
  For each push constant that is statically used by a bound shader, a push constant value \textbf{must} have been set for the same pipeline bind point, with a \texttt{VkPipelineLayout} that is compatible for push constants, with the \texttt{VkPipelineLayout} or \texttt{VkDescriptorSetLayout} and \texttt{VkPushConstantRange} arrays used to create the current \texttt{VkPipeline} or \texttt{VkShaderEXT}, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-maintenance4-08602
  If the \texttt{maintenance4} feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value \textbf{must} have been set for the same pipeline bind point, with a \texttt{VkPipelineLayout} that is compatible for push constants, with the \texttt{VkPipelineLayout} or \texttt{VkDescriptorSetLayout} and \texttt{VkPushConstantRange} arrays used to create the current \texttt{VkPipeline} or \texttt{VkShaderEXT}, as described in Pipeline Layout Compatibility

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08114
  Descriptors in each bound descriptor set, specified via \texttt{vkCmdBindDescriptorSets}, \textbf{must} be valid if they are statically used by the \texttt{VkPipeline} bound to the pipeline bind point used by this command and the bound \texttt{VkPipeline} was not created with \texttt{VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT}
If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` **must** have been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

Describing in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, **must** be valid if they are dynamically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

Describing in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, **must** be valid if they are dynamically used by any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command

If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdSetDescriptorBufferOffsetsEXT`, the bound `VkPipeline` **must** have been created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

If a descriptor is dynamically used with a `VkPipeline` created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory **must** be resident

If a descriptor is dynamically used with a `VkShaderEXT` created with a `VkDescriptorSetLayout` that was created with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory **must** be resident

If the `shaderObject` feature is not enabled, a valid pipeline **must** be bound to the pipeline bind point used by this command

If the `shaderObject` is enabled, either a valid pipeline **must** be bound to the pipeline bind point used by this command, or a valid combination of valid and `VK_NULL_HANDLE` shader objects **must** be bound to every supported shader stage corresponding to the pipeline bind point used by this command

If a pipeline is bound to the pipeline bind point used by this command, there **must** not have been any calls to dynamic state setting commands for any state not specified as dynamic in the `VkPipeline` object bound to the pipeline bind point used by this command, since that pipeline was bound

If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler **must** not be used to sample from any `VkImage` with a `VkImageView` of the type...
VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY, VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08610
If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08611
If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-uniformBuffers-06935
If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08612
If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-storageBuffers-06936
If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08613
If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-commandBuffer-02707
If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-06550
If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y'C
\textit{C} conversion, that object must only be used with \texttt{OpImageSample*} or \texttt{OpImageSparseSample*} instructions.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-ConstOffset-06551
  If a bound shader accesses a \texttt{VkSampler} or \texttt{VkImageView} object that enables sampler Y'C conversion, that object must not use the \texttt{ConstOffset} and \texttt{Offset} operands.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-viewType-07752
  If a \texttt{VkImageView} is accessed as a result of this command, then the image view's viewType must match the \texttt{Dim} operand of the \texttt{OpTypeImage} as described in Instruction/Sampler/Image View Validation.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-format-07753
  If a \texttt{VkImageView} is accessed as a result of this command, then the numeric type of the image view's \texttt{format} and the Sampled Type operand of the \texttt{OpTypeImage} must match.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpImageWrite-08795
  If a \texttt{VkImageView} created with a format other than \texttt{VK_FORMAT_A8_UNORM_KHR} is accessed using \texttt{OpImageWrite} as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the image view's format.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpImageWrite-08796
  If a \texttt{VkImageView} created with the format \texttt{VK_FORMAT_A8_UNORM_KHR} is accessed using \texttt{OpImageWrite} as a result of this command, then the Type of the Texel operand of that instruction must have four components.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-SampledType-04470
  If a \texttt{VkImageView} with a \texttt{VkFormat} that has a 64-bit component width is accessed as a result of this command, the SampledType of the \texttt{OpTypeImage} operand of that instruction must have a Width of 64.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-SampledType-04471
  If a \texttt{VkImageView} with a \texttt{VkFormat} that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the \texttt{OpTypeImage} operand of that instruction must have a Width of 32.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-SampledType-04472
  If a \texttt{VkBufferView} with a \texttt{VkFormat} that has a 64-bit component width is accessed as a result of this command, the SampledType of the \texttt{OpTypeImage} operand of that instruction must have a Width of 64.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-SampledType-04473
  If a \texttt{VkBufferView} with a \texttt{VkFormat} that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the \texttt{OpTypeImage} operand of that instruction must have a Width of 32.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-sparseImageInt64Atomics-04474
  If the \texttt{sparseImageInt64Atomics} feature is not enabled, \texttt{VkImage} objects created with the \texttt{VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT} flag must not be accessed by atomic instructions.
through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-sparseImageInt64Atomics-04475**
  If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpImageWeightedSampleQCOM-06971**
  If `OpImageWeightedSampleQCOM` is used to sample a `VkImage` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_INDEXED_IMAGE_BIT_QCOM`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpImageWeightedSampleQCOM-06972**
  If `OpImageWeightedSampleQCOM` uses a `VkImage` as a sample weight image as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpImageBoxFilterQCOM-06973**
  If `OpImageBoxFilterQCOM` is used to sample a `VkImage` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_BOX_FILTER_IMAGE_BIT_QCOM`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpImageBlockMatchWindowSSDQCOM-06974**
  If `OpImageBlockMatchWindowSSDQCOM` is used to read from a `VkImage` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MISMATCHING_IMAGE_BIT_QCOM`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpImageBlockMatchWindowSADQCOM-06975**
  If `OpImageBlockMatchWindowSADQCOM` is used to read from a `VkImage` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MISMATCHING_IMAGE_BIT_QCOM`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpImageBlockMatchGatherSSDQCOM-06976**
  If `OpImageBlockMatchGatherSSDQCOM` or `OpImageBlockMatchGatherSADQCOM` uses a `VkSampler` as a result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpImageBoxFilterQCOM-06977**
  If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, or `OpImageBlockMatchSSDQCOM` uses a `VkSampler` as a result of this command, then the sampler must have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpImageBlockMatchWindow-09215**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to
read from an `VkImageView` as a result of this command, then the image view’s format features **must** contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpImageBlockMatchWindow-09216**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view’s format **must** be a single-component format.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpImageBlockMatchWindow-09217**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` read from a reference image as result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07288**
  Any shader invocation executed by this command **must** terminate.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-renderPass-02684**
  The current render pass **must** be compatible with the `renderPass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-subpass-02685**
  The subpass index of the current render pass **must** be equal to the `subpass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07748**
  If any shader statically accesses an input attachment, a valid descriptor **must** be bound to the pipeline via a descriptor set.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-OpTypeImage-07468**
  If any shader executed by this pipeline accesses an `OpTypeImage` variable with a `Dim` operand of `SubpassData`, it **must** be decorated with an `InputAttachmentIndex` that corresponds to a valid input attachment in the current subpass.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07469**
  Input attachment views accessed in a subpass **must** be created with the same `VkFormat` as the corresponding subpass definition, and be created with a `VkImageView` that is compatible with the attachment referenced by the subpass’ `pInputAttachments[InputAttachmentIndex]` in the currently bound `VkFramebuffer` as specified by Fragment Input Attachment Compatibility.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-06537**
  Memory backing image subresources used as attachments in the current render pass **must** not be written in any way other than as an attachment by this command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-09000**
  If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:

  - the `VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT` is set on the currently bound pipeline or
  - the last call to `vkCmdSetAttachmentFeedbackLoopEnableEXT` included
VK_IMAGE_ASPECT_COLOR_BIT and

- there is no currently bound graphics pipeline or
- the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-09001
  If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:
  - the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
  - the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_DEPTH_BIT and
    - there is no currently bound graphics pipeline or
    - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-09002
  If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:
  - the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
  - the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_STENCIL_BIT and
    - there is no currently bound graphics pipeline or
    - the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-09003
  If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-06539
  If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command must not write to that image subresource as an attachment

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-06886
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, depth writes must be disabled

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-06887
If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back writeMask are not zero, and stencil test is enabled, all stencil ops must be VK_STENCIL_OP_KEEP

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07831
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_VIEWPORT dynamic state enabled then `vkCmdSetViewport` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07832
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SCISSOR dynamic state enabled then `vkCmdSetScissor` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07833
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LINE_WIDTH dynamic state enabled then `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08617
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to VK_POLYGON_MODE_LINE, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08618
  If a shader object is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08619
  If a shader object that outputs line primitives is bound to the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT stage, `vkCmdSetLineWidth` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07834
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BIAS dynamic state enabled then `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08620
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to VK_FALSE, and the most recent call to `vkCmdSetDepthBiasEnable` in the current command buffer set `depthBiasEnable` to VK_TRUE, `vkCmdSetDepthBias` or `vkCmdSetDepthBias2EXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07835
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_BLEND_CONSTANTS dynamic state enabled then `vkCmdSetBlendConstants`
must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08621
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetColorBlendEnableEXT in the current command buffer set any element of pColorBlendEnables to VK_TRUE, and the most recent call to vkCmdSetColorBlendEquationEXT in the current command buffer set the same element of pColorBlendEquations to a VkColorBlendEquationEXT structure with any VkBlendFactor member with a value of VK_BLEND_FACTOR_CONSTANT_COLOR, VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR, VK_BLEND_FACTOR_CONSTANT_ALPHA, or VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA, vkCmdSetBlendConstants must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07836
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BOUNDS dynamic state enabled then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08622
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDepthBoundsTestEnable in the current command buffer set depthBoundsTestEnable to VK_TRUE, then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07837
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK dynamic state enabled then vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08623
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07838
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_WRITE_MASK dynamic state enabled then vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08624
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07839
If the bound graphics pipeline state was created with the

`VK_DYNAMIC_STATE_STENCIL_REFERENCE` dynamic state enabled then

`vkCmdSetStencilReference` must have been called in the current command buffer prior to

drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08625
If a shader object is bound to any graphics stage, and the most recent call to
`vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to
`VK_TRUE`, `vkCmdSetStencilReference` must have been called in the current command buffer
prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-maxMultiviewInstanceIndex-02688
If the draw is recorded in a render pass instance with multiview enabled, the maximum
instance index must be less than or equal to `VkPhysicalDeviceMultiviewProperties`::
`maxMultiviewInstanceIndex`

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-sampleLocationsEnable-02689
If the bound graphics pipeline was created with
`VkPipelineSampleLocationsStateCreateInfoEXT`::
`sampleLocationsEnable` set to `VK_TRUE` and the current subpass has a depth/stencil attachment, then that attachment must have been
created with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-06666
If the bound graphics pipeline state was created with the

`VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` dynamic state enabled then

`vkCmdSetSampleLocationsEXT` must have been called in the current command buffer
prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08626
If a shader object is bound to any graphics stage, and the most recent call to
`vkCmdSetSampleLocationsEnableEXT` in the current command buffer set
`sampleLocationsEnable` to `VK_TRUE`, and the most recent call to
`vkCmdSetRasterizerDiscardEnable` in the current command buffer set
`rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEXT` must have been
called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-sampleLocationsPerPixel-07934
If the bound graphics pipeline state was created with the

`VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled, then the

`sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must
equal the `rasterizationSamples` member of the `VkPipelineMultisampleStateCreateInfo` structure the bound graphics pipeline has been created with

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07840
If the bound graphics pipeline state was created with the

`VK_DYNAMIC_STATE_CULL_MODE` dynamic state enabled then `vkCmdSetCullMode` must have been called in the current
command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08627
If a shader object is bound to any graphics stage, and the most recent call to
`vkCmdSetRasterizerDiscardEnable` in the current command buffer set
`rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCullMode` must have been called in the
current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` dynamic state enabled then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP` dynamic state enabled then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthTestEnable` in the current command buffer set `depthTestEnable` to `VK_TRUE`, then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command.
prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08632**
  If a shader object is bound to any graphics stage, and the **depthBounds** feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07847**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE** dynamic state enabled then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08633**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07848**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_STENCIL_OP** dynamic state enabled then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08634**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-viewportCount-03417**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT** dynamic state enabled, but not the **VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT** dynamic state enabled, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `VkPipelineViewportStateCreateInfo`::`scissorCount` of the pipeline

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-scissorCount-03418**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT** dynamic state enabled, but not the **VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT** dynamic state enabled, then `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `scissorCount` parameter of `vkCmdSetScissorWithCount` must match the `VkPipelineViewportStateCreateInfo`::`viewportCount` of the pipeline

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-viewportCount-03419**
  If the bound graphics pipeline state was created with both the **VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT** and **VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT** dynamic
states enabled then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08635**
  If a shader object is bound to any graphics stage, then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-viewportCount-04137**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportWScalingStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-viewportCount-04138**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-09232**
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then `vkCmdSetViewportWScalingNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08636**
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-viewportCount-04139**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportShadingRateImageStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-viewportCount-04140**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-viewportCount-04140**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, and the `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-viewportCount-04140**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.
vkCmdSetViewportWithCount

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-shadingRateImage-09233
  If the shadingRateImage feature is enabled, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, then vkCmdSetCoarseSampleOrderNV must
  have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-shadingRateImage-09234
  If a shader object is bound to any graphics stage, and the shadingRateImage
  feature is enabled on the device, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, and the most recent
  call to vkCmdSetShadingRateImageEnableNV in the current command buffer set
  shadingRateImageEnable to VK_TRUE, then vkCmdSetViewportShadingRatePaletteNV must
  have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08637
  If a shader object is bound to any graphics stage, and the shadingRateImage
  feature is enabled on the device, then the viewportCount parameter in the last call to
  vkCmdSetViewportShadingRatePaletteNV must be greater than or equal to the
  viewportCount parameter in the last call to vkCmdSetViewportWithCount

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-VkPipelineViewportCreateInfo-04141
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_VIEWPORT_WITHCOUNT dynamic state enabled and a
  VkPipelineViewportSwizzleStateCreateInfoNV structure chained from
  VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have
  been created with VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount
greater or equal to the viewportCount parameter in the last call to
  vkCmdSetViewportWithCount

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-VkPipelineViewportCreateInfo-04142
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_VIEWPORT_WITHCOUNT dynamic state enabled and a
  VkPipelineViewportExclusiveScissorStateCreateInfoNV structure chained from
  VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have
  been created with VkPipelineViewportExclusiveScissorStateCreateInfoNV
  ::exclusiveScissorCount greater or equal to the viewportCount parameter in the last call to
  vkCmdSetViewportWithCount

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07878
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV dynamic state enabled
  then vkCmdSetExclusiveScissorEnableNV must have been called in the current command
  buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07879
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV dynamic state enabled then
  vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to
  this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-exclusiveScissor-09235
  If a shader object is bound to any graphics stage, and the exclusiveScissor
  feature is...
enabled, then `vkCmdSetExclusiveScissorEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08638**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetExclusiveScissorEnableNV` in the current command buffer set any element of `pExclusiveScissorEnables` to `VK_TRUE`, then `vkCmdSetExclusiveScissorEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-04876**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE` dynamic state enabled then `vkCmdSetRasterizerDiscardEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08639**
  If a shader object is bound to any graphics stage, then `vkCmdSetRasterizerDiscardEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-04877**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE` dynamic state enabled then `vkCmdSetDepthBiasEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08640**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthBiasEnable` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-logicOp-04878**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LOGIC_OP_EXT` dynamic state enabled then `vkCmdSetLogicOpEXT` must have been called in the current command buffer prior to this drawing command and the `logicOp` must be a valid `VkLogicOp` value

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-primitiveFragmentShadingRateWithMultipleViewports-04552**
  If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must be 1
If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, and any shader object bound to a graphics stage writes to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must be 1.

If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view’s `format features` do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the `blendEnable` member of the corresponding element of the `pAttachments` member of `pColorBlendState` must be `VK_FALSE`.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then for each color attachment in the render pass, if the corresponding image view’s `format features` do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the corresponding member of `pColorBlendEnables` in the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer that affected that attachment index must have been `VK_FALSE`.

If rasterization is not disabled in the bound graphics pipeline, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then `rasterizationSamples` for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments.

If a shader object is bound to any graphics stage, the current render pass instance must have been begun with `vkCmdBeginRendering`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment.
If the current render pass instance was begun with VkCmdBeginRendering, the imageView member of pStencilAttachment is not VK_NULL_HANDLE, and the layout member of pStencilAttachment is VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL, this command must not write any values to the stencil attachment.

If the current render pass instance was begun with VkCmdBeginRendering, the imageView member of pDepthAttachment is not VK_NULL_HANDLE, and the layout member of pDepthAttachment is VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL, this command must not write any values to the depth attachment.

If the current render pass instance was begun with VkCmdBeginRendering, the imageView member of pStencilAttachment is not VK_NULL_HANDLE, and the layout member of pStencilAttachment is VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL, this command must not write any values to the stencil attachment.

If the current render pass instance was begun with VkCmdBeginRendering, the imageView member of pDepthAttachment is not VK_NULL_HANDLE, and the layout member of pDepthAttachment is VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL, this command must not write any values to the depth attachment.

If the current render pass instance was begun with VkCmdBeginRendering, the imageView member of pStencilAttachment is not VK_NULL_HANDLE, and the layout member of pStencilAttachment is VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL, this command must not write any values to the stencil attachment.

If the current render pass instance was begun with VkCmdBeginRendering, the currently bound graphics pipeline must have been created with a VkPipelineRenderingCreateInfo::viewMask equal to VkRenderingInfo::viewMask.

If the current render pass instance was begun with VkCmdBeginRendering, the currently bound graphics pipeline must have been created with a VkPipelineRenderingCreateInfo::colorAttachmentCount equal to VkRenderingInfo::colorAttachmentCount.

If the dynamicRenderingUnusedAttachments feature is not enabled, and the current render pass instance was begun with VkCmdBeginRendering and VkRenderingInfo::colorAttachmentCount greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with an imageView not equal to VK_NULL_HANDLE must have been created with a VkFormat equal to the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the currently bound graphics pipeline.

If the dynamicRenderingUnusedAttachments feature is enabled, and the current render pass
instance was begun with vkCmdBeginRendering and VkRenderingInfo::colorAttachmentCount greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView not equal to VK_NULL_HANDLE must have been created with a VkFormat equal to the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the currently bound graphics pipeline, or the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats, if it exists, must be VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-dynamicRenderingUnusedAttachments-08912
  If the dynamicRenderingUnusedAttachments feature is not enabled, and the current render pass instance was begun with vkCmdBeginRendering and VkRenderingInfo::colorAttachmentCount greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with a imageView equal to VK_NULL_HANDLE must have the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the currently bound pipeline equal to VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07749
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT dynamic state enabled then vkCmdSetColorWriteEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08646
  If the colorWriteEnable feature is enabled on the device, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorWriteEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-attachmentCount-07750
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT dynamic state enabled then the attachmentCount parameter of vkCmdSetColorWriteEnableEXT must be greater than or equal to the VkPipelineColorBlendStateCreateInfo::attachmentCount of the currently bound graphics pipeline

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08647
  If the colorWriteEnable feature is enabled on the device, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then the attachmentCount parameter of most recent call to vkCmdSetColorWriteEnableEXT in the current command buffer must be greater than or equal to the number of color attachments in the current render pass instance

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07751
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT dynamic state enabled then vkCmdSetDiscardRectangleEXT must have been called in the current command buffer prior to this drawing command for each discard rectangle in
- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07880**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-rasterizerDiscardEnable-09236**
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDiscardRectangleEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08648**
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDiscardRectangleEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07881**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08649**
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDiscardRectangleEnableEXT` in the current command buffer set `discardRectangleEnable` to `VK_TRUE`, then `vkCmdSetDiscardRectangleModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-dynamicRenderingUnusedAttachments-08913**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline must be equal to `VK_FORMAT_UNDEFINED`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-dynamicRenderingUnusedAttachments-08914**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline must be equal to the `VkFormat` used to create `VkRenderingInfo::pDepthAttachment->imageView`.
If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo::pDepthAttachment->imageView`, the value of the format must be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to `VK_FORMAT_UNDEFINED`.

If current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to the `VkFormat` used to create `VkRenderingInfo::pStencilAttachment->imageView`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo::pStencilAttachment->imageView`, the value of the format must be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView` was not `VK_NULL_HANDLE`, the currently bound graphics pipeline must have been created with `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`.

If the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView` was not `VK_NULL_HANDLE`, the currently bound graphics pipeline must have been created with `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT`.

If the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the current render pass instance was begun with `vkCmdBeginRendering` with `VkRenderingInfo::colorAttachmentCount`
parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the corresponding element of the `pColorAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-pDepthAttachment-06186**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-pStencilAttachment-06187**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-multisampledRenderToSingleSampled-07285**
  If the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the value of `rasterizationSamples` for the currently bound graphics pipeline.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-multisampledRenderToSingleSampled-07286**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-multisampledRenderToSingleSampled-07287**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not
VK_NULL_HANDLE, the value of rasterizationSamples for the currently bound graphics pipeline must be equal to the sample count used to create VkRenderingInfo::pStencilAttachment->imageView

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-pNext-07935
  If this command has been called inside a render pass instance started with vkCmdBeginRendering, and the pNext chain of VkRenderingInfo includes a VkMultisampledRenderToSingleSampledInfoEXT structure with multisampledRenderToSingleSampledEnable equal to VK_TRUE, then the value of rasterizationSamples for the currently bound graphics pipeline must be equal to VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-renderPass-06198
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline must have been created with a VkGraphicsPipelineCreateInfo::renderPass equal to VK_NULL_HANDLE

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-pColorAttachments-08963
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the VkRenderingInfo::pColorAttachments->imageView was not VK_NULL_HANDLE, then the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the pipeline must not be VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-pDepthAttachment-08964
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, then the VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the pipeline must not be VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-pStencilAttachment-08965
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound, stencil test is enabled and the VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, then the VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the pipeline must not be VK_FORMAT_UNDEFINED

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-primitivesGeneratedQueryWithRasterizerDiscard-06708
  If the primitivesGeneratedQueryWithRasterizerDiscard feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, rasterization discard must not be enabled

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-primitivesGeneratedQueryWithNonZeroStreams-06709
  If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, the bound graphics pipeline must not have been created with a non-zero value in VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07619
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT` dynamic state enabled then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07620
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-09237
If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08650
If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07621
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08651
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07622
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` dynamic state enabled then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08652
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07623
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` dynamic state enabled then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08653
If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleMaskEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07624
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled then vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-alphaToCoverageEnable-08919
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled, and alphaToCoverageEnable was VK_TRUE in the last call to vkCmdSetAlphaToCoverageEnableEXT, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08654
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-alphaToCoverageEnable-08920
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetAlphaToCoverageEnableEXT in the current command buffer set alphaToCoverageEnable to VK_TRUE, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07625
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT dynamic state enabled then vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08655
  If the alphaToOne feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07626
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT dynamic state enabled then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08656
  If the logicOp feature is enabled, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command
• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07627
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08657
If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07628
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08658
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` for any attachment set that attachment's value in `pColorBlendEnables` to `VK_TRUE`, then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07629
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08659
If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07630
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` dynamic state enabled then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08660
If the `geometryStreams` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_GEOMETRY_BIT` stage, then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07631
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.
command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08661**
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetConservativeRasterizationModeEXT` *must* have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07632**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` *must* have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08662**
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetConservativeRasterizationModeEXT` in the current command buffer set `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`, then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` *must* have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07633**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` *must* have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08663**
  If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` *must* have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07634**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` *must* have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08664**
  If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEnableEXT` *must* have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07635**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` *must* have been called in the current command buffer prior to this drawing command.
prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07636**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT` dynamic state enabled then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08665**
  If the `VK_EXT_provoking_vertex` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07637**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08666**
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08667**
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08668**
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07638**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` dynamic state enabled then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08669**
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08670**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` dynamic state enabled then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command
If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08671**
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07849**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_EXT` dynamic state enabled then `vkCmdSetLineStippleEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08672**
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetLineStippleEnableEXT` in the current command buffer set `stippledLineEnable` to `VK_TRUE`, then `vkCmdSetLineStippleEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07639**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT` dynamic state enabled then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08673**
  If the `depthClipControl` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipNegativeOneToOneEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07640**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV` dynamic state enabled then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08674**
  If the `VK_NV_clip_space_w_scaling` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07641**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08675**
  If the `VK_NV_viewport_swizzle` extension is enabled, and a shader object is bound to any...
graphics stage, then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07642**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08676**
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07643**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` dynamic state enabled then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08677**
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set `coverageToColorEnable` to `VK_TRUE`, then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07644**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08678**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07645**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08679**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationModeNV` in the current command buffer set...
If coverageModulationMode to any value other than `VK_COVERAGE_MODULATION_MODE_NONE_NV`, then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07646**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08680**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationTableEnableNV` in the current command buffer set `coverageModulationTableEnable` to `VK_TRUE`, then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07647**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV` dynamic state enabled then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-pipelineFragmentShadingRate-09238**
  If the `pipelineFragmentShadingRate` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFragmentShadingRateKHR` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08681**
  If the `shadingRateImage` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07648**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV` dynamic state enabled then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08682**
  If the `representativeFragmentTest` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07649**
  If the bound graphics pipeline state was created with the
**VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV** dynamic state enabled then **vkCmdSetCoverageReductionModeNV** must have been called in the current command buffer prior to this drawing command

- **VUID-vk.CmdDrawMeshTasksIndirectCountEXT-None-08683**
  If the **coverageReductionMode** feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set **rasterizerDiscardEnable** to **VK_FALSE**, then **vkCmdSetCoverageReductionModeNV** must have been called in the current command buffer prior to this drawing command

- **VUID-vk.CmdDrawMeshTasksIndirectCountEXT-pColorBlendEnables-07470**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT** state enabled and the last call to **vkCmdSetColorBlendEnableEXT** set **pColorBlendEnables** for any attachment to **VK_TRUE**, then for those attachments in the subpass the corresponding image view’s format features must contain **VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT**

- **VUID-vk.CmdDrawMeshTasksIndirectCountEXT-rasterizationSamples-07471**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT** state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the **rasterizationSamples** in the last call to **vkCmdSetRasterizationSamplesEXT** must follow the rules for a zero-attachment subpass

- **VUID-vk.CmdDrawMeshTasksIndirectCountEXT-samples-07472**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SAMPLE_MASK_EXT** state enabled and the **VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT** state disabled, then the **samples** parameter in the last call to **vkCmdSetSampleMaskEXT** must be greater or equal to the **VkPipelineMultisampleStateCreateInfo::rasterizationSamples** parameter used to create the bound graphics pipeline

- **VUID-vk.CmdDrawMeshTasksIndirectCountEXT-samples-07473**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SAMPLE_MASK_EXT** state and **VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT** states enabled, then the **samples** parameter in the last call to **vkCmdSetSampleMaskEXT** must be greater or equal to the **rasterizationSamples** parameter in the last call to **vkCmdSetRasterizationSamplesEXT**

- **VUID-vk.CmdDrawMeshTasksIndirectCountEXT-rasterizationSamples-07474**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT** state enabled, and neither the **VK_AMD_mixed_attachment_samples** nor the **VK_NV_framebuffer_mixed_samples** extensions are enabled, then the **rasterizationSamples** in the last call to **vkCmdSetRasterizationSamplesEXT** must be the same as the current subpass color and/or depth/stencil attachments

- **VUID-vk.CmdDrawMeshTasksIndirectCountEXT-None-09211**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT** state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a
VkMultisampledRenderToSingleSampledInfoEXT structure with multisampledRenderToSingleSampledEnable equal to VK_TRUE, then the rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT must be the same as the rasterizationSamples member of that structure

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-firstAttachment-07476
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendEnableEXT calls must specify an enable for all active color attachments in the current subpass

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-firstAttachment-07477
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT dynamic state enabled then vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendEquationEXT calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-firstAttachment-07478
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT dynamic state enabled then vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorWriteMaskEXT calls must specify the color write mask for all active color attachments in the current subpass

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-firstAttachment-07479
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT dynamic state enabled then vkCmdSetColorBlendAdvancedEXT must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendAdvancedEXT calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-advancedBlendMaxColorAttachments-07480
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT and VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic states enabled and the last calls to vkCmdSetColorBlendEnableEXT and vkCmdSetColorBlendAdvancedEXT have enabled advanced blending, then the number of active color attachments in the current subpass must not exceed advancedBlendMaxColorAttachments

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-primitivesGeneratedQueryWithNonZeroStreams-07481
If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the
VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, and the bound graphics pipeline was created with VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT state enabled, the last call to vkCmdSetRasterizationStreamEXT must have set the rasterizationStream to zero.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-sampleLocationsPerPixel-07482
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state disabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples member of the VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-sampleLocationsPerPixel-07483
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples parameter of the last call to vkCmdSetRasterizationSamplesEXT.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-sampleLocationsEnable-07484
  If the bound graphics pipeline was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-sampleLocationsEnable-07485
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the sampleLocationsInfo.sampleLocationGridSize.width in the last call to vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-sampleLocationsEnable-07486
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the sampleLocationsInfo.sampleLocationGridSize.height in the last call to vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples.

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-sampleLocationsEnable-07487
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, the fragment shader code must not statically use the extended instruction `InterpolateAtSample`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-sampleLocationsEnable-07936**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.width` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.width` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling the value of `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-sampleLocationsEnable-07937**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.height` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.height` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling the value of `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-sampleLocationsEnable-07938**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationsPerPixel` must equal `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-coverageModulationTableEnable-07488**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageModulationTableEnableNV` set `coverageModulationTableEnable` to `VK_TRUE`, then the `coverageModulationTableCount` parameter in the last call to `vkCmdSetCoverageModulationTableNV` must equal the current `rasterizationSamples` divided by the number of color samples in the current subpass.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-rasterizationSamples-07489**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current `rasterizationSamples` must be the same as the sample count of the depth/stencil attachment.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-coverageToColorEnable-07490**
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageToColorEnableNV` set the `coverageToColorEnable` to `VK_TRUE`, then the current subpass must have a color attachment at the location selected by the last call to `vkCmdSetCoverageToColorLocationNV` `coverageToColorLocation`, with a `VkFormat` of `VK_FORMAT_R8_UINT`, `VK_FORMAT_R8_SINT`, `VK_FORMAT_R16_UINT`, `VK_FORMAT_R16_SINT`, `VK_FORMAT_R32_UINT`, or `VK_FORMAT_R32_SINT`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-coverageReductionMode-07491**
  If this `VK_NV_coverage_reduction_mode` extension is enabled, the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, the current coverage reduction mode `coverageReductionMode`, then the current `rasterizationSamples`, and the sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by `vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-viewportCount-07492**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV` ::viewportCount greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-viewportCount-07493**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportSwizzleNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-rasterizationSamples-07494**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if the current subpass has any color attachments and `rasterizationSamples` of the last call to `vkCmdSetRasterizationSamplesEXT` is greater than the number of color samples, then the pipeline `sampleShadingEnable` must be `VK_FALSE`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-stippledLineEnable-07495**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT`, then the `stippledRectangularLines` feature must be enabled.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-stippledLineEnable-07496**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is...
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT`, then the `stippledSmoothLines` feature **must** be enabled

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT`, then the `stippledRectangularLines` feature **must** be enabled and `VkPhysicalDeviceLimits::strictLines` **must** be `VK_TRUE`
vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08686
  If there is no bound graphics pipeline, and the tessellationShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08687
  If there is no bound graphics pipeline, and the geometryShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_GEOMETRY_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08688
  If there is no bound graphics pipeline, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_FRAGMENT_BIT

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08689
  If there is no bound graphics pipeline, and the taskShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_TASK_BIT_EXT

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08690
  If there is no bound graphics pipeline, and the meshShader feature is enabled, vkCmdBindShadersEXT must have been called in the current command buffer with pStages with an element of VK_SHADER_STAGE_MESH_BIT_EXT

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08693
  If there is no bound graphics pipeline, and at least one of the taskShader and meshShader features is enabled, one of the VK_SHADER_STAGE_VERTEX_BIT or VK_SHADER_STAGE_MESH_BIT_EXT stages must have a valid VkShaderEXT bound, and the other must have no VkShaderEXT bound

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08694
  If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_MESH_BIT_EXT stage, and that VkShaderEXT was created without the VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT flag, a valid VkShaderEXT must be bound to the VK_SHADER_STAGE_TASK_BIT_EXT stage

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08695
  If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_MESH_BIT_EXT stage, and that VkShaderEXT was created with the VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT flag, there must be no VkShaderEXT bound to the VK_SHADER_STAGE_TASK_BIT_EXT stage

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08696
  If there is no bound graphics pipeline, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, there must be no VkShaderEXT bound to either the VK_SHADER_STAGE_TASK_BIT_EXT stage or the VK_SHADER_STAGE_MESH_BIT_EXT stage

• VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08698
  If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, then all shaders created with the
VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag in the same vkCreateShadersEXT call must also be bound

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08699
  If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, any stages in between stages whose shaders which did not create a shader with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag as part of the same vkCreateShadersEXT call must not have any VkShaderEXT bound

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08878
  All bound graphics shader objects must have been created with identical or identically defined push constant ranges

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08879
  All bound graphics shader objects must have been created with identical or identically defined arrays of descriptor set layouts

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-08880
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage and the attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-pDynamicStates-08715
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE set in VkPipelineDynamicStateCreateInfo ::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable parameter in the last call to vkCmdSetDepthWriteEnable must be VK_FALSE

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-pDynamicStates-08716
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_STENCIL_WRITE_MASK set in VkPipelineDynamicStateCreateInfo ::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpStencilAttachmentReadEXT, the writeMask parameter in the last call to vkCmdSetStencilWriteMask must be 0

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-09116
  If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT, and the format of any color attachment is VK_FORMAT_E5B9G9R9_UFLOAT_PACK32, the corresponding element of the pColorWriteMasks parameter of vkCmdSetColorWriteMaskEXT must either include all of VK_COLOR_COMPONENT_R_BIT, VK_COLOR_COMPONENT_G_BIT, and VK_COLOR_COMPONENT_B_BIT, or none of them

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-maxFragmentDualSrcAttachments-09239
  If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of Location for any output attachment statically used in the Fragment Execution Model executed by this command must be less than maxFragmentDualSrcAttachments

- VUID-vkCmdDrawMeshTasksIndirectCountEXT-stage-06480
The bound graphics pipeline **must** not have been created with the `VkPipelineShaderStageCreateInfo::stage` member of an element of `VkGraphicsPipelineCreateInfo::pStages` set to `VK_SHADER_STAGE_VERTEX_BIT`, `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`, `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` or `VK_SHADER_STAGE_GEOMETRY_BIT`.

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07074**
  Transform Feedback Queries **must** not be active

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-07075**
  Primitives Generated Queries **must** not be active

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-pipelineStatistics-07076**
  The `pipelineStatistics` member used to create any active Pipeline Statistics Query **must** not contain `VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_VERTICES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_PRIMITIVES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_VERTEX_SHADER_INVOCATIONS_BIT`, `VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_INVOCATIONS_BIT`, `VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_PRIMITIVES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_CLIPPING_INVOCATIONS_BIT`, `VK_QUERY_PIPELINE_STATISTIC_CLIPPING_PRIMITIVES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_CONTROL_SHADER_PATCHES_BIT`, or `VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_EVALUATION_SHADER_INVOCATIONS_BIT`

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-buffer-02708**
  If `buffer` is non-sparse then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-buffer-02709**
  `buffer` **must** have been created with the `VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT` bit set

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-offset-02710**
  `offset` **must** be a multiple of 4

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-commandBuffer-02711**
  `commandBuffer` **must** not be a protected command buffer

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-countBuffer-02714**
  If `countBuffer` is non-sparse then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-countBuffer-02715**
  `countBuffer` **must** have been created with the `VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT` bit set

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-countBufferOffset-02716**
  `countBufferOffset` **must** be a multiple of 4

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-countBuffer-02717**
  The count stored in `countBuffer` **must** be less than or equal to `VkPhysicalDeviceLimits::maxDrawIndirectCount`

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-countBufferOffset-04129**
  `countBufferOffset + sizeof(uint32_t))` **must** be less than or equal to the size of `countBuffer`

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-None-04445**
If `drawIndirectCount` is not enabled this function **must** not be used

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-stride-07096**
  
  `stride` **must** be a multiple of 4 and **must** be greater than or equal to `sizeof(VkDrawMeshTasksIndirectCommandEXT)`

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-maxDrawCount-07097**
  
  If `maxDrawCount` is greater than or equal to 1, `(stride × (maxDrawCount - 1) + offset + sizeof(VkDrawMeshTasksIndirectCommandEXT))` **must** be less than or equal to the size of `buffer`

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-countBuffer-07098**
  
  If the count stored in `countBuffer` is equal to 1, `(offset + sizeof(VkDrawMeshTasksIndirectCommandEXT))` **must** be less than or equal to the size of `buffer`

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-MeshEXT-07100**
  
  The current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` **must** contain a shader stage using the `MeshEXT Execution Model`

### Valid Usage (Implicit)

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-commandBuffer-parameter**
  
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-buffer-parameter**
  
  `buffer` **must** be a valid `VkBuffer` handle

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-countBuffer-parameter**
  
  `countBuffer` **must** be a valid `VkBuffer` handle

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-commandBuffer-recording**
  
  `commandBuffer` **must** be in the recording state

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-commandBuffer-cmdpool**
  
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics operations

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-renderpass**
  
  This command **must** only be called inside of a render pass instance

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-videocoding**
  
  This command **must** only be called outside of a video coding scope

- **VUID-vkCmdDrawMeshTasksIndirectCountEXT-commonparent**
  
  Each of `buffer`, `commandBuffer`, and `countBuffer` **must** have been created, allocated, or retrieved from the same `VkDevice`

### Host Synchronization

- Host access to `commandBuffer` **must** be externally synchronized
Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized.

### Command Properties

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#### 21.6. Programmable Cluster Culling Shading

In this drawing approach, clusters are generated by the cluster culling shader stage. It operates similarly to dispatching compute as the shaders make use of workgroups.

To record a cluster culling shader drawing command, call:

```c
// Provided by VK_HUAWEI_cluster_culling_shader
void vkCmdDrawClusterHUAWEI(
    VkCommandBuffer commandBuffer,
    uint32_t groupCountX,
    uint32_t groupCountY,
    uint32_t groupCountZ);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `groupCountX` is the number of local workgroups to dispatch in the X dimension.
- `groupCountY` is the number of local workgroups to dispatch in the Y dimension.
- `groupCountZ` is the number of local workgroups to dispatch in the Z dimension.

When the command is executed, a global workgroup consisting of `groupCountX*groupCountY*groupCountZ` local workgroup is assembled. Note that the cluster culling shader pipeline only accepts `vkCmdDrawClusterHUAWEI` and `vkCmdDrawClusterIndirectHUAWEI` as drawing commands.

#### Valid Usage

- VUID-vkCmdDrawClusterHUAWEI-magFilter-04553
  If a VkSampler created with magFilter or minFilter equal to VK_FILTER_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- VUID-vkCmdDrawClusterHUAWEI-mipmapMode-04770
  If a VkSampler created with mipmapMode equal to VK_SAMPLER_MIPMAP_MODE_LINEAR and
compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- VUID-vkCmdDrawClusterHUAWEI-None-06479
  If a VkImageView is sampled with depth comparison, the image view's format features must contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT

- VUID-vkCmdDrawClusterHUAWEI-None-02691
  If a VkImageView is accessed using atomic operations as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

- VUID-vkCmdDrawClusterHUAWEI-None-07888
  If a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

- VUID-vkCmdDrawClusterHUAWEI-None-02692
  If a VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT

- VUID-vkCmdDrawClusterHUAWEI-None-02693
  If the VK_EXT_filter_cubic extension is not enabled and any VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, it must not have a VkImageViewType of VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

- VUID-vkCmdDrawClusterHUAWEI-filterCubic-02694
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2

- VUID-vkCmdDrawClusterHUAWEI-filterCubicMinmax-02695
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT with a reduction mode of either VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX as a result of this command must have a VkImageViewType and format that supports cubic filtering together with minmax filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax returned by vkGetPhysicalDeviceImageFormatProperties2

- VUID-vkCmdDrawClusterHUAWEI-cubicRangeClamp-09212
  If the cubicRangeClamp feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must not have a VkSamplerReductionModeCreateInfo::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM

- VUID-vkCmdDrawClusterHUAWEI-reductionMode-09213
  Any VkImageView being sampled with a VkSamplerReductionModeCreateInfo::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM as a result of this command must sample with VK_FILTER_CUBIC_EXT
If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`.

Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

For any `VkImageView` being written as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view's `format features` must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

For any `VkImageView` being read as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view's `format features` must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`.

Any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view's `buffer features` must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

Any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown` then the view's `buffer features` must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`.

For each set `n` that is statically used by a bound shader, a descriptor set must have been bound to `n` at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set `n`, with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

If the `maintenance4` feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

For each set `n` that is statically used by a bound shader, a descriptor set must have been bound to `n` at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set `n`, with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.
Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, **must** be valid if they are statically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was not created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- **VUID-vkCmdDrawClusterHUAWEI-None-08115**
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` **must** have been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- **VUID-vkCmdDrawClusterHUAWEI-None-08116**
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, **must** be valid if they are dynamically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- **VUID-vkCmdDrawClusterHUAWEI-None-08604**
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, **must** be valid if they are dynamically used by any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command

- **VUID-vkCmdDrawClusterHUAWEI-None-08117**
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdSetDescriptorBufferOffsetsEXT`, the bound `VkPipeline` **must** have been created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- **VUID-vkCmdDrawClusterHUAWEI-None-08119**
  If a descriptor is dynamically used with a `VkPipeline` created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory **must** be resident

- **VUID-vkCmdDrawClusterHUAWEI-None-08605**
  If a descriptor is dynamically used with a `VkShaderEXT` created with a `VkDescriptorSetLayout` that was created with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory **must** be resident

- **VUID-vkCmdDrawClusterHUAWEI-None-08606**
  If the `shaderObject` feature is not enabled, a valid pipeline **must** be bound to the pipeline bind point used by this command

- **VUID-vkCmdDrawClusterHUAWEI-None-08607**
  If the `shaderObject` is enabled, either a valid pipeline **must** be bound to the pipeline bind point used by this command, or a valid combination of valid and `VK_NULL_HANDLE` shader objects **must** be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- **VUID-vkCmdDrawClusterHUAWEI-None-08608**
  If a pipeline is bound to the pipeline bind point used by this command, there **must** not have been any calls to dynamic state setting commands for any state not specified as dynamic in the `VkPipeline` object bound to the pipeline bind point used by this command, since that pipeline was bound

- **VUID-vkCmdDrawClusterHUAWEI-None-08609**

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If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used to sample from any VkImage with a VkImageView of the type VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY, VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage

• VUID-vkCmdDrawClusterHUAWEI-None-08610
If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage

• VUID-vkCmdDrawClusterHUAWEI-None-08611
If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage

• VUID-vkCmdDrawClusterHUAWEI-uniformBuffers-06935
If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawClusterHUAWEI-None-08612
If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawClusterHUAWEI-storageBuffers-06936
If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawClusterHUAWEI-None-08613
If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawClusterHUAWEI-commandBuffer-02707
If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, any resource accessed by `bound shaders` must not be a protected resource

- **VUID-vkCmdDrawClusterHUAWEI-None-06550**
  If a bound shader accesses a `VkSampler` or `VkImageView` object that enables sampler Y’C₈₂C₆ conversion, that object must only be used with `OpImageSample*` or `OpImageSparseSample*` instructions

- **VUID-vkCmdDrawClusterHUAWEI-ConstOffset-06551**
  If a bound shader accesses a `VkSampler` or `VkImageView` object that enables sampler Y’C₈₂C₆ conversion, that object must not use the `ConstOffset` and `Offset` operands

- **VUID-vkCmdDrawClusterHUAWEI-viewType-07752**
  If a `VkImageView` is accessed as a result of this command, then the image view’s `viewType` must match the `Dim` operand of the `OpTypeImage` as described in `Instruction/Sampler/Image View Validation`

- **VUID-vkCmdDrawClusterHUAWEI-format-07753**
  If a `VkImageView` is accessed as a result of this command, then the numeric type of the image view’s `format` and the `Sampled Type` operand of the `OpTypeImage` must match

- **VUID-vkCmdDrawClusterHUAWEI-OpImageWrite-08795**
  If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have at least as many components as the image view’s format

- **VUID-vkCmdDrawClusterHUAWEI-OpImageWrite-08796**
  If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have four components

- **VUID-vkCmdDrawClusterHUAWEI-OpImageWrite-04469**
  If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have at least as many components as the buffer view’s format

- **VUID-vkCmdDrawClusterHUAWEI-SampledType-04470**
  If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64

- **VUID-vkCmdDrawClusterHUAWEI-SampledType-04471**
  If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 32

- **VUID-vkCmdDrawClusterHUAWEI-SampledType-04472**
  If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64

- **VUID-vkCmdDrawClusterHUAWEI-SampledType-04473**
  If a `VkBufferView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that
instruction must have a Width of 32

- VUID-vkCmdDrawClusterHUAWEI-sparseImageInt64Atomics-04474
  If the sparseImageInt64Atomics feature is not enabled, VkImage objects created with the VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- VUID-vkCmdDrawClusterHUAWEI-sparseImageInt64Atomics-04475
  If the sparseImageInt64Atomics feature is not enabled, VkBuffer objects created with the VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- VUID-vkCmdDrawClusterHUAWEI-OpImageWeightedSampleQCOM-06971
  If OpImageWeightedSampleQCOM is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM

- VUID-vkCmdDrawClusterHUAWEI-OpImageWeightedSampleQCOM-06972
  If OpImageWeightedSampleQCOM uses a VkImageView as a sample weight image as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM

- VUID-vkCmdDrawClusterHUAWEI-OpImageBoxFilterQCOM-06973
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM

- VUID-vkCmdDrawClusterHUAWEI-OpImageBlockMatchSSDQCOM-06974
  If OpImageBlockMatchSSDQCOM is used to read from a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdDrawClusterHUAWEI-OpImageBlockMatchSADQCOM-06975
  If OpImageBlockMatchSADQCOM is used to read from an VkImageView as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- VUID-vkCmdDrawClusterHUAWEI-OpImageWeightedSampleQCOM-06976
  If any command other than OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, or OpImageBlockMatchSSDQCOM uses a VkSampler as a result of this command, then the sampler must have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM
command, then the sampler must not have been created with
VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM

- VUID-vkCmdDrawClusterHUAWEI-OpImageBlockMatchWindow-09215
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to
  read from an VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdDrawClusterHUAWEI-OpImageBlockMatchWindow-09216
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to
  read from an VkImageView as a result of this command, then the image view’s format must be a single-component format.

- VUID-vkCmdDrawClusterHUAWEI-OpImageBlockMatchWindow-09217
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM read from a reference
  image as result of this command, then the specified reference coordinates must not fail
  integer texel coordinate validation

- VUID-vkCmdDrawClusterHUAWEI-None-07288
  Any shader invocation executed by this command must terminate

- VUID-vkCmdDrawClusterHUAWEI-renderPass-02684
  The current render pass must be compatible with the renderPass member of the
  VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to
  VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdDrawClusterHUAWEI-subpass-02685
  The subpass index of the current render pass must be equal to the subpass member of the
  VkGraphicsPipelineCreateInfo structure specified when creating the VkPipeline bound to
  VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdDrawClusterHUAWEI-None-07748
  If any shader statically accesses an input attachment, a valid descriptor must be bound to
  the pipeline via a descriptor set

- VUID-vkCmdDrawClusterHUAWEI-OpTypeImage-07468
  If any shader executed by this pipeline accesses an OpTypeImage variable with a Dim
  operand of SubpassData, it must be decorated with an InputAttachmentIndex that
  corresponds to a valid input attachment in the current subpass

- VUID-vkCmdDrawClusterHUAWEI-None-07469
  Input attachment views accessed in a subpass must be created with the same VkFormat
  as the corresponding subpass definition, and be created with a VkImageView that is
  compatible with the attachment referenced by the subpass’ pInputAttachments
  [InputAttachmentIndex] in the currently bound VkFramebuffer as specified by Fragment
  Input Attachment Compatibility

- VUID-vkCmdDrawClusterHUAWEI-None-06537
  Memory backing image subresources used as attachments in the current render pass
  must not be written in any way other than as an attachment by this command

- VUID-vkCmdDrawClusterHUAWEI-None-09000
  If a color attachment is written by any prior command in this subpass or by the load,
  store, or resolve operations for this subpass, it is not in the
VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:

◦ the VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or

◦ the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_COLOR_BIT and

  ▪ there is no currently bound graphics pipeline or
  ▪ the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawClusterHUAWEI-None-09001
If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:

◦ the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or

◦ the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_DEPTH_BIT and

  ▪ there is no currently bound graphics pipeline or
  ▪ the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawClusterHUAWEI-None-09002
If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:

◦ the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or

◦ the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_STENCIL_BIT and

  ▪ there is no currently bound graphics pipeline or
  ▪ the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

• VUID-vkCmdDrawClusterHUAWEI-None-09003
If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command

• VUID-vkCmdDrawClusterHUAWEI-None-06539
If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command must not write to that image subresource as an attachment
• **VUID-vkCmdDrawClusterHUAWEI-None-06886**
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, **depth writes must be disabled**.

• **VUID-vkCmdDrawClusterHUAWEI-None-06887**
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back **writeMask are not zero**, and stencil test is enabled, **all stencil ops must be VK_STENCIL_OP_KEEP**.

• **VUID-vkCmdDrawClusterHUAWEI-None-07831**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_VIEWPORT** dynamic state enabled then **vkCmdSetViewport must have been called in the current command buffer prior to this drawing command**.

• **VUID-vkCmdDrawClusterHUAWEI-None-07832**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SCISSOR** dynamic state enabled then **vkCmdSetScissor must have been called in the current command buffer prior to this drawing command**.

• **VUID-vkCmdDrawClusterHUAWEI-None-07833**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_LINE_WIDTH** dynamic state enabled then **vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command**.

• **VUID-vkCmdDrawClusterHUAWEI-None-08617**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetPolygonModeEXT** in the current command buffer set **polygonMode** to **VK_POLYGON_MODE_LINE**, **vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command**.

• **VUID-vkCmdDrawClusterHUAWEI-None-08618**
  If a shader object is bound to the **VK_SHADER_STAGE_VERTEX_BIT** stage, and the most recent call to **vkCmdSetPrimitiveTopology** in the current command buffer set **primitiveTopology** to any line topology, **vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command**.

• **VUID-vkCmdDrawClusterHUAWEI-None-08619**
  If a shader object that outputs line primitives is bound to the **VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT** or **VK_SHADER_STAGE_GEOMETRY_BIT** stage, **vkCmdSetLineWidth must have been called in the current command buffer prior to this drawing command**.

• **VUID-vkCmdDrawClusterHUAWEI-None-07834**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_DEPTH_BIAS** dynamic state enabled then **vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current command buffer prior to this drawing command**.

• **VUID-vkCmdDrawClusterHUAWEI-None-08620**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set **rasterizerDiscardEnable to VK_FALSE**, and the most recent call to **vkCmdSetDepthBiasEnable** in the current command buffer set **depthBiasEnable to VK_TRUE**, **vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current
command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-07835**
  If the bound graphics pipeline state was created with the
  `VK_DYNAMIC_STATE_BLEND_CONSTANTS` dynamic state enabled then `vkCmdSetBlendConstants`
  must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-08621**
  If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent
  call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
  `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to
  `vkCmdSetColorBlendEnableEXT` in the current command buffer set any element of
  `pColorBlendEnables` to `VK_TRUE`, and the most recent call to
  `vkCmdSetColorBlendEquationEXT` in the current command buffer set the same element of
  `pColorBlendEquations` to a `VkColorBlendEquationEXT` structure with any
  `VkBlendFactor` member with a value of `VK_BLEND_FACTOR_CONSTANT_COLOR`,
  `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR`, `VK_BLEND_FACTOR_CONSTANT_ALPHA`, or
  `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA`, `vkCmdSetBlendConstants` must have been
  called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-07836**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS`
  dynamic state enabled then `vkCmdSetDepthBounds` must have been called in the current
  command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-08622**
  If a shader object is bound to any graphics stage, and the most recent call to
  `vkCmdSetRasterizerDiscardEnable` in the current command buffer set
  `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to
  `vkCmdSetDepthBoundsTestEnable` in the current command buffer set
  `depthBoundsTestEnable` to `VK_TRUE`, then `vkCmdSetDepthBounds` must have been called in
  the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-07837**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK`
  dynamic state enabled then `vkCmdSetStencilCompareMask` must have been called in the current
  command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-08623**
  If a shader object is bound to any graphics stage, and the most recent call to
  `vkCmdSetStencilTestEnable` in the current command buffer set
  `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilCompareMask` must have been called in the current
  command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-07838**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_WRITE_MASK`
  dynamic state enabled then `vkCmdSetStencilWriteMask` must have been called in the current
  command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-08624**
  If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawClusterHUAWEI-None-07839
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_REFERENCE dynamic state enabled then vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawClusterHUAWEI-None-08625
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawClusterHUAWEI-None-08626
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawClusterHUAWEI-maxMultiviewInstanceIndex-02688
  If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex

• VUID-vkCmdDrawClusterHUAWEI-sampleLocationsEnable-02689
  If the bound graphics pipeline was created with VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable set to VK_TRUE and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set

• VUID-vkCmdDrawClusterHUAWEI-None-06666
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT dynamic state enabled then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawClusterHUAWEI-None-08626
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetSampleLocationsEnableEXT in the current command buffer set sampleLocationsEnable to VK_TRUE, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawClusterHUAWEI-sampleLocationsPerPixel-07934
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples member of the VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with

• VUID-vkCmdDrawClusterHUAWEI-None-07840
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_CULL_MODE dynamic state enabled then vkCmdSetCullMode must have been called in the current command buffer prior to this drawing command
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` dynamic state enabled then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthTestEnable` in the current command buffer set `depthTestEnable` to `VK_TRUE`, then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.
prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-07846**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthBoundsTestEnable must` have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-08632**
  If a shader object is bound to any graphics stage, and the `depthBounds` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `vkCmdSetDepthBoundsTestEnable must` have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-07847**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE` dynamic state enabled then `vkCmdSetStencilTestEnable must` have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-08633**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetStencilTestEnable must` have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-07848**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_OP` dynamic state enabled then `vkCmdSetStencilOp must` have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-08634**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, then `vkCmdSetStencilOp must` have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-03417**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, then `vkCmdSetViewportWithCount must` have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount must` match the `VkPipelineViewportStateCreateInfo::scissorCount` of the pipeline

- **VUID-vkCmdDrawClusterHUAWEI-scissorCount-03418**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, then `vkCmdSetScissorWithCount must` have been called in the current command buffer prior
to this drawing command, and the `scissorCount` parameter of `vkCmdSetScissorWithCount` must match the `viewportCount` parameter of `VkPipelineViewportStateCreateInfo`.

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-03419**
  If the bound graphics pipeline state was created with both the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic states enabled then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-04137**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportWScalingStateCreateInfoNV`:

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-04138**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-04139**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportShadingRateImageStateCreateInfoNV`:

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-04140**
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then `vkCmdSetViewportWScalingNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-08635**
  If a shader object is bound to any graphics stage, then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-09232**
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-08636**
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-04134**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportStateCreateInfo`:

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-04140**
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then `vkCmdSetViewportWScalingNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-08636**
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-04139**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportShadingRateImageStateCreateInfoNV`:
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`

- **VUID-vkCmdDrawClusterHUAWEI-shadingRateImage-09233**
  If the `shadingRateImage` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set rasterizerDiscardEnable to `VK_FALSE`, then `vkCmdSetCoarseSampleOrderNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-shadingRateImage-09234**
  If a shader object is bound to any graphics stage, and the `shadingRateImage` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set rasterizerDiscardEnable to `VK_FALSE`, and the most recent call to `vkCmdSetShadingRateImageEnableNV` in the current command buffer set shadingRateImageEnable to `VK_TRUE`, then `vkCmdSetViewportShadingRatePaletteNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-08637**
  If a shader object is bound to any graphics stage, and the `shadingRateImage` feature is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`

- **VUID-vkCmdDrawClusterHUAWEI-VkPipelineViewportCreateInfo-04141**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportSwizzleStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`

- **VUID-vkCmdDrawClusterHUAWEI-VkPipelineViewportCreateInfo-04142**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportExclusiveScissorStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline must have been created with `VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`

- **VUID-vkCmdDrawClusterHUAWEI-None-07878**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV` dynamic state enabled then `vkCmdSetExclusiveScissorEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-07879**
  If the bound graphics pipeline state was created with the...
If a shader object is bound to any graphics stage, and the `exclusiveScissor` feature is enabled, then `vkCmdSetExclusiveScissorEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE` dynamic state enabled then `vkCmdSetRasterizerDiscardEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, then `vkCmdSetRasterizerDiscardEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE` dynamic state enabled then `vkCmdSetDepthBiasEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LOGIC_OP_EXT` dynamic state enabled then `vkCmdSetLogicOpEXT` must have been called in the current command buffer prior to this drawing command and the `logicOp` must be a valid `VkLogicOp` value.

If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the `logicOp` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEXT` must have been called in the current command buffer prior to this drawing command and the `logicOp` must be a valid `VkLogicOp` value.
If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must be 1.

- **VUID-vkCmdDrawClusterHUAWEI-primitiveFragmentShadingRateWithMultipleViewports-08642**
  If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, and any shader object bound to a graphics stage writes to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must be 1.

- **VUID-vkCmdDrawClusterHUAWEI-blendEnable-04727**
  If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view’s format features do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the `blendEnable` member of the corresponding element of the `pAttachments` member of `pColorBlendState` must be `VK_FALSE`.

- **VUID-vkCmdDrawClusterHUAWEI-None-08643**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then for each color attachment in the render pass, if the corresponding image view’s format features do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the corresponding member of `pColorBlendEnables` in the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer that affected that attachment index must have been `VK_FALSE`.

- **VUID-vkCmdDrawClusterHUAWEI-multisampledRenderToSingleSampled-07284**
  If rasterization is not disabled in the bound graphics pipeline, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then `rasterizationSamples` for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawClusterHUAWEI-None-08644**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then the most recent call to `vkCmdSetRasterizationSamplesEXT` in the current command buffer must have set `rasterizationSamples` to be the same as the number of samples for the current render pass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawClusterHUAWEI-None-08876**
  If a shader object is bound to any graphics stage, the current render pass instance must have been begun with `vkCmdBeginRendering`.
If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the depth attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the stencil attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, this command **must** not write any values to the depth attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the stencil attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, this command **must** not write any values to the depth attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`, this command **must** not write any values to the stencil attachment.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline **must** have been created with a `VkPipelineRenderingCreateInfo`::`viewMask` equal to `VkRenderingInfo`::`viewMask`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline **must** have been created with a `VkPipelineRenderingCreateInfo`::`colorAttachmentCount` equal to `VkRenderingInfo`::`colorAttachmentCount`.

If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo`::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo`::`pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` **must** have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo`::`pColorAttachmentFormats` used to create the currently
bound graphics pipeline

- **VUID-vkCmdDrawClusterHUAWEI-dynamicRenderingUnusedAttachments-08911**

  If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderPassInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderPassInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline, or the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`.

- **VUID-vkCmdDrawClusterHUAWEI-dynamicRenderingUnusedAttachments-08912**

  If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderPassInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderPassInfo::pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` must have the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`.

- **VUID-vkCmdDrawClusterHUAWEI-attachmentCount-07750**

  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then the `attachmentCount` parameter of `vkCmdSetColorWriteEnableEXT` must be greater than or equal to the `VkPipelineColorBlendStateCreateInfo::attachmentCount` of the currently bound graphics pipeline.

- **VUID-vkCmdDrawClusterHUAWEI-attachmentCount-08647**

  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `attachmentCount` parameter of the most recent call to `vkCmdSetColorWriteEnableEXT` in the current command buffer must be greater than or equal to the number of color attachments in the current render pass instance.

- **VUID-vkCmdDrawClusterHUAWEI-attachmentCount-07751**

  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` dynamic state enabled then...
vkCmdSetDiscardRectangleEXT must have been called in the current command buffer prior to this drawing command for each discard rectangle in VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount

- VUID-vkCmdDrawClusterHUAWEI-None-07880
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT dynamic state enabled then vkCmdSetDiscardRectangleEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-rasterizerDiscardEnable-09236
  If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDiscardRectangleEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-08648
  If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDiscardRectangleEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07881
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT dynamic state enabled then vkCmdSetDiscardRectangleModeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-08649
  If the VK_EXT_discard_rectangles extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDiscardRectangleEnableEXT in the current command buffer set discardRectangleEnable to VK_TRUE, then vkCmdSetDiscardRectangleModeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-dynamicRenderingUnusedAttachments-08913
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawClusterHUAWEI-dynamicRenderingUnusedAttachments-08914
  If current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to the VkFormat used to create VkRenderingInfo::pDepthAttachment->imageView
If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo::pDepthAttachment->imageView`, the value of the format must be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to the `VkFormat` used to create `VkRenderingInfo::pStencilAttachment->imageView`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo::pStencilAttachment->imageView`, the value of the format must be `VK_FORMAT_UNDEFINED`.

If the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView` was not `VK_NULL_HANDLE`, the currently bound graphics pipeline must have been created with `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`.

If the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView` was not `VK_NULL_HANDLE`, the currently bound graphics pipeline must have been created with `VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT`.

If the current bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the corresponding element of the `pColorAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to...
create the currently bound graphics pipeline

• VUID-vkCmdDrawClusterHUAWEI-pDepthAttachment-06186
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`

• VUID-vkCmdDrawClusterHUAWEI-pStencilAttachment-06187
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`

• VUID-vkCmdDrawClusterHUAWEI-multisampledRenderToSingleSampled-07285
  If the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the value of `rasterizationSamples` for the currently bound graphics pipeline

• VUID-vkCmdDrawClusterHUAWEI-multisampledRenderToSingleSampled-07286
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`

• VUID-vkCmdDrawClusterHUAWEI-multisampledRenderToSingleSampled-07287
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`

• VUID-vkCmdDrawClusterHUAWEI-pNext-07935
  If this command has been called inside a render pass instance started with `vkCmdBeginRendering`, and the `pNext` chain of `VkRenderingInfo` includes a
VkMultisampledRenderToSingleSampledInfoEXT structure with multisampledRenderToSingleSampledEnable equal to VK_TRUE, then the value of rasterizationSamples for the currently bound graphics pipeline must be equal to VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples

- VUID-vkCmdDrawClusterHUAWEI-renderPass-06198
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline must have been created with a VkGraphicsPipelineCreateInfo::renderPass equal to VK_NULL_HANDLE

- VUID-vkCmdDrawClusterHUAWEI-pColorAttachments-08963
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the VkRenderingInfo::pColorAttachments->imageView was not VK_NULL_HANDLE, then the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the pipeline must not be VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawClusterHUAWEI-pDepthAttachment-08964
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, then the VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the pipeline must not be VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawClusterHUAWEI-pStencilAttachment-08965
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound, stencil test is enabled and the VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, then the VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the pipeline must not be VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawClusterHUAWEI-primitivesGeneratedQueryWithRasterizerDiscard-06708
  If the primitivesGeneratedQueryWithRasterizerDiscard feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, rasterization discard must not be enabled

- VUID-vkCmdDrawClusterHUAWEI-primitivesGeneratedQueryWithNonZeroStreams-06709
  If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, the bound graphics pipeline must not have been created with a non-zero value in VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream

- VUID-vkCmdDrawClusterHUAWEI-None-07619
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT dynamic state enabled then vkCmdSetTessellationDomainOriginEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07620
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT dynamic state enabled then
vkCmdSetDepthClampEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-09237
  If a shader object is bound to the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT stage, then vkCmdSetTessellationDomainOriginEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-08650
  If the depthClamp feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDepthClampEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07621
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_POLYGON_MODE_EXT dynamic state enabled then vkCmdSetPolygonModeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-08651
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetPolygonModeEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07622
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT dynamic state enabled then vkCmdSetRasterizationSamplesEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-08652
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetRasterizationSamplesEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07623
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_MASK_EXT dynamic state enabled then vkCmdSetSampleMaskEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-08653
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleMaskEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07624
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled then vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command
buffer prior to this drawing command

• **VUID-vkCmdDrawClusterHUAWEI-alphaToCoverageEnable-08919**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled, and `alphaToCoverageEnable` was `VK_TRUE` in the last call to `vkCmdSetAlphaToCoverageEnableEXT`, then the **Fragment Output Interface must contain** a variable for the alpha Component word in **Location 0 at Index 0**

• **VUID-vkCmdDrawClusterHUAWEI-None-08654**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then **vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command buffer prior to this drawing command**

• **VUID-vkCmdDrawClusterHUAWEI-alphaToCoverageEnable-08920**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetAlphaToCoverageEnableEXT` in the current command buffer set `alphaToCoverageEnable` to `VK_TRUE`, then the **Fragment Output Interface must contain** a variable for the alpha Component word in **Location 0 at Index 0**

• **VUID-vkCmdDrawClusterHUAWEI-None-07625**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT` dynamic state enabled then **vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command**

• **VUID-vkCmdDrawClusterHUAWEI-None-08655**
  If the `alphaToOne` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then **vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command**

• **VUID-vkCmdDrawClusterHUAWEI-None-07626**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT` dynamic state enabled then **vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command**

• **VUID-vkCmdDrawClusterHUAWEI-None-08656**
  If the `logicOp` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then **vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command**

• **VUID-vkCmdDrawClusterHUAWEI-None-07627**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then **vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command**

• **VUID-vkCmdDrawClusterHUAWEI-None-08657**
If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterHUAWEI-None-07628**
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterHUAWEI-None-08658**
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` for any attachment set that attachment's value in `pColorBlendEnables` to `VK_TRUE`, then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterHUAWEI-None-07629**
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterHUAWEI-None-08659**
If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorBlendEnableEXT` for any attachment set that attachment's value in `pColorBlendEnables` to `VK_TRUE`, then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterHUAWEI-None-07630**
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` dynamic state enabled then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterHUAWEI-None-08660**
If the `geometryStreams` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_GEOMETRY_BIT` stage, then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterHUAWEI-None-07631**
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterHUAWEI-None-08661**
If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.
must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07632
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-08662
  If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetConservativeRasterizationMode` in the current command buffer set `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`, then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07633
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-08663
  If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07634
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-08664
  If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07635
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07636
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT` dynamic state enabled then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command
If the `VK_EXT_provoking_vertex` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic state enabled, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` dynamic state enabled, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` dynamic state enabled, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.
line primitives is bound to the tessellation evaluation or geometry stage, then \texttt{vkCmdSetLineStippleEnableEXT} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07849
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_LINE\_STIPPLE\_EXT} dynamic state enabled then \texttt{vkCmdSetLineStippleEXT} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-08672
  If the \texttt{VK\_EXT\_line\_rasterization} extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetLineStippleEnableEXT} in the current command buffer set \texttt{stippledLineEnable} to \texttt{VK\_TRUE}, then \texttt{vkCmdSetLineStippleEXT} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07639
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_DEPTH\_CLIP\_NEGATIVE\_ONE\_TO\_ONE\_EXT} dynamic state enabled then \texttt{vkCmdSetDepthClipNegativeOneToOneEXT} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-08673
  If the \texttt{depthClipControl} feature is enabled, and a shader object is bound to any graphics stage, then \texttt{vkCmdSetDepthClipNegativeOneToOneEXT} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07640
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_VIEWPORT\_W\_SCALING\_ENABLE\_NV} dynamic state enabled then \texttt{vkCmdSetViewportWScalingEnableNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-08674
  If the \texttt{VK\_NV\_clip\_space\_w\_scaling} extension is enabled, and a shader object is bound to any graphics stage, then \texttt{vkCmdSetViewportWScalingEnableNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07641
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_VIEWPORT\_SWIZZLE\_NV} dynamic state enabled then \texttt{vkCmdSetViewportSwizzleNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-08675
  If the \texttt{VK\_NV\_viewport\_swizzle} extension is enabled, and a shader object is bound to any graphics stage, then \texttt{vkCmdSetViewportSwizzleNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterHUAWEI-None-07642
  If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_COVERAGE\_TO\_COLOR\_ENABLE\_NV} dynamic state enabled then \texttt{vkCmdSetCoverageToColorEnableNV} \textbf{must} have been called in the current command buffer prior to this drawing command
If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` dynamic state enabled then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set `coverageToColorEnable` to `VK_TRUE`, then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationModeNV` in the current command buffer set `coverageModulationMode` to any value other than `VK_COVERAGE_MODULATION_MODE_NONE_NV`, then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command.
buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-08680**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationTableEnableNV` in the current command buffer set `coverageModulationTableEnable` to `VK_TRUE`, then `vkCmdSetCoverageModulationTableNV must` have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-07647**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV` dynamic state enabled then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-pipelineFragmentShadingRate-09238**
  If the `pipelineFragmentShadingRate` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFragmentShadingRateKHR` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-08681**
  If the `shadingRateImage` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-07648**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV` dynamic state enabled then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-08682**
  If the `representativeFragmentTest` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-07649**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-None-08683**
  If the `coverageReductionMode` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then
vkCmdSetCoverageReductionModeNV must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterHUAWEI-pColorBlendEnables-07470**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT state enabled and the last call to vkCmdSetColorBlendEnableEXT set pColorBlendEnables for any attachment to VK_TRUE, then for those attachments in the subpass the corresponding image view's format features must contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT.

- **VUID-vkCmdDrawClusterHUAWEI-rasterizationSamples-07471**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT must follow the rules for a zero-attachment subpass.

- **VUID-vkCmdDrawClusterHUAWEI-samples-07472**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_MASK_EXT state enabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state disabled, then the samples parameter in the last call to vkCmdSetSampleMaskEXT must be greater or equal to the VkPipelineMultisampleStateCreateInfo::rasterizationSamples parameter used to create the bound graphics pipeline.

- **VUID-vkCmdDrawClusterHUAWEI-samples-07473**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_MASK_EXT state and VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT states enabled, then the samples parameter in the last call to vkCmdSetSampleMaskEXT must be greater or equal to the rasterizationSamples parameter in the last call to vkCmdSetRasterizationSamplesEXT.

- **VUID-vkCmdDrawClusterHUAWEI-rasterizationSamples-07474**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, and neither the VK_AMD_mixed_attachment_samples nor the VK_NV_framebuffer_mixed_samples extensions are enabled, then the rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT must be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawClusterHUAWEI-None-09211**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a VkMultisampledRenderToSingleSampledInfoEXT structure with multisampledRenderToSingleSampledEnable equal to VK_TRUE, then the rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT must be the same as the rasterizationSamples member of that structure.

- **VUID-vkCmdDrawClusterHUAWEI-firstAttachment-07476**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then
vkCmdSetColorBlendEnableEXT **must** have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEnableEXT` calls **must** specify an enable for all active color attachments in the current subpass.

- **VUID-vkCmdDrawClusterHUAWEI-firstAttachment-07477**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled, then `vkCmdSetColorBlendEquationEXT` **must** have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEquationEXT` calls **must** specify the blend equations for all active color attachments in the current subpass where blending is enabled.

- **VUID-vkCmdDrawClusterHUAWEI-firstAttachment-07478**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled, then `vkCmd setColorWriteMaskEXT` **must** have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmd setColorWriteMaskEXT` calls **must** specify the color write mask for all active color attachments in the current subpass.

- **VUID-vkCmdDrawClusterHUAWEI-firstAttachment-07479**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled, then `vkCmd setColorBlendAdvancedEXT` **must** have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmd setColorBlendAdvancedEXT` calls **must** specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled.

- **VUID-vkCmdDrawClusterHUAWEI-advancedBlendMaxColorAttachments-07480**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` and `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic states enabled and the last calls to `vkCmd setColorBlendEnableEXT` and `vkCmd setColorBlendAdvancedEXT` have enabled advanced blending, then the number of active color attachments in the current subpass **must** not exceed `advancedBlendMaxColorAttachments`.

- **VUID-vkCmdDrawClusterHUAWEI-primitivesGeneratedQueryWithNonZeroStreams-07481**
  If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, and the bound graphics pipeline was created with `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` state enabled, the last call to `vkCmd setRasterizationStreamEXT` **must** have set the `rasterizationStream` to zero.

- **VUID-vkCmdDrawClusterHUAWEI-sampleLocationsPerPixel-07482**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmd setSampleLocationsEXT` **must** equal the `rasterizationSamples` member of the
VkPipelineMultisampleStateCreateInfo structure the bound graphics pipeline has been created with

- **UUID-vkCmdDrawClusterHUAWEI-sampleLocationsPerPixel-07483**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, then the sampleLocationsPerPixel member of pSampleLocationsInfo in the last call to vkCmdSetSampleLocationsEXT must equal the rasterizationSamples parameter of the last call to vkCmdSetRasterizationSamplesEXT.

- **UUID-vkCmdDrawClusterHUAWEI-sampleLocationsEnable-07484**
  If the bound graphics pipeline was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set.

- **UUID-vkCmdDrawClusterHUAWEI-sampleLocationsEnable-07485**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the sampleLocationsInfo.sampleLocationGridSize.width in the last call to vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples.

- **UUID-vkCmdDrawClusterHUAWEI-sampleLocationsEnable-07486**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the sampleLocationsInfo.sampleLocationGridSize.height in the last call to vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples.

- **UUID-vkCmdDrawClusterHUAWEI-sampleLocationsEnable-07487**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, the fragment shader code must not statically use the extended instruction InterpolateAtSample.

- **UUID-vkCmdDrawClusterHUAWEI-sampleLocationsEnable-07936**
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXTENSION state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXTENSION state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the...
bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.width` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.width` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling the value of `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawClusterHUAWEI-sampleLocationsEnable-07937**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationGridSize.height` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.height` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling the value of `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawClusterHUAWEI-sampleLocationsEnable-07938**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the bound graphics pipeline is `VK_TRUE` or `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, then, `sampleLocationsInfo.sampleLocationsPerPixel` must equal `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawClusterHUAWEI-coverageModulationTableEnable-07488**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageModulationTableEnableNV` set `coverageModulationTableEnable` to `VK_TRUE`, then the `coverageModulationTableCount` parameter in the last call to `vkCmdSetCoverageModulationTableNV` must equal the current `rasterizationSamples` divided by the number of color samples in the current subpass.

- **VUID-vkCmdDrawClusterHUAWEI-rasterizationSamples-07489**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current `rasterizationSamples` must be the same as the sample count of the depth/stencil attachment.

- **VUID-vkCmdDrawClusterHUAWEI-coverageToColorEnable-07490**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageToColorEnableNV` set `coverageToColorEnable` to `VK_TRUE`, then the current subpass must have a color attachment at the location selected by the last call to `vkCmdSetCoverageToColorLocationNV` with a `VkFormat` of `VK_FORMAT_R8_UINT`, `VK_FORMAT_R8_SINT`, `VK_FORMAT_R16_UINT`, `VK_FORMAT_R16_SINT`, `VK_FORMAT_R32_UINT`, or `VK_FORMAT_R32_SINT`.

- **VUID-vkCmdDrawClusterHUAWEI-coverageReductionMode-07491**
  If this `VK_NV_coverage_reduction_mode` extension is enabled, the bound graphics pipeline...
state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, the current coverage reduction mode `coverageReductionMode`, then the current `rasterizationSamples`, and the sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by `vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV`.

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-07492**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV`::`viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawClusterHUAWEI-viewportCount-07493**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportSwizzleNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawClusterHUAWEI-rasterizationSamples-07494**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if the current subpass has any color attachments and `rasterizationSamples` of the last call to `vkCmdSetRasterizationSamplesEXT` is greater than the number of color samples, then the pipeline `sampleShadingEnable` must be `VK_FALSE`.

- **VUID-vkCmdDrawClusterHUAWEI-stippledLineEnable-07495**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT`, then the `stippledRectangularLines` feature must be enabled.

- **VUID-vkCmdDrawClusterHUAWEI-stippledLineEnable-07496**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT`, then the `stippledBresenhamLines` feature must be enabled.

- **VUID-vkCmdDrawClusterHUAWEI-stippledLineEnable-07497**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT`, then the `stippledSmoothLines` feature must be enabled.
• **VUID-vkCmdDrawClusterHUAWEI-stippledLineEnable-07498**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` or `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic states enabled, and if the current `stippledLineEnable` state is `VK_TRUE` and the current `lineRasterizationMode` state is `VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT`, then the `stippledRectangularLines` feature **must** be enabled and `VkPhysicalDeviceLimits::strictLines` **must** be `VK_TRUE`.

• **VUID-vkCmdDrawClusterHUAWEI-conservativePointAndLineRasterization-07499**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled, `conservativePointAndLineRasterization` is not supported, and the effective primitive topology output by the last pre-rasterization shader stage is a line or point, then the `conservativeRasterizationMode` set by the last call to `vkCmdSetConservativeRasterizationModeEXT` **must** be `VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT`.

• **VUID-vkCmdDrawClusterHUAWEI-stage-07073**
  If the currently bound pipeline was created with the `VkPipelineShaderStageCreateInfo::stage` member of an element of `VkGraphicsPipelineCreateInfo::pStages` set to `VK_SHADER_STAGE_VERTEX_BIT`, `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`, `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` or `VK_SHADER_STAGE_GEOMETRY_BIT`, then **Mesh Shader Queries** **must** not be active.

• **VUID-vkCmdDrawClusterHUAWEI-None-08877**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` dynamic state `vkCmdSetAttachmentFeedbackLoopEnableEXT` **must** have been called in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawClusterHUAWEI-None-07850**
  If dynamic state was inherited from `VkCommandBufferInheritanceViewportScissorInfoNV`, it **must** be set in the current command buffer prior to this drawing command.

• **VUID-vkCmdDrawClusterHUAWEI-None-08684**
  If there is no bound graphics pipeline, `vkCmdBindShadersEXT` **must** have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_VERTEX_BIT`.

• **VUID-vkCmdDrawClusterHUAWEI-None-08685**
  If there is no bound graphics pipeline, and the `tessellationShader` feature is enabled, `vkCmdBindShadersEXT` **must** have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`.

• **VUID-vkCmdDrawClusterHUAWEI-None-08686**
  If there is no bound graphics pipeline, and the `tessellationShader` feature is enabled, `vkCmdBindShadersEXT` **must** have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`.

• **VUID-vkCmdDrawClusterHUAWEI-None-08687**
  If there is no bound graphics pipeline, and the `geometryShader` feature is enabled, `vkCmdBindShadersEXT` **must** have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_GEOMETRY_BIT`.
If there is no bound graphics pipeline, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_FRAGMENT_BIT`

If there is no bound graphics pipeline, and the `taskShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TASK_BIT_EXT`

If there is no bound graphics pipeline, and the `meshShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_MESH_BIT_EXT`

If there is no bound graphics pipeline, and at least one of the `taskShader` and `meshShader` features is enabled, one of the `VK_SHADER_STAGE_VERTEX_BIT` or `VK_SHADER_STAGE_MESH_BIT_EXT` stages must have a valid `VkShaderEXT` bound, and the other must have no `VkShaderEXT` bound

If there is no bound graphics pipeline, and both the `taskShader` and `meshShader` features are enabled, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that `VkShaderEXT` was created without the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, a valid `VkShaderEXT` must be bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage

If there is no bound graphics pipeline, and both the `taskShader` and `meshShader` features are enabled, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that `VkShaderEXT` was created with the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, there must be no `VkShaderEXT` bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage

If any graphics shader is bound which was created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag, then all shaders created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag in the same `vkCreateShadersEXT` call must also be bound

If any graphics shader is bound which was created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag, any stages in between stages whose shaders which did not create a shader with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag as part of the same `vkCreateShadersEXT` call must not have any `VkShaderEXT` bound

All bound graphics shader objects must have been created with identical or identically defined push constant ranges
All bound graphics shader objects must have been created with identical or identically defined arrays of descriptor set layouts.

If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage and the `attachmentFeedbackLoopDynamicState` feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, `vkCmdSetAttachmentFeedbackLoopEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state includes a fragment shader stage, was created with `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`, and the fragment shader declares the `EarlyFragmentTests` execution mode and uses `OpDepthAttachmentReadEXT`, the `depthWriteEnable` parameter in the last call to `vkCmdSetDepthWriteEnable` must be `VK_FALSE`.

If the bound graphics pipeline state includes a fragment shader stage, was created with `VK_DYNAMIC_STATE_STENCIL_WRITE_MASK` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`, and the fragment shader declares the `EarlyFragmentTests` execution mode and uses `OpStencilAttachmentReadEXT`, the `writeMask` parameter in the last call to `vkCmdSetStencilWriteMask` must be `0`.

If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT`, and the format of any color attachment is `VK_FORMAT_E5B9G9R9_UFLOAT_PACK32`, the corresponding element of the `pColorWriteMasks` parameter of `vkCmdSetColorWriteMaskEXT` must either include all of `VK_COLOR_COMPONENT_R_BIT`, `VK_COLOR_COMPONENT_G_BIT`, and `VK_COLOR_COMPONENT_B_BIT`, or none of them.

If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of `Location` for any output attachment statically used in the Fragment Execution Model executed by this command must be less than `maxFragmentDualSrcAttachments`.

The bound graphics pipeline must not have been created with the `VkPipelineShaderStageCreateInfo::stage` member of an element of `VkGraphicsPipelineCreateInfo::pStages` set to `VK_SHADER_STAGE_VERTEX_BIT`, `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`, `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`, or `VK_SHADER_STAGE_GEOMETRY_BIT`.

Transform Feedback Queries must not be active.

Primitives Generated Queries must not be active.

pipelineStatistics-07076
The `pipelineStatistics` member used to create any active Pipeline Statistics Query must not contain `VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_VERTICES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_PRIMITIVES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_VERTEX_SHADER_INVOCATIONS_BIT`, `VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_INVOCATIONS_BIT`, `VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_PRIMITIVES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_CLIPPING_INVOCATIONS_BIT`, `VK_QUERY_PIPELINE_STATISTIC_CLIPPING_PRIMITIVES_BIT`, `VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_CONTROL_SHADER_PATCHES_BIT`, or `VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_EVALUATION_SHADER_INVOCATIONS_BIT`.

- **VUID-vkCmdDrawClusterHUAWEI-None-07819**
  The `pipelineStatistics` member used to create any active Pipeline Statistics Query must not contain `VK_QUERY_PIPELINE_STATISTIC_TASK_SHADER_INVOCATIONS_BIT_EXT`, or `VK_QUERY_PIPELINE_STATISTIC_MESH_SHADER_INVOCATIONS_BIT_EXT`.

- **VUID-vkCmdDrawClusterHUAWEI-groupCountX-07820**
  `groupCountX` must be less than or equal to `VkPhysicalDeviceClusterCullingShaderPropertiesHUAWEI::maxWorkGroupCount[0]`.

- **VUID-vkCmdDrawClusterHUAWEI-groupCountY-07821**
  `groupCountY` must be less than or equal to `VkPhysicalDeviceClusterCullingShaderPropertiesHUAWEI::maxWorkGroupCount[1]`.

- **VUID-vkCmdDrawClusterHUAWEI-groupCountZ-07822**
  `groupCountZ` must be less than or equal to `VkPhysicalDeviceClusterCullingShaderPropertiesHUAWEI::maxWorkGroupCount[2]`.

- **VUID-vkCmdDrawClusterHUAWEI-ClusterCullingHUAWEI-07823**
  The current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` must contain a shader stage using the `ClusterCullingHUAWEI` Execution Model.

### Valid Usage (Implicit)

- **VUID-vkCmdDrawClusterHUAWEI-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- **VUID-vkCmdDrawClusterHUAWEI-commandBuffer-recording**
  `commandBuffer` must be in the recording state.

- **VUID-vkCmdDrawClusterHUAWEI-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations.

- **VUID-vkCmdDrawClusterHUAWEI-renderpass**
  This command must only be called inside of a render pass instance.

- **VUID-vkCmdDrawClusterHUAWEI-videocoding**
  This command must only be called outside of a video coding scope.
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

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To record an indirect cluster culling drawing command, call:

```cpp
// Provided by VK_HUAWEI_cluster_culling_shader
void vkCmdDrawClusterIndirectHUAWEI(
    VkCommandBuffer commandBuffer,
    VkBuffer buffer,
    VkDeviceSize offset);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `buffer` is the buffer containing draw parameters.
- `offset` is the byte offset into `buffer` where parameters begin.

`vkCmdDrawClusterIndirectHUAWEI` behaves similarly to `vkCmdDrawClusterHUAWEI` except that the parameters are read by the device from a buffer during execution. The parameters of the dispatch are encoded in a `VkDispatchIndirectCommand` structure taken from buffer starting at offset. Note the cluster culling shader pipeline only accepts `vkCmdDrawClusterHUAWEI` and `vkCmdDrawClusterIndirectHUAWEI` as drawing commands.

Valid Usage

- VUID-vkCmdDrawClusterIndirectHUAWEI-magFilter-04553
  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- VUID-vkCmdDrawClusterIndirectHUAWEI-mipmapMode-04770
  If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view’s format features must contain...
• VUID-vkCmdDrawClusterIndirectHUAWEI-None-06479
  If a VkImageView is sampled with depth comparison, the image view’s format features must contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-02691
  If a VkImageView is accessed using atomic operations as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-07888
  If a VkImageView is accessed using atomic operations as a result of this command, then the storage texel buffer’s format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-02692
  If a VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-02693
  If the VK_EXT_filter_cubic extension is not enabled and any VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, it must not have a VkImageViewType of VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

• VUID-vkCmdDrawClusterIndirectHUAWEI-filterCubic-02694
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2

• VUID-vkCmdDrawClusterIndirectHUAWEI-filterCubicMinmax-02695
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT with a reduction mode of either VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX as a result of this command must have a VkImageViewType and format that supports cubic filtering together with minmax filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax returned by vkGetPhysicalDeviceImageFormatProperties2

• VUID-vkCmdDrawClusterIndirectHUAWEI-cubicRangeClamp-09212
  If the cubicRangeClamp feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command

  must not have a VkSamplerReductionModeCreateInfo

  reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM

• VUID-vkCmdDrawClusterIndirectHUAWEI-reductionMode-09213
  Any VkImageView being sampled with a VkSamplerReductionModeCreateInfo::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM as a result of this command must sample with VK_FILTER_CUBIC_EXT

• VUID-vkCmdDrawClusterIndirectHUAWEI-selectableCubicWeights-09214
If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-flags-02696**
  Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-OpTypeImage-07027**
  For any `VkImageView` being written as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view's `format features` must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-OpTypeImage-07028**
  For any `VkImageView` being read as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view's `format features` must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-OpTypeImage-07029**
  For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view's `buffer features` must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-OpTypeImage-07030**
  Any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown` then the view's `buffer features` must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08600**
  For each set `n` that is statically used by a `bound shader`, a descriptor set must have been bound to `n` at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set `n`, with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in `Pipeline Layout Compatibility`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08601**
  For each push constant that is statically used by a `bound shader`, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in `Pipeline Layout Compatibility`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-maintenance4-08602**
  If the `maintenance4` feature is not enabled, then for each push constant that is statically used by a `bound shader`, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in `Pipeline Layout Compatibility`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08114**
  Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, must be
If the descriptors used by the \texttt{VkPipeline} bound to the pipeline bind point were specified via \texttt{vkCmdBindDescriptorSets}, the bound \texttt{VkPipeline} must have been created without \texttt{VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT}

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08115
  If the descriptors used by the \texttt{VkPipeline} bound to the pipeline bind point were specified via \texttt{vkCmdBindDescriptorSets}, the bound \texttt{VkPipeline} must have been created without \texttt{VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT}

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08116
  Descriptors in bound descriptor buffers, specified via \texttt{vkCmdSetDescriptorBufferOffsetsEXT}, must be valid if they are dynamically used by the \texttt{VkPipeline} bound to the pipeline bind point used by this command and the bound \texttt{VkPipeline} was created with \texttt{VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT}

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08604
  Descriptors in bound descriptor buffers, specified via \texttt{vkCmdSetDescriptorBufferOffsetsEXT}, must be valid if they are dynamically used by any \texttt{VkShaderEXT} bound to a stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08605
  Descriptors in bound descriptor buffers, specified via \texttt{vkCmdSetDescriptorBufferOffsetsEXT}, must be valid if they are dynamically used by any \texttt{VkShaderEXT} bound to a stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08606
  If the descriptor is dynamically used with a \texttt{VkPipeline} created with \texttt{VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT}, the descriptor memory must be resident

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08607
  If a descriptor is dynamically used with a \texttt{VkPipeline} created with \texttt{VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT}, the descriptor memory must be resident

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08608
  If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the \texttt{VkPipeline} object bound to the pipeline bind point used by this command, since that pipeline was bound

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08609
  If the \texttt{VkPipeline} object bound to the pipeline bind point used by this command or any
VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used to sample from any VkImage with a VkImageView of the type VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY, VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-08610
If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-08611
If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage

• VUID-vkCmdDrawClusterIndirectHUAWEI-uniformBuffers-06935
If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-08612
If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawClusterIndirectHUAWEI-storageBuffers-06936
If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-08613
If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDrawClusterIndirectHUAWEI-commandBuffer-02707
If commandBuffer is an unprotected command buffer and protectedNoFault is not supported,
any resource accessed by **bound shaders** must not be a protected resource

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-06550
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y’C C_a conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions

- VUID-vkCmdDrawClusterIndirectHUAWEI-ConstOffset-06551
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y’C C_a conversion, that object must not use the ConstOffset and Offset operands

- VUID-vkCmdDrawClusterIndirectHUAWEI-viewType-07752
  If a VkImageView is accessed as a result of this command, then the image view’s viewType must match the Dim operand of the OpTypeImage as described in Instruction/Sampler/Image View Validation

- VUID-vkCmdDrawClusterIndirectHUAWEI-format-07753
  If a VkImageView is accessed as a result of this command, then the numeric type of the image view’s format and the Sampled Type operand of the OpTypeImage must match

- VUID-vkCmdDrawClusterIndirectHUAWEI-OpImageWrite-08795
  If a VkImageView created with a format other than VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the image view’s format

- VUID-vkCmdDrawClusterIndirectHUAWEI-OpImageWrite-08796
  If a VkImageView created with the format VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have four components

- VUID-vkCmdDrawClusterIndirectHUAWEI-OpImageWrite-04469
  If a VkBufferView is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the buffer view’s format

- VUID-vkCmdDrawClusterIndirectHUAWEI-SampledType-04470
  If a VkImageView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64

- VUID-vkCmdDrawClusterIndirectHUAWEI-SampledType-04471
  If a VkImageView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

- VUID-vkCmdDrawClusterIndirectHUAWEI-SampledType-04472
  If a VkBufferView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64

- VUID-vkCmdDrawClusterIndirectHUAWEI-SampledType-04473
  If a VkBufferView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32
If the `sparseImageInt64Atomics` feature is not enabled, `VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

If `OpImageWeightedSampleQCOM` is used to sample a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`.

If `OpImageWeightedSampleQCOM` uses a `VkImageView` as a sample weight image as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`.

If `OpImageBoxFilterQCOM` is used to sample a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM`.

If `OpImageBlockMatchSSDQCOM` is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.

If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowsADQCOM`, `OpImageBlockMatchWindowGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, or `OpImageBlockMatchSSDQCOM` uses a `VkSampler` as a result of this command, then the sampler must have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowsADQCOM`, `OpImageBlockMatchWindowGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must not have been created with...
If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format **must** be a single-component format.

If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from a reference image as result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation.

Any shader invocation executed by this command **must** terminate.

The current render pass **must** be compatible with the `renderPass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

The subpass index of the current render pass **must** be equal to the `subpass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

If any shader statically accesses an input attachment, a valid descriptor **must** be bound to the pipeline via a descriptor set.

If any shader executed by this pipeline accesses an `OpTypeImage` variable with a `Dim` operand of `SubpassData`, it **must** be decorated with an `InputAttachmentIndex` that corresponds to a valid input attachment in the current subpass.

Input attachment views accessed in a subpass **must** be created with the same `VkFormat` as the corresponding subpass definition, and be created with a `VkImageView` that is compatible with the attachment referenced by the subpass' `pInputAttachments[InputAttachmentIndex]` in the currently bound `VkFramebuffer` as specified by Fragment Input Attachment Compatibility.

Memory backing image subresources used as attachments in the current render pass **must** not be written in any way other than as an attachment by this command.

If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout, and either:
the VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or

the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_COLOR_BIT and

- there is no currently bound graphics pipeline or
- the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-09001
If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:

- the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
- the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_DEPTH_BIT and

- there is no currently bound graphics pipeline or
- the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-09002
If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT image layout, and either:

- the VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT is set on the currently bound pipeline or
- the last call to vkCmdSetAttachmentFeedbackLoopEnableEXT included VK_IMAGE_ASPECT_STENCIL_BIT and

- there is no currently bound graphics pipeline or
- the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT it must not be accessed in any way other than as an attachment by this command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-09003
If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it must not be accessed in any way other than as an attachment, storage image, or sampled image by this command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-06539
If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command must not write to that image subresource as an attachment

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-06886

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If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, **depth writes must be disabled**

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-06887
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back **writeMask** are not zero, and stencil test is enabled, **all stencil ops must be VK_STENCIL_OP_KEEP**

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-07831
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_VIEWPORT** dynamic state enabled then **vkCmdSetViewport** must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-07832
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SCISSOR** dynamic state enabled then **vkCmdSetScissor** must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-07833
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_LINE_WIDTH** dynamic state enabled then **vkCmdSetLineWidth** must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08617
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetPolygonModeEXT** in the current command buffer set **polygonMode** to **VK_POLYGON_MODE_LINE**, **vkCmdSetLineWidth** must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08618
  If a shader object is bound to the **VK_SHADER_STAGE_VERTEX_BIT** stage, and the most recent call to **vkCmdSetPrimitiveTopology** in the current command buffer set **primitiveTopology** to any line topology, **vkCmdSetLineWidth** must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08619
  If a shader object that outputs line primitives is bound to the **VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT** or **VK_SHADER_STAGE_GEOMETRY_BIT** stage, **vkCmdSetLineWidth** must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-07834
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_DEPTH_BIAS** dynamic state enabled then **vkCmdSetDepthBias** or **vkCmdSetDepthBias2EXT** must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08620
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set **rasterizerDiscardEnable** to **VK_FALSE**, and the most recent call to **vkCmdSetDepthBiasEnable** in the current command buffer set **depthBiasEnable** to **VK_TRUE**, **vkCmdSetDepthBias** or **vkCmdSetDepthBias2EXT** must have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_BLEND_CONSTANTS` dynamic state enabled then `vkCmdSetBlendConstants` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetColorEnableEXT` in the current command buffer set any element of `pColorEnable` to `VK_TRUE`, and the most recent call to `vkCmdSetDepthEnable` in the current command buffer set the same element of `pDepthEnable` to `VK_TRUE`, then `vkCmdSetBlendConstants` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS` dynamic state enabled then `vkCmdSetDepthBounds` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthEnable` in the current command buffer set `depthEnable` to `VK_TRUE`, then `vkCmdSetDepthBounds` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK` dynamic state enabled then `vkCmdSetStencilCompareMask` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilCompareMask` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_WRITE_MASK` dynamic state enabled then `vkCmdSetStencilWriteMask` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, `vkCmdSetStencilWriteMask` must have been called in the current command buffer prior to this drawing command.
**VK_TRUE**, **vkCmdSetStencilWriteMask** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07839**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_STENCIL_REFERENCE** dynamic state enabled then **vkCmdSetStencilReference** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08625**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetStencilTestEnable** in the current command buffer set **stencilTestEnable** to **VK_TRUE**, **vkCmdSetStencilReference** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-maxMultiviewInstanceIndex-02688**
  If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to **VkPhysicalDeviceMultiviewProperties**:maxMultiviewInstanceIndex

- **VUID-vkCmdDrawClusterIndirectHUAWEI-sampleLocationsEnable-02689**
  If the bound graphics pipeline was created with **VkPipelineSampleLocationsStateCreateInfoEXT**:sampleLocationsEnable set to **VK_TRUE** and the current subpass has a depth/stencil attachment, then that attachment must have been created with the **VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT** bit set

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-06666**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT** dynamic state enabled then **vkCmdSetSampleLocationsEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08626**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetSampleLocationsEnableEXT** in the current command buffer set sampleLocationsEnable to **VK_TRUE**, and the most recent call to **vkCmdSetRasterizerDiscardEnable** in the current command buffer set rasterizerDiscardEnable to **VK_FALSE**, then **vkCmdSetSampleLocationsEXT** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-sampleLocationsPerPixel-07934**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT** state enabled, then the **sampleLocationsPerPixel** member of pSampleLocationsInfo in the last call to **vkCmdSetSampleLocationsEXT** must equal the **rasterizationSamples** member of the **VkPipelineMultisampleStateCreateInfo** structure the bound graphics pipeline has been created with

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07840**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_CULL_MODE** dynamic state enabled then **vkCmdSetCullMode** must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08627**
If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCullMode` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07841**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08628**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFrontFace` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07843**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_FRONT_FACE` dynamic state enabled then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08629**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthTestEnable` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07844**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08630**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthWriteEnable` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07845**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP` dynamic state enabled then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08631**
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthTestEnable` in the current command buffer set `depthTestEnable` to `VK_TRUE`, then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the `depthBounds` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE` dynamic state enabled then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_OP` dynamic state enabled then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `VkPipelineViewportStateCreateInfo::scissorCount` of the pipeline.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, then `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `scissorCount` parameter of `vkCmdSetScissorWithCount` must match the `VkPipelineViewportStateCreateInfo::viewportCount` of the pipeline.
must match the `VkPipelineViewportStateCreateInfo::viewportCount` of the pipeline.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-viewportCount-03419**
  If the bound graphics pipeline state was created with both the `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic states enabled then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08635**
  If a shader object is bound to any graphics stage, then both `vkCmdSetViewportWithCount` and `vkCmdSetScissorWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must match the `scissorCount` parameter of `vkCmdSetScissorWithCount`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-viewportCount-04137**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportWScalingStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-viewportCount-04138**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-09232**
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then `vkCmdSetViewportWScalingNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08636**
  If a shader object is bound to any graphics stage, and the `VK_NV_clip_space_w_scaling` extension is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWScalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-viewportCount-04139**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportShadingRateImageStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-viewportCount-04140**
  If the bound graphics pipeline state was created with the
If the shadingRateImage feature is enabled, and the most recent call to 

\texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set 

rasterizerDiscardEnable to \texttt{VK\_FALSE}, then \texttt{vkCmdSetCoarseSampleOrderNV} must have been called in the current command buffer prior to this drawing command.

- \textbf{VUID-vkCmdDrawClusterIndirectHUAWEI-shadingRateImage-09234}

If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, and the most recent call to 

\texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set shadingRateImageEnable to \texttt{VK\_TRUE}, then \texttt{vkCmdSetViewportShadingRatePaletteNV} must have been called in the current command buffer prior to this drawing command.

- \textbf{VUID-vkCmdDrawClusterIndirectHUAWEI-None-08637}

If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, then the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount} must be greater than or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}.

- \textbf{VUID-vkCmdDraw_cluster_indirectHUAWEI-VkPipelineViewportCreateInfo-04141}

If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_VIEWPORT\_WITH\_COUNT} dynamic state enabled and a 

\texttt{VkPipelineViewportSwizzleStateCreateInfoNV} structure chained from 

\texttt{VkPipelineViewportStateCreateInfo}, then the bound graphics pipeline must have been created with \texttt{VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount} greater or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}.

- \textbf{VUID-vkCmdDraw_cluster_indirectHUAWEI-VkPipelineViewportCreateInfo-04142}

If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_VIEWPORT\_WITH\_COUNT} dynamic state enabled and a 

\texttt{VkPipelineViewportExclusiveScissorStateCreateInfoNV} structure chained from 

\texttt{VkPipelineViewportStateCreateInfo}, then the bound graphics pipeline must have been created with \texttt{VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount} greater or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}.

- \textbf{VUID-vkCmdDraw_cluster_indirectHUAWEI-None-07878}

If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_EXCLUSIVE\_SCISSOR\_ENABLE\_NV} dynamic state enabled then 

\texttt{vkCmdSetExclusiveScissorEnableNV} must have been called in the current command buffer prior to this drawing command.

- \textbf{VUID-vkCmdDraw_cluster_indirectHUAWEI-None-07879}

If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_EXCLUSIVE\_SCISSOR\_NV} dynamic state enabled then
vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-exclusiveScissor-09235
  If a shader object is bound to any graphics stage, and the exclusiveScissor feature is enabled, then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08638
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetExclusiveScissorEnableNV in the current command buffer set any element of pExclusiveScissorEnables to VK_TRUE, then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-04876
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE dynamic state enabled then vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08639
  If a shader object is bound to any graphics stage, then vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-04877
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE dynamic state enabled then vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08640
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-logicOp-04878
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_EXT dynamic state enabled then vkCmdSetLogicOpEXT must have been called in the current command buffer prior to this drawing command and the logicOp must be a valid VkLogicOp value

- VUID-vkCmdDrawClusterIndirectHUAWEI-primitiveFragmentShadingRateWithMultipleViewports-04552
  If the primitiveFragmentShadingRateWithMultipleViewports limit is not supported, the
bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must be 1

- VUID-vkCmdDrawClusterIndirectHUAWEI-primitiveFragmentShadingRateWithMultipleViewports-08642
  If the `primitiveFragmentShadingRateWithMultipleViewports` limit is not supported, and any shader object bound to a graphics stage writes to the `PrimitiveShadingRateKHR` built-in, then `vkCmdSetViewportWithCount` must have been called in the current command buffer prior to this drawing command, and the `viewportCount` parameter of `vkCmdSetViewportWithCount` must be 1

- VUID-vkCmdDrawClusterIndirectHUAWEI-blendEnable-04727
  If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view's `format features` do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the `blendEnable` member of the corresponding element of the `pAttachments` member of `pColorBlendState` must be `VK_FALSE`

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08643
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then for each color attachment in the render pass, if the corresponding image view's `format features` do not contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`, then the corresponding member of `pColorBlendEnables` in the most recent call to `vkCmdSetColorBlendEnableEXT` in the current command buffer that affected that attachment index must have been `VK_FALSE`

- VUID-vkCmdDrawClusterIndirectHUAWEI-multisampledRenderToSingleSampled-07284
  If rasterization is not disabled in the bound graphics pipeline, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then `rasterizationSamples` for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08644
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and none of the `VK_AMD_mixed_attachment_samples` extension, the `VK_NV_framebuffer_mixed_samples` extension, or the `multisampledRenderToSingleSampled` feature is enabled, then the most recent call to `vkCmdSetRasterizationSamplesEXT` in the current command buffer must have set `rasterizationSamples` to be the same as the number of samples for the current render pass color and/or depth/stencil attachments

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08876
  If a shader object is bound to any graphics stage, the current render pass instance must have been begun with `vkCmdBeginRendering`

- VUID-vkCmdDrawClusterIndirectHUAWEI-imageView-06172
If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment

- VUID-vkCmdDrawClusterIndirectHUAWEI-imageView-06173
If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment

- VUID-vkCmdDrawClusterIndirectHUAWEI-imageView-06174
If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`, this command must not write any values to the depth attachment

- VUID-vkCmdDrawClusterIndirectHUAWEI-imageView-06175
If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment

- VUID-vkCmdDrawClusterIndirectHUAWEI-imageView-06176
If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pDepthAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pDepthAttachment` is `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, this command must not write any values to the depth attachment

- VUID-vkCmdDrawClusterIndirectHUAWEI-imageView-06177
If the current render pass instance was begun with `vkCmdBeginRendering`, the `imageView` member of `pStencilAttachment` is not `VK_NULL_HANDLE`, and the `layout` member of `pStencilAttachment` is `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL`, this command must not write any values to the stencil attachment

- VUID-vkCmdDrawClusterIndirectHUAWEI-viewMask-06178
If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo`::`viewMask` equal to `VkRenderingInfo`::`viewMask`

- VUID-vkCmdDrawClusterIndirectHUAWEI-colorAttachmentCount-06179
If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline must have been created with a `VkPipelineRenderingCreateInfo`::`colorAttachmentCount` equal to `VkRenderingInfo`::`colorAttachmentCount`

- VUID-vkCmdDrawClusterIndirectHUAWEI-dynamicRenderingUnusedAttachments-08910
If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo`::`colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo`::`pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo`::`pColorAttachmentFormats` used to create the currently bound graphics pipeline
If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline, or the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats`, if it exists, must be `VK_FORMAT_UNDEFINED`

If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` must have the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then the `attachmentCount` parameter of `vkCmdSetColorWriteEnableEXT` must be greater than or equal to the `VkPipelineColorBlendStateCreateInfo::attachmentCount` of the currently bound graphics pipeline.

If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `attachmentCount` parameter of most recent call to `vkCmdSetColorWriteEnableEXT` in the current command buffer must be greater than or equal to the number of color attachments in the current render pass instance.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEXT` must have been called in the current command buffer.
Prior to this drawing command for each discard rectangle in 
*VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount*

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07880**
  If the bound graphics pipeline state was created with the 
  *VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT* dynamic state enabled then 
  *vkCmdSetDiscardRectangleEnableEXT* must have been called in the current command 
  buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-rasterizerDiscardEnable-09236**
  If the *VK_EXT_discard_rectangles* extension is enabled, and a shader object is bound to any 
  graphics stage, and the most recent call to *vkCmdSetRasterizerDiscardEnable* in the 
  current command buffer set *rasterizerDiscardEnable* to *VK_FALSE*, then 
  *vkCmdSetDiscardRectangleEnableEXT* must have been called in the current command 
  buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08648**
  If the *VK_EXT_discard_rectangles* extension is enabled, and a shader object is bound to any 
  graphics stage, and the most recent call to *vkCmdSetRasterizerDiscardEnable* in the 
  current command buffer set *rasterizerDiscardEnable* to *VK_FALSE*, then 
  *vkCmdSetDiscardRectangleEnableEXT* must have been called in the current command 
  buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07881**
  If the bound graphics pipeline state was created with the 
  *VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT* dynamic state enabled then 
  *vkCmdSetDiscardRectangleModeEXT* must have been called in the current command 
  buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08649**
  If the *VK_EXT_discard_rectangles* extension is enabled, and a shader object is bound to any 
  graphics stage, and the most recent call to *vkCmdSetRasterizerDiscardEnable* in the 
  current command buffer set *rasterizerDiscardEnable* to *VK_FALSE*, and the most recent call 
  to *vkCmdSetDiscardRectangleEnableEXT* in the current command buffer set 
  *discardRectangleEnable* to *VK_TRUE*, then *vkCmdSetDiscardRectangleModeEXT* must have 
  been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-dynamicRenderingUnusedAttachments-08913**
  If the current render pass instance was begun with *vkCmdBeginRendering*, the 
  *dynamicRenderingUnusedAttachments* feature is not enabled, and *VkRenderingInfo::pDepthAttachment->imageView* was *VK_NULL_HANDLE*, the value of 
  *VkPipelineRenderingCreateInfo::depthAttachmentFormat* used to create the currently bound 
  graphics pipeline must be equal to *VK_FORMAT_UNDEFINED*

- **VUID-vkCmdDrawClusterIndirectHUAWEI-dynamicRenderingUnusedAttachments-08914**
  If current render pass instance was begun with *vkCmdBeginRendering*, the 
  *dynamicRenderingUnusedAttachments* feature is not enabled, and *VkRenderingInfo::pDepthAttachment->imageView* was not *VK_NULL_HANDLE*, the value of 
  *VkPipelineRenderingCreateInfo::depthAttachmentFormat* used to create the currently bound 
  graphics pipeline must be equal to the *VkFormat* used to create *VkRenderingInfo::pDepthAttachment->imageView*

- **VUID-vkCmdDrawClusterIndirectHUAWEI-dynamicRenderingUnusedAttachments-08915**
If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the currently bound graphics pipeline was not equal to the `VkFormat` used to create `VkRenderingInfo::pDepthAttachment->imageView`, the value of the format must be `VK_FORMAT_UNDEFINED`

- VUID-vkCmdDrawClusterIndirectHUAWEI-dynamicRenderingUnusedAttachments-08916
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to `VK_FORMAT_UNDEFINED`

- VUID-vkCmdDrawClusterIndirectHUAWEI-dynamicRenderingUnusedAttachments-08918
  If the current render pass instance was begun with `vkCmdBeginRendering`, the `dynamicRenderingUnusedAttachments` feature is enabled, `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, and the value of `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the currently bound graphics pipeline must be equal to `VK_FORMAT_UNDEFINED`

- VUID-vkCmdDrawClusterIndirectHUAWEI-colorAttachmentCount-06185
  If the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the corresponding element of the `pColorAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline
If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created with a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of the `depthStencilAttachmentSamples` member of `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` used to create the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

If the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` with a `VkRenderingInfo::colorAttachmentCount` parameter greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the value of `rasterizationSamples` for the currently bound graphics pipeline.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

If this command has been called inside a render pass instance started with `vkCmdBeginRendering`, and the `pNext` chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the value of...
rasterizationSamples for the currently bound graphics pipeline must be equal to VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples

- VUID-vkCmdDrawClusterIndirectHUAWEI-renderPass-06198
  If the current render pass instance was begun with vkCmdBeginRendering, the currently bound pipeline must have been created with a VkGraphicsPipelineCreateInfo::renderPass equal to VK_NULL_HANDLE

- VUID-vkCmdDrawClusterIndirectHUAWEI-pColorAttachments-08963
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the VkRenderingInfo::pColorAttachments->imageView was not VK_NULL_HANDLE, then the corresponding element of VkPipelineRenderingCreateInfo::pColorAttachmentFormats used to create the pipeline must not be VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawClusterIndirectHUAWEI-pDepthAttachment-08964
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, then the VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the pipeline must not be VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawClusterIndirectHUAWEI-pStencilAttachment-08965
  If the current render pass instance was begun with vkCmdBeginRendering, there is a graphics pipeline bound, stencil test is enabled and the VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, then the VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the pipeline must not be VK_FORMAT_UNDEFINED

- VUID-vkCmdDrawClusterIndirectHUAWEI-primitivesGeneratedQueryWithRasterizerDiscard-06708
  If the primitivesGeneratedQueryWithRasterizerDiscard feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, rasterization discard must not be enabled

- VUID-vkCmdDrawClusterIndirectHUAWEI-primitivesGeneratedQueryWithNonZeroStreams-06709
  If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT query is active, the bound graphics pipeline must not have been created with a non-zero value in VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-07619
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT dynamic state enabled then vkCmdSetTessellationDomainOriginEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-07620
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT dynamic state enabled then vkCmdSetDepthClampEnableEXT must have been called in the current command buffer
prior to this drawing command

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-09237
  If a shader object is bound to the `VK_SHADER_STAGE_TESSIONEVALUATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-08650
  If the depthClamp feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-07621
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_POLYGON_MODE_EXT` dynamic state enabled then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-08651
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-07622
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` dynamic state enabled then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-08652
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then `vkCmdSetRasterizationSamplesEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-07623
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` dynamic state enabled then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-08653
  If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then `vkCmdSetSampleMaskEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-07624
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` dynamic state enabled, and `alphaToCoverageEnable` was `VK_TRUE` in the last call to `vkCmdSetAlphaToCoverageEnableEXT`, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetAlphaToCoverageEnableEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetAlphaToCoverageEnableEXT` in the current command buffer set `alphaToCoverageEnable` to `VK_TRUE`, then the Fragment Output Interface must contain a variable for the alpha Component word in Location 0 at Index 0.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT` dynamic state enabled then `vkCmdSetAlphaToOneEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `alphaToOne` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetAlphaToOneEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT` dynamic state enabled then `vkCmdSetLogicOpEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the `logicOp` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetLogicOpEnableEXT` must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the
VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT dynamic state enabled then
vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then
vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command.

If the geometryStreams feature is enabled, and a shader object is bound to the
VK_SHADER_STAGE_GEOMETRY_BIT stage, then
vkCmdSetRasterizationStreamEXT must have been called in the current command buffer prior to this drawing command.

If the VK_EXT_conservative_rasterization extension is enabled, and a shader object is
bound to any graphics stage, and the most recent call to
vkCmdSetRasterizerDiscardEnable in the current command buffer set
rasterizerDiscardEnable to VK_FALSE, then
vkCmdSetConservativeRasterizationModeEXT must have been called in the current command buffer prior to this drawing command.
• VUID-vkCmdDrawClusterIndirectHUAWEI-None-07632
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-08662
If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetConservativeRasterizationModeEXT` in the current command buffer set `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`, then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-07633
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-08663
If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-07634
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-08664
If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-07635
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-07636
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT` dynamic state enabled then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-08665
If the `VK_EXT_provoking_vertex` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-07637
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08666
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08667
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08668
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08669
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08670
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineStippleEnableEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdDrawClusterIndirectHUAWEI-None-08671
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then
*vkCmdSetLineStippleEnableEXT* must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07849**
  If the bound graphics pipeline state was created with the *VK_DYNAMIC_STATE_LINE_STIPPLE_EXT* dynamic state enabled then *vkCmdSetLineStippleEXT* must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08672**
  If the *VK_EXT_line_rasterization* extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to *vkCmdSetLineStippleEnableEXT* in the current command buffer set *stippledLineEnable* to *VK_TRUE*, then *vkCmdSetLineStippleEXT* must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07639**
  If the bound graphics pipeline state was created with the *VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT* dynamic state enabled then *vkCmdSetDepthClipNegativeOneToOneEXT* must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08673**
  If the `depthClipControl` feature is enabled, and a shader object is bound to any graphics stage, then *vkCmdSetDepthClipNegativeOneToOneEXT* must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07640**
  If the bound graphics pipeline state was created with the *VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV* dynamic state enabled then *vkCmdSetViewportWScalingEnableNV* must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08674**
  If the `VK_NV_clip_space_w_scaling` extension is enabled, and a shader object is bound to any graphics stage, then *vkCmdSetViewportWScalingEnableNV* must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07641**
  If the bound graphics pipeline state was created with the *VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV* dynamic state enabled then *vkCmdSetViewportSwizzleNV* must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08675**
  If the `VK_NV_viewport_swizzle` extension is enabled, and a shader object is bound to any graphics stage, then *vkCmdSetViewportSwizzleNV* must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07642**
  If the bound graphics pipeline state was created with the *VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV* dynamic state enabled then *vkCmdSetCoverageToColorEnableNV* must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08676**
If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07643**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` dynamic state enabled then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08677**
  If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set `coverageToColorEnable` to `VK_TRUE`, then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07644**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08678**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07645**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-08679**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationModeNV` in the current command buffer set `coverageModulationMode` to any value other than `VK_COVERAGE_MODULATION_MODE_NONE_NV`, then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-07646**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command.
If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationTableEnableNV` in the current command buffer set `coverageModulationTableEnable` to `VK_TRUE`, then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV` dynamic state enabled then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command.

If the pipeline fragment shading rate feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFragmentShadingRateKHR` must have been called in the current command buffer prior to this drawing command.

If the shading rate image feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV` dynamic state enabled then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command.

If the representative fragment test feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetRepresentativeFragmentTestEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command.

If the coverage reduction mode feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageReductionModeNV` must have been called in the current command buffer prior to this drawing command.
buffer prior to this drawing command

- **VUID-vkCmdDrawClusterIndirectHUAWEI-pColorBlendEnables-07470**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` state enabled and the last call to `vkCmdSetColorBlendEnableEXT` set `pColorBlendEnables` for any attachment to `VK_TRUE`, then for those attachments in the subpass the corresponding image view’s format features must contain `VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-rasterizationSamples-07471**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must follow the rules for a zero-attachment subpass.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-samples-07472**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state disabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `VkPipelineMultisampleStateCreateInfo::rasterizationSamples` parameter used to create the bound graphics pipeline.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-samples-07473**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-rasterizationSamples-07474**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and neither the `VK_AMD_mixed_attachment_samples` nor the `VK_NV_framebuffer_mixed_samples` extensions are enabled, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-None-09211**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the `rasterizationSamples` member of that structure.

- **VUID-vkCmdDrawClusterIndirectHUAWEI-firstAttachment-07476**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer.
prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of vkCmdSetColorBlendEnableEXT calls must specify an enable for all active color attachments in the current subpass

- VUID-vkCmdDrawClusterIndirectHUAWEI-firstAttachment-07477
If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_COLOR\_BLEND\_EQUATION\_EXT} dynamic state enabled then \texttt{vkCmdSetColorBlendEquationEXT} must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of \texttt{vkCmdSetColorBlendEquationEXT} calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled

- VUID-vkCmdDrawClusterIndirectHUAWEI-firstAttachment-07478
If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_COLOR\_WRITE\_MASK\_EXT} dynamic state enabled then \texttt{vkCmdSetColorWriteMaskEXT} must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of \texttt{vkCmdSetColorWriteMaskEXT} calls must specify the color write mask for all active color attachments in the current subpass

- VUID-vkCmdDrawClusterIndirectHUAWEI-firstAttachment-07479
If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_COLOR\_BLEND\_ADVANCED\_EXT} dynamic state enabled then \texttt{vkCmdSetColorBlendAdvancedEXT} must have been called in the current command buffer prior to this drawing command, and the attachments specified by the firstAttachment and attachmentCount parameters of \texttt{vkCmdSetColorBlendAdvancedEXT} calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled

- VUID-vkCmdDrawClusterIndirectHUAWEI-advancedBlendMaxColorAttachments-07480
If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_COLOR\_BLEND\_ADVANCED\_EXT} and \texttt{VK\_DYNAMIC\_STATE\_COLOR\_BLEND\_ENABLE\_EXT} dynamic states enabled and the last calls to \texttt{vkCmdSetColorBlendEnableEXT} and \texttt{vkCmdSetColorBlendAdvancedEXT} have enabled advanced blending, then the number of active color attachments in the current subpass must not exceed advancedBlendMaxColorAttachments

- VUID-vkCmdDrawClusterIndirectHUAWEI-primitivesGeneratedQueryWithNonZeroStreams-07481
If the primitivesGeneratedQueryWithNonZeroStreams feature is not enabled and the \texttt{VK\_QUERY\_TYPE\_PRIMITIVES\_GENERATED\_EXT} query is active, and the bound graphics pipeline was created with \texttt{VK\_DYNAMIC\_STATE\_RASTERIZATION\_STREAM\_EXT} state enabled, the last call to \texttt{vkCmdSetRasterizationStreamEXT} must have set the rasterizationStream to zero

- VUID-vkCmdDrawClusterIndirectHUAWEI-sampleLocationsPerPixel-07482
If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_SAMPLE\_LOCATIONS\_EXT} state enabled and the \texttt{VK\_DYNAMIC\_STATE\_RASTERIZATION\_SAMPLES\_EXT} state disabled, then the sampleLocationsPerPixel member of \texttt{pSampleLocationsInfo} in the last call to \texttt{vkCmdSetSampleLocationsEXT} must equal the rasterizationSamples member of the
**VkPipelineMultisampleStateCreateInfo** structure the bound graphics pipeline has been created with

- VUID-vkCmdDrawClusterIndirectHUAWEI-sampleLocationsPerPixel-07483
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, then the `sampleLocationsPerPixel` member of `pSampleLocationsInfo` in the last call to `vkCmdSetSampleLocationsEXT` must equal the `rasterizationSamples` parameter of the last call to `vkCmdSetRasterizationSamplesEXT`

- VUID-vkCmdDrawClusterIndirectHUAWEI-sampleLocationsEnable-07484
  If the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the `VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT` bit set

- VUID-vkCmdDrawClusterIndirectHUAWEI-sampleLocationsEnable-07485
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state enabled and the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, then the `sampleLocationsInfo.sampleLocationGridSize.width` in the last call to `vkCmdSetSampleLocationsEXT` must evenly divide `VkMultisamplePropertiesEXT::sampleLocationGridSize.width` as returned by `vkGetPhysicalDeviceMultisamplePropertiesEXT` with a `samples` parameter equaling `rasterizationSamples`

- VUID-vkCmdDrawClusterIndirectHUAWEI-sampleLocationsEnable-07486
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` state enabled, and if `sampleLocationsEnable` was `VK_TRUE` in the last call to `vkCmdSetSampleLocationsEnableEXT`, the fragment shader code must not statically use the extended instruction `InterpolateAtSample`

- VUID-vkCmdDrawClusterIndirectHUAWEI-sampleLocationsEnable-07936
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` state disabled and the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, the `sampleLocationsEnable` member of a `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` in the
bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.width must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawClusterIndirectHUAWEI-sampleLocationsEnable-07937
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.height must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawClusterIndirectHUAWEI-sampleLocationsEnable-07938
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationsPerPixel must equal rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

- VUID-vkCmdDrawClusterIndirectHUAWEI-coverageModulationTableEnable-07488
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV state enabled and the last call to vkCmdSetCoverageModulationTableEnableNV set coverageModulationTableEnable to VK_TRUE, then the coverageModulationTableCount parameter in the last call to vkCmdSetCoverageModulationTableNV must equal the current rasterizationSamples divided by the number of color samples in the current subpass

- VUID-vkCmdDrawClusterIndirectHUAWEI-rasterizationSamples-07489
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current rasterizationSamples must be the same as the sample count of the depth/stencil attachment

- VUID-vkCmdDrawClusterIndirectHUAWEI-coverageToColorEnable-07490
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV state enabled and the last call to vkCmdSetCoverageToColorEnableNV set coverageToColorEnable to VK_TRUE, then the coverageToColorLocation parameter in the last call to vkCmdSetCoverageToColorLocationNV must have a color attachment at the location selected by the last call to vkCmdSetCoverageToColorLocationNV coverageToColorLocation, with a VkFormat of VK_FORMAT_R8_UINT, VK_FORMAT_R8_SINT, VK_FORMAT_R16_UINT, VK_FORMAT_R16_SINT, VK_FORMAT_R32_UINT, or VK_FORMAT_R32_SINT

- VUID-vkCmdDrawClusterIndirectHUAWEI-coverageReductionMode-07491
  If this VK_NV_coverage_reduction_mode extension is enabled, the bound graphics pipeline
state was created with the VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV and 
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT states enabled, the current coverage 
reduction mode coverageReductionMode, then the current rasterizationSamples, and the 
sample counts for the color and depth/stencil attachments (if the subpass has them) must 
be a valid combination returned by 
vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV

- VUID-vkCmdDrawClusterIndirectHUAWEI-viewportCount-07492
  If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, but not the 
VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic state enabled, then the bound graphics 
pipeline must have been created with VkPipelineViewportSwizzleStateCreateInfoNV 
::viewportCount greater or equal to the viewportCount parameter in the last call to 
vkCmdSetViewportWithCount

- VUID-vkCmdDrawClusterIndirectHUAWEI-viewportCount-07493
  If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT and VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV dynamic states enabled then the viewportCount parameter in the last call to 
vkCmdSetViewportSwizzleNV must be greater than or equal to the viewportCount 
parameter in the last call to vkCmdSetViewportWithCount

- VUID-vkCmdDrawClusterIndirectHUAWEI-rasterizationSamples-07494
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and if the current subpass 
has any color attachments and rasterizationSamples of the last call to 
vkCmdSetRasterizationSamplesEXT is greater than the number of color samples, then the pipeline sampleShadingEnable must be VK_FALSE

- VUID-vkCmdDrawClusterIndirectHUAWEI-stippledLineEnable-07495
  If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or 
VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current 
stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is 
VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT, then the stippledRectangularLines feature 
must be enabled

- VUID-vkCmdDrawClusterIndirectHUAWEI-stippledLineEnable-07496
  If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or 
VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current 
stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is 
VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT, then the stippledBresenhamLines feature must 
be enabled

- VUID-vkCmdDrawClusterIndirectHUAWEI-stippledLineEnable-07497
  If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT or 
VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT dynamic states enabled, and if the current 
stippledLineEnable state is VK_TRUE and the current lineRasterizationMode state is 
VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT, then the stippledSmoothLines feature 
must be enabled
If the bound graphics pipeline state was created with the 
\texttt{VK\_DYNAMIC\_STATE\_LINE\_STIPPLE\_ENABLE\_EXT} or 
\texttt{VK\_DYNAMIC\_STATE\_LINE\_RASTERIZATION\_MODE\_EXT} dynamic states enabled, and if the current 
stippledLineEnable state is \texttt{VK\_TRUE} and the current lineRasterizationMode state is 
\texttt{VK\_LINE\_RASTERIZATION\_MODE\_DEFAULT\_EXT}, then the stippledRectangularLines feature must 
be enabled and \texttt{VkPhysicalDeviceLimits.stippledLineEnable} must be \texttt{VK\_TRUE}.

If the bound graphics pipeline state was created with the 
\texttt{VK\_DYNAMIC\_STATE\_CONSERVATIVE\_RASTERIZATION\_MODE\_EXT} dynamic state enabled, 
\texttt{conservativePointAndLineRasterization} is not supported, and the effective primitive 
topology output by the last pre-rasterization shader stage is a line or point, then the 
\texttt{conservativeRasterizationMode} set by the last call to 
\texttt{vkCmdSetConservativeRasterizationModeEXT} must be 
\texttt{VK\_CONSERVATIVE\_RASTERIZATION\_MODE\_DISABLED\_EXT}.

If the currently bound pipeline was created with the \texttt{VkPipelineShaderStageCreateInfo.stage} member of an element of \texttt{VkGraphicsPipelineCreateInfo.pStages} set to 
\texttt{VK\_SHADER\_STAGE\_VERTEX\_BIT}, \texttt{VK\_SHADER\_STAGE\_TESSELLATION\_CONTROL\_BIT}, 
\texttt{VK\_SHADER\_STAGE\_TESSELLATION\_EVALUATION\_BIT} or \texttt{VK\_SHADER\_STAGE\_GEOMETRY\_BIT}, then \texttt{Mesh} 
\texttt{Shader Queries} must not be active.

If the bound graphics pipeline state was created with the 
\texttt{VK\_DYNAMIC\_STATE\_ATTACHMENT\_FEEDBACK\_LOOP\_ENABLE\_EXT} dynamic state 
\texttt{vkCmdSetAttachmentFeedbackLoopEnableEXT} must have been called in the current 
command buffer prior to this drawing command.

If dynamic state was inherited from 
\texttt{VkCommandBufferInheritanceViewportScissorInfoNV}, it must be set in the current 
command buffer prior to this drawing command.

If there is no bound graphics pipeline, \texttt{vkCmdBindShadersEXT} must have been called in the current 
command buffer with \texttt{pStages} with an element of \texttt{VK\_SHADER\_STAGE\_VERTEX\_BIT}.

If there is no bound graphics pipeline, and the \texttt{tessellationShader} feature is enabled, 
\texttt{vkCmdBindShadersEXT} must have been called in the current command buffer with \texttt{pStages} 
with an element of \texttt{VK\_SHADER\_STAGE\_TESSELLATION\_CONTROL\_BIT}.

If there is no bound graphics pipeline, and the \texttt{tessellationShader} feature is enabled, 
\texttt{vkCmdBindShadersEXT} must have been called in the current command buffer with \texttt{pStages} 
with an element of \texttt{VK\_SHADER\_STAGE\_TESSELLATION\_EVALUATION\_BIT}.

If there is no bound graphics pipeline, and the \texttt{geometryShader} feature is enabled, 
\texttt{vkCmdBindShadersEXT} must have been called in the current command buffer with \texttt{pStages} 
with an element of \texttt{VK\_SHADER\_STAGE\_GEOMETRY\_BIT}.
If there is no bound graphics pipeline, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_FRAGMENT_BIT`.

If there is no bound graphics pipeline, and the `taskShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TASK_BIT_EXT`.

If there is no bound graphics pipeline, and the `meshShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_MESH_BIT_EXT`.

If there is no bound graphics pipeline, and at least one of the `taskShader` and `meshShader` features is enabled, one of the `VK_SHADER_STAGE_VERTEX_BIT` or `VK_SHADER_STAGE_MESH_BIT_EXT` stages must have a valid `VkShaderEXT` bound, and the other must have no `VkShaderEXT` bound.

If there is no bound graphics pipeline, and both the `taskShader` and `meshShader` features are enabled, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that `VkShaderEXT` was created without the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, a valid `VkShaderEXT` must be bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage.

If there is no bound graphics pipeline, and both the `taskShader` and `meshShader` features are enabled, and a valid `VkShaderEXT` is bound to the `VK_SHADER_STAGE_MESH_BIT_EXT` stage, and that `VkShaderEXT` was created with the `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT` flag, there must be no `VkShaderEXT` bound to the `VK_SHADER_STAGE_TASK_BIT_EXT` stage.

If any graphics shader is bound which was created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag, then all shaders created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag in the same `vkCreateShadersEXT` call must also be bound.

If any graphics shader is bound which was created with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag, any stages in between stages whose shaders did not create a shader with the `VK_SHADER_CREATE_LINK_STAGE_BIT_EXT` flag as part of the same `vkCreateShadersEXT` call must not have any `VkShaderEXT` bound.

All bound graphics shader objects must have been created with identical or identically defined push constant ranges.
• VUID-vkCmdDrawClusterIndirectHUAWEI-None-08879
  All bound graphics shader objects must have been created with identical or identically defined arrays of descriptor set layouts

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-08880
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage and the attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdDrawClusterIndirectHUAWEI-pDynamicStates-08715
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable parameter in the last call to vkCmdSetDepthWriteEnable must be VK_FALSE

• VUID-vkCmdDrawClusterIndirectHUAWEI-pDynamicStates-08716
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_STENCIL_WRITE_MASK set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpStencilAttachmentReadEXT, the writeMask parameter in the last call to vkCmdSetStencilWriteMask must be 0

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-09116
  If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT, and the format of any color attachment is VK_FORMAT_E5B9G9R9_UFLOAT_PACK32, the corresponding element of the pColorWriteMasks parameter of vkCmdSetColorWriteMaskEXT must either include all of VK_COLOR_COMPONENT_R_BIT, VK_COLOR_COMPONENT_G_BIT, and VK_COLOR_COMPONENT_B_BIT, or none of them

• VUID-vkCmdDrawClusterIndirectHUAWEI-maxFragmentDualSrcAttachments-09239
  If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of Location for any output attachment statically used in the Fragment Execution Model executed by this command must be less than maxFragmentDualSrcAttachments

• VUID-vkCmdDrawClusterIndirectHUAWEI-stage-06480
  The bound graphics pipeline must not have been created with the VkPipelineShaderStageCreateInfo::stage member of an element of VkGraphicsPipelineCreateInfo::pStages set to VK_SHADER_STAGE_VERTEX_BIT, VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT, VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT or VK_SHADER_STAGE_GEOMETRY_BIT

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-07074
  Transform Feedback Queries must not be active

• VUID-vkCmdDrawClusterIndirectHUAWEI-None-07075
  Primitives Generated Queries must not be active

• VUID-vkCmdDrawClusterIndirectHUAWEI-pipelineStatistics-07076
The `pipelineStatistics` member used to create any active Pipeline Statistics Query must not contain:
- `VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_VERTICES_BIT`,
- `VK_QUERY_PIPELINE_STATISTIC_INPUT_ASSEMBLY_PRIMITIVES_BIT`,
- `VK_QUERY_PIPELINE_STATISTIC_VERTEX_SHADER_INVOCATIONS_BIT`,
- `VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_INVOCATIONS_BIT`,
- `VK_QUERY_PIPELINE_STATISTIC_GEOMETRY_SHADER_PRIMITIVES_BIT`,
- `VK_QUERY_PIPELINE_STATISTIC_CLIPPING_INVOCATIONS_BIT`,
- `VK_QUERY_PIPELINE_STATISTIC_CLIPPING_PRIMITIVES_BIT`,
- `VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_CONTROL_SHADER_PATCHES_BIT`, or
- `VK_QUERY_PIPELINE_STATISTIC_TESSELLATION_EVALUATION_SHADER_INVOCATIONS_BIT`

• **VUID-vkCmdDrawClusterIndirectHUAWEI-drawCount-02718**
  If the `multiDrawIndirect` feature is not enabled, `drawCount` must be 0 or 1

• **VUID-vkCmdDrawClusterIndirectHUAWEI-drawCount-02719**
  `drawCount` must be less than or equal to `VkPhysicalDeviceLimits::maxDrawIndirectCount`

• **VUID-vkCmdDrawClusterIndirectHUAWEI-ClusterCullingHUAWEI-07824**
  The current pipeline bound to `VK_PIPELINE_BIND_POINT_GRAPHICS` must contain a shader stage using the `ClusterCullingHUAWEI` Execution Model.

• **VUID-vkCmdDrawClusterIndirectHUAWEI-offset-07918**
  `offset` must be a multiple of `VkPhysicalDeviceClusterCullingShaderPropertiesHUAWEI::indirectBufferOffsetAlignment`

---

**Valid Usage (Implicit)**

• **VUID-vkCmdDrawClusterIndirectHUAWEI-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle

• **VUID-vkCmdDrawClusterIndirectHUAWEI-buffer-parameter**
  `buffer` must be a valid `VkBuffer` handle

• **VUID-vkCmdDrawClusterIndirectHUAWEI-commandBuffer-recording**
  `commandBuffer` must be in the recording state

• **VUID-vkCmdDrawClusterIndirectHUAWEI-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations

• **VUID-vkCmdDrawClusterIndirectHUAWEI-renderpass**
  This command must only be called inside of a render pass instance

• **VUID-vkCmdDrawClusterIndirectHUAWEI-videocoding**
  This command must only be called outside of a video coding scope

• **VUID-vkCmdDrawClusterIndirectHUAWEI-commonparent**
  Both of `buffer`, and `commandBuffer` must have been created, allocated, or retrieved from the same `VkDevice`
Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Inside</td>
<td>Outside</td>
<td>Graphics</td>
<td>Action</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Chapter 22. Fixed-Function Vertex Processing

Vertex fetching is controlled via configurable state, as a logically distinct graphics pipeline stage.

22.1. Vertex Attributes

Vertex shaders can define input variables, which receive vertex attribute data transferred from one or more VkBuffer(s) by drawing commands. Vertex shader input variables are bound to buffers via an indirect binding where the vertex shader associates a vertex input attribute number with each variable, vertex input attributes are associated to vertex input bindings on a per-pipeline basis, and vertex input bindings are associated with specific buffers on a per-draw basis via the vkCmdBindVertexBuffers command. Vertex input attribute and vertex input binding descriptions also contain format information controlling how data is extracted from buffer memory and converted to the format expected by the vertex shader.

There are VkPhysicalDeviceLimits::maxVertexInputAttributes number of vertex input attributes and VkPhysicalDeviceLimits::maxVertexInputBindings number of vertex input bindings (each referred to by zero-based indices), where there are at least as many vertex input attributes as there are vertex input bindings. Applications can store multiple vertex input attributes interleaved in a single buffer, and use a single vertex input binding to access those attributes.

In GLSL, vertex shaders associate input variables with a vertex input attribute number using the location layout qualifier. The Component layout qualifier associates components of a vertex shader input variable with components of a vertex input attribute.

**GLSL example**

```glsl
// Assign location M to variableName
layout (location=M, component=2) in vec2 variableName;

// Assign locations [N,N+L) to the array elements of variableNameArray
layout (location=N) in vec4 variableNameArray[L];
```

In SPIR-V, vertex shaders associate input variables with a vertex input attribute number using the Location decoration. The Component decoration associates components of a vertex shader input variable with components of a vertex input attribute. The Location and Component decorations are specified via the OpDecorate instruction.

**SPIR-V example**

```spir-v
...%1 = OpExtInstImport "GLSL.std.450"
...
OpName %9 "variableName"
OpName %15 "variableNameArray"
OpDecorate %18 BuiltIn VertexIndex
```

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22.1.1. Attribute Location and Component Assignment

The Location decoration specifies which vertex input attribute is used to read and interpret the data that a variable will consume.

When a vertex shader input variable declared using a 16- or 32-bit scalar or vector data type is assigned a Location, its value(s) are taken from the components of the input attribute specified with the corresponding VkVertexInputAttributeDescription::location. The components used depend on the type of variable and the Component decoration specified in the variable declaration, as identified in Input attribute components accessed by 16-bit and 32-bit input variables. Any 16-bit or 32-bit scalar or vector input will consume a single Location. For 16-bit and 32-bit data types, missing components are filled in with default values as described below.

If an implementation supports storageInputOutput16, vertex shader input variables can have a width of 16 bits.

Table 32. Input attribute components accessed by 16-bit and 32-bit input variables

<table>
<thead>
<tr>
<th>16-bit or 32-bit data type</th>
<th>Component decoration</th>
<th>Components consumed</th>
</tr>
</thead>
<tbody>
<tr>
<td>scalar</td>
<td>0 or unspecified</td>
<td>(x, o, o, o)</td>
</tr>
<tr>
<td>scalar</td>
<td>1</td>
<td>(o, y, o, o)</td>
</tr>
<tr>
<td>scalar</td>
<td>2</td>
<td>(o, o, z, o)</td>
</tr>
<tr>
<td>scalar</td>
<td>3</td>
<td>(o, o, o, w)</td>
</tr>
<tr>
<td>two-component vector</td>
<td>0 or unspecified</td>
<td>(x, y, o, o)</td>
</tr>
<tr>
<td>two-component vector</td>
<td>1</td>
<td>(o, y, z, o)</td>
</tr>
<tr>
<td>two-component vector</td>
<td>2</td>
<td>(o, o, z, w)</td>
</tr>
</tbody>
</table>
Components indicated by “o” are available for use by other input variables which are sourced from the same attribute, and if used, are either filled with the corresponding component from the input format (if present), or the default value.

When a vertex shader input variable declared using a 32-bit floating point matrix type is assigned a Location $i$, its values are taken from consecutive input attributes starting with the corresponding `VkVertexInputAttributeDescription::location`. Such matrices are treated as an array of column vectors with values taken from the input attributes identified in Input attributes accessed by 32-bit input matrix variables. The `VkVertexInputAttributeDescription::format` must be specified with a `VkFormat` that corresponds to the appropriate type of column vector. The `Component` decoration must not be used with matrix types.

Table 33. Input attributes accessed by 32-bit input matrix variables

<table>
<thead>
<tr>
<th>Data type</th>
<th>Column vector type</th>
<th>Locations consumed</th>
<th>Components consumed</th>
</tr>
</thead>
<tbody>
<tr>
<td>mat2</td>
<td>two-component vector</td>
<td>i, i+1</td>
<td>(x, y, o, o), (x, y, o, o)</td>
</tr>
<tr>
<td>mat2x3</td>
<td>three-component vector</td>
<td>i, i+1</td>
<td>(x, y, z, o), (x, y, z, o)</td>
</tr>
<tr>
<td>mat2x4</td>
<td>four-component vector</td>
<td>i, i+1</td>
<td>(x, y, z, w), (x, y, z, w)</td>
</tr>
<tr>
<td>mat3x2</td>
<td>two-component vector</td>
<td>i, i+1, i+2</td>
<td>(x, y, o, o), (x, y, o, o), (x, y, o, o)</td>
</tr>
<tr>
<td>mat3</td>
<td>three-component vector</td>
<td>i, i+1, i+2</td>
<td>(x, y, z, o), (x, y, z, o), (x, y, z, o)</td>
</tr>
<tr>
<td>mat3x4</td>
<td>four-component vector</td>
<td>i, i+1, i+2</td>
<td>(x, y, z, w), (x, y, z, w), (x, y, z, w)</td>
</tr>
<tr>
<td>mat4x2</td>
<td>two-component vector</td>
<td>i, i+1, i+2, i+3</td>
<td>(x, y, o, o), (x, y, o, o), (x, y, o, o), (x, y, o, o)</td>
</tr>
<tr>
<td>mat4x3</td>
<td>three-component vector</td>
<td>i, i+1, i+2, i+3</td>
<td>(x, y, z, o), (x, y, z, o), (x, y, z, o), (x, y, z, o)</td>
</tr>
<tr>
<td>mat4</td>
<td>four-component vector</td>
<td>i, i+1, i+2, i+3</td>
<td>(x, y, z, w), (x, y, z, w), (x, y, z, w), (x, y, z, w)</td>
</tr>
</tbody>
</table>

Components indicated by “o” are available for use by other input variables which are sourced from the same attribute, and if used, are either filled with the corresponding component from the input format (if present), or the default value.

When a vertex shader input variable declared using a scalar or vector 64-bit data type is assigned a Location $i$, its values are taken from consecutive input attributes starting with the corresponding
VkVertexInputAttributeDescription::location. The Location slots and Component words used depend on the type of variable and the Component decoration specified in the variable declaration, as identified in Input attribute locations and components accessed by 64-bit input variables. For 64-bit data types, no default attribute values are provided. Input variables must not use more components than provided by the attribute.

Table 34. Input attribute locations and components accessed by 64-bit input variables

<table>
<thead>
<tr>
<th>Input format</th>
<th>Locations consumed</th>
<th>64-bit data type</th>
<th>Location decoration</th>
<th>Component decoration</th>
<th>32-bit component consumed</th>
</tr>
</thead>
<tbody>
<tr>
<td>R64</td>
<td>i</td>
<td>scalar</td>
<td>i</td>
<td>0 or unspecified</td>
<td>(x, y, -, -)</td>
</tr>
<tr>
<td>R64G64</td>
<td>i</td>
<td>scalar</td>
<td>i</td>
<td>0 or unspecified</td>
<td>(x, y, o, o)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>scalar</td>
<td>i</td>
<td>2</td>
<td>(o, o, z, w)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>two-component vector</td>
<td>i</td>
<td>0 or unspecified</td>
<td>(x, y, z, w)</td>
</tr>
<tr>
<td>R64G64B64</td>
<td>i, i+1</td>
<td>scalar</td>
<td>i</td>
<td>0 or unspecified</td>
<td>(x, y, o, o), (o, o, -, -)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>scalar</td>
<td>i</td>
<td>2</td>
<td>(o, o, z, w), (o, o, -, -)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>scalar</td>
<td>i+1</td>
<td>0 or unspecified</td>
<td>(o, o, o, o), (x, y, -, -)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>two-component vector</td>
<td>i</td>
<td>0 or unspecified</td>
<td>(x, y, z, w), (o, o, -, -)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>three-component vector</td>
<td>i</td>
<td>unspecified</td>
<td>(x, y, z, w), (x, y, -, -)</td>
</tr>
<tr>
<td>R64G64B64A64</td>
<td>i, i+1</td>
<td>scalar</td>
<td>i</td>
<td>0 or unspecified</td>
<td>(x, y, o, o), (o, o, o, o)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>scalar</td>
<td>i</td>
<td>2</td>
<td>(o, o, z, w), (o, o, o, o)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>scalar</td>
<td>i+1</td>
<td>0 or unspecified</td>
<td>(o, o, o, o), (x, y, o, o)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>scalar</td>
<td>i+1</td>
<td>2</td>
<td>(o, o, o, o), (o, o, z, w)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>two-component vector</td>
<td>i</td>
<td>0 or unspecified</td>
<td>(x, y, z, w), (o, o, o, o)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>two-component vector</td>
<td>i+1</td>
<td>0 or unspecified</td>
<td>(o, o, o, o), (x, y, z, w)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>three-component vector</td>
<td>i</td>
<td>unspecified</td>
<td>(x, y, z, w), (x, y, o, o)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>four-component vector</td>
<td>i</td>
<td>unspecified</td>
<td>(x, y, z, w), (x, y, z, w)</td>
</tr>
</tbody>
</table>
Components indicated by “o” are available for use by other input variables which are sourced from
the same attribute. Components indicated by “-” are not available for input variables as there are
no default values provided for 64-bit data types, and there is no data provided by the input format.

When a vertex shader input variable declared using a 64-bit floating-point matrix type is assigned a
\textbf{Location} \(i\), its values are taken from consecutive input attribute locations. Such matrices are treated
as an array of column vectors with values taken from the input attributes as shown in \textbf{Input
attribute locations and components accessed by 64-bit input variables}. Each column vector starts at
the \textbf{Location} immediately following the last \textbf{Location} of the previous column vector. The number of
attributes and components assigned to each matrix is determined by the matrix dimensions and
ranges from two to eight locations.

When a vertex shader input variable declared using an array type is assigned a location, its values
are taken from consecutive input attributes starting with the corresponding \textbf{VkVertexInputAttributeDescription}::\textit{location}. The number of attributes and components assigned to
each element are determined according to the data type of the array elements and \textbf{Component
decoration} (if any) specified in the declaration of the array, as described above. Each element of the
array, in order, is assigned to consecutive locations, but all at the same specified component within
each location.

Only input variables declared with the data types and component decorations as specified above
are supported. Two variables are allowed to share the same \textbf{Location} slot only if their \textbf{Component
words} do not overlap. If multiple variables share the same \textbf{Location} slot, they \textbf{must} all have the
same SPIR-V floating-point component type or all have the same width scalar type components.

\section*{22.2. Vertex Input Description}

Applications specify vertex input attribute and vertex input binding descriptions as part of graphics
pipeline creation by setting the \textbf{VkGraphicsPipelineCreateInfo}::\textbf{pVertexInputState} pointer to a
\textbf{VkPipelineVertexInputStateCreateInfo} structure. Alternatively, if the graphics pipeline is created
with the \textbf{VK_DYNAMIC_STATE_VERTEX_INPUT_EXT} dynamic state enabled, then the vertex input attribute
and vertex input binding descriptions are specified dynamically with \textbf{vkCmdSetVertexInputEXT},
and the \textbf{VkGraphicsPipelineCreateInfo}::\textbf{pVertexInputState} pointer is ignored.

The \textbf{VkPipelineVertexInputStateCreateInfo} structure is defined as:

\begin{verbatim}
// Provided by VK_VERSION_1_0
typedef struct VkPipelineVertexInputStateCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkPipelineVertexInputStateCreateFlags flags;
    uint32_t vertexBindingDescriptionCount;
    const VkVertexInputBindingDescription* pVertexBindingDescriptions;
    uint32_t vertexAttributeDescriptionCount;
    const VkVertexInputAttributeDescription* pVertexAttributeDescriptions;
} VkPipelineVertexInputStateCreateInfo;
\end{verbatim}

\begin{itemize}
    \item \textbf{sType} is a \textbf{VkStructureType} value identifying this structure.
\end{itemize}
• `pNext` is NULL or a pointer to a structure extending this structure.
• `flags` is reserved for future use.
• `vertexBindingDescriptionCount` is the number of vertex binding descriptions provided in `pVertexBindingDescriptions`.
• `pVertexBindingDescriptions` is a pointer to an array of `VkVertexInputBindingDescription` structures.
• `vertexAttributeDescriptionCount` is the number of vertex attribute descriptions provided in `pVertexAttributeDescriptions`.
• `pVertexAttributeDescriptions` is a pointer to an array of `VkVertexInputAttributeDescription` structures.

### Valid Usage

- **VUID-VkPipelineVertexInputStateCreateInfo-vertexBindingDescriptionCount-00613**
  vertexBindingDescriptionCount must be less than or equal to `VkPhysicalDeviceLimits::maxVertexInputBindings`

- **VUID-VkPipelineVertexInputStateCreateInfo-vertexAttributeDescriptionCount-00614**
  vertexAttributeDescriptionCount must be less than or equal to `VkPhysicalDeviceLimits::maxVertexInputAttributes`

- **VUID-VkPipelineVertexInputStateCreateInfo-binding-00615**
  For every binding specified by each element of `pVertexAttributeDescriptions`, a `VkVertexInputBindingDescription` must exist in `pVertexBindingDescriptions` with the same value of binding

- **VUID-VkPipelineVertexInputStateCreateInfo-pVertexBindingDescriptions-00616**
  All elements of `pVertexBindingDescriptions` must describe distinct binding numbers

- **VUID-VkPipelineVertexInputStateCreateInfo-pVertexAttributeDescriptions-00617**
  All elements of `pVertexAttributeDescriptions` must describe distinct attribute locations

### Valid Usage (Implicit)

- **VUID-VkPipelineVertexInputStateCreateInfo-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_VERTEX_INPUT_STATE_CREATE_INFO`

- **VUID-VkPipelineVertexInputStateCreateInfo-pNext-pNext**
  `pNext` must be NULL or a pointer to a valid instance of `VkPipelineVertexInputDivisorStateCreateInfoEXT`

- **VUID-VkPipelineVertexInputStateCreateInfo-sType-unique**
  The `sType` value of each struct in the `pNext` chain must be unique

- **VUID-VkPipelineVertexInputStateCreateInfo-flags-zerobitmask**
  `flags` must be 0

- **VUID-VkPipelineVertexInputStateCreateInfo-pVertexBindingDescriptions-parameter**
  If `vertexBindingDescriptionCount` is not 0, `pVertexBindingDescriptions` must be a valid
pointer to an array of valid VkVertexInputBindingDescription structures

- VUID-VkPipelineVertexInputStateCreateInfo-pVertexAttributeDescriptions-parameter
  If vertexAttributeDescriptionCount is not 0, pVertexAttributeDescriptions must be a valid pointer to an array of valid VkVertexInputAttributeDescription structures

// Provided by VK_VERSION_1_0
typedef VkFlags VkPipelineVertexInputStateCreateFlags;

VkPipelineVertexInputStateCreateFlags is a bitmask type for setting a mask, but is currently reserved for future use.

Each vertex input binding is specified by the VkVertexInputBindingDescription structure, defined as:

// Provided by VK_VERSION_1_0
typedef struct VkVertexInputBindingDescription {
  uint32_t binding;
  uint32_t stride;
  VkVertexInputRate inputRate;
} VkVertexInputBindingDescription;

- binding is the binding number that this structure describes.
- stride is the byte stride between consecutive elements within the buffer.
- inputRate is a VkVertexInputRate value specifying whether vertex attribute addressing is a function of the vertex index or of the instance index.

Valid Usage

- VUID-VkVertexInputBindingDescription-binding-00618
  binding must be less than VkPhysicalDeviceLimits::maxVertexInputBindings

- VUID-VkVertexInputBindingDescription-stride-00619
  stride must be less than or equal to VkPhysicalDeviceLimits::maxVertexInputBindingStride

- VUID-VkVertexInputBindingDescription-stride-04456
  If the VK_KHR_portability_subset extension is enabled, stride must be a multiple of, and at least as large as, VkPhysicalDevicePortabilitySubsetPropertiesKHR::minVertexInputBindingStrideAlignment

Valid Usage (Implicit)

- VUID-VkVertexInputBindingDescription-inputRate-parameter
  inputRate must be a valid VkVertexInputRate value
Possible values of `VkVertexInputBindingDescription::inputRate`, specifying the rate at which vertex attributes are pulled from buffers, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkVertexInputRate {
    VK_VERTEX_INPUT_RATE_VERTEX = 0,
    VK_VERTEX_INPUT_RATE_INSTANCE = 1,
} VkVertexInputRate;
```

- `VK_VERTEX_INPUT_RATE_VERTEX` specifies that vertex attribute addressing is a function of the vertex index.
- `VK_VERTEX_INPUT_RATE_INSTANCE` specifies that vertex attribute addressing is a function of the instance index.

Each vertex input attribute is specified by the `VkVertexInputAttributeDescription` structure, defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkVertexInputAttributeDescription {
    uint32_t location;
    uint32_t binding;
    VkFormat format;
    uint32_t offset;
} VkVertexInputAttributeDescription;
```

- `location` is the shader input location number for this attribute.
- `binding` is the binding number which this attribute takes its data from.
- `format` is the size and type of the vertex attribute data.
- `offset` is a byte offset of this attribute relative to the start of an element in the vertex input binding.

### Valid Usage

- **VUID-VkVertexInputAttributeDescription-location-00620**
  `location` must be less than `VkPhysicalDeviceLimits::maxVertexInputAttributes`

- **VUID-VkVertexInputAttributeDescription-binding-00621**
  `binding` must be less than `VkPhysicalDeviceLimits::maxVertexInputBindings`

- **VUID-VkVertexInputAttributeDescription-offset-00622**
  `offset` must be less than or equal to `VkPhysicalDeviceLimits::maxVertexInputAttributeOffset`

- **VUID-VkVertexInputAttributeDescription-format-00623**
  The format features of `format` must contain `VK_FORMAT_FEATURE_VERTEX_BUFFER_BIT`

- **VUID-VkVertexInputAttributeDescription-vertexAttributeAccessBeyondStride-04457**
If the `VK_KHR_portability_subset` extension is enabled, and `VkPhysicalDevicePortabilitySubsetFeaturesKHR::vertexAttributeAccessBeyondStride` is `VK_FALSE`, the sum of `offset` plus the size of the vertex attribute data described by `format` must not be greater than `stride` in the `VkVertexInputBindingDescription` referenced in `binding`.

Valid Usage (Implicit)

- VUID-VkVertexInputAttributeDescription-format-parameter
  
  `format` must be a valid `VkFormat` value

To dynamically set the vertex input attribute and vertex input binding descriptions, call:

```
// Provided by VK_EXT_shader_object, VK_EXT_vertex_input_dynamic_state
void vkCmdSetVertexInputEXT(
    VkCommandBuffer commandBuffer,
    uint32_t vertexBindingDescriptionCount,
    const VkVertexInputBindingDescription2EXT* pVertexBindingDescriptions,
    uint32_t vertexAttributeDescriptionCount,
    const VkVertexInputAttributeDescription2EXT* pVertexAttributeDescriptions);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `vertexBindingDescriptionCount` is the number of vertex binding descriptions provided in `pVertexBindingDescriptions`.
- `pVertexBindingDescriptions` is a pointer to an array of `VkVertexInputBindingDescription2EXT` structures.
- `vertexAttributeDescriptionCount` is the number of vertex attribute descriptions provided in `pVertexAttributeDescriptions`.
- `pVertexAttributeDescriptions` is a pointer to an array of `VkVertexInputAttributeDescription2EXT` structures.

This command sets the vertex input attribute and vertex input binding descriptions state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE` dynamic state enabled, or when the bound pipeline state object was also created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE` dynamic state enabled, then `vkCmdBindVertexBuffers2` can be used instead of `vkCmdSetVertexInputEXT` to dynamically set the stride.
Valid Usage

- **VUID-vkCmdSetVertexInputEXT-None-08546**
  Either the `vertexInputDynamicState` feature or the `shaderObject` feature or both must be enabled.

- **VUID-vkCmdSetVertexInputEXT-vertexBindingDescriptionCount-04791**
  `vertexBindingDescriptionCount` must be less than or equal to `VkPhysicalDeviceLimits::maxVertexInputBindings`.

- **VUID-vkCmdSetVertexInputEXT-vertexAttributeDescriptionCount-04792**
  `vertexAttributeDescriptionCount` must be less than or equal to `VkPhysicalDeviceLimits::maxVertexInputAttributes`.

- **VUID-vkCmdSetVertexInputEXT-binding-04793**
  For every binding specified by each element of `pVertexAttributeDescriptions`, a `VkVertexInputBindingDescription2EXT` must exist in `pVertexBindingDescriptions` with the same value of binding.

- **VUID-vkCmdSetVertexInputEXT-pVertexBindingDescriptions-04794**
  All elements of `pVertexBindingDescriptions` must describe distinct binding numbers.

- **VUID-vkCmdSetVertexInputEXT-pVertexAttributeDescriptions-04795**
  All elements of `pVertexAttributeDescriptions` must describe distinct attribute locations.

Valid Usage (Implicit)

- **VUID-vkCmdSetVertexInputEXT-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- **VUID-vkCmdSetVertexInputEXT-pVertexBindingDescriptions-parameter**
  If `vertexBindingDescriptionCount` is not 0, `pVertexBindingDescriptions` must be a valid pointer to an array of `vertexBindingDescriptionCount` valid `VkVertexInputBindingDescription2EXT` structures.

- **VUID-vkCmdSetVertexInputEXT-pVertexAttributeDescriptions-parameter**
  If `vertexAttributeDescriptionCount` is not 0, `pVertexAttributeDescriptions` must be a valid pointer to an array of `vertexAttributeDescriptionCount` valid `VkVertexInputAttributeDescription2EXT` structures.

- **VUID-vkCmdSetVertexInputEXT-commandBuffer-recording**
  `commandBuffer` must be in the recording state.

- **VUID-vkCmdSetVertexInputEXT-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations.

- **VUID-vkCmdSetVertexInputEXT-videocoding**
  This command must only be called outside of a video coding scope.
Host Synchronization

- Host access to `commandBuffer` **must** be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized.

## Command Properties

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The `VkVertexInputBindingDescription2EXT` structure is defined as:

```c
// Provided by VK_EXT_shader_object, VK_EXT_vertex_input_dynamic_state
typedef struct VkVertexInputBindingDescription2EXT {
    VkStructureType sType;
    void* pNext;
    uint32_t binding;
    uint32_t stride;
    VkVertexInputRate inputRate;
    uint32_t divisor;
} VkVertexInputBindingDescription2EXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `binding` is the binding number that this structure describes.
- `stride` is the byte stride between consecutive elements within the buffer.
- `inputRate` is a `VkVertexInputRate` value specifying whether vertex attribute addressing is a function of the vertex index or of the instance index.
- `divisor` is the number of successive instances that will use the same value of the vertex attribute when instanced rendering is enabled. This member **can** be set to a value other than 1 if the `vertexAttributeInstanceRateDivisor` feature is enabled. For example, if the divisor is N, the same vertex attribute will be applied to N successive instances before moving on to the next vertex attribute. The maximum value of `divisor` is implementation-dependent and can be queried using `VkPhysicalDeviceVertexAttributeDivisorPropertiesEXT::maxVertexAttribDivisor`. A value of 0 **can** be used for the divisor if the `vertexAttributeInstanceRateZeroDivisor` feature is enabled. In this case, the same vertex attribute will be applied to all instances.
Valid Usage

• VUID-VkVertexInputBindingDescription2EXT-binding-04796
  binding must be less than VkPhysicalDeviceLimits::maxVertexInputBindings

• VUID-VkVertexInputBindingDescription2EXT-stride-04797
  stride must be less than or equal to VkPhysicalDeviceLimits::maxVertexInputBindingStride

• VUID-VkVertexInputBindingDescription2EXT-divisor-04798
  If the vertexAttributeInstanceRateZeroDivisor feature is not enabled, divisor must not be 0

• VUID-VkVertexInputBindingDescription2EXT-divisor-04799
  If the vertexAttributeInstanceRateDivisor feature is not enabled, divisor must be 1

• VUID-VkVertexInputBindingDescription2EXT-divisor-06226
  divisor must be a value between 0 and VkPhysicalDeviceVertexAttributeDivisorPropertiesEXT::maxVertexAttribDivisor, inclusive

• VUID-VkVertexInputBindingDescription2EXT-divisor-06227
  If divisor is not 1 then inputRate must be of type VK_VERTEX_INPUT_RATE_INSTANCE

Valid Usage (Implicit)

• VUID-VkVertexInputBindingDescription2EXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_VERTEX_INPUT_BINDING_DESCRIPTION_2_EXT

• VUID-VkVertexInputBindingDescription2EXT-inputRate-parameter
  inputRate must be a valid VkVertexInputRate value

The VkVertexInputAttributeDescription2EXT structure is defined as:

```c
// Provided by VK_EXT_shader_object, VK_EXT_vertex_input_dynamic_state
typedef struct VkVertexInputAttributeDescription2EXT {
    VkStructureType sType;
    void* pNext;
    uint32_t location;
    uint32_t binding;
    VkFormat format;
    uint32_t offset;
} VkVertexInputAttributeDescription2EXT;
```

• sType is a VkStructureType value identifying this structure.

• pNext is NULL or a pointer to a structure extending this structure.

• location is the shader input location number for this attribute.

• binding is the binding number which this attribute takes its data from.

• format is the size and type of the vertex attribute data.
• **offset** is a byte offset of this attribute relative to the start of an element in the vertex input binding.

### Valid Usage

- **VUID-VkVertexInputAttributeDescription2EXT-location-06228**
  
  `location` **must** be less than `VkPhysicalDeviceLimits::maxVertexInputAttributes`

- **VUID-VkVertexInputAttributeDescription2EXT-binding-06229**
  
  `binding` **must** be less than `VkPhysicalDeviceLimits::maxVertexInputBindings`

- **VUID-VkVertexInputAttributeDescription2EXT-offset-06230**
  
  `offset` **must** be less than or equal to `VkPhysicalDeviceLimits::maxVertexInputAttributeOffset`

- **VUID-VkVertexInputAttributeDescription2EXT-format-04805**
  
  The **format features of `format`** must contain `VK_FORMAT_FEATURE_VERTEX_BUFFER_BIT`

- **VUID-VkVertexInputAttributeDescription2EXT-vertexAttributeAccessBeyondStride-04806**
  
  If the `VK_KHR_portability_subset` extension is enabled, and `VkPhysicalDevicePortabilitySubsetFeaturesKHR::vertexAttributeAccessBeyondStride` is `VK_FALSE`, the sum of `offset` plus the size of the vertex attribute data described by `format` **must** not be greater than `stride` in the `VkVertexInputBindingDescription2EXT` referenced in `binding`

### Valid Usage (Implicit)

- **VUID-VkVertexInputAttributeDescription2EXT-sType-sType**
  
  `sType` **must** be `VK_STRUCTURE_TYPE_VERTEX_INPUT_ATTRIBUTE_DESCRIPTION_2_EXT`

- **VUID-VkVertexInputAttributeDescription2EXT-format-parameter**
  
  `format` **must** be a valid `VkFormat` value

To bind vertex buffers to a command buffer for use in subsequent drawing commands, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdBindVertexBuffers(
    VkCommandBuffer              commandBuffer,  
    uint32_t                     firstBinding,   
    uint32_t                     bindingCount,  
    const VkBuffer*              pBuffers,      
    const VkDeviceSize*          pOffsets);
```

- **commandBuffer** is the command buffer into which the command is recorded.
- **firstBinding** is the index of the first vertex input binding whose state is updated by the command.
- **bindingCount** is the number of vertex input bindings whose state is updated by the command.
• `pBuffers` is a pointer to an array of buffer handles.
• `pOffsets` is a pointer to an array of buffer offsets.

The values taken from elements `i` of `pBuffers` and `pOffsets` replace the current state for the vertex input binding `firstBinding + i`, for `i` in `[0, bindingCount)`. The vertex input binding is updated to start at the offset indicated by `pOffsets[i]` from the start of the buffer `pBuffers[i]`. All vertex input attributes that use each of these bindings will use these updated addresses in their address calculations for subsequent drawing commands. If the `nullDescriptor` feature is enabled, elements of `pBuffers` can be `VK_NULL_HANDLE`, and can be used by the vertex shader. If a vertex input attribute is bound to a vertex input binding that is `VK_NULL_HANDLE`, the values taken from memory are considered to be zero, and missing G, B, or A components are filled with (0,0,1).

### Valid Usage

- **VUID-vkCmdBindVertexBuffers-firstBinding-00624**
  
  `firstBinding` must be less than `VkPhysicalDeviceLimits::maxVertexInputBindings`

- **VUID-vkCmdBindVertexBuffers-firstBinding-00625**
  
  The sum of `firstBinding` and `bindingCount` must be less than or equal to `VkPhysicalDeviceLimits::maxVertexInputBindings`

- **VUID-vkCmdBindVertexBuffers-pOffsets-00626**
  
  All elements of `pOffsets` must be less than the size of the corresponding element in `pBuffers`

- **VUID-vkCmdBindVertexBuffers-pBuffers-00627**
  
  All elements of `pBuffers` must have been created with the `VK_BUFFER_USAGE_VERTEX_BUFFER_BIT` flag

- **VUID-vkCmdBindVertexBuffers-pBuffers-00628**
  
  Each element of `pBuffers` that is non-sparse must be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdBindVertexBuffers-pBuffers-04001**
  
  If the `nullDescriptor` feature is not enabled, all elements of `pBuffers` must not be `VK_NULL_HANDLE`

- **VUID-vkCmdBindVertexBuffers-pBuffers-04002**
  
  If an element of `pBuffers` is `VK_NULL_HANDLE`, then the corresponding element of `pOffsets` must be zero

### Valid Usage (Implicit)

- **VUID-vkCmdBindVertexBuffers-commandBuffer-parameter**
  
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- **VUID-vkCmdBindVertexBuffers-pBuffers-parameter**
  
  `pBuffers` must be a valid pointer to an array of `bindingCount` valid or `VK_NULL_HANDLE` `VkBuffer` handles

- **VUID-vkCmdBindVertexBuffers-pOffsets-parameter**
  
  `pOffsets` must be a valid pointer to an array of `bindingCount` valid or `VK_NULL_HANDLE` `VkDeviceAddress` handles
The provided function call is:

```c
// Provided by VK_VERSION_1_3
void vkCmdBindVertexBuffers2(
    VkCommandBuffer commandBuffer,
    uint32_t firstBinding,
    uint32_t bindingCount,
    const VkBuffer* pBuffers,
    const VkDeviceSize* pOffsets,
    const VkDeviceSize* pSizes,
    const VkDeviceSize* pStrides);
```

Alternatively, to bind vertex buffers, along with their sizes and strides, to a command buffer for use in subsequent drawing commands, call:
```c
void vkCmdBindVertexBuffer2EXT(
    VkCommandBuffer commandBuffer,
    uint32_t firstBinding,
    uint32_t bindingCount,
    const VkBuffer* pBuffers,
    const VkDeviceSize* pOffsets,
    const VkDeviceSize* pSizes,
    const VkDeviceSize* pStrides);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `firstBinding` is the index of the first vertex input binding whose state is updated by the command.
- `bindingCount` is the number of vertex input bindings whose state is updated by the command.
- `pBuffers` is a pointer to an array of buffer handles.
- `pOffsets` is a pointer to an array of buffer offsets.
- `pSizes` is `NULL` or a pointer to an array of the size in bytes of vertex data bound from `pBuffers`.
- `pStrides` is `NULL` or a pointer to an array of buffer strides.

The values taken from elements i of `pBuffers` and `pOffsets` replace the current state for the vertex input binding `firstBinding + i`, for i in `[0, bindingCount)`. The vertex input binding is updated to start at the offset indicated by `pOffsets[i]` from the start of the buffer `pBuffers[i]`. If `pSizes` is not `NULL` then `pSizes[i]` specifies the bound size of the vertex buffer starting from the corresponding elements of `pBuffers[i]` plus `pOffsets[i]`. If `pSizes[i]` is `VK_WHOLE_SIZE` then the bound size is from `pBuffers[i]` plus `pOffsets[i]` to the end of the buffer `pBuffers[i]`. All vertex input attributes that use each of these bindings will use these updated addresses in their address calculations for subsequent drawing commands. If the `nullDescriptor` feature is enabled, elements of `pBuffers` can be `VK_NULL_HANDLE`, and can be used by the vertex shader. If a vertex input attribute is bound to a vertex input binding that is `VK_NULL_HANDLE`, the values taken from memory are considered to be zero, and missing G, B, or A components are filled with `(0,0,1)`.

This command also dynamically sets the byte strides between consecutive elements within buffer `pBuffers[i]` to the corresponding `pStrides[i]` value when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, strides are specified by the `VkVertexInputBindingDescription::stride` values used to create the currently active pipeline.

If drawing using shader objects or if the bound pipeline state object was also created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled then `vkCmdSetVertexInputEXT` can be used instead of `vkCmdBindVertexBufferBuffers2` to set the stride.

**Note**

Unlike the static state to set the same, `pStrides` must be between 0 and the maximum extent of the attributes in the binding. `vkCmdSetVertexInputEXT` does not have this restriction so can be used if other stride values are desired.
Valid Usage

- VUID-vkCmdBindVertexBuffers2-firstBinding-03355
  
  firstBinding must be less than VkPhysicalDeviceLimits::maxVertexInputBindings

- VUID-vkCmdBindVertexBuffers2-firstBinding-03356
  
  The sum of firstBinding and bindingCount must be less than or equal to VkPhysicalDeviceLimits::maxVertexInputBindings

- VUID-vkCmdBindVertexBuffers2-pOffsets-03357
  
  If pSizes is not NULL, all elements of pOffsets must be less than the size of the corresponding element in pBuffers

- VUID-vkCmdBindVertexBuffers2-pSizes-03358
  
  If pSizes is not NULL, all elements of pOffsets plus pSizes, where pSizes is not VK_WHOLE_SIZE, must be less than or equal to the size of the corresponding element in pBuffers

- VUID-vkCmdBindVertexBuffers2-pBuffers-03359
  
  All elements of pBuffers must have been created with the VK_BUFFER_USAGE_VERTEX_BUFFER_BIT flag

- VUID-vkCmdBindVertexBuffers2-pBuffers-03360
  
  Each element of pBuffers that is non-sparse must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdBindVertexBuffers2-pBuffers-04111
  
  If the nullDescriptor feature is not enabled, all elements of pBuffers must not be VK_NULL_HANDLE

- VUID-vkCmdBindVertexBuffers2-pBuffers-04112
  
  If an element of pBuffers is VK_NULL_HANDLE, then the corresponding element of pOffsets must be zero

- VUID-vkCmdBindVertexBuffers2-pStrides-03362
  
  If pStrides is not NULL each element of pStrides must be less than or equal to VkPhysicalDeviceLimits::maxVertexInputBindingStride

- VUID-vkCmdBindVertexBuffers2-pStrides-06209
  
  If pStrides is not NULL each element of pStrides must be either 0 or greater than or equal to the maximum extent of all vertex input attributes fetched from the corresponding binding, where the extent is calculated as the VkVertexInputAttributeDescription::offset plus VkVertexInputAttributeDescription::format size

Valid Usage (Implicit)

- VUID-vkCmdBindVertexBuffers2-commandBuffer-parameter
  
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdBindVertexBuffers2-pBuffers-parameter
  
  pBuffers must be a valid pointer to an array of bindingCount valid or VK_NULL_HANDLE VkBuffer handles
• VUID-vkCmdBindVertexBuffers2-pOffsets-parameter
  pOffsets must be a valid pointer to an array of bindingCount VkDeviceSize values

• VUID-vkCmdBindVertexBuffers2-pSizes-parameter
  If pSizes is not NULL, pSizes must be a valid pointer to an array of bindingCount VkDeviceSize values

• VUID-vkCmdBindVertexBuffers2-pStrides-parameter
  If pStrides is not NULL, pStrides must be a valid pointer to an array of bindingCount VkDeviceSize values

• VUID-vkCmdBindVertexBuffers2-commandBuffer-recording
  commandBuffer must be in the recording state

• VUID-vkCmdBindVertexBuffers2-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

• VUID-vkCmdBindVertexBuffers2-videocoding
  This command must only be called outside of a video coding scope

• VUID-vkCmdBindVertexBuffers2-bindingCount-arraylength
  If any of pSizes, or pStrides are not NULL, bindingCount must be greater than 0

• VUID-vkCmdBindVertexBuffers2-commonparent
  Both of commandBuffer, and the elements of pBuffers that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice

---

Host Synchronization

• Host access to commandBuffer must be externally synchronized
• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

---

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22.3. Vertex Attribute Divisor in Instanced Rendering

If the vertexAttributeInstanceRateDivisor feature is enabled and the pNext chain of VkPipelineVertexInputStateCreateInfo includes a VkPipelineVertexInputDivisorStateCreateInfoEXT structure, then that structure controls how vertex attributes are assigned to an instance when instanced rendering is enabled.
The `VkPipelineVertexInputDivisorStateCreateInfoEXT` structure is defined as:

```c
typedef struct VkPipelineVertexInputDivisorStateCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    uint32_t vertexBindingDivisorCount;
    const VkVertexInputBindingDivisorDescriptionEXT* pVertexBindingDivisors;
} VkPipelineVertexInputDivisorStateCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `vertexBindingDivisorCount` is the number of elements in the `pVertexBindingDivisors` array.
- `pVertexBindingDivisors` is a pointer to an array of `VkVertexInputBindingDivisorDescriptionEXT` structures specifying the divisor value for each binding.

### Valid Usage (Implicit)

- VUID-VkPipelineVertexInputDivisorStateCreateInfoEXT-sType-sType `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_VERTEX_INPUT_DIVISOR_STATE_CREATE_INFO_EXT`.
- VUID-VkPipelineVertexInputDivisorStateCreateInfoEXT-pVertexBindingDivisors-parameter `pVertexBindingDivisors` must be a valid pointer to an array of `vertexBindingDivisorCount` `VkVertexInputBindingDivisorDescriptionEXT` structures.
- VUID-VkPipelineVertexInputDivisorStateCreateInfoEXT-vertexBindingDivisorCount-arraylength `vertexBindingDivisorCount` must be greater than 0.

The individual divisor values per binding are specified using the `VkVertexInputBindingDivisorDescriptionEXT` structure which is defined as:

```c
typedef struct VkVertexInputBindingDivisorDescriptionEXT {
    uint32_t binding;
    uint32_t divisor;
} VkVertexInputBindingDivisorDescriptionEXT;
```

- `binding` is the binding number for which the divisor is specified.
- `divisor` is the number of successive instances that will use the same value of the vertex attribute when instanced rendering is enabled. For example, if the divisor is N, the same vertex attribute will be applied to N successive instances before moving on to the next vertex attribute. The maximum value of `divisor` is implementation-dependent and can be queried using `VkPhysicalDeviceVertexAttributeDivisorPropertiesEXT::maxVertexAttribDivisor`. A value of 0 can...
be used for the divisor if the `vertexAttributeInstanceRateZeroDivisor` feature is enabled. In this case, the same vertex attribute will be applied to all instances.

If this structure is not used to define a divisor value for an attribute, then the divisor has a logical default value of 1.

**Valid Usage**

- VUID-VkVertexInputBindingDivisorDescriptionEXT-binding-01869
  binding must be less than `VkPhysicalDeviceLimits::maxVertexInputBindings`

- VUID-VkVertexInputBindingDivisorDescriptionEXT-vertexAttributeInstanceRateZeroDivisor-02228
  If the `vertexAttributeInstanceRateZeroDivisor` feature is not enabled, divisor must not be 0

- VUID-VkVertexInputBindingDivisorDescriptionEXT-vertexAttributeInstanceRateDivisor-02229
  If the `vertexAttributeInstanceRateDivisor` feature is not enabled, divisor must be 1

- VUID-VkVertexInputBindingDivisorDescriptionEXT-divisor-01870
  divisor must be a value between 0 and `VkPhysicalDeviceVertexAttributeDivisorPropertiesEXT::maxVertexAttribDivisor`, inclusive

- VUID-VkVertexInputBindingDivisorDescriptionEXT-inputRate-01871
  `VkVertexInputBindingDescription::inputRate` must be of type `VK_VERTEX_INPUT_RATE_INSTANCE` for this binding

### 22.4. Vertex Input Address Calculation

The address of each attribute for each `vertexIndex` and `instanceIndex` is calculated as follows:

- Let `attribDesc` be the member of `VkPipelineVertexInputStateCreateInfo::pVertexAttributeDescriptions` with `VkVertexInputAttributeDescription::location` equal to the vertex input attribute number.

- Let `bindingDesc` be the member of `VkPipelineVertexInputStateCreateInfo::pVertexBindingDescriptions` with `VkVertexInputAttributeDescription::binding` equal to `attribDesc.binding`.

- Let `vertexIndex` be the index of the vertex within the draw (a value between `firstVertex` and `firstVertex+vertexCount` for `vkCmdDraw`, or a value taken from the index buffer plus `vertexOffset` for `vkCmdDrawIndexed`), and let `instanceIndex` be the instance number of the draw (a value between `firstInstance` and `firstInstance+instanceCount`).

- Let `offset` be an array of offsets into the currently bound vertex buffers specified during `vkCmdBindVertexBuffers` or `vkCmdBindVertexBuffers2` with `pOffsets`.

- Let `divisor` be the member of `VkPipelineVertexInputDivisorStateCreateInfoEXT::pVertexBindingDivisors` with `VkVertexInputBindingDivisorDescriptionEXT::binding` equal to `attribDesc.binding`.
bufferBindingAddress = buffer[binding].baseAddress + offset[binding];

if (bindingDesc.inputRate == VK_VERTEX_INPUT_RATE_VERTEX)
    effectiveVertexOffset = vertexIndex * bindingDesc.stride;
else
    if (divisor == 0)
        effectiveVertexOffset = firstInstance * bindingDesc.stride;
    else
        effectiveVertexOffset = (firstInstance + ((instanceIndex - firstInstance) / divisor)) * bindingDesc.stride;

attribAddress = bufferBindingAddress + effectiveVertexOffset + attribDesc.offset;

### 22.4.1. Vertex Input Extraction

For each attribute, raw data is extracted starting at `attribAddress` and is converted from the `VkVertexInputAttributeDescription`'s `format` to either floating-point, unsigned integer, or signed integer based on the numeric type of `format`. The numeric type of `format` **must** match the numeric type of the input variable in the shader. The input variable in the shader **must** be declared as a 64-bit data type if and only if `format` is a 64-bit data type. If `format` is a packed format, `attribAddress` **must** be a multiple of the size in bytes of the whole attribute data type as described in Packed Formats. Otherwise, `attribAddress` **must** be a multiple of the size in bytes of the component type indicated by `format` (see Formats). For attributes that are not 64-bit data types, each component is converted to the format of the input variable based on its type and size (as defined in the Format Definition section for each `VkFormat`), using the appropriate equations in 16-Bit Floating-Point Numbers, Unsigned 11-Bit Floating-Point Numbers, Unsigned 10-Bit Floating-Point Numbers, Fixed-Point Data Conversion, and Shared Exponent to RGB. Signed integer components smaller than 32 bits are sign-extended. Attributes that are not 64-bit data types are expanded to four components in the same way as described in conversion to RGBA. The number of components in the vertex shader input variable need not exactly match the number of components in the format. If the vertex shader has fewer components, the extra components are discarded.
Chapter 23. Tessellation

Tessellation involves three pipeline stages. First, a tessellation control shader transforms control points of a patch and can produce per-patch data. Second, a fixed-function tessellator generates multiple primitives corresponding to a tessellation of the patch in (u,v) or (u,v,w) parameter space. Third, a tessellation evaluation shader transforms the vertices of the tessellated patch, for example to compute their positions and attributes as part of the tessellated surface. The tessellator is enabled when the pipeline contains both a tessellation control shader and a tessellation evaluation shader.

23.1. Tessellator

If a pipeline includes both tessellation shaders (control and evaluation), the tessellator consumes each input patch (after vertex shading) and produces a new set of independent primitives (points, lines, or triangles). These primitives are logically produced by subdividing a geometric primitive (rectangle or triangle) according to the per-patch outer and inner tessellation levels written by the tessellation control shader. These levels are specified using the built-in variables TessLevelOuter and TessLevelInner, respectively. This subdivision is performed in an implementation-dependent manner. If no tessellation shaders are present in the pipeline, the tessellator is disabled and incoming primitives are passed through without modification.

The type of subdivision performed by the tessellator is specified by an OpExecutionMode instruction using one of the Triangles, Quads, or IsoLines execution modes. When using shader objects, this instruction must be specified in the tessellation evaluation shader, and may also be specified in the tessellation control shader. When using pipelines, this instruction may be specified in either the tessellation evaluation or tessellation control shader. When using shader objects, tessellation-related modes that are required must be specified in the tessellation evaluation shader, and may also be specified in the tessellation control shader. Other tessellation-related modes may be specified in the tessellation evaluation shader. When using pipelines, other tessellation-related execution modes can also be specified in either the tessellation control or tessellation evaluation shaders.

Any tessellation-related modes specified in both the tessellation control and tessellation evaluation shaders must be the same.

Tessellation execution modes include:

- Triangles, Quads, and IsoLines. These control the type of subdivision and topology of the output primitives. When using shader objects, one mode must be set in at least the tessellation evaluation stage. When using pipelines, one mode must be set in at least one of the tessellation shader stages. If the VK_KHR_portability_subset extension is enabled, and VkPhysicalDevicePortabilitySubsetFeaturesKHR::tessellationIsolines is VK_FALSE, then isoline tessellation is not supported by the implementation, and IsoLines must not be used in either tessellation shader stage.

- VertexOrderCw and VertexOrderCcw. These control the orientation of triangles generated by the tessellator. When using shader objects, one mode must be set in at least the tessellation evaluation stage. When using pipelines, one mode must be set in at least one of the tessellation shader stages.
shader stages.

- **PointMode.** Controls generation of points rather than triangles or lines. This functionality defaults to disabled, and is enabled if either shader stage includes the execution mode. When using shader objects, if PointMode is set in the tessellation control stage, it must be identically set in the tessellation evaluation stage. If the VK_KHR_portability_subset extension is enabled, and VkPhysicalDevicePortabilitySubsetFeaturesKHR::tessellationPointMode is VK_FALSE, then point mode tessellation is not supported by the implementation, and PointMode must not be used in either tessellation shader stage.

- **SpacingEqual, SpacingFractionalEven,** and **SpacingFractionalOdd.** Controls the spacing of segments on the edges of tessellated primitives. When using shader objects, one mode must be set in at least the tessellation evaluation stage. When using pipelines, one mode must be set in at least one of the tessellation shader stages.

- **OutputVertices.** Controls the size of the output patch of the tessellation control shader. When using shader objects, one value must be set in at least the tessellation control stage. When using pipelines, one value must be set in at least one of the tessellation shader stages.

For triangles, the tessellator subdivides a triangle primitive into smaller triangles. For quads, the tessellator subdivides a rectangle primitive into smaller triangles. For isolines, the tessellator subdivides a rectangle primitive into a collection of line segments arranged in strips stretching across the rectangle in the u dimension (i.e. the coordinates in TessCoord are of the form (0,x) through (1,x) for all tessellation evaluation shader invocations that share a line).

Each vertex produced by the tessellator has an associated (u,v,w) or (u,v) position in a normalized parameter space, with parameter values in the range [0,1], as illustrated in figures Domain parameterization for tessellation primitive modes (upper-left origin) and Domain parameterization for tessellation primitive modes (lower-left origin). The domain space can have either an upper-left or lower-left origin, selected by the domainOrigin member of VkPipelineTessellationDomainOriginStateCreateInfo.
Figure 15. Domain parameterization for tessellation primitive modes (upper-left origin)
In the domain parameterization diagrams, the coordinates illustrate the value of \texttt{TessCoord} at the corners of the domain. The labels on the edges indicate the inner (IL0 and IL1) and outer (OL0 through OL3) tessellation level values used to control the number of subdivisions along each edge of the domain.

For triangles, the vertex’s position is a barycentric coordinate \((u,v,w)\), where \(u + v + w = 1.0\), and indicates the relative influence of the three vertices of the triangle on the position of the vertex. For quads and isolines, the position is a \((u,v)\) coordinate indicating the relative horizontal and vertical position of the vertex relative to the subdivided rectangle. The subdivision process is explained in more detail in subsequent sections.

### 23.2. Tessellator Patch Discard

A patch is discarded by the tessellator if any relevant outer tessellation level is less than or equal to zero.

Patches will also be discarded if any relevant outer tessellation level corresponds to a floating-point
NaN (not a number) in implementations supporting NaN.

No new primitives are generated and the tessellation evaluation shader is not executed for patches that are discarded. For Quads, all four outer levels are relevant. For Triangles and IsoLines, only the first three or two outer levels, respectively, are relevant. Negative inner levels will not cause a patch to be discarded; they will be clamped as described below.

### 23.3. Tessellator Spacing

Each of the tessellation levels is used to determine the number and spacing of segments used to subdivide a corresponding edge. The method used to derive the number and spacing of segments is specified by an `OpExecutionMode` in the tessellation control or tessellation evaluation shader using one of the identifiers `SpacingEqual`, `SpacingFractionalEven`, or `SpacingFractionalOdd`.

If `SpacingEqual` is used, the floating-point tessellation level is first clamped to \([1, \text{maxLevel}]\), where \(\text{maxLevel}\) is the implementation-dependent maximum tessellation level (\(\text{VkPhysicalDeviceLimits}::\text{maxTessellationGenerationLevel}\)). The result is rounded up to the nearest integer \(n\), and the corresponding edge is divided into \(n\) segments of equal length in (u,v) space.

If `SpacingFractionalEven` is used, the tessellation level is first clamped to \([2, \text{maxLevel}]\) and then rounded up to the nearest even integer \(n\). If `SpacingFractionalOdd` is used, the tessellation level is clamped to \([1, \text{maxLevel} - 1]\) and then rounded up to the nearest odd integer \(n\). If \(n\) is one, the edge will not be subdivided. Otherwise, the corresponding edge will be divided into \(n - 2\) segments of equal length, and two additional segments of equal length that are typically shorter than the other segments. The length of the two additional segments relative to the others will decrease monotonically with \(n - f\), where \(f\) is the clamped floating-point tessellation level. When \(n - f\) is zero, the additional segments will have equal length to the other segments. As \(n - f\) approaches 2.0, the relative length of the additional segments approaches zero. The two additional segments must be placed symmetrically on opposite sides of the subdivided edge. The relative location of these two segments is implementation-dependent, but must be identical for any pair of subdivided edges with identical values of \(f\).

When tessellating triangles or quads using point mode with fractional odd spacing, the tessellator may produce interior vertices that are positioned on the edge of the patch if an inner tessellation level is less than or equal to one. Such vertices are considered distinct from vertices produced by subdividing the outer edge of the patch, even if there are pairs of vertices with identical coordinates.

### 23.4. Tessellation Primitive Ordering

Few guarantees are provided for the relative ordering of primitives produced by tessellation, as they pertain to primitive order.

- The output primitives generated from each input primitive are passed to subsequent pipeline stages in an implementation-dependent order.
- All output primitives generated from a given input primitive are passed to subsequent pipeline stages before any output primitives generated from subsequent input primitives.
23.5. Tessellator Vertex Winding Order

When the tessellator produces triangles (in the Triangles or Quads modes), the orientation of all triangles is specified with an OpExecutionMode of VertexOrderCw or VertexOrderCcW in the tessellation control or tessellation evaluation shaders. If the order is VertexOrderCw, the vertices of all generated triangles will have clockwise ordering in (u,v) or (u,v,w) space. If the order is VertexOrderCcW, the vertices will have counter-clockwise ordering in that space.

If the tessellation domain has an upper-left origin, the vertices of a triangle have counter-clockwise ordering if

\[ a = u_0 v_1 - u_1 v_0 + u_1 v_2 - u_2 v_1 + u_2 v_0 - u_0 v_2 \]

is negative, and clockwise ordering if \( a \) is positive. \( u_i \) and \( v_i \) are the \( u \) and \( v \) coordinates in normalized parameter space of the \( i \)th vertex of the triangle. If the tessellation domain has a lower-left origin, the vertices of a triangle have counter-clockwise ordering if \( a \) is positive, and clockwise ordering if \( a \) is negative.

**Note**
The value \( a \) is proportional (with a positive factor) to the signed area of the triangle.

In Triangles mode, even though the vertex coordinates have a \( w \) value, it does not participate directly in the computation of \( a \), being an affine combination of \( u \) and \( v \).

23.6. Triangle Tessellation

If the tessellation primitive mode is Triangles, an equilateral triangle is subdivided into a collection of triangles covering the area of the original triangle. First, the original triangle is subdivided into a collection of concentric equilateral triangles. The edges of each of these triangles are subdivided, and the area between each triangle pair is filled by triangles produced by joining the vertices on the subdivided edges. The number of concentric triangles and the number of subdivisions along each triangle except the outermost is derived from the first inner tessellation level. The edges of the outermost triangle are subdivided independently, using the first, second, and third outer tessellation levels to control the number of subdivisions of the \( u = 0 \) (left), \( v = 0 \) (bottom), and \( w = 0 \) (right) edges, respectively. The second inner tessellation level and the fourth outer tessellation level have no effect in this mode.

If the first inner tessellation level and all three outer tessellation levels are exactly one after clamping and rounding, only a single triangle with \((u,v,w)\) coordinates of \((0,0,1)\), \((1,0,0)\), and \((0,1,0)\) is generated. If the inner tessellation level is one and any of the outer tessellation levels is greater than one, the inner tessellation level is treated as though it were originally specified as \( 1 + \varepsilon \) and will result in a two- or three-segment subdivision depending on the tessellation spacing. When used with fractional odd spacing, the three-segment subdivision may produce inner vertices positioned on the edge of the triangle.
If any tessellation level is greater than one, tessellation begins by producing a set of concentric inner triangles and subdividing their edges. First, the three outer edges are temporarily subdivided using the clamped and rounded first inner tessellation level and the specified tessellation spacing, generating $n$ segments. For the outermost inner triangle, the inner triangle is degenerate—a single point at the center of the triangle—if $n$ is two. Otherwise, for each corner of the outer triangle, an inner triangle corner is produced at the intersection of two lines extended perpendicular to the corner’s two adjacent edges running through the vertex of the subdivided outer edge nearest that corner. If $n$ is three, the edges of the inner triangle are not subdivided and it is the final triangle in the set of concentric triangles. Otherwise, each edge of the inner triangle is divided into $n - 2$ segments, with the $n - 1$ vertices of this subdivision produced by intersecting the inner edge with lines perpendicular to the edge running through the $n - 1$ innermost vertices of the subdivision of the outer edge. Once the outermost inner triangle is subdivided, the previous subdivision process repeats itself, using the generated triangle as an outer triangle. This subdivision process is illustrated in Inner Triangle Tessellation.

![Inner Triangle Tessellation](image)

**Caption**

In the Inner Triangle Tessellation diagram, inner tessellation levels of (a) four and (b) five are shown (not to scale). Solid black circles depict vertices along the edges of the concentric triangles. The edges of inner triangles are subdivided by intersecting the edge with segments perpendicular to the edge passing through each inner vertex of the subdivided outer edge. Dotted lines depict edges connecting corresponding vertices on the inner and outer triangle edges.

Once all the concentric triangles are produced and their edges are subdivided, the area between each pair of adjacent inner triangles is filled completely with a set of non-overlapping triangles. In this subdivision, two of the three vertices of each triangle are taken from adjacent vertices on a subdivided edge of one triangle; the third is one of the vertices on the corresponding edge of the other triangle. If the innermost triangle is degenerate (i.e., a point), the triangle containing it is subdivided into six triangles by connecting each of the six vertices on that triangle with the center point. If the innermost triangle is not degenerate, that triangle is added to the set of generated triangles as-is.
After the area corresponding to any inner triangles is filled, the tessellator generates triangles to cover the area between the outermost triangle and the outermost inner triangle. To do this, the temporary subdivision of the outer triangle edge above is discarded. Instead, the $u = 0$, $v = 0$, and $w = 0$ edges are subdivided according to the first, second, and third outer tessellation levels, respectively, and the tessellation spacing. The original subdivision of the first inner triangle is retained. The area between the outer and first inner triangles is completely filled by non-overlapping triangles as described above. If the first (and only) inner triangle is degenerate, a set of triangles is produced by connecting each vertex on the outer triangle edges with the center point. After all triangles are generated, each vertex in the subdivided triangle is assigned a barycentric $(u,v,w)$ coordinate based on its location relative to the three vertices of the outer triangle.

The algorithm used to subdivide the triangular domain in $(u,v,w)$ space into individual triangles is implementation-dependent. However, the set of triangles produced will completely cover the domain, and no portion of the domain will be covered by multiple triangles.

Output triangles are generated with a topology similar to triangle lists, except that the order in which each triangle is generated, and the order in which the vertices are generated for each triangle, are implementation-dependent. However, the order of vertices in each triangle is consistent across the domain as described in Tessellator Vertex Winding Order.

### 23.7. Quad Tessellation

If the tessellation primitive mode is Quads, a rectangle is subdivided into a collection of triangles covering the area of the original rectangle. First, the original rectangle is subdivided into a regular mesh of rectangles, where the number of rectangles along the $u = 0$ and $u = 1$ (vertical) and $v = 0$ and $v = 1$ (horizontal) edges are derived from the first and second inner tessellation levels, respectively. All rectangles, except those adjacent to one of the outer rectangle edges, are decomposed into triangle pairs. The outermost rectangle edges are subdivided independently, using the first, second, third, and fourth outer tessellation levels to control the number of subdivisions of the $u = 0$ (left), $v = 0$ (bottom), $u = 1$ (right), and $v = 1$ (top) edges, respectively. The area between the inner rectangles of the mesh and the outer rectangle edges are filled by triangles produced by joining the vertices on the subdivided outer edges to the vertices on the edge of the inner rectangle mesh.

If both clamped inner tessellation levels and all four clamped outer tessellation levels are exactly one, only a single triangle pair covering the outer rectangle is generated. Otherwise, if either clamped inner tessellation level is one, that tessellation level is treated as though it was originally specified as $1 + \varepsilon$ and will result in a two- or three-segment subdivision depending on the tessellation spacing. When used with fractional odd spacing, the three-segment subdivision may produce inner vertices positioned on the edge of the rectangle.

If any tessellation level is greater than one, tessellation begins by subdividing the $u = 0$ and $u = 1$ edges of the outer rectangle into $m$ segments using the clamped and rounded first inner tessellation level and the tessellation spacing. The $v = 0$ and $v = 1$ edges are subdivided into $n$ segments using the second inner tessellation level. Each vertex on the $u = 0$ and $v = 0$ edges are joined with the corresponding vertex on the $u = 1$ and $v = 1$ edges to produce a set of vertical and horizontal lines that divide the rectangle into a grid of smaller rectangles. The primitive generator emits a pair of
non-overlapping triangles covering each such rectangle not adjacent to an edge of the outer rectangle. The boundary of the region covered by these triangles forms an inner rectangle, the edges of which are subdivided by the grid vertices that lie on the edge. If either \( m \) or \( n \) is two, the inner rectangle is degenerate, and one or both of the rectangle's edges consist of a single point. This subdivision is illustrated in Figure **Inner Quad Tessellation**.

![Inner Quad Tessellation](image)

**Figure 18. Inner Quad Tessellation**

**Caption**

In the **Inner Quad Tessellation** diagram, inner quad tessellation levels of (a) \((4,2)\) and (b) \((7,4)\) are shown. The regions highlighted in red in figure (b) depict the 10 inner rectangles, each of which will be subdivided into two triangles. Solid black circles depict vertices on the boundary of the outer and inner rectangles, where the inner rectangle of figure (a) is degenerate (a single line segment). Dotted lines depict the horizontal and vertical edges connecting corresponding vertices on the inner and outer rectangle edges.

After the area corresponding to the inner rectangle is filled, the tessellator **must** produce triangles to cover the area between the inner and outer rectangles. To do this, the subdivision of the outer rectangle edge above is discarded. Instead, the \( u = 0, v = 0, u = 1, \) and \( v = 1 \) edges are subdivided according to the first, second, third, and fourth outer tessellation levels, respectively, and the tessellation spacing. The original subdivision of the inner rectangle is retained. The area between the outer and inner rectangles is completely filled by non-overlapping triangles. Two of the three vertices of each triangle are adjacent vertices on a subdivided edge of one rectangle; the third is one of the vertices on the corresponding edge of the other rectangle. If either edge of the innermost rectangle is degenerate, the area near the corresponding outer edges is filled by connecting each vertex on the outer edge with the single vertex making up the inner edge.

The algorithm used to subdivide the rectangular domain in \((u,v)\) space into individual triangles is implementation-dependent. However, the set of triangles produced will completely cover the domain, and no portion of the domain will be covered by multiple triangles.

Output triangles are generated with a topology similar to **triangle lists**, except that the order in which each triangle is generated, and the order in which the vertices are generated for each triangle, are implementation-dependent. However, the order of vertices in each triangle is...
consistent across the domain as described in Tessellator Vertex Winding Order.

23.8. Isoline Tessellation

If the tessellation primitive mode is Isolines, a set of independent horizontal line segments is drawn. The segments are arranged into connected strips called isolines, where the vertices of each isoline have a constant v coordinate and u coordinates covering the full range [0,1]. The number of isolines generated is derived from the first outer tessellation level; the number of segments in each isoline is derived from the second outer tessellation level. Both inner tessellation levels and the third and fourth outer tessellation levels have no effect in this mode.

As with quad tessellation above, isoline tessellation begins with a rectangle. The \( u = 0 \) and \( u = 1 \) edges of the rectangle are subdivided according to the first outer tessellation level. For the purposes of this subdivision, the tessellation spacing mode is ignored and treated as equal_spacing. An isoline is drawn connecting each vertex on the \( u = 0 \) rectangle edge to the corresponding vertex on the \( u = 1 \) rectangle edge, except that no line is drawn between \((0,1)\) and \((1,1)\). If the number of isolines on the subdivided \( u = 0 \) and \( u = 1 \) edges is \( n \), this process will result in \( n \) equally spaced lines with constant v coordinates of 0, \( \frac{1}{n}, \frac{2}{n}, \ldots, \frac{n-1}{n} \).

Each of the \( n \) isolines is then subdivided according to the second outer tessellation level and the tessellation spacing, resulting in \( m \) line segments. Each segment of each line is emitted by the tessellator. These line segments are generated with a topology similar to line lists, except that the order in which each line is generated, and the order in which the vertices are generated for each line segment, are implementation-dependent.

**Note**

If the `VK_KHR_portability_subset` extension is enabled, and `VkPhysicalDevicePortabilitySubsetFeaturesKHR::tessellationIsolines` is `VK_FALSE`, then isoline tessellation is not supported by the implementation.

23.9. Tessellation Point Mode

For all primitive modes, the tessellator is capable of generating points instead of lines or triangles. If the tessellation control or tessellation evaluation shader specifies the `OpExecutionMode PointMode`, the primitive generator will generate one point for each distinct vertex produced by tessellation, rather than emitting triangles or lines. Otherwise, the tessellator will produce a collection of line segments or triangles according to the primitive mode. These points are generated with a topology similar to point lists, except the order in which the points are generated for each input primitive is undefined.

**Note**

If the `VK_KHR_portability_subset` extension is enabled, and `VkPhysicalDevicePortabilitySubsetFeaturesKHR::tessellationPointMode` is `VK_FALSE`, then tessellation point mode is not supported by the implementation.
23.10. Tessellation Pipeline State

The `pTessellationState` member of `VkGraphicsPipelineCreateInfo` is a pointer to a `VkPipelineTessellationStateCreateInfo` structure.

The `VkPipelineTessellationStateCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPipelineTessellationStateCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkPipelineTessellationStateCreateFlags flags;
    uint32_t patchControlPoints;
} VkPipelineTessellationStateCreateInfo;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is reserved for future use.
- `patchControlPoints` is the number of control points per patch.

### Valid Usage

- `VUID-VkPipelineTessellationStateCreateInfo-patchControlPoints-01214`
  - `patchControlPoints` must be greater than zero and less than or equal to `VkPhysicalDeviceLimits::maxTessellationPatchSize`

### Valid Usage (Implicit)

- `VUID-VkPipelineTessellationStateCreateInfo-sType-sType`
  - `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_TESSELLATION_STATE_CREATE_INFO`
- `VUID-VkPipelineTessellationStateCreateInfo-pNext-pNext`
  - `pNext` must be `NULL` or a pointer to a valid instance of `VkPipelineTessellationDomainOriginStateCreateInfo`
- `VUID-VkPipelineTessellationStateCreateInfo-sType-unique`
  - The `sType` value of each struct in the `pNext` chain must be unique
- `VUID-VkPipelineTessellationStateCreateInfo-flags-zerobitmask`
  - `flags` must be `0`

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkPipelineTessellationStateCreateFlags;
```

`VkPipelineTessellationStateCreateFlags` is a bitmask type for setting a mask, but is currently
reserved for future use.

The `VkPipelineTessellationDomainOriginStateCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPipelineTessellationDomainOriginStateCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkTessellationDomainOrigin domainOrigin;
} VkPipelineTessellationDomainOriginStateCreateInfo;
```

or the equivalent

```c
// Provided by VK_KHR_maintenance2
typedef VkPipelineTessellationDomainOriginStateCreateInfo
    VkPipelineTessellationDomainOriginStateCreateInfoKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **domainOrigin** is a `VkTessellationDomainOrigin` value controlling the origin of the tessellation domain space.

If the `VkPipelineTessellationDomainOriginStateCreateInfo` structure is included in the `pNext` chain of `VkPipelineTessellationStateCreateInfo`, it controls the origin of the tessellation domain. If this structure is not present, it is as if `domainOrigin` was `VK_TESSELLATION_DOMAIN_ORIGIN_UPPER_LEFT`.

### Valid Usage (Implicit)

- **VUID-VkPipelineTessellationDomainOriginStateCreateInfo-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_TESSELLATION_DOMAIN_ORIGIN_STATE_CREATE_INFO`
- **VUID-VkPipelineTessellationDomainOriginStateCreateInfo-domainOrigin-parameter**
  - `domainOrigin` must be a valid `VkTessellationDomainOrigin` value

The possible tessellation domain origins are specified by the `VkTessellationDomainOrigin` enumeration:

```c
// Provided by VK_VERSION_1_1
typedef enum VkTessellationDomainOrigin {
    VK_TESSELLATION_DOMAIN_ORIGIN_UPPER_LEFT = 0,
    VK_TESSELLATION_DOMAIN_ORIGIN_LOWER_LEFT = 1,
    // Provided by VK_KHR_maintenance2
    VK_TESSELLATION_DOMAIN_ORIGIN_UPPER_LEFT_KHR =
        VK_TESSELLATION_DOMAIN_ORIGIN_UPPER_LEFT,
    // Provided by VK_KHR_maintenance2
    VK_TESSELLATION_DOMAIN_ORIGIN_LOWER_LEFT_KHR =
        VK_TESSELLATION_DOMAIN_ORIGIN_LOWER_LEFT
} VkTessellationDomainOrigin;
```
or the equivalent

```c
// Provided by VK_KHR_maintenance2
typedef VkTessellationDomainOrigin VkTessellationDomainOriginKHR;
```

- `VK_TESSELLATION_DOMAIN_ORIGIN_UPPER_LEFT` specifies that the origin of the domain space is in the upper left corner, as shown in figure Domain parameterization for tessellation primitive modes (upper-left origin).
- `VK_TESSELLATION_DOMAIN_ORIGIN_LOWER_LEFT` specifies that the origin of the domain space is in the lower left corner, as shown in figure Domain parameterization for tessellation primitive modes (lower-left origin).

This enum affects how the `VertexOrderCw` and `VertexOrderCcw` tessellation execution modes are interpreted, since the winding is defined relative to the orientation of the domain.

To **dynamically set** the origin of the tessellation domain space, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
void vkCmdSetTessellationDomainOriginEXT(
    VkCommandBuffer commandBuffer,
    VkTessellationDomainOrigin domainOrigin);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `domainOrigin` specifies the origin of the tessellation domain space.

This command sets the origin of the tessellation domain space for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineTessellationDomainOriginStateCreateInfo::domainOrigin` value used to create the currently active pipeline.

**Valid Usage**

- VUID-vkCmdSetTessellationDomainOriginEXT-None-08576
  
  Either the `extendedDynamicState3TessellationDomainOrigin` feature or the `shaderObject` feature or both **must** be enabled

**Valid Usage (Implicit)**

- VUID-vkCmdSetTessellationDomainOriginEXT-commandBuffer-parameter
**commandBuffer** must be a valid `VkCommandBuffer` handle

- **VUID-vkCmdSetTessellationDomainOriginEXT-domainOrigin-parameter**
  domainOrigin must be a valid `VkTessellationDomainOrigin` value

- **VUID-vkCmdSetTessellationDomainOriginEXT-commandBuffer-recording**
  commandBuffer must be in the recording state

- **VUID-vkCmdSetTessellationDomainOriginEXT-commandBuffer-cmdpool**
  The `VkCommandPool` that commandBuffer was allocated from must support graphics operations

- **VUID-vkCmdSetTessellationDomainOriginEXT-videocoding**
  This command must only be called outside of a video coding scope

### Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the `VkCommandPool` that commandBuffer was allocated from must be externally synchronized

### Command Properties

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Chapter 24. Geometry Shading

The geometry shader operates on a group of vertices and their associated data assembled from a single input primitive, and emits zero or more output primitives and the group of vertices and their associated data required for each output primitive. Geometry shading is enabled when a geometry shader is included in the pipeline.

24.1. Geometry Shader Input Primitives

Each geometry shader invocation has access to all vertices in the primitive (and their associated data), which are presented to the shader as an array of inputs.

The input primitive type expected by the geometry shader is specified with an `OpExecutionMode` instruction in the geometry shader, and must match the incoming primitive type specified by either the pipeline's primitive topology if tessellation is inactive, or the tessellation mode if tessellation is active, as follows:

- An input primitive type of `InputPoints` must only be used with a pipeline topology of `VK_PRIMITIVE_TOPOLOGY_POINT_LIST`, or with a tessellation shader specifying `PointMode`. The input arrays always contain one element, as described by the point list topology or tessellation in point mode.

- An input primitive type of `InputLines` must only be used with a pipeline topology of `VK_PRIMITIVE_TOPOLOGY_LINE_LIST` or `VK_PRIMITIVE_TOPOLOGY_LINE_STRIP`, or with a tessellation shader specifying `IsoLines` that does not specify `PointMode`. The input arrays always contain two elements, as described by the line list topology or line strip topology, or by isoline tessellation.

- An input primitive type of `InputLinesAdjacency` must only be used when tessellation is inactive, with a pipeline topology of `VK_PRIMITIVE_TOPOLOGY_LINE_LIST_WITH_ADJACENCY` or `VK_PRIMITIVE_TOPOLOGY_LINE_STRIP_WITH_ADJACENCY`. The input arrays always contain four elements, as described by the line list with adjacency topology or line strip with adjacency topology.

- An input primitive type of `Triangles` must only be used with a pipeline topology of `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST`, `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP`, or `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN`; or with a tessellation shader specifying `Quads` or `Triangles` that does not specify `PointMode`. The input arrays always contain three elements, as described by the triangle list topology, triangle strip topology, or triangle fan topology, or by triangle or quad tessellation. Vertices may be in a different absolute order than specified by the topology, but must adhere to the specified winding order.

- An input primitive type of `InputTrianglesAdjacency` must only be used when tessellation is inactive, with a pipeline topology of `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST_WITH_ADJACENCY` or `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP_WITH_ADJACENCY`. The input arrays always contain six elements, as described by the triangle list with adjacency topology or triangle strip with adjacency topology. Vertices may be in a different absolute order than specified by the topology, but must adhere to the specified winding order, and the vertices making up the main primitive must still occur at the first, third, and fifth index.
24.2. Geometry Shader Output Primitives

A geometry shader generates primitives in one of three output modes: points, line strips, or triangle strips. The primitive mode is specified in the shader using an `OpExecutionMode` instruction with the `OutputPoints`, `OutputLineStrip` or `OutputTriangleStrip` modes, respectively. Each geometry shader must include exactly one output primitive mode.

The vertices output by the geometry shader are assembled into points, lines, or triangles based on the output primitive type and the resulting primitives are then further processed as described in Rasterization. If the number of vertices emitted by the geometry shader is not sufficient to produce a single primitive, vertices corresponding to incomplete primitives are not processed by subsequent pipeline stages. The number of vertices output by the geometry shader is limited to a maximum count specified in the shader.

The maximum output vertex count is specified in the shader using an `OpExecutionMode` instruction with the mode set to `OutputVertices` and the maximum number of vertices that will be produced by the geometry shader specified as a literal. Each geometry shader must specify a maximum output vertex count.

24.3. Multiple Invocations of Geometry Shaders

Geometry shaders can be invoked more than one time for each input primitive. This is known as geometry shader instancing and is requested by including an `OpExecutionMode` instruction with mode specified as `Invocations` and the number of invocations specified as an integer literal.

In this mode, the geometry shader will execute at least n times for each input primitive, where n is the number of invocations specified in the `OpExecutionMode` instruction. The instance number is available to each invocation as a built-in input using `InvocationId`.

24.4. Geometry Shader Primitive Ordering

Limited guarantees are provided for the relative ordering of primitives produced by a geometry shader, as they pertain to primitive order.

- For instanced geometry shaders, the output primitives generated from each input primitive are passed to subsequent pipeline stages using the invocation number to order the primitives, from least to greatest.
- All output primitives generated from a given input primitive are passed to subsequent pipeline stages before any output primitives generated from subsequent input primitives.

24.5. Geometry Shader Passthrough

A geometry shader that uses the `PassthroughNV` decoration on a variable in its input interface is considered a passthrough geometry shader. Output primitives in a passthrough geometry shader must have the same topology as the input primitive and are not produced by emitting vertices. The vertices of the output primitive have two different types of attributes, per-vertex and per-primitive. Geometry shader input variables with `PassthroughNV` decoration are considered to produce per-
vertex outputs, where values for each output vertex are copied from the corresponding input vertex. Any built-in or user-defined geometry shader outputs are considered per-primitive in a passthrough geometry shader, where a single output value is copied to all output vertices.

The remainder of this section details the usage of the PassthroughNV decoration and modifications to the interface matching rules when using passthrough geometry shaders.

### 24.5.1. PassthroughNV Decoration

Decorating a geometry shader input variable with the PassthroughNV decoration indicates that values of this input are copied through to the corresponding vertex of the output primitive. Input variables and block members which do not have the PassthroughNV decoration are consumed by the geometry shader without being passed through to subsequent stages.

The PassthroughNV decoration must only be used within a geometry shader.

Any variable decorated with PassthroughNV must be declared using the Input storage class.

The PassthroughNV decoration must not be used with any of:

- an input primitive type other than InputPoints, InputLines, or Triangles, as specified by the mode for OpExecutionMode.
- an invocation count other than one, as specified by the Invocations mode for OpExecutionMode.
- an OpEntryPoint which statically uses the OpEmitVertex or OpEndPrimitive instructions.
- a variable decorated with the InvocationId built-in decoration.
- a variable decorated with the PrimitiveId built-in decoration that is declared using the Input storage class.

### 24.5.2. Passthrough Interface Matching

When a passthrough geometry shader is in use, the Interface Matching rules involving the geometry shader input and output interfaces operate as described in this section.

For the purposes of matching passthrough geometry shader inputs with outputs of the previous pipeline stages, the PassthroughNV decoration is ignored.

For the purposes of matching the outputs of the geometry shader with subsequent pipeline stages, each input variable with the PassthroughNV decoration is considered to add an equivalent output variable with the same type, decoration (other than PassthroughNV), number, and declaration order on the output interface. The output variable declaration corresponding to an input variable decorated with PassthroughNV will be identical to the input declaration, except that the outermost array dimension of such variables is removed. The output block declaration corresponding to an input block decorated with PassthroughNV or having members decorated with PassthroughNV will be identical to the input declaration, except that the outermost array dimension of such declaration is removed.

If an input block is decorated with PassthroughNV, the equivalent output block contains all the members of the input block. Otherwise, the equivalent output block contains only those input block
members decorated with \texttt{PassthroughNV}. All members of the corresponding output block are assigned \texttt{Location} and \texttt{Component} decorations identical to those assigned to the corresponding input block members.

Output variables and blocks generated from inputs decorated with \texttt{PassthroughNV} will only exist for the purposes of interface matching; these declarations are not available to geometry shader code or listed in the module interface.

For the purposes of component counting, passthrough geometry shaders count all statically used input variable components declared with the \texttt{PassthroughNV} decoration as output components as well, since their values will be copied to the output primitive produced by the geometry shader.
Chapter 25. Mesh Shading

Task and mesh shaders operate in workgroups to produce a collection of primitives that will be processed by subsequent stages of the graphics pipeline.

Work on the mesh pipeline is initiated by the application drawing a set of mesh tasks organized in global workgroups. If the optional task shader is active, each workgroup triggers the execution of task shader invocations that will create a new set of mesh workgroups upon completion. Each of these created workgroups, or each of the original workgroups if no task shader is present, triggers the execution of mesh shader invocations.

Each mesh shader workgroup emits zero or more output primitives along with the group of vertices and their associated data required for each output primitive.

25.1. Task Shader Input

For every workgroup issued via the drawing commands a group of task shader invocations is executed. There are no inputs other than the builtin workgroup identifiers.

25.2. Task Shader Output

The task shader can emit zero or more mesh workgroups to be generated. Shaders using the TaskNV Execution Model can do so using the built-in variable TaskCountNV. This value must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesNV::maxTaskOutputCount. Shaders using the TaskEXT Execution Model can do so using the OpEmitMeshTasksEXT instruction. The groupCountX, groupCountY and groupCountZ arguments passed to this instruction must be less than or equal to the respective dimension within VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupCount. The product of these arguments must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupTotalCount.

The task shader can also pass user-defined data to all mesh shader invocations that it creates. Shaders using the TaskNV Execution Model can do so by writing to output variables that are decorated with PerTaskNV. They are available as inputs in mesh shaders. Shaders using the TaskEXT Execution Model can do so by writing to a payload variable with TaskPayloadWorkgroupEXT storage class that is passed to the OpEmitMeshTasksEXT instruction.

25.3. Mesh Generation

If a task shader exists, the mesh assembler creates a variable amount of mesh workgroups depending on each task's output. If there is no task shader, the drawing commands emit the mesh shader invocations directly.

25.4. Mesh Shader Input

The only inputs available to the mesh shader are variables identifying the specific workgroup and invocation and, if applicable, any outputs written as PerTaskNV or the payload variable passed to the
The `OpEmitMeshTasksEXT` instruction by the task shader that spawned the mesh shader's workgroup. The mesh shader can operate without a task shader as well.

## 25.5. Mesh Shader Output

A mesh shader generates primitives in one of three output modes: points, lines, or triangles. For shaders using the MeshNV Execution Model the primitive mode is specified in the shader using an `OpExecutionMode` instruction with the OutputPoints, OutputLinesNV, or OutputTrianglesNV modes, respectively. For shaders using the MeshEXT Execution Model the primitive mode is specified in the shader using an `OpExecutionMode` instruction with the OutputPoints, OutputLinesEXT, or OutputTrianglesEXT modes, respectively. Each mesh shader must include exactly one output primitive mode.

For shaders using the MeshNV Execution Model the maximum output vertex count is specified as a literal in the shader using an `OpExecutionMode` instruction with the mode set to OutputVertices and must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesNV::maxMeshOutputVertices`. For shaders using the MeshEXT Execution Model the maximum output vertex count is specified as a literal in the shader using an `OpExecutionMode` instruction with the mode set to OutputVertices and must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshOutputVertices`.

For shaders using the MeshNV Execution Model the maximum output primitive count is specified as a literal in the shader using an `OpExecutionMode` instruction with the mode set to OutputPrimitivesNV and must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesNV::maxMeshOutputPrimitives`. For shaders using the MeshEXT Execution Model the maximum output primitive count is specified as a literal in the shader using an `OpExecutionMode` instruction with the mode set to OutputPrimitivesEXT, and must be less than or equal to `VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshOutputPrimitives`.

For shaders using the MeshNV Execution Model the number of primitives output by the mesh shader is provided via writing to the built-in variable PrimitiveCountNV and must be less than or equal to the maximum output primitive count specified in the shader. A variable decorated with PrimitiveIndicesNV is an output array of local index values into the vertex output arrays from which primitives are assembled according to the output primitive type. For shaders using the MeshEXT Execution Model the number of vertices and primitives output by the mesh shader is provided via calling the OpSetMeshOutputsEXT instruction. The vertexCount argument must be less than or equal to the maximum output vertex count specified in the shader. The primitiveCount argument must be less than or equal to the maximum output primitive count specified in the shader.

Depending on the output primitive mode an appropriately-decorated variable is the output array of local index values into the vertex output arrays from which primitives are assembled according to the output primitive type:

- `OutputPoints` uses the PrimitivePointIndicesEXT decoration.
- `OutputLinesEXT` uses the PrimitiveLineIndicesEXT decoration.
- `OutputTrianglesEXT` uses the PrimitiveTriangleIndicesEXT decoration.

These resulting primitives are then further processed as described in Rasterization.
With the exception of primitive indices, all output built-ins and custom attributes count towards the total storage size occupied by output variables in mesh shaders. This size can be calculated as follows, taking into account the fact that the number of effective scalar attributes is 4 times the number of effective locations used according to the location assignment rules. Let \( v \) be the number of views, \( n_v \) be the number of effective scalar per-vertex attributes not dependent on \( \text{ViewIndex} \), \( n_{v\text{pv}} \) be the number of effective scalar per-vertex attributes dependent on \( \text{ViewIndex} \), \( m_v \) be the maximum number of vertices specified by the \( \text{OutputVertices Execution Mode} \), \( g_v \) be \( \text{meshOutputPerVertexGranularity} \), \( n_p \) be the number of effective scalar per-primitive attributes not dependent on \( \text{ViewIndex} \), \( n_{p\text{pv}} \) be the number of effective scalar per-primitive attributes dependent on \( \text{ViewIndex} \), \( m_p \) be the maximum number of primitives specified by the \( \text{OutputPrimitivesEXT Execution Mode} \) and \( g_p \) be \( \text{meshOutputPerPrimitiveGranularity} \):

\[
(n_v + (n_{v\text{pv}} \times v)) \times 4 \times \text{align}(m_v, g_v) + (n_p + (n_{p\text{pv}} \times v)) \times 4 \times \text{align}(m_p, g_p)
\]

### 25.6. Mesh Shader Per-View Outputs

The mesh shader outputs decorated with the \( \text{PositionPerViewNV} \), \( \text{ClipDistancePerViewNV} \), \( \text{CullDistancePerViewNV} \), \( \text{LayerPerViewNV} \), and \( \text{ViewportMaskPerViewNV} \) built-in decorations are the per-view versions of the single-view variables with equivalent names (that is \( \text{Position} \), \( \text{ClipDistance} \), \( \text{CullDistance} \), \( \text{Layer} \), and \( \text{ViewportMaskNV} \), respectively). If a shader statically assigns a value to any element of a per-view array it must not statically assign a value to the equivalent single-view variable.

Each of these outputs is considered arrayed, with separate values for each view. The view number is used to index the first dimension of these arrays.

The second dimension of the \( \text{ClipDistancePerViewNV} \), and \( \text{CullDistancePerViewNV} \) arrays have the same requirements as the \( \text{ClipDistance} \), and \( \text{CullDistance} \) arrays.

If a mesh shader output is per-view, the corresponding fragment shader input is taken from the element of the per-view output array that corresponds to the view that is currently being processed by the fragment shader.

These per-view outputs are available only in shaders using the \( \text{MeshNV Execution Model} \). They are not available in shaders using the \( \text{MeshEXT Execution Model} \).

### 25.7. Mesh Shader Primitive Ordering

Following guarantees are provided for the relative ordering of primitives produced by a mesh shader, as they pertain to primitive order.

- When a task shader is used, mesh workgroups spawned from lower tasks will be ordered prior those workgroups from subsequent tasks.
- All output primitives generated from a given mesh workgroup are passed to subsequent pipeline stages before any output primitives generated from subsequent input workgroups.
- All output primitives within a mesh workgroup, will be generated in the ordering provided by the builtin primitive indexbuffer (from low address to high address).
Chapter 26. Cluster Culling Shading

This shader type has an execution environment similar to that of a compute shader, where a collection of shader invocations form a workgroup and cooperate to perform coarse level geometry culling and LOD selection. A shader invocation can emit a set of built-in output variables via a new built-in function. The cluster culling shader organizes these emitted variables into a drawing command used by the subsequent rendering pipeline.

26.1. Cluster Culling Shader Input

The only inputs available to the cluster culling shader are variables identifying the specific workgroup and invocation.

26.2. Cluster Culling Shader Output

If a cluster survives after culling in a cluster culling shader invocation, a drawing command to draw this cluster should be emitted by this shader invocation for further rendering processing. There are two types of drawing command, indexed mode and non-indexed mode. Both type of drawing commands consist of a set of built-in output variables which have a similar definition to VkDrawIndexedIndirectCommand and VkDrawIndirectCommand members.

Cluster culling shaders have the following built-in output variables:

- built-in variable `IndexCountHUAWEI` is the number of vertices to draw.
- built-in variable `VertexCountHUAWEI` is the number of vertices to draw.
- built-in variable `InstanceCountHUAWEI` is the number of instances to draw.
- built-in variable `FirstIndexHUAWEI` is the base index within the index buffer.
- built-in variable `FirstVertexHUAWEI` is the index of the first vertex to draw
- built-in variable `VertexOffsetHUAWEI` is the value added to the vertex index before indexing into the vertex buffer.
- built-in variable `FirstInstanceHUAWEI` is the instance ID of the first instance to draw.
- built-in variable `ClusterIDHUAWEI` is the index of cluster being rendered by this drawing command. When cluster culling shader is enabled, `ClusterIDHUAWEI` will replace `gl_DrawID` pass to vertex shader.

26.3. Cluster Culling Shader Cluster Ordering

- When a cluster culling shader is used, all output clusters generated by `DispatchClusterHUAWEI()` in a given workgroup are passed to subsequent pipeline stage before any cluster generated from subsequent workgroup.
- In a workgroup, the order of output clusters generated by `DispatchClusterHUAWEI()` is specified by the local invocation id, from lower to higher values.
- If any cluster culling invocation in the workgroup does not call `DispatchClusterHUAWEI()`, no
cluster will be sent to the subsequent rendering pipeline.

- Any cluster culling shader invocation may also call `DispatchClusterHUAWEI()` many times as shown below:

```cpp
// Cluster Culling Shader sample code:

DispatchClusterHUAWEI();  // dispatch 0
......
DispatchClusterHUAWEI();  // dispatch 1
......
DispatchClusterHUAWEI();  // dispatch 2
......
```

In this case, the output sequence of clusters in a workgroup are specified as shown below (in case of 32 shader invocations in a workgroup):

1. shader invocation0.dispatch0
2. shader invocation1.dispatch0,
   ...........
32. shader invocation31.dispatch0
33. shader invocation0.dispatch1
34. shader invocation1.dispatch1
   ...........
64. shader invocation31.dispatch1
65. shader invocation0.dispatch2
66. shader invocation1.dispatch2
   ...........
96. shader Invocation31.dispatch2

26.4. Cluster Culling Shader Primitive Ordering

Following guarantees are provided for the relative ordering of primitives produced by a cluster culling shader, as they pertain to primitive order.

- Limited guarantees are provided for the relative ordering of primitives produced by a cluster culling shader, as they pertain to primitive order.

- The order of primitives in a given cluster is specified by the content of

  - `DispatchClusterHUAWEI()` with indexed output built-in variables, vertices sourced from a lower index buffer addresses to higher addresses.
  - `DispatchClusterHUAWEI()` with non-indexed output built-in variables, from vertices with a lower numbered vertexIndex to a higher numbered vertexIndex.
Chapter 27. Fixed-Function Vertex Post-Processing

After pre-rasterization shader stages, the following fixed-function operations are applied to vertices of the resulting primitives:

- Transform feedback (see Transform Feedback)
- Viewport swizzle (see Viewport Swizzle)
- Flat shading (see Flat Shading).
- Primitive clipping, including client-defined half-spaces (see Primitive Clipping).
- Shader output attribute clipping (see Clipping Shader Outputs).
- Clip space W scaling (see Controlling Viewport W Scaling).
- Perspective division on clip coordinates (see Coordinate Transformations).
- Viewport mapping, including depth range scaling (see Controlling the Viewport).
- Front face determination for polygon primitives (see Basic Polygon Rasterization).

Next, rasterization is performed on primitives as described in chapter Rasterization.

27.1. Transform Feedback

Before any other fixed-function vertex post-processing, vertex outputs from the last shader in the pre-rasterization shader stage can be written out to one or more transform feedback buffers bound to the command buffer. To capture vertex outputs the last pre-rasterization shader stage shader must be declared with the Xfb execution mode. Outputs decorated with XfbBuffer will be written out to the corresponding transform feedback buffers bound to the command buffer when transform feedback is active. Transform feedback buffers are bound to the command buffer by using vkCmdBindTransformFeedbackBuffersEXT. Transform feedback is made active by calling vkCmdBeginTransformFeedbackEXT and made inactive by calling vkCmdEndTransformFeedbackEXT. After vertex data is written it is possible to use vkCmdDrawIndirectByteCountEXT to start a new draw where the vertexCount is derived from the number of bytes written by a previous transform feedback.

When an individual point, line, or triangle primitive reaches the transform feedback stage while transform feedback is active, the values of the specified output variables are assembled into primitives and appended to the bound transform feedback buffers. After activating transform feedback, the values of the first assembled primitive are written at the starting offsets of the bound transform feedback buffers, and subsequent primitives are appended to the buffer. If the optional pCounterBuffers and pCounterBufferOffsets parameters are specified, the starting points within the transform feedback buffers are adjusted so data is appended to the previously written values indicated by the value stored by the implementation in the counter buffer.

For multi-vertex primitives, all values for a given vertex are written before writing values for any other vertex. When transformFeedbackPreservesProvokingVertex is not enabled, implementations may write out any vertex within the primitive first, but all subsequent vertices for that primitive
must be written out in a consistent winding order defined as follows:

- If neither geometry or tessellation shading is active, vertices within a primitive are appended according to the winding order described by the primitive topology defined by the VkPipelineInputAssemblyStateCreateInfo:topology used to execute the drawing command.

- If geometry shading is active, vertices within a primitive are appended according to the winding order described by the primitive topology defined by the OutputPoints, OutputLineStrips, or OutputTriangleStrips execution mode.

- If tessellation shading is active but geometry shading is not, vertices within a primitive are appended according to the winding order defined by triangle tessellation, quad tessellation, and isoline tessellation.

When transformFeedbackPreservesProvokingVertex is enabled, then in addition to writing vertices with a consistent winding order, the vertex order must preserve the provoking vertex of each primitive:

- When the pipeline's provoking vertex mode is VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT, the primitive's provoking vertex must be the first vertex written.

- When the pipeline's provoking vertex mode is VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT, the primitive's provoking vertex must be the last vertex written.

If transformFeedbackPreservesTriangleFanProvokingVertex is VK_FALSE, neither geometry nor tessellation shading is active, and the primitive topology is VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN, then the first vertex written from each primitive is implementation-defined even when transformFeedbackPreservesProvokingVertex is enabled.

When capturing vertices, the stride associated with each transform feedback buffer, as indicated by the XfbStride decoration, indicates the number of bytes of storage reserved for each vertex in the transform feedback buffer. For every vertex captured, each output attribute with a Offset decoration will be written to the storage reserved for the vertex at the associated transform feedback buffer. When writing output variables that are arrays or structures, individual array elements or structure members are written tightly packed in order. For vector types, individual components are written in order. For matrix types, outputs are written as an array of column vectors.

If any component of an output with an assigned transform feedback offset was not written to by its shader, the value recorded for that component is undefined. All components of an output variable must be written at an offset aligned to the size of the component. The size of each component of an output variable must be at least 32-bits. When capturing a vertex, any portion of the reserved storage not associated with an output variable with an assigned transform feedback offset will be unmodified.

When transform feedback is inactive, no vertices are recorded. If there is a valid counter buffer handle and counter buffer offset in the pCounterBuffers and pCounterBufferOffsets arrays, writes to the corresponding transform feedback buffer will start at the byte offset represented by the value stored in the counter buffer location.

Individual lines or triangles of a strip or fan primitive will be extracted and recorded separately.
Incomplete primitives are not recorded.

When using a geometry shader that emits vertices to multiple vertex streams, a primitive will be assembled and output for each stream when there are enough vertices emitted for the output primitive type. All outputs assigned to a given transform feedback buffer are required to come from a single vertex stream.

The sizes of the transform feedback buffers are defined by the \texttt{vkCmdBindTransformFeedbackBuffersEXT} \texttt{pSizes} parameter for each of the bound buffers, or the size of the bound buffer, whichever is the lesser. If there is less space remaining in any of the transform feedback buffers than the size of all of the vertex data for that primitive based on the \texttt{XfbStride} for that \texttt{XfbBuffer} then no vertex data of that primitive is recorded in any transform feedback buffer, and the value for the number of primitives written in the corresponding \texttt{VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT} query for all transform feedback buffers is no longer incremented.

Any outputs made to a \texttt{XfbBuffer} that is not bound to a transform feedback buffer is ignored.

To bind transform feedback buffers to a command buffer for use in subsequent drawing commands, call:

\begin{verbatim}
void vkCmdBindTransformFeedbackBuffersEXT(
    VkCommandBuffer commandBuffer,
    uint32_t firstBinding,
    uint32_t bindingCount,
    const VkBuffer* pBuffers,
    const VkDeviceSize* pOffsets,
    const VkDeviceSize* pSizes);
\end{verbatim}

- \texttt{commandBuffer} is the command buffer into which the command is recorded.
- \texttt{firstBinding} is the index of the first transform feedback binding whose state is updated by the command.
- \texttt{bindingCount} is the number of transform feedback bindings whose state is updated by the command.
- \texttt{pBuffers} is a pointer to an array of buffer handles.
- \texttt{pOffsets} is a pointer to an array of buffer offsets.
- \texttt{pSizes} is NULL or a pointer to an array of \texttt{VkDeviceSize} buffer sizes, specifying the maximum number of bytes to capture to the corresponding transform feedback buffer. If \texttt{pSizes} is NULL, or the value of the \texttt{pSizes} array element is \texttt{VK_WHOLE_SIZE}, then the maximum number of bytes captured will be the size of the corresponding buffer minus the buffer offset.

The values taken from elements \texttt{i} of \texttt{pBuffers}, \texttt{pOffsets} and \texttt{pSizes} replace the current state for the transform feedback binding \texttt{firstBinding + i}, for \texttt{i} in \texttt{[0, bindingCount)}. The transform feedback binding is updated to start at the offset indicated by \texttt{pOffsets[i]} from the start of the buffer \texttt{pBuffers[i]}.
Valid Usage

- VUID-vkCmdBindTransformFeedbackBuffersEXT-transformFeedback-02355
  VkPhysicalDeviceTransformFeedbackFeaturesEXT::transformFeedback must be enabled

- VUID-vkCmdBindTransformFeedbackBuffersEXT-firstBinding-02356
  firstBinding must be less than VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackBuffers

- VUID-vkCmdBindTransformFeedbackBuffersEXT-firstBinding-02357
  The sum of firstBinding and bindingCount must be less than or equal to
  VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackBuffers

- VUID-vkCmdBindTransformFeedbackBuffersEXT-pOffsets-02358
  All elements of pOffsets must be less than the size of the corresponding element in pBuffers

- VUID-vkCmdBindTransformFeedbackBuffersEXT-pOffsets-02359
  All elements of pOffsets must be a multiple of 4

- VUID-vkCmdBindTransformFeedbackBuffersEXT-pBuffers-02360
  All elements of pBuffers must have been created with the VK_BUFFER_USAGE_TRANSFORM_FEEDBACK_BUFFER_BIT_EXT flag

- VUID-vkCmdBindTransformFeedbackBuffersEXT-pSize-02361
  If the optional pSize array is specified, each element of pSizes must either be
  VK_WHOLE_SIZE, or be less than or equal to
  VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackBufferSize

- VUID-vkCmdBindTransformFeedbackBuffersEXT-pSizes-02362
  All elements of pSizes must be either VK_WHOLE_SIZE, or less than or equal to the size of the corresponding buffer in pBuffers

- VUID-vkCmdBindTransformFeedbackBuffersEXT-pOffsets-02363
  All elements of pOffsets plus pSizes, where the pSizes element is not VK_WHOLE_SIZE, must be
  less than or equal to the size of the corresponding buffer in pBuffers

- VUID-vkCmdBindTransformFeedbackBuffersEXT-pBuffers-02364
  Each element of pBuffers that is non-sparse must be bound completely and contiguously
to a single VkDeviceMemory object

- VUID-vkCmdBindTransformFeedbackBuffersEXT-None-02365
  Transform feedback must not be active when the vkCmdBindTransformFeedbackBuffersEXT command is recorded

Valid Usage (Implicit)

- VUID-vkCmdBindTransformFeedbackBuffersEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdBindTransformFeedbackBuffersEXT-pBuffers-parameter
  pBuffers must be a valid pointer to an array of bindingCount valid VkBuffer handles
Host Synchronization

- Host access to \texttt{commandBuffer} must be externally synchronized.
- Host access to the \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from must be externally synchronized.

Command Properties

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</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Transform feedback for specific transform feedback buffers is made active by calling:

```c
// Provided by VK_EXT_transform_feedback
void vkCmdBeginTransformFeedbackEXT(  
    VkCommandBuffer commandBuffer,  
    uint32_t firstCounterBuffer,  
    uint32_t counterBufferCount,  
    const VkBuffer* pCounterBuffers,  
    const VkDeviceSize* pCounterBufferOffsets);
```

- \texttt{commandBuffer} is the command buffer into which the command is recorded.
- \texttt{firstCounterBuffer} is the index of the first transform feedback buffer corresponding to \texttt{pCounterBuffers[0]} and \texttt{pCounterBufferOffsets[0]}.  

VUID-vkCmdBindTransformFeedbackBuffersEXT-pOffsets-parameter
\texttt{pOffsets} must be a valid pointer to an array of bindingCount \texttt{VkDeviceSize} values.

VUID-vkCmdBindTransformFeedbackBuffersEXT-commandBuffer-recording
\texttt{commandBuffer} must be in the recording state.

VUID-vkCmdBindTransformFeedbackBuffersEXT-commandBuffer-cmdpool
The \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from must support graphics operations.

VUID-vkCmdBindTransformFeedbackBuffersEXT-videocoding
This command must only be called outside of a video coding scope.

VUID-vkCmdBindTransformFeedbackBuffersEXT-bindingCount-arraylength
bindingCount must be greater than 0.

VUID-vkCmdBindTransformFeedbackBuffersEXT-commonparent
Both of \texttt{commandBuffer}, and the elements of \texttt{pBuffers} must have been created, allocated, or retrieved from the same \texttt{VkDevice}.
counterBufferCount is the size of the pCounterBuffers and pCounterBufferOffsets arrays.

pCounterBuffers is NULL or a pointer to an array of VkBuffer handles to counter buffers. Each buffer contains a 4 byte integer value representing the byte offset from the start of the corresponding transform feedback buffer from where to start capturing vertex data. If the byte offset stored to the counter buffer location was done using vkCmdEndTransformFeedbackEXT it can be used to resume transform feedback from the previous location. If pCounterBuffers is NULL, then transform feedback will start capturing vertex data to byte offset zero in all bound transform feedback buffers. For each element of pCounterBuffers that is VK_NULL_HANDLE, transform feedback will start capturing vertex data to byte zero in the corresponding bound transform feedback buffer.

pCounterBufferOffsets is NULL or a pointer to an array of VkDeviceSize values specifying offsets within each of the pCounterBuffers where the counter values were previously written. The location in each counter buffer at these offsets must be large enough to contain 4 bytes of data. This data is the number of bytes captured by the previous transform feedback to this buffer. If pCounterBufferOffsets is NULL, then it is assumed the offsets are zero.

The active transform feedback buffers will capture primitives emitted from the corresponding XfbBuffer in the bound graphics pipeline. Any XfbBuffer emitted that does not output to an active transform feedback buffer will not be captured.

Valid Usage

- VUID-vkCmdBeginTransformFeedbackEXT-transformFeedback-02366
  VkPhysicalDeviceTransformFeedbackFeaturesEXT::transformFeedback must be enabled

- VUID-vkCmdBeginTransformFeedbackEXT-None-02367
  Transform feedback must not be active

- VUID-vkCmdBeginTransformFeedbackEXT-firstCounterBuffer-02368
  firstCounterBuffer must be less than VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackBuffers

- VUID-vkCmdBeginTransformFeedbackEXT-firstCounterBuffer-02369
  The sum of firstCounterBuffer and counterBufferCount must be less than or equal to VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackBuffers

- VUID-vkCmdBeginTransformFeedbackEXT-counterBufferCount-02607
  If counterBufferCount is not 0, and pCounterBuffers is not NULL, pCounterBuffers must be a valid pointer to an array of counterBufferCount VkBuffer handles that are either valid or VK_NULL_HANDLE

- VUID-vkCmdBeginTransformFeedbackEXT-pCounterBufferOffsets-02370
  For each buffer handle in the array, if it is not VK_NULL_HANDLE it must reference a buffer large enough to hold 4 bytes at the corresponding offset from the pCounterBufferOffsets array

- VUID-vkCmdBeginTransformFeedbackEXT-pCounterBuffer-02371
  If pCounterBuffer is NULL, then pCounterBufferOffsets must also be NULL

- VUID-vkCmdBeginTransformFeedbackEXT-pCounterBuffers-02372
  For each buffer handle in the pCounterBuffers array that is not VK_NULL_HANDLE it must
have been created with a usage value containing VK_BUFFER_USAGE_TRANSFORM_FEEDBACK_COUNTER_BUFFER_BIT_EXT

- VUID-vkCmdBeginTransformFeedbackEXT-None-06233
  A valid graphics pipeline must be bound to VK_PIPELINE_BIND_POINT_GRAPHICS

- VUID-vkCmdBeginTransformFeedbackEXT-None-04128
  The last pre-rasterization shader stage of the bound graphics pipeline must have been declared with the Xfb execution mode

- VUID-vkCmdBeginTransformFeedbackEXT-None-02373
  Transform feedback must not be made active in a render pass instance with multiview enabled

Valid Usage (Implicit)

- VUID-vkCmdBeginTransformFeedbackEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdBeginTransformFeedbackEXT-pCounterBufferOffsets-parameter
  If counterBufferCount is not 0, and pCounterBufferOffsets is not NULL, pCounterBufferOffsets must be a valid pointer to an array of counterBufferCount VkDeviceSize values

- VUID-vkCmdBeginTransformFeedbackEXT-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdBeginTransformFeedbackEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdBeginTransformFeedbackEXT-renderpass
  This command must only be called inside of a render pass instance

- VUID-vkCmdBeginTransformFeedbackEXT-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdBeginTransformFeedbackEXT-commonparent
  Both of commandBuffer, and the elements of pCounterBuffers that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
Transform feedback for specific transform feedback buffers is made inactive by calling:

```c
void vkCmdEndTransformFeedbackEXT(
    VkCommandBuffer commandBuffer,
    uint32_t firstCounterBuffer,
    uint32_t counterBufferCount,
    const VkBuffer* pCounterBuffers,
    const VkDeviceSize* pCounterBufferOffsets);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `firstCounterBuffer` is the index of the first transform feedback buffer corresponding to `pCounterBuffers[0]` and `pCounterBufferOffsets[0]`.
- `counterBufferCount` is the size of the `pCounterBuffers` and `pCounterBufferOffsets` arrays.
- `pCounterBuffers` is NULL or a pointer to an array of `VkBuffer` handles to counter buffers. The counter buffers are used to record the current byte positions of each transform feedback buffer where the next vertex output data would be captured. This can be used by a subsequent `vkCmdBeginTransformFeedbackEXT` call to resume transform feedback capture from this position. It can also be used by `vkCmdDrawIndirectByteCountEXT` to determine the vertex count of the draw call.
- `pCounterBufferOffsets` is NULL or a pointer to an array of `VkDeviceSize` values specifying offsets within each of the `pCounterBuffers` where the counter values can be written. The location in each counter buffer at these offsets must be large enough to contain 4 bytes of data. The data stored at this location is the byte offset from the start of the transform feedback buffer binding where the next vertex data would be written. If `pCounterBufferOffsets` is NULL, then it is assumed the offsets are zero.

### Valid Usage

- VUID-vkCmdEndTransformFeedbackEXT-transformFeedback-02374
  `VkPhysicalDeviceTransformFeedbackFeaturesEXT::transformFeedback` must be enabled

- VUID-vkCmdEndTransformFeedbackEXT-None-02375
  Transform feedback must be active

- VUID-vkCmdEndTransformFeedbackEXT-firstCounterBuffer-02376
  `firstCounterBuffer` must be less than `VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackBuffers`
The sum of firstCounterBuffer and counterBufferCount must be less than or equal to VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackBuffers.

If counterBufferCount is not 0, and pCounterBuffers is not NULL, pCounterBuffers must be a valid pointer to an array of counterBufferCount VkBuffer handles that are either valid or VK_NULL_HANDLE.

For each buffer handle in the array, if it is not VK_NULL_HANDLE it must reference a buffer large enough to hold 4 bytes at the corresponding offset from the pCounterBufferOffsets array.

If pCounterBuffer is NULL, then pCounterBufferOffsets must also be NULL.

For each buffer handle in the pCounterBuffers array that is not VK_NULL_HANDLE it must have been created with a usage value containing VK_BUFFER_USAGE_TRANSFORM_FEEDBACK_COUNTER_BUFFER_BIT_EXT.

Host Synchronization

Host access to commandBuffer must be externally synchronized.
• Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

### Command Properties

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### 27.2. Viewport Swizzle

Each primitive sent to a given viewport has a swizzle and optional negation applied to its clip coordinates. The swizzle that is applied depends on the viewport index, and is controlled by the `VkPipelineViewportSwizzleStateCreateInfoNV` pipeline state:

```c
// Provided by VK_NV_viewport_swizzle
typedef struct VkPipelineViewportSwizzleStateCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkPipelineViewportSwizzleStateCreateFlagsNV flags;
    uint32_t viewportCount;
    const VkViewportSwizzleNV* pViewportSwizzles;
} VkPipelineViewportSwizzleStateCreateInfoNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is reserved for future use.
- `viewportCount` is the number of viewport swizzles used by the pipeline.
- `pViewportSwizzles` is a pointer to an array of `VkViewportSwizzleNV` structures, defining the viewport swizzles.

### Valid Usage

- `VUID-VkPipelineViewportSwizzleStateCreateInfoNV-viewportCount-01215` viewportCount must be greater than or equal to the `viewportCount` set in `VkPipelineViewportStateCreateInfo`

### Valid Usage (Implicit)

- `VUID-VkPipelineViewportSwizzleStateCreateInfoNV-sType-sType`
The **sType** must be `VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_SWIZZLE_STATE_CREATE_INFO_NV`.

- VUID-VkPipelineViewportSwizzleStateCreateInfoNV-flags-zerobitmask  
  flags must be 0

- VUID-VkPipelineViewportSwizzleStateCreateInfoNV-pViewportSwizzles-parameter  
  pViewportSwizzles must be a valid pointer to an array of `viewportCount` valid `VkViewportSwizzleNV` structures

- VUID-VkPipelineViewportSwizzleStateCreateInfoNV-viewportCount-arraylength  
  `viewportCount` must be greater than 0

---

```c
// Provided by VK_NV_viewport_swizzle
typedef VkFlags VkPipelineViewportSwizzleStateCreateFlagsNV;
```

`VkPipelineViewportSwizzleStateCreateFlagsNV` is a bitmask type for setting a mask, but is currently reserved for future use.

The `VkPipelineViewportSwizzleStateCreateInfoNV` state is set by adding this structure to the `pNext` chain of a `VkPipelineViewportStateCreateInfo` structure and setting the graphics pipeline state with `vkCreateGraphicsPipelines`.

To dynamically set the viewport swizzle state, call:

```c
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_viewport_swizzle,  
// VK_EXT_shader_object with VK_NV_viewport_swizzle
void vkCmdSetViewportSwizzleNV(  
    VkCommandBuffer commandBuffer,  
    uint32_t firstViewport,  
    uint32_t viewportCount,  
    const VkViewportSwizzleNV* pViewportSwizzles);
```

- commandBuffer is the command buffer into which the command will be recorded.
- firstViewport is the index of the first viewport whose parameters are updated by the command.
- viewportCount is the number of viewports whose parameters are updated by the command.
- pViewportSwizzles is a pointer to an array of `VkViewportSwizzleNV` structures specifying viewport swizzles.

This command sets the viewport swizzle state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount`, and `VkPipelineViewportSwizzleStateCreateInfoNV::pViewportSwizzles` values used to create the currently active pipeline.
Valid Usage

- VUID-vkCmdSetViewportSwizzleNV-None-08578
  Either the extendedDynamicState3ViewportSwizzle feature or the shaderObject feature or both must be enabled.

Valid Usage (Implicit)

- VUID-vkCmdSetViewportSwizzleNV-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle.

- VUID-vkCmdSetViewportSwizzleNV-pViewportSwizzles-parameter
  pViewportSwizzles must be a valid pointer to an array of viewportCount valid VkViewportSwizzleNV structures.

- VUID-vkCmdSetViewportSwizzleNV-commandBuffer-recording
  commandBuffer must be in the recording state.

- VUID-vkCmdSetViewportSwizzleNV-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations.

- VUID-vkCmdSetViewportSwizzleNV-videocoding
  This command must only be called outside of a video coding scope.

- VUID-vkCmdSetViewportSwizzleNV-viewportCount-arraylength
  viewportCount must be greater than 0.

Host Synchronization

- Host access to commandBuffer must be externally synchronized.

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized.

Command Properties

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<td>Both</td>
<td>Outside</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Each viewport specified from 0 to viewportCount - 1 has its x,y,z,w swizzle state set to the corresponding x, y, z and w in the VkViewportSwizzleNV structure. Each component is of type VkViewportCoordinateSwizzleNV, which determines the type of swizzle for that component. The value of x computes the new x component of the position as:
if (x == VK_VIEWPORT_COORDINATE_SWIZZLE_POSITIVE_X_NV) x' = x;
if (x == VK_VIEWPORT_COORDINATE_SWIZZLE_NEGATIVE_X_NV) x' = -x;
if (x == VK_VIEWPORT_COORDINATE_SWIZZLE_POSITIVE_Y_NV) x' = y;
if (x == VK_VIEWPORT_COORDINATE_SWIZZLE_NEGATIVE_Y_NV) x' = -y;
if (x == VK_VIEWPORT_COORDINATE_SWIZZLE_POSITIVE_Z_NV) x' = z;
if (x == VK_VIEWPORT_COORDINATE_SWIZZLE_NEGATIVE_Z_NV) x' = -z;
if (x == VK_VIEWPORT_COORDINATE_SWIZZLE_POSITIVE_W_NV) x' = w;
if (x == VK_VIEWPORT_COORDINATE_SWIZZLE_NEGATIVE_W_NV) x' = -w;

Similar selections are performed for the y, z, and w coordinates. This swizzling is applied before clipping and perspective divide. If the swizzle for an active viewport index is not specified, the swizzle for x is VK_VIEWPORT_COORDINATE_SWIZZLE_POSITIVE_X_NV, y is VK_VIEWPORT_COORDINATE_SWIZZLE_POSITIVE_Y_NV, z is VK_VIEWPORT_COORDINATE_SWIZZLE_POSITIVE_Z_NV and w is VK_VIEWPORT_COORDINATE_SWIZZLE_POSITIVE_W_NV.

Viewport swizzle parameters are specified by setting the pNext pointer of VkGraphicsPipelineCreateInfo to point to a VkPipelineViewportSwizzleStateCreateInfoNV structure. VkPipelineViewportSwizzleStateCreateInfoNV uses VkViewportSwizzleNV to set the viewport swizzle parameters.

The VkViewportSwizzleNV structure is defined as:

```c
// Provided by VK_NV_viewport_swizzle
typedef struct VkViewportSwizzleNV {
    VkViewportCoordinateSwizzleNV x;
    VkViewportCoordinateSwizzleNV y;
    VkViewportCoordinateSwizzleNV z;
    VkViewportCoordinateSwizzleNV w;
} VkViewportSwizzleNV;
```

- x is a VkViewportCoordinateSwizzleNV value specifying the swizzle operation to apply to the x component of the primitive
- y is a VkViewportCoordinateSwizzleNV value specifying the swizzle operation to apply to the y component of the primitive
- z is a VkViewportCoordinateSwizzleNV value specifying the swizzle operation to apply to the z component of the primitive
- w is a VkViewportCoordinateSwizzleNV value specifying the swizzle operation to apply to the w component of the primitive

**Valid Usage (Implicit)**

- VUID-VkViewportSwizzleNV-x-parameter
  x must be a valid VkViewportCoordinateSwizzleNV value
- VUID-VkViewportSwizzleNV-y-parameter
  y must be a valid VkViewportCoordinateSwizzleNV value
Possible values of the `VkViewportSwizzleNV::x`, `y`, `z`, and `w` members, specifying swizzling of the corresponding components of primitives, are:

```c
// Provided by VK_NV_viewport_swizzle
typedef enum VkViewportCoordinateSwizzleNV {
    VK_VIEWPORT_COORDINATE_SWIZZLE_POSITIVE_X_NV = 0,
    VK_VIEWPORT_COORDINATE_SWIZZLE_NEGATIVE_X_NV = 1,
    VK_VIEWPORT_COORDINATE_SWIZZLE_POSITIVE_Y_NV = 2,
    VK_VIEWPORT_COORDINATE_SWIZZLE_NEGATIVE_Y_NV = 3,
    VK_VIEWPORT_COORDINATE_SWIZZLE_POSITIVE_Z_NV = 4,
    VK_VIEWPORT_COORDINATE_SWIZZLE_NEGATIVE_Z_NV = 5,
    VK_VIEWPORT_COORDINATE_SWIZZLE_POSITIVE_W_NV = 6,
    VK_VIEWPORT_COORDINATE_SWIZZLE_NEGATIVE_W_NV = 7,
} VkViewportCoordinateSwizzleNV;
```

These values are described in detail in Viewport Swizzle.

### 27.3. Flat Shading

*Flat shading* a vertex output attribute means to assign all vertices of the primitive the same value for that output. The output values assigned are those of the *provoking vertex* of the primitive. Flat shading is applied to those vertex attributes that match fragment input attributes which are decorated as `Flat`.

If neither *mesh*, *geometry* nor *tessellation shading* is active, the provoking vertex is determined by the *primitive topology* defined by `VkPipelineInputAssemblyStateCreateInfo:topology` used to execute the *drawing command*.

If a shader using *MeshNV Execution Model* is active, the provoking vertex is determined by the *primitive topology* defined by the `OutputPoints`, `OutputLinesNV`, or `OutputTrianglesNV` execution mode.

If a shader using *MeshEXT Execution Model* is active, the provoking vertex is determined by the *primitive topology* defined by the `OutputPoints`, `OutputLinesEXT`, or `OutputTrianglesEXT` execution mode.

If *geometry shading* is active, the provoking vertex is determined by the *primitive topology* defined by the `OutputPoints`, `OutputLineStrips`, or `OutputTriangleStrips` execution mode.

If *tessellation shading* is active but *geometry shading* is not, the provoking vertex may be any of the vertices in each primitive.

For a given primitive topology, the pipeline’s provoking vertex mode determines which vertex is
the provoking vertex. To specify the provoking vertex mode, include a
\texttt{VkPipelineRasterizationProvokingVertexStateCreateInfoEXT} structure in the
\texttt{VkPipelineRasterizationStateCreateInfo::pNext} chain when creating the pipeline.

The \texttt{VkPipelineRasterizationProvokingVertexStateCreateInfoEXT} structure is defined as:

```c
// Provided by VK_EXT_provoking_vertex
typedef struct VkPipelineRasterizationProvokingVertexStateCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkProvokingVertexModeEXT provokingVertexMode;
} VkPipelineRasterizationProvokingVertexStateCreateInfoEXT;
```

- \texttt{sType} is a \texttt{VkStructureType} value identifying this structure.
- \texttt{pNext} is \texttt{NULL} or a pointer to a structure extending this structure.
- \texttt{provokingVertexMode} is a \texttt{VkProvokingVertexModeEXT} value selecting the provoking vertex mode.

If this struct is not provided when creating the pipeline, the pipeline will use the
\texttt{VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT} mode.

If the \texttt{provokingVertexModePerPipeline} limit is \texttt{VK_FALSE}, then all pipelines bound within a render
pass instance \textbf{must} have the same \texttt{provokingVertexMode}.

**Valid Usage**

- \textbf{VUID-VkPipelineRasterizationProvokingVertexStateCreateInfoEXT-provokingVertexMode-04883}
  If \texttt{provokingVertexMode} is \texttt{VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT}, then the
  \texttt{provokingVertexLast} feature \textbf{must} be enabled

**Valid Usage (Implicit)**

- \textbf{VUID-VkPipelineRasterizationProvokingVertexStateCreateInfoEXT-sType-sType}
  \texttt{sType} \textbf{must} be \texttt{VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_PROVOKING_VERTEX_STATE_CREATE_INFO_EXT}
- \textbf{VUID-VkPipelineRasterizationProvokingVertexStateCreateInfoEXT-provokingVertexMode-parameter}
  \texttt{provokingVertexMode} \textbf{must} be a valid \texttt{VkProvokingVertexModeEXT} value

Possible values of \texttt{VkPipelineRasterizationProvokingVertexStateCreateInfoEXT::provokingVertexMode}
are:

```c
// Provided by VK_EXT_provoking_vertex
```
typedef enum VkProvokingVertexModeEXT {
    VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT = 0,
    VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT = 1,
} VkProvokingVertexModeEXT;

- VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT specifies that the provoking vertex is the first non-adjacency vertex in the list of vertices used by a primitive.
- VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT specifies that the provoking vertex is the last non-adjacency vertex in the list of vertices used by a primitive.

These modes are described more precisely in Primitive Topologies.

To dynamically set the provokingVertexMode state, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
void vkCmdSetProvokingVertexModeEXT(
    VkCommandBuffer commandBuffer,
    VkProvokingVertexModeEXT provokingVertexMode);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `provokingVertexMode` specifies the provokingVertexMode state.

This command sets the provokingVertexMode state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT set in VkPipelineDynamicStateCreateInfo::pDynamicStates. Otherwise, this state is specified by the VkPipelineRasterizationProvokingVertexStateCreateInfoEXT::provokingVertexMode value used to create the currently active pipeline.

---

### Valid Usage

- **VUID-vkCmdSetProvokingVertexModeEXT-None-08580**
  Either the extendedDynamicState3ProvokingVertexMode feature or the shaderObject feature or both must be enabled

- **VUID-vkCmdSetProvokingVertexModeEXT-provokingVertexMode-07447**
  If provokingVertexMode is VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT, then the provokingVertexLast feature must be enabled

---

### Valid Usage (Implicit)

- **VUID-vkCmdSetProvokingVertexModeEXT-commandBuffer-parameter**
  `commandBuffer` must be a valid VkCommandBuffer handle

- **VUID-vkCmdSetProvokingVertexModeEXT-provokingVertexMode-parameter**
  `provokingVertexMode` must be a valid VkProvokingVertexModeEXT value
• VUID-vkCmdSetProvokingVertexModeEXT-commandBuffer-recording
  
  CommandBuffer must be in the recording state

• VUID-vkCmdSetProvokingVertexModeEXT-commandBuffer-cmdpool
  
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

• VUID-vkCmdSetProvokingVertexModeEXT-videoencoding
  
  This command must only be called outside of a video coding scope

Host Synchronization

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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27.4. Primitive Clipping

Primitives are culled against the cull volume and then clipped to the clip volume. In clip coordinates, the view volume is defined by:

\[-w_c \leq x_c \leq w_c\]
\[-w_c \leq y_c \leq w_c\]
\[-m \leq z_c \leq w_c\]

where if VkPipelineViewportDepthClipControlCreateInfoEXT::negativeOneToOne is VK_TRUE \(m\) is equal to \(-w\), otherwise \(m\) is equal to zero.

This view volume can be further restricted by as many as VkPhysicalDeviceLimits::maxClipDistances client-defined half-spaces.

The cull volume is the intersection of up to VkPhysicalDeviceLimits::maxCullDistances client-defined half-spaces (if no client-defined cull half-spaces are enabled, culling against the cull volume is skipped).

A shader must write a single cull distance for each enabled cull half-space to elements of the CullDistance array. If the cull distance for any enabled cull half-space is negative for all of the vertices of the primitive under consideration, the primitive is discarded. Otherwise the primitive is clipped against the clip volume as defined below.
The clip volume is the intersection of up to \( \text{VkPhysicalDeviceLimits::maxClipDistances} \) client-defined half-spaces with the view volume (if no client-defined clip half-spaces are enabled, the clip volume is the view volume).

A shader \textbf{must} write a single clip distance for each enabled clip half-space to elements of the \texttt{ClipDistance} array. Clip half-space \( i \) is then given by the set of points satisfying the inequality

\[ c_i(P) \geq 0 \]

where \( c_i(P) \) is the clip distance \( i \) at point \( P \). For point primitives, \( c_i(P) \) is simply the clip distance for the vertex in question. For line and triangle primitives, per-vertex clip distances are interpolated using a weighted mean, with weights derived according to the algorithms described in sections Basic Line Segment Rasterization and Basic Polygon Rasterization, using the perspective interpolation equations.

The number of client-defined clip and cull half-spaces that are enabled is determined by the explicit size of the built-in arrays \texttt{ClipDistance} and \texttt{CullDistance}, respectively, declared as an output in the interface of the entry point of the final shader stage before clipping.

If \texttt{VkPipelineRasterizationDepthClipStateCreateInfoEXT} is present in the graphics pipeline state then depth clipping is disabled if \texttt{VkPipelineRasterizationDepthClipStateCreateInfoEXT::depthClipEnable} is \texttt{VK_FALSE}. Otherwise, if \texttt{VkPipelineRasterizationDepthClipStateCreateInfoEXT} is not present, depth clipping is disabled when \texttt{VkPipelineRasterizationStateCreateInfo::depthClampEnable} is \texttt{VK_TRUE}.

To \textit{dynamically set} enable or disable depth clamping, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
void vkCmdSetDepthClampEnableEXT( VkCommandBuffer commandBuffer, VkBool32 depthClampEnable);
```

- \texttt{commandBuffer} is the command buffer into which the command will be recorded.
- \texttt{depthClampEnable} specifies whether depth clamping is enabled.

This command sets whether depth clamping is enabled or disabled for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with \texttt{VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT} set in \texttt{VkPipelineDynamicStateCreateInfo::pDynamicStates}. Otherwise, this state is specified by the \texttt{VkPipelineRasterizationStateCreateInfo::depthClampEnable} value used to create the currently active pipeline.

If the depth clamping state is changed dynamically, and the pipeline was not created with \texttt{VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT} enabled, then depth clipping is enabled when depth clamping is disabled and vice versa.
Valid Usage

• VUID-vkCmdSetDepthClipEnableEXT-None-08582
  Either the extendedDynamicState3DepthClipEnable feature or the shaderObject feature or both must be enabled

• VUID-vkCmdSetDepthClipEnableEXT-depthClamp-07449
  If the depthClamp feature is not enabled, depthClampEnable must be VK_FALSE

Valid Usage (Implicit)

• VUID-vkCmdSetDepthClipEnableEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

• VUID-vkCmdSetDepthClipEnableEXT-commandBuffer-recording
  commandBuffer must be in the recording state

• VUID-vkCmdSetDepthClipEnableEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

• VUID-vkCmdSetDepthClipEnableEXT-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To dynamically set enable or disable depth clipping, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
void vkCmdSetDepthClipEnableEXT(VkCommandBuffer commandBuffer, VkBool32 depthClipEnable);
```
• `commandBuffer` is the command buffer into which the command will be recorded.

• `depthClipEnable` specifies whether depth clipping is enabled.

This command sets whether depth clipping is enabled or disabled for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineRasterizationDepthClipStateCreateInfoEXT::depthClipEnable` value used to create the currently active pipeline, or is set to the inverse of `VkPipelineRasterizationStateCreateInfo::depthClampEnable` if `VkPipelineRasterizationDepthClipStateCreateInfoEXT` is not specified.

### Valid Usage

- VUID-vkCmdSetDepthClipEnableEXT-None-08584
  Either the `extendedDynamicState3DepthClipEnable` feature or the `shaderObject` feature or both **must** be enabled

- VUID-vkCmdSetDepthClipEnableEXT-depthClipEnable-07451
  The `depthClipEnable` feature **must** be enabled

### Valid Usage (Implicit)

- VUID-vkCmdSetDepthClipEnableEXT-commandBuffer-parameter
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- VUID-vkCmdSetDepthClipEnableEXT-commandBuffer-recording
  `commandBuffer` **must** be in the recording state

- VUID-vkCmdSetDepthClipEnableEXT-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics operations

- VUID-vkCmdSetDepthClipEnableEXT-videocoding
  This command **must** only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` **must** be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized
When depth clipping is disabled, the plane equation

\[ z_m \leq z_c \leq w_c \]

(see the clip volume definition above) is ignored by view volume clipping (effectively, there is no near or far plane clipping).

If the primitive under consideration is a point or line segment, then clipping passes it unchanged if its vertices lie entirely within the clip volume.

Possible values of `VkPhysicalDevicePointSizeClippingProperties::pointClippingBehavior`, specifying clipping behavior of a point primitive whose vertex lies outside the clip volume, are:

```c
// Provided by VK_VERSION_1_1
typedef enum VkPointClippingBehavior {
    VK_POINT_CLIPPING_BEHAVIOR_ALL_CLIP_PLANES = 0,
    VK_POINT_CLIPPING_BEHAVIOR_USER_CLIP_PLANES_ONLY = 1,
} VkPointClippingBehavior;
```

or the equivalent

```c
// Provided by VK_KHR_maintenance2
typedef VkPointClippingBehavior VkPointClippingBehaviorKHR;
```

- `VK_POINT_CLIPPING_BEHAVIOR_ALL_CLIP_PLANES` specifies that the primitive is discarded if the vertex lies outside any clip plane, including the planes bounding the view volume.
- `VK_POINT_CLIPPING_BEHAVIOR_USER_CLIP_PLANES_ONLY` specifies that the primitive is discarded only if the vertex lies outside any user clip plane.

If either of a line segment's vertices lie outside of the clip volume, the line segment **may** be clipped, with new vertex coordinates computed for each vertex that lies outside the clip volume. A clipped
line segment endpoint lies on both the original line segment and the boundary of the clip volume.

This clipping produces a value, \(0 \leq t \leq 1\), for each clipped vertex. If the coordinates of a clipped vertex are \(P\) and the unclipped line segment's vertex coordinates are \(P_1\) and \(P_2\), then \(t\) satisfies the following equation

\[ P = tP_1 + (1-t)P_2. \]

t is used to clip vertex output attributes as described in *Clipping Shader Outputs*.

If the primitive is a polygon, it passes unchanged if every one of its edges lies entirely inside the clip volume, and is either clipped or discarded otherwise. If the edges of the polygon intersect the boundary of the clip volume, the intersecting edges are reconnected by new edges that lie along the boundary of the clip volume - in some cases requiring the introduction of new vertices into a polygon.

If a polygon intersects an edge of the clip volume's boundary, the clipped polygon *must* include a point on this boundary edge.

Primitives rendered with user-defined half-spaces *must* satisfy a complementarity criterion. Suppose a series of primitives is drawn where each vertex \(i\) has a single specified clip distance \(d_i\) (or a number of similarly specified clip distances, if multiple half-spaces are enabled). Next, suppose that the same series of primitives are drawn again with each such clip distance replaced by \(-d_i\) (and the graphics pipeline is otherwise the same). In this case, primitives *must* not be missing any pixels, and pixels *must* not be drawn twice in regions where those primitives are cut by the clip planes.

The *VkPipelineViewportDepthClipControlCreateInfoEXT* structure is defined as:

```c
// Provided by VK_EXT_depth_clip_control
typedef struct VkPipelineViewportDepthClipControlCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkBool32 negativeOneToOne;
} VkPipelineViewportDepthClipControlCreateInfoEXT;
```

- \(sType\) is a *VkStructureType* value identifying this structure.
- \(pNext\) is NULL or a pointer to a structure extending this structure.
- \(negativeOneToOne\) sets the \(z_m\) in the *view volume* to \(-w_c\).

**Valid Usage**

- VUID-VkPipelineViewportDepthClipControlCreateInfoEXT-negativeOneToOne-06470
  If \(depthClipControl\) is not enabled, \(negativeOneToOne\) *must* be *VK_FALSE*
To dynamically set `negativeOneToOne`, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
void vkCmdSetDepthClipNegativeOneToOneEXT(
    VkCommandBuffer commandBuffer,
    VkBool32 negativeOneToOne);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `negativeOneToOne` specifies the `negativeOneToOne` state.

This command sets the `negativeOneToOne` state for subsequent drawing commands when drawing using `shader objects`, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineViewportDepthClipControlCreateInfoEXT::negativeOneToOne` value used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetDepthClipNegativeOneToOneEXT-None-08586
  Either the `extendedDynamicState3DepthClipNegativeOneToOne` feature or the `shaderObject` feature or both must be enabled

- VUID-vkCmdSetDepthClipNegativeOneToOneEXT-depthClipControl-07453
  The `depthClipControl` feature must be enabled

### Valid Usage (Implicit)

- VUID-vkCmdSetDepthClipNegativeOneToOneEXT-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdSetDepthClipNegativeOneToOneEXT-commandBuffer-recording
  `commandBuffer` must be in the recording state

- VUID-vkCmdSetDepthClipNegativeOneToOneEXT-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations

- VUID-vkCmdSetDepthClipNegativeOneToOneEXT-videocoding
  This command must only be called outside of a video coding scope
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

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27.5. Clipping Shader Outputs

Next, vertex output attributes are clipped. The output values associated with a vertex that lies within the clip volume are unaffected by clipping. If a primitive is clipped, however, the output values assigned to vertices produced by clipping are clipped.

Let the output values assigned to the two vertices \( P_1 \) and \( P_2 \) of an unclipped edge be \( c_1 \) and \( c_2 \). The value of \( t \) (see Primitive Clipping) for a clipped point \( P \) is used to obtain the output value associated with \( P \) as

\[
c = t \, c_1 + (1-t) \, c_2.
\]

(Multiplying an output value by a scalar means multiplying each of \( x, y, z \), and \( w \) by the scalar.)

Since this computation is performed in clip space before division by \( w_c \), clipped output values are perspective-correct.

Polygon clipping creates a clipped vertex along an edge of the clip volume’s boundary. This situation is handled by noting that polygon clipping proceeds by clipping against one half-space at a time. Output value clipping is done in the same way, so that clipped points always occur at the intersection of polygon edges (possibly already clipped) with the clip volume’s boundary.

For vertex output attributes whose matching fragment input attributes are decorated with `NoPerspective`, the value of \( t \) used to obtain the output value associated with \( P \) will be adjusted to produce results that vary linearly in framebuffer space.

Output attributes of integer or unsigned integer type must always be flat shaded. Flat shaded attributes are constant over the primitive being rasterized (see Basic Line Segment Rasterization and Basic Polygon Rasterization), and no interpolation is performed. The output value \( c \) is taken from either \( c_1 \) or \( c_2 \), since flat shading has already occurred and the two values are identical.
27.6. Controlling Viewport W Scaling

If viewport W scaling is enabled, the W component of the clip coordinate is modified by the provided coefficients from the corresponding viewport as follows.

\[ w' = x_{\text{coeff}} \cdot x + y_{\text{coeff}} \cdot y + w_c \]

The `VkPipelineViewportWScalingStateCreateInfoNV` structure is defined as:

```c
// Provided by VK_NV_clip_space_w_scaling
typedef struct VkPipelineViewportWScalingStateCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkBool32 viewportWScalingEnable;
    uint32_t viewportCount;
    const VkViewportWScalingNV* pViewportWScalings;
} VkPipelineViewportWScalingStateCreateInfoNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `viewportWScalingEnable` controls whether viewport W scaling is enabled.
- `viewportCount` is the number of viewports used by W scaling, and must match the number of viewports in the pipeline if viewport W scaling is enabled.
- `pViewportWScalings` is a pointer to an array of `VkViewportWScalingNV` structures defining the W scaling parameters for the corresponding viewports. If the viewport W scaling state is dynamic, this member is ignored.

Valid Usage (Implicit)

- VUID-VkPipelineViewportWScalingStateCreateInfoNV-sType-sType `sType must be VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_W_SCALING_STATE_CREATE_INFO_NV`
- VUID-VkPipelineViewportWScalingStateCreateInfoNV-viewportCount-arraylength `viewportCount must be greater than 0`

The `VkPipelineViewportWScalingStateCreateInfoNV` state is set by adding this structure to the `pNext` chain of a `VkPipelineViewportStateCreateInfo` structure and setting the graphics pipeline state with `vkCreateGraphicsPipelines`.

To dynamically set the `viewportWScalingEnable` state, call:

```c
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_clip_space_w_scaling,
// VK_EXT_shader_object with VK_NV_clip_space_w_scaling
void vkCmdSetViewportWScalingEnableNV(
    VkCommandBuffer commandBuffer,```

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• **commandBuffer** is the command buffer into which the command will be recorded.

• **viewportWScalingEnable** specifies the viewportWScalingEnable state.

This command sets the viewportWScalingEnable state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with VK_DYNAMIC STATE_VIEWPORT_W_SCALING_ENABLE_NV set in VkPipelineDynamicStateCreateInfo::pDynamicStates. Otherwise, this state is specified by the VkPipelineViewportWScalingStateCreateInfoNV::viewportWScalingEnable value used to create the currently active pipeline.

## Valid Usage

- VUID-vkCmdSetViewportWScalingEnableNV-None-08594
  Either the extendedDynamicState3ViewportWScalingEnable feature or the shaderObject feature or both must be enabled

## Valid Usage (Implicit)

- VUID-vkCmdSetViewportWScalingEnableNV-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdSetViewportWScalingEnableNV-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdSetViewportWScalingEnableNV-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdSetViewportWScalingEnableNV-videocoding
  This command must only be called outside of a video coding scope

## Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
To dynamically set the viewport W scaling parameters, call:

```c
// Provided by VK_NV_clip_space_w_scaling
void vkCmdSetViewportWScalingNV(
    VkCommandBuffer commandBuffer,
    uint32_t firstViewport,
    uint32_t viewportCount,
    const VkViewportWScalingNV* pViewportWScalings);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `firstViewport` is the index of the first viewport whose parameters are updated by the command.
- `viewportCount` is the number of viewports whose parameters are updated by the command.
- `pViewportWScalings` is a pointer to an array of `VkViewportWScalingNV` structures specifying viewport parameters.

The viewport parameters taken from element i of `pViewportWScalings` replace the current state for the viewport index `firstViewport + i`, for i in [0, `viewportCount`).

This command sets the viewport W scaling for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineViewportWScalingStateCreateInfoNV::pViewportWScalings` values used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetViewportWScalingNV-firstViewport-01324
  
  The sum of `firstViewport` and `viewportCount` must be between 1 and `VkPhysicalDeviceLimits::maxViewports`, inclusive
**VkViewportWScalingNV structures**

- VUID-vkCmdSetViewportWScalingNV-commandBuffer-recording
  
  commandBuffer must be in the recording state

- VUID-vkCmdSetViewportWScalingNV-commandBuffer-cmdpool
  
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdSetViewportWScalingNV-videocoding
  
  This command must only be called outside of a video coding scope

- VUID-vkCmdSetViewportWScalingNV-viewportCount-arraylength
  
  viewportCount must be greater than 0

**Host Synchronization**

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

**Command Properties**

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Both VkPipelineViewportWScalingStateCreateInfoNV and vkCmdSetViewportWScalingNV use VkViewportWScalingNV to set the viewport transformation parameters.

The VkViewportWScalingNV structure is defined as:

```c
// Provided by VK_NV_clip_space_w_scaling
typedef struct VkViewportWScalingNV {
    float xcoeff;
    float ycoeff;
} VkViewportWScalingNV;
```

- xcoeff and ycoeff are the viewport's W scaling factor for x and y respectively.

**27.7. Coordinate Transformations**

*Clip coordinates* for a vertex result from shader execution, which yields a vertex coordinate *Position*. 
Perspective division on clip coordinates yields *normalized device coordinates*, followed by a viewport transformation (see *Controlling the Viewport*) to convert these coordinates into *framebuffer coordinates*.

If a vertex in clip coordinates has a position given by

\[
\begin{pmatrix}
  x_c \\
  y_c \\
  z_c \\
  w_c
\end{pmatrix}
\]

then the vertex’s normalized device coordinates are

\[
\begin{pmatrix}
  x_d \\
  y_d \\
  z_d
\end{pmatrix} = \begin{pmatrix}
  x_c \\
  y_c \\
  z_c \\
  w_c
\end{pmatrix}
\]

### 27.8. Render Pass Transform

A *render pass transform* can be enabled for render pass instances. The clip coordinates \((x_c, y_c)\) that result from vertex shader execution are transformed by a rotation of 0, 90, 180, or 270 degrees in the XY plane, centered at the origin.

When *Render pass transform* is enabled, the transform applies to all primitives for all subpasses of the render pass. The transformed vertex in clip coordinates has a position given by

\[
\begin{pmatrix}
  x_{c_{\text{trans}}} \\
  y_{c_{\text{trans}}} \\
  z_{c_{\text{trans}}}
\end{pmatrix} = \begin{pmatrix}
  x_c \cos \theta - y_c \sin \theta \\
  x_c \sin \theta + y_c \cos \theta \\
  z_c
\end{pmatrix}
\]

where

- \(\theta\) is 0 degrees for *VK_SURFACE_TRANSFORM_IDENTITY_BIT_KHR*
- \(\theta\) is 90 degrees for *VK_SURFACE_TRANSFORM_ROTATE_90_BIT_KHR*
- \(\theta\) is 180 degrees for *VK_SURFACE_TRANSFORM_ROTATE_180_BIT_KHR*
- \(\theta\) is 270 degrees for *VK_SURFACE_TRANSFORM_ROTATE_270_BIT_KHR*

The transformed vertex’s normalized device coordinates are

\[
\begin{pmatrix}
  x_d \\
  y_d \\
  z_d
\end{pmatrix} = \begin{pmatrix}
  x_{c_{\text{trans}}} \\
  y_{c_{\text{trans}}} \\
  z_{c_{\text{trans}}}
\end{pmatrix}
\]
When render pass transform is enabled for a render pass instance, the following additional features are enabled:

- Each `VkViewport` specified by either `VkPipelineViewportStateCreateInfo::pViewports` or `vkCmdSetViewport` will have its width/height \((p_x, p_y)\) and its center \((o_x, o_y)\) similarly transformed by the implementation.

- Each scissor specified by `VkPipelineViewportStateCreateInfo::pScissors` or `vkCmdSetScissor` will have its \((\text{offset}_x, \text{offset}_y)\) and \((\text{extent}_x, \text{extent}_y)\) similarly transformed by the implementation.

- The `renderArea` specified in `VkCommandBufferInheritanceRenderPassTransformInfoQCOM` and `VkRenderPassBeginInfo` will be similarly transformed by the implementation.

- The \((x, y)\) components of shader variables with built-in decorations `FragCoord`, `SamplePosition`, or `PointCoord` will be similarly transformed by the implementation.

- The \((x, y)\) components of the `offset` operand of the `InterpolateAtOffset` extended instruction will be similarly transformed by the implementation.

- The values returned by SPIR-V derivative instructions `OpDPdx`, `OpDPdy`, `OpDPdxCourse`, `OpDPdyCourse`, `OpDPdxFine`, `OpDPdyFine` will be similarly transformed by the implementation.

The net result of the above, is that applications can act as if rendering to a framebuffer oriented with the `VkSurfaceCapabilitiesKHR::currentTransform`. In other words, applications can act as if the presentation engine will be performing the transformation of the swapchain image after rendering and prior to presentation to the user. In fact, the transformation of the various items cited above are being handled by the implementation as the rendering takes place.

### 27.9. Controlling the Viewport

The viewport transformation is determined by the selected viewport's width and height in pixels, \(p_x\) and \(p_y\), respectively, and its center \((o_x, o_y)\) (also in pixels), as well as its depth range min and max determining a depth range scale value \(p_z\) and a depth range bias value \(o_z\) (defined below). The vertex's framebuffer coordinates \((x_f, y_f, z_f)\) are given by

\[
x_f = (p_x / 2) x_d + o_x
\]

\[
y_f = (p_y / 2) y_d + o_y
\]

\[
z_f = p_z \times z_d + o_z
\]

Multiple viewports are available, numbered zero up to `VkPhysicalDeviceLimits::maxViewports` minus one. The number of viewports used by a pipeline is controlled by the `viewportCount` member of the `VkPipelineViewportStateCreateInfo` structure used in pipeline creation.

\(x_f\) and \(y_f\) have limited precision, where the number of fractional bits retained is specified by `VkPhysicalDeviceLimits::subPixelPrecisionBits`. When rasterizing line segments, the number of fractional bits is specified by `VkPhysicalDeviceLineRasterizationPropertiesEXT`.
The `VkPipelineViewportStateCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPipelineViewportStateCreateInfo {
    VkStructureType          sType;
    const void*              pNext;
    VkPipelineViewportStateCreateFlags flags;
    uint32_t                  viewportCount;
    const VkViewport*         pViewports;
    uint32_t                  scissorCount;
    const VkRect2D*           pScissors;
} VkPipelineViewportStateCreateInfo;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is reserved for future use.
- `viewportCount` is the number of viewports used by the pipeline.
- `pViewports` is a pointer to an array of `VkViewport` structures, defining the viewport transforms. If the viewport state is dynamic, this member is ignored.
- `scissorCount` is the number of `scissors` and must match the number of viewports.
- `pScissors` is a pointer to an array of `VkRect2D` structures defining the rectangular bounds of the scissor for the corresponding viewport. If the scissor state is dynamic, this member is ignored.

### Valid Usage

- **VUID-VkPipelineViewportStateCreateInfo-viewportCount-01216**
  If the `multiViewport` feature is not enabled, `viewportCount` must not be greater than 1
- **VUID-VkPipelineViewportStateCreateInfo-scissorCount-01217**
  If the `multiViewport` feature is not enabled, `scissorCount` must not be greater than 1
- **VUID-VkPipelineViewportStateCreateInfo-viewportCount-01218**
  `viewportCount` must be less than or equal to `VkPhysicalDeviceLimits::maxViewports`
- **VUID-VkPipelineViewportStateCreateInfo-scissorCount-01219**
  `scissorCount` must be less than or equal to `VkPhysicalDeviceLimits::maxViewports`
- **VUID-VkPipelineViewportStateCreateInfo-x-02821**
  The `x` and `y` members of `offset` member of any element of `pScissors` must be greater than or equal to 0
- **VUID-VkPipelineViewportStateCreateInfo-offset-02822**
  Evaluation of `(offset.x + extent.width)` must not cause a signed integer addition overflow for any element of `pScissors`
- **VUID-VkPipelineViewportStateCreateInfo-offset-02823**
  Evaluation of `(offset.y + extent.height)` must not cause a signed integer addition overflow for any element of `pScissors`
overflow for any element of pScissors

- **VUID-VkPipelineViewportStateCreateInfo-scissorCount-04134**
  If `scissorCount` and `viewportCount` are both not dynamic, then `scissorCount` and `viewportCount` must be identical

- **VUID-VkPipelineViewportStateCreateInfo-viewportCount-04135**
  If the graphics pipeline is being created with `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` set then `viewportCount` must be 0, otherwise it must be greater than 0

- **VUID-VkPipelineViewportStateCreateInfo-scissorCount-04136**
  If the graphics pipeline is being created with `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` set then `scissorCount` must be 0, otherwise it must be greater than 0

- **VUID-VkPipelineViewportStateCreateInfo-viewportWScalingEnable-01726**
  If the `viewportWScalingEnable` member of a `VkPipelineViewportWScalingStateCreateInfoNV` structure included in the `pNext` chain is `VK_TRUE`, the `viewportCount` member of the `VkPipelineViewportWScalingStateCreateInfoNV` structure must be greater than or equal to `VkPipelineViewportStateCreateInfo::viewportCount`

---

**Valid Usage (Implicit)**

- **VUID-VkPipelineViewportStateCreateInfo-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_STATE_CREATE_INFO`

- **VUID-VkPipelineViewportStateCreateInfo-pNext-pNext**
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkPipelineViewportCoarseSampleOrderStateCreateInfoNV`, `VkPipelineViewportDepthClipControlCreateInfoEXT`, `VkPipelineViewportExclusiveScissorStateCreateInfoNV`, `VkPipelineViewportShadingRateImageStateCreateInfoNV`, `VkPipelineViewportSwizzleStateCreateInfoNV`, or `VkPipelineViewportWScalingStateCreateInfoNV`

- **VUID-VkPipelineViewportStateCreateInfo-sType-unique**
  The `sType` value of each struct in the `pNext` chain must be unique

- **VUID-VkPipelineViewportStateCreateInfo-flags-zerobitmask**
  `flags` must be 0

---

To **dynamically set** the viewport count and viewports, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdSetViewportWithCount(
  VkCommandBuffer commandBuffer,
  uint32_t viewportCount,
  const VkViewport* pViewports);
```
or the equivalent command

```
void vkCmdSetViewportWithCountEXT(
    VkCommandBuffer commandBuffer,
    uint32_t viewportCount,
    const VkViewport* pViewports);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `viewportCount` specifies the viewport count.
- `pViewports` specifies the viewports to use for drawing.

This command sets the viewport count and viewports state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the corresponding `VkPipelineViewportStateCreateInfo::viewportCount` and `pViewports` values used to create the currently active pipeline.

**Valid Usage**

- **VUID-vkCmdSetViewportWithCount-None-08971**
  At least one of the following must be true:
  - the `extendedDynamicState` feature is enabled
  - the `shaderObject` feature is enabled
  - the value of `VkApplicationInfo::apiVersion` used to create the `VkInstance` parent of `commandBuffer` is greater than or equal to Version 1.3

- **VUID-vkCmdSetViewportWithCount-viewportCount-03394**
  `viewportCount` must be between 1 and `VkPhysicalDeviceLimits::maxViewports`, inclusive

- **VUID-vkCmdSetViewportWithCount-viewportCount-03395**
  If the `multiViewport` feature is not enabled, `viewportCount` must be 1

- **VUID-vkCmdSetViewportWithCount-commandBuffer-04819**
  `commandBuffer` must not have `VkCommandBufferInheritanceViewportScissorInfoNV::viewportScissor2D` enabled

**Valid Usage (Implicit)**

- **VUID-vkCmdSetViewportWithCount-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- **VUID-vkCmdSetViewportWithCount-pViewports-parameter**
  `pViewports` must be a valid pointer to an array of `viewportCount` valid `VkViewport` structures

- **VUID-vkCmdSetViewportWithCount-commandBuffer-recording**
commandBuffer must be in the recording state

- VUID-vkCmdSetViewportWithCount-commandBuffer-cmdpool
  - The VkCommandPool that commandBuffer was allocated from must support graphics operations
- VUID-vkCmdSetViewportWithCount-vidcoding
  - This command must only be called outside of a video coding scope
- VUID-vkCmdSetViewportWithCount-viewportCount-arraylength
  - viewportCount must be greater than 0

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To dynamically set the scissor count and scissor rectangular bounds, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdSetScissorWithCount(VkCommandBuffer commandBuffer,
                               uint32_t scissorCount,
                               const VkRect2D* pScissors);
```

or the equivalent command

```c
// Provided by VK_EXT_extended_dynamic_state, VK_EXT_shader_object
void vkCmdSetScissorWithCountEXT(VkCommandBuffer commandBuffer,
                                  uint32_t scissorCount,
                                  const VkRect2D* pScissors);
```

- commandBuffer is the command buffer into which the command will be recorded.
- scissorCount specifies the scissor count.
- pScissors specifies the scissors to use for drawing.
This command sets the scissor count and scissor rectangular bounds state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the corresponding `VkPipelineViewportStateCreateInfo::scissorCount` and `pScissors` values used to create the currently active pipeline.

### Valid Usage

- **VUID-vkCmdSetScissorWithCount-None-08971**
  At least one of the following **must** be true:
  - the `extendedDynamicState` feature is enabled
  - the `shaderObject` feature is enabled
  - the value of `VkApplicationInfo::apiVersion` used to create the `VkInstance` parent of `commandBuffer` is greater than or equal to Version 1.3

- **VUID-vkCmdSetScissorWithCount-scissorCount-03397**
  `scissorCount` **must** be between 1 and `VkPhysicalDeviceLimits::maxViewports`, inclusive

- **VUID-vkCmdSetScissorWithCount-scissorCount-03398**
  If the `multiViewport` feature is not enabled, `scissorCount` **must** be 1

- **VUID-vkCmdSetScissorWithCount-x-03399**
  The `x` and `y` members of `offset` member of any element of `pScissors` **must** be greater than or equal to 0

- **VUID-vkCmdSetScissorWithCount-offset-03400**
  Evaluation of `(offset.x + extent.width)` **must** not cause a signed integer addition overflow for any element of `pScissors`

- **VUID-vkCmdSetScissorWithCount-offset-03401**
  Evaluation of `(offset.y + extent.height)` **must** not cause a signed integer addition overflow for any element of `pScissors`

- **VUID-vkCmdSetScissorWithCount-commandBuffer-04820**
  `commandBuffer` **must** not have `VkCommandBufferInheritanceViewportScissorInfoNV::viewportScissor2D` enabled

### Valid Usage (Implicit)

- **VUID-vkCmdSetScissorWithCount-commandBuffer-parameter**
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- **VUID-vkCmdSetScissorWithCount-pScissors-parameter**
  `pScissors` **must** be a valid pointer to an array of `scissorCount` `VkRect2D` structures

- **VUID-vkCmdSetScissorWithCount-commandBuffer-recording**
  `commandBuffer` **must** be in the recording state

- **VUID-vkCmdSetScissorWithCount-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics operations
This command must only be called outside of a video coding scope.

scissorCount must be greater than 0.

**Host Synchronization**

- Host access to commandBuffer must be externally synchronized.
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized.

**Command Properties**

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</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

// Provided by VK_VERSION_1_0

typedef VkFlags VkPipelineViewportStateCreateFlags;

VkPipelineViewportStateCreateFlags is a bitmask type for setting a mask, but is currently reserved for future use.

A pre-rasterization shader stage can direct each primitive to zero or more viewports. The destination viewports for a primitive are selected by the last active pre-rasterization shader stage that has an output variable decorated with ViewportIndex (selecting a single viewport) or ViewportMaskNV (selecting multiple viewports). The viewport transform uses the viewport corresponding to either the value assigned to ViewportIndex or one of the bits set in ViewportMaskNV, and taken from an implementation-dependent vertex of each primitive. If ViewportIndex or any of the bits in ViewportMaskNV are outside the range zero to viewportCount minus one for a primitive, or if the last active pre-rasterization shader stage did not assign a value to either ViewportIndex or ViewportMaskNV for all vertices of a primitive due to flow control, the values resulting from the viewport transformation of the vertices of such primitives are undefined. If the last pre-rasterization shader stage does not have an output decorated with ViewportIndex or ViewportMaskNV, the viewport numbered zero is used by the viewport transformation.

A single vertex can be used in more than one individual primitive, in primitives such as VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP. In this case, the viewport transformation is applied separately for each primitive.

To dynamically set the viewport transformation parameters, call:
void vkCmdSetViewport(
    VkCommandBuffer commandBuffer,       
    uint32_t firstViewport,              
    uint32_t viewportCount,              
    const VkViewport* pViewports);      

- `commandBuffer` is the command buffer into which the command will be recorded.
- `firstViewport` is the index of the first viewport whose parameters are updated by the command.
- `viewportCount` is the number of viewports whose parameters are updated by the command.
- `pViewports` is a pointer to an array of `VkViewport` structures specifying viewport parameters.

This command sets the viewport transformation parameters state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_VIEWPORT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineViewportStateCreateInfo::pViewports` values used to create the currently active pipeline.

The viewport parameters taken from element `i` of `pViewports` replace the current state for the viewport index `firstViewport + i`, for `i` in `[0, viewportCount)`.

### Valid Usage

- VUID-vkCmdSetViewport-firstViewport-01223
  The sum of `firstViewport` and `viewportCount` must be between `1` and `VkPhysicalDeviceLimits::maxViewports`, inclusive

- VUID-vkCmdSetViewport-firstViewport-01224
  If the `multiViewport` feature is not enabled, `firstViewport` must be `0`

- VUID-vkCmdSetViewport-viewportCount-01225
  If the `multiViewport` feature is not enabled, `viewportCount` must be `1`

- VUID-vkCmdSetViewport-commandBuffer-04821
  `commandBuffer` must not have `VkCommandBufferInheritanceViewportScissorInfoNV::viewportScissor2D` enabled

### Valid Usage (Implicit)

- VUID-vkCmdSetViewport-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdSetViewport-pViewports-parameter
  `pViewports` must be a valid pointer to an array of `viewportCount` valid `VkViewport` structures

- VUID-vkCmdSetViewport-commandBuffer-recording
  `commandBuffer` must be in the recording state
• VUID-vkCmdSetViewport-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

• VUID-vkCmdSetViewport-videocoding
  This command must only be called outside of a video coding scope

• VUID-vkCmdSetViewport-viewportCount-arraylength
  viewportCount must be greater than 0

Host Synchronization

• Host access to commandBuffer must be externally synchronized
• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

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Both VkPipelineViewportStateCreateInfo and vkCmdSetViewport use VkViewport to set the viewport transformation parameters.

The VkViewport structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkViewport {
    float x;
    float y;
    float width;
    float height;
    float minDepth;
    float maxDepth;
} VkViewport;
```

• x and y are the viewport's upper left corner (x,y).
• width and height are the viewport's width and height, respectively.
• minDepth and maxDepth are the depth range for the viewport.

Note
Despite their names, minDepth can be less than, equal to, or greater than maxDepth.
The framebuffer depth coordinate \( z \) may be represented using either a fixed-point or floating-point representation. However, a floating-point representation must be used if the depth/stencil attachment has a floating-point depth component. If an \( m \)-bit fixed-point representation is used, we assume that it represents each value \( k \frac{1}{2^m - 1} \), where \( k \in \{0, 1, ..., 2^m - 1\} \), as \( k \) (e.g. 1.0 is represented in binary as a string of all ones).

The viewport parameters shown in the above equations are found from these values as

\[
\begin{align*}
o_x &= x + \frac{\text{width}}{2} \\
o_y &= y + \frac{\text{height}}{2} \\
o_z &= \minDepth \text{ (or (maxDepth + minDepth) / 2 if VkPipelineViewportDepthClipControlCreateInfoEXT::negativeOneToOne is VK_TRUE)}
\end{align*}
\]

\[
\begin{align*}
p_x &= \text{width} \\
p_y &= \text{height} \\
p_z &= \maxDepth - \minDepth \text{ (or (maxDepth - minDepth) / 2 if VkPipelineViewportDepthClipControlCreateInfoEXT::negativeOneToOne is VK_TRUE)}
\end{align*}
\]

If a render pass transform is enabled, the values \((p_x, p_y)\) and \((o_x, o_y)\) defining the viewport are transformed as described in render pass transform before participating in the viewport transform.

The application can specify a negative term for \( \text{height} \), which has the effect of negating the \( y \) coordinate in clip space before performing the transform. When using a negative \( \text{height} \), the application should also adjust the \( y \) value to point to the lower left corner of the viewport instead of the upper left corner. Using the negative \( \text{height} \) allows the application to avoid having to negate the \( y \) component of the \( \text{Position} \) output from the last pre-rasterization shader stage.

The width and height of the implementation-dependent maximum viewport dimensions must be greater than or equal to the width and height of the largest image which can be created and attached to a framebuffer.

The floating-point viewport bounds are represented with an implementation-dependent precision.

**Valid Usage**

- VUID-VkViewport-width-01770
  \( \text{width} \) must be greater than 0.0
- VUID-VkViewport-width-01771
width must be less than or equal to \( \text{VkPhysicalDeviceLimits::maxViewportDimensions}[0] \)

- **VUID-VkViewport-apiVersion-07917**
  If the **VK_KHR_maintenance1** extension is not enabled, the **VK_AMD_negative_viewport_height** extension is not enabled, and **VkPhysicalDeviceProperties::apiVersion** is less than Vulkan 1.1, height must be greater than 0.0

- **VUID-VkViewport-height-01773**
  The absolute value of height must be less than or equal to **VkPhysicalDeviceLimits::maxViewportDimensions[1]**

- **VUID-VkViewport-x-01774**
  x must be greater than or equal to **viewportBoundsRange[0]**

- **VUID-VkViewport-x-01232**
  \((x + \text{width})\) must be less than or equal to **viewportBoundsRange[1]**

- **VUID-VkViewport-y-01775**
  y must be greater than or equal to **viewportBoundsRange[0]**

- **VUID-VkViewport-y-01776**
  y must be less than or equal to **viewportBoundsRange[1]**

- **VUID-VkViewport-y-01777**
  \((y + \text{height})\) must be greater than or equal to **viewportBoundsRange[0]**

- **VUID-VkViewport-y-01233**
  \((y + \text{height})\) must be less than or equal to **viewportBoundsRange[1]**

- **VUID-VkViewport-minDepth-01234**
  If the **VK_EXT_depth_range_unrestricted** extension is not enabled, \( \text{minDepth} \) must be between \( 0.0 \) and \( 1.0 \), inclusive

- **VUID-VkViewport-maxDepth-01235**
  If the **VK_EXT_depth_range_unrestricted** extension is not enabled, \( \text{maxDepth} \) must be between \( 0.0 \) and \( 1.0 \), inclusive
Chapter 28. Rasterization

Rasterization is the process by which a primitive is converted to a two-dimensional image. Each discrete location of this image contains associated data such as depth, color, or other attributes.

Rasterizing a primitive begins by determining which squares of an integer grid in framebuffer coordinates are occupied by the primitive, and assigning one or more depth values to each such square. This process is described below for points, lines, and polygons.

A grid square, including its (x,y) framebuffer coordinates, z (depth), and associated data added by fragment shaders, is called a fragment. A fragment is located by its upper left corner, which lies on integer grid coordinates.

Rasterization operations also refer to a fragment’s sample locations, which are offset by fractional values from its upper left corner. The rasterization rules for points, lines, and triangles involve testing whether each sample location is inside the primitive. Fragments need not actually be square, and rasterization rules are not affected by the aspect ratio of fragments. Display of non-square grids, however, will cause rasterized points and line segments to appear fatter in one direction than the other.

We assume that fragments are square, since it simplifies antialiasing and texturing. After rasterization, fragments are processed by fragment operations.

Several factors affect rasterization, including the members of VkPipelineRasterizationStateCreateInfo and VkPipelineMultisampleStateCreateInfo.

The VkPipelineRasterizationStateCreateInfo structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPipelineRasterizationStateCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkPipelineRasterizationStateCreateFlags flags;
    VkBool32 depthClampEnable;
    VkBool32 rasterizerDiscardEnable;
    VkPolygonMode polygonMode;
    VkCullModeFlags cullMode;
    VkFrontFace frontFace;
    VkBool32 depthBiasEnable;
    float depthBiasConstantFactor;
    float depthBiasClamp;
    float depthBiasSlopeFactor;
    float lineWidth;
} VkPipelineRasterizationStateCreateInfo;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `flags` is reserved for future use.
• **depthClampEnable** controls whether to clamp the fragment’s depth values as described in **Depth Test**. If the pipeline is not created with **VkPipelineRasterizationDepthClipStateCreateInfoEXT** present then enabling depth clamp will also disable clipping primitives to the z planes of the frustrum as described in **Primitive Clipping**. Otherwise depth clipping is controlled by the state set in **VkPipelineRasterizationDepthClipStateCreateInfoEXT**.

• **rasterizerDiscardEnable** controls whether primitives are discarded immediately before the rasterization stage.

• **polygonMode** is the triangle rendering mode. See **VkPolygonMode**.

• **cullMode** is the triangle facing direction used for primitive culling. See **VkCullModeFlagBits**.

• **frontFace** is a **VkFrontFace** value specifying the front-facing triangle orientation to be used for culling.

• **depthBiasEnable** controls whether to bias fragment depth values.

• **depthBiasConstantFactor** is a scalar factor controlling the constant depth value added to each fragment.

• **depthBiasClamp** is the maximum (or minimum) depth bias of a fragment.

• **depthBiasSlopeFactor** is a scalar factor applied to a fragment's slope in depth bias calculations.

• **lineWidth** is the width of rasterized line segments.

The application can also add a **VkPipelineRasterizationStateRasterizationOrderAMD** structure to the **pNext** chain of a **VkPipelineRasterizationStateCreateInfo** structure. This structure enables selecting the rasterization order to use when rendering with the corresponding graphics pipeline as described in **Rasterization Order**.

### Valid Usage

• VUID-VkPipelineRasterizationStateCreateInfo-depthClampEnable-00782
  If the **depthClamp** feature is not enabled, **depthClampEnable** must be **VK_FALSE**

• VUID-VkPipelineRasterizationStateCreateInfo-polygonMode-01507
  If the **fillModeNonSolid** feature is not enabled, **polygonMode** must be **VK_POLYGON_MODE_FILL**
  or **VK_POLYGON_MODE_FILL_RECTANGLE_NV**

• VUID-VkPipelineRasterizationStateCreateInfo-polygonMode-01414
  If the **VK_NV_fill_rectangle** extension is not enabled, **polygonMode** must not be
  **VK_POLYGON_MODE_FILL_RECTANGLE_NV**

• VUID-VkPipelineRasterizationStateCreateInfo-pointPolygons-04458
  If the **VK_KHR_portability_subset** extension is enabled, and
  **VkPhysicalDevicePortabilitySubsetFeaturesKHR::pointPolygons** is **VK_FALSE**, and
  **rasterizerDiscardEnable** is **VK_FALSE**, **polygonMode** must not be **VK_POLYGON_MODE_POINT**

### Valid Usage (Implicit)

• VUID-VkPipelineRasterizationStateCreateInfo-sType-sType
  **sType** must be **VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_STATE_CREATE_INFO**
Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkDepthBiasRepresentationInfoEXT`, `VkPipelineRasterizationConservativeStateCreateInfoEXT`, `VkPipelineRasterizationDepthClipStateCreateInfoEXT`, `VkPipelineRasterizationLineStateCreateInfoEXT`, `VkPipelineRasterizationProvokingVertexStateCreateInfoEXT`, `VkPipelineRasterizationStateRasterizationOrderAMD`, or `VkPipelineRasterizationStateStreamCreateInfoEXT`.

The `sType` value of each struct in the `pNext` chain must be unique.

Flags must be 0.

Polygon mode must be a valid `VkPolygonMode` value.

Cull mode must be a valid combination of `VkCullModeFlagBits` values.

Front face must be a valid `VkFrontFace` value.

`VkPipelineRasterizationStateCreateFlags` is a bitmask type for setting a mask, but is currently reserved for future use.

If the `pNext` chain of `VkPipelineRasterizationStateCreateInfo` includes a `VkPipelineRasterizationDepthClipStateCreateInfoEXT` structure, then that structure controls whether depth clipping is enabled or disabled.

The `VkPipelineRasterizationDepthClipStateCreateInfoEXT` structure is defined as:

```
// Provided by VK_EXT_depth_clip_enable
typedef struct VkPipelineRasterizationDepthClipStateCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkPipelineRasterizationDepthClipStateCreateFlagsEXT flags;
    VkBool32 depthClipEnable;
} VkPipelineRasterizationDepthClipStateCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is reserved for future use.
• **depthClipEnable** controls whether depth clipping is enabled as described in **Primitive Clipping**.

### Valid Usage (Implicit)

- **VUID-VkPipelineRasterizationDepthClipStateCreateInfoEXT-sType-sType**
  - **sType** must be **VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_DEPTH_CLIP_STATE_CREATE_INFO_EXT**

- **VUID-VkPipelineRasterizationDepthClipStateCreateInfoEXT-flags-zerobitmask**
  - **flags** must be 0

```c
// Provided by VK_EXT_depth_clip_enable
typedef VkFlags VkPipelineRasterizationDepthClipStateCreateInfoEXT;
```

**VkPipelineRasterizationDepthClipStateCreateInfoEXT** is a bitmask type for setting a mask, but is currently reserved for future use.

The **VkPipelineMultisampleStateCreateInfo** structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPipelineMultisampleStateCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkPipelineMultisampleStateCreateFlags flags;
    VkSampleCountFlagBits rasterizationSamples;
    VkBool32 sampleShadingEnable;
    float minSampleShading;
    const VkSampleMask* pSampleMask;
    VkBool32 alphaToCoverageEnable;
    VkBool32 alphaToOneEnable;
} VkPipelineMultisampleStateCreateInfo;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **rasterizationSamples** is a **VkSampleCountFlagBits** value specifying the number of samples used in rasterization. This value is ignored for the purposes of setting the number of samples used in rasterization if the pipeline is created with the **VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT** dynamic state set, but if **VK_DYNAMIC_STATE_SAMPLE_MASK_EXT** dynamic state is not set, it is still used to define the size of the **pSampleMask** array as described below.

- **sampleShadingEnable** can be used to enable **Sample Shading**.
- **minSampleShading** specifies a minimum fraction of sample shading if **sampleShadingEnable** is set to **VK_TRUE**.
- **pSampleMask** is a pointer to an array of **VkSampleMask** values used in the **sample mask test**.
• **alphaToCoverageEnable** controls whether a temporary coverage value is generated based on the alpha component of the fragment’s first color output as specified in the Multisample Coverage section.

• **alphaToOneEnable** controls whether the alpha component of the fragment’s first color output is replaced with one as described in Multisample Coverage.

Each bit in the sample mask is associated with a unique sample index as defined for the coverage mask. Each bit b for mask word w in the sample mask corresponds to sample index i, where i = 32 × w + b. pSampleMask has a length equal to \( \lceil \frac{\text{rasterizationSamples}}{32} \rceil \) words.

If pSampleMask is NULL, it is treated as if the mask has all bits set to 1.

### Valid Usage

- VUID-VkPipelineMultisampleStateCreateInfo-sampleShadingEnable-00784
  If the sampleRateShading feature is not enabled, sampleShadingEnable must be VK_FALSE

- VUID-VkPipelineMultisampleStateCreateInfo-alphaToOneEnable-00785
  If the alphaToOne feature is not enabled, alphaToOneEnable must be VK_FALSE

- VUID-VkPipelineMultisampleStateCreateInfo-minSampleShading-00786
  minSampleShading must be in the range [0,1]

- VUID-VkPipelineMultisampleStateCreateInfo-rasterizationSamples-01415
  If the VK_NV_framebuffer_mixed_samples extension is enabled, and if the subpass has any color attachments and rasterizationSamples is greater than the number of color samples, then sampleShadingEnable must be VK_FALSE

### Valid Usage (Implicit)

- VUID-VkPipelineMultisampleStateCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_PIPELINE_MULTISAMPLE_STATE_CREATE_INFO

- VUID-VkPipelineMultisampleStateCreateInfo-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkPipelineCoverageModulationStateCreateInfoNV, VkPipelineCoverageReductionStateCreateInfoNV, VkPipelineCoverageToColorStateCreateInfoNV, or VkPipelineSampleLocationsStateCreateInfoEXT

- VUID-VkPipelineMultisampleStateCreateInfo-sType-unique
  The sType value of each struct in the pNext chain must be unique

- VUID-VkPipelineMultisampleStateCreateInfo-flags-zerobitmask
  flags must be 0

- VUID-VkPipelineMultisampleStateCreateInfo-rasterizationSamples-parameter
  rasterizationSamples must be a valid VkSampleCountFlagBits value

- VUID-VkPipelineMultisampleStateCreateInfo-pSampleMask-parameter
  If pSampleMask is not NULL, pSampleMask must be a valid pointer to an array of
VkSampleMask values

// Provided by VK_VERSION_1_0
typedef VkFlags VkPipelineMultisampleStateCreateFlags;

VkPipelineMultisampleStateCreateFlags is a bitmask type for setting a mask, but is currently reserved for future use.

The elements of the sample mask array are of type VkSampleMask, each representing 32 bits of coverage information:

// Provided by VK_VERSION_1_0
typedef uint32_t VkSampleMask;

Rasterization only generates fragments which cover one or more pixels inside the framebuffer. Pixels outside the framebuffer are never considered covered in the fragment. Fragments which would be produced by application of any of the primitive rasterization rules described below but which lie outside the framebuffer are not produced, nor are they processed by any later stage of the pipeline, including any of the fragment operations.

Surviving fragments are processed by fragment shaders. Fragment shaders determine associated data for fragments, and can also modify or replace their assigned depth values.

28.1. Discarding Primitives Before Rasterization

Primitives are discarded before rasterization if the rasterizerDiscardEnable member of VkPipelineRasterizationStateCreateInfo is enabled. When enabled, primitives are discarded after they are processed by the last active shader stage in the pipeline before rasterization.

To dynamically enable whether primitives are discarded before the rasterization stage, call:

// Provided by VK_VERSION_1_3
void vkCmdSetRasterizerDiscardEnable(
    VkCommandBuffer commandBuffer,
    VkBool32 rasterizerDiscardEnable);

or the equivalent command

// Provided by VK_EXT_extended_dynamic_state2, VK_EXT_shader_object
void vkCmdSetRasterizerDiscardEnableEXT(
    VkCommandBuffer commandBuffer,
    VkBool32 rasterizerDiscardEnable);

• commandBuffer is the command buffer into which the command will be recorded.
• `rasterizerDiscardEnable` controls whether primitives are discarded immediately before the rasterization stage.

This command sets the discard enable for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineRasterizationStateCreateInfo::rasterizerDiscardEnable` value used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetRasterizerDiscardEnable-None-08970
  At least one of the following **must** be true:
  - the `extendedDynamicState2` feature is enabled
  - the `shaderObject` feature is enabled
  - the value of `VkApplicationInfo::apiVersion` used to create the `VkInstance` parent of `commandBuffer` is greater than or equal to Version 1.3

### Valid Usage (Implicit)

- VUID-vkCmdSetRasterizerDiscardEnable-commandBuffer-parameter
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- VUID-vkCmdSetRasterizerDiscardEnable-commandBuffer-recording
  `commandBuffer` **must** be in the recording state

- VUID-vkCmdSetRasterizerDiscardEnable-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics operations

- VUID-vkCmdSetRasterizerDiscardEnable-videocoding
  This command **must** only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` **must** be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized
28.2. Controlling the Vertex Stream Used for Rasterization

By default, vertex data output from the last pre-rasterization shader stage are directed to vertex stream zero. Geometry shaders can emit primitives to multiple independent vertex streams. Each vertex emitted by the geometry shader is directed at one of the vertex streams. As vertices are received on each vertex stream, they are arranged into primitives of the type specified by the geometry shader output primitive type. The shading language instructions `OpEndPrimitive` and `OpEndStreamPrimitive` can be used to end the primitive being assembled on a given vertex stream and start a new empty primitive of the same type. An implementation supports up to `VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackStreams` streams, which is at least 1. The individual streams are numbered 0 through `maxTransformFeedbackStreams` minus 1. There is no requirement on the order of the streams to which vertices are emitted, and the number of vertices emitted to each vertex stream can be completely independent, subject only to the `VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackStreamDataSize` and `VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackBufferDataSize` limits. The primitives output from all vertex streams are passed to the transform feedback stage to be captured to transform feedback buffers in the manner specified by the last pre-rasterization shader stage shader's `XfbBuffer`, `XfbStride`, and `Offsets` decorations on the output interface variables in the graphics pipeline. To use a vertex stream other than zero, or to use multiple streams, the `GeometryStreams` capability must be specified.

By default, the primitives output from vertex stream zero are rasterized. If the implementation supports the `VkPhysicalDeviceTransformFeedbackPropertiesEXT::transformFeedbackRasterizationStreamSelect` property it is possible to rasterize a vertex stream other than zero.

By default, geometry shaders that emit vertices to multiple vertex streams are limited to using only the `OutputPoints` output primitive type. If the implementation supports the `VkPhysicalDeviceTransformFeedbackPropertiesEXT::transformFeedbackStreamsLinesTriangles` property it is possible to emit `OutputLineStrip` or `OutputTriangleStrip` in addition to `OutputPoints`.

The vertex stream used for rasterization is specified by adding a `VkPipelineRasterizationStateStreamCreateInfoEXT` structure to the `pNext` chain of a `VkPipelineRasterizationStateCreateInfo` structure.

The `VkPipelineRasterizationStateStreamCreateInfoEXT` structure is defined as:
typedef struct VkPipelineRasterizationStateStreamCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkPipelineRasterizationStateStreamCreateFlagsEXT flags;
    uint32_t rasterizationStream;
} VkPipelineRasterizationStateStreamCreateInfoEXT;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is reserved for future use.
- `rasterizationStream` is the vertex stream selected for rasterization.

If this structure is not present, `rasterizationStream` is assumed to be zero.

Valid Usage

- VUID-VkPipelineRasterizationStateStreamCreateInfoEXT-geometryStreams-02324
  `VkPhysicalDeviceTransformFeedbackFeaturesEXT::geometryStreams` must be enabled
- VUID-VkPipelineRasterizationStateStreamCreateInfoEXT-rasterizationStream-02325
  `rasterizationStream` must be less than `VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackStreams`
- VUID-VkPipelineRasterizationStateStreamCreateInfoEXT-rasterizationStream-02326
  `rasterizationStream` must be zero if `VkPhysicalDeviceTransformFeedbackPropertiesEXT::transformFeedbackRasterizationStreamSelect` is `VK_FALSE`

Valid Usage (Implicit)

- VUID-VkPipelineRasterizationStateStreamCreateInfoEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_STATE_STREAM_CREATE_INFO_EXT`
- VUID-VkPipelineRasterizationStateStreamCreateInfoEXT-flags-zerobitmask
  `flags` must be 0

typedef VkFlags VkPipelineRasterizationStateStreamCreateFlagsEXT;

`VkPipelineRasterizationStateStreamCreateFlagsEXT` is a bitmask type for setting a mask, but is currently reserved for future use.

To dynamically set the `rasterizationStream` state, call:
void vkCmdSetRasterizationStreamEXT(
    VkCommandBuffer commandBuffer,
    uint32_t rasterizationStream);

- `commandBuffer` is the command buffer into which the command will be recorded.
- `rasterizationStream` specifies the `rasterizationStream` state.

This command sets the `rasterizationStream` state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream` value used to create the currently active pipeline.

### Valid Usage

- **VUID-vkCmdSetRasterizationStreamEXT-None-08550**
  Either the `extendedDynamicState3RasterizationStream` feature or the `shaderObject` feature or both **must** be enabled

- **VUID-vkCmdSetRasterizationStreamEXT-transformFeedback-07411**
  The `transformFeedback` feature **must** be enabled

- **VUID-vkCmdSetRasterizationStreamEXT-rasterizationStream-07412**
  `rasterizationStream` **must** be less than `VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackStreams`

- **VUID-vkCmdSetRasterizationStreamEXT-rasterizationStream-07413**
  `rasterizationStream` **must** be zero if `VkPhysicalDeviceTransformFeedbackPropertiesEXT::transformFeedbackRasterizationStreamSelect` is `VK_FALSE`

### Valid Usage (Implicit)

- **VUID-vkCmdSetRasterizationStreamEXT-commandBuffer-parameter**
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- **VUID-vkCmdSetRasterizationStreamEXT-commandBuffer-recording**
  `commandBuffer` **must** be in the recording state

- **VUID-vkCmdSetRasterizationStreamEXT-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics operations

- **VUID-vkCmdSetRasterizationStreamEXT-videocoding**
  This command **must** only be called outside of a video coding scope
Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics</td>
<td>State</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

28.3. Rasterization Order

Within a subpass of a render pass instance, for a given (x,y,layer,sample) sample location, the following operations are guaranteed to execute in rasterization order, for each separate primitive that includes that sample location:

1. Fragment operations, in the order defined
2. Blending, logic operations, and color writes

Execution of these operations for each primitive in a subpass occurs in an order determined by the application.

The rasterization order to use for a graphics pipeline is specified by adding a VkPipelineRasterizationStateRasterizationOrderAMD structure to the pNext chain of a VkPipelineRasterizationStateCreateInfo structure.

The VkPipelineRasterizationStateRasterizationOrderAMD structure is defined as:

```
// Provided by VK_AMD_rasterization_order
typedef struct VkPipelineRasterizationStateRasterizationOrderAMD {
    VkStructureType       sType;
    const void*           pNext;
    VkRasterizationOrderAMD  rasterizationOrder;
} VkPipelineRasterizationStateRasterizationOrderAMD;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **rasterizationOrder** is a VkRasterizationOrderAMD value specifying the primitive rasterization order to use.
Valid Usage (Implicit)

- VUID-VkPipelineRasterizationStateRasterizationOrderAMD-sType-sType
  sType must be VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_STATE_RASTERIZATION_ORDER_AMD
- VUID-VkPipelineRasterizationStateRasterizationOrderAMD-rasterizationOrder-parameter
  rasterizationOrder must be a valid VkRasterizationOrderAMD value

If the VK_AMD_rasterization_order device extension is not enabled or the application does not request a particular rasterization order through specifying a VkPipelineRasterizationStateRasterizationOrderAMD structure then the rasterization order used by the graphics pipeline defaults to VK_RASTERIZATION_ORDER_STRICT_AMD.

Possible values of VkPipelineRasterizationStateRasterizationOrderAMD::rasterizationOrder, specifying the primitive rasterization order, are:

```c
// Provided by VK_AMD_rasterization_order
typedef enum VkRasterizationOrderAMD {
    VK_RASTERIZATION_ORDER_STRICT_AMD = 0,
    VK_RASTERIZATION_ORDER_RELAXED_AMD = 1,
} VkRasterizationOrderAMD;
```

- VK_RASTERIZATION_ORDER_STRICT_AMD specifies that operations for each primitive in a subpass must occur in primitive order.
- VK_RASTERIZATION_ORDER_RELAXED_AMD specifies that operations for each primitive in a subpass may not occur in primitive order.

### 28.4. Multisampling

Multisampling is a mechanism to antialias all Vulkan primitives: points, lines, and polygons. The technique is to sample all primitives multiple times at each pixel. Each sample in each framebuffer attachment has storage for a color, depth, and/or stencil value, such that per-fragment operations apply to each sample independently. The color sample values can be later resolved to a single color (see Resolving Multisample Images and the Render Pass chapter for more details on how to resolve multisample images to non-multisample images).

Vulkan defines rasterization rules for single-sample modes in a way that is equivalent to a multisample mode with a single sample in the center of each fragment.

Each fragment includes a coverage mask with a single bit for each sample in the fragment, and a number of depth values and associated data for each sample.

It is understood that each pixel has rasterizationSamples locations associated with it. These locations are exact positions, rather than regions or areas, and each is referred to as a sample point. The sample points associated with a pixel must be located inside or on the boundary of the unit square that is considered to bound the pixel. Furthermore, the relative locations of sample points may be identical for each pixel in the framebuffer, or they may differ.
If the render pass has a fragment density map attachment, each fragment only has `rasterizationSamples` locations associated with it regardless of how many pixels are covered in the fragment area. Fragment sample locations are defined as if the fragment had an area of (1,1) and its sample points must be located within these bounds. Their actual location in the framebuffer is calculated by scaling the sample location by the fragment area. Attachments with storage for multiple samples per pixel are located at the pixel sample locations. Otherwise, the fragment’s sample locations are generally used for evaluation of associated data and fragment operations.

If the current pipeline includes a fragment shader with one or more variables in its interface decorated with `Sample` and `Input`, the data associated with those variables will be assigned independently for each sample. The values for each sample must be evaluated at the location of the sample. The data associated with any other variables not decorated with `Sample` and `Input` need not be evaluated independently for each sample.

A coverage mask is generated for each fragment, based on which samples within that fragment are determined to be within the area of the primitive that generated the fragment.

Single pixel fragments and multi-pixel fragments defined by a fragment density map have one set of samples. Multi-pixel fragments defined by a shading rate image have one set of samples per pixel. Multi-pixel fragments defined by setting the fragment shading rate have one set of samples per pixel. Each set of samples has a number of samples determined by `VkPipelineMultisampleStateCreateInfo::rasterizationSamples`. Each sample in a set is assigned a unique sample index `i` in the range `[0, rasterizationSamples)`. To dynamically set the `rasterizationSamples`, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
void vkCmdSetRasterizationSamplesEXT(
    VkCommandBuffer commandBuffer,
    VkSampleCountFlagBits rasterizationSamples);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `rasterizationSamples` specifies `rasterizationSamples`.

This command sets the `rasterizationSamples` for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineMultisampleStateCreateInfo::rasterizationSamples` value used to create the currently active pipeline.

**Valid Usage**

- VUID-vkCmdSetRasterizationSamplesEXT-None-08552
  Either the `extendedDynamicState3RasterizationSamples` feature or the `shaderObject` feature or both must be enabled
Valid Usage (Implicit)

- VUID-vkCmdSetRasterizationSamplesEXT-commandBuffer-parameter commandBuffer must be a valid VkCommandBuffer handle
- VUID-vkCmdSetRasterizationSamplesEXT-rasterizationSamples-parameter rasterizationSamples must be a valid VkSampleCountFlagBits value
- VUID-vkCmdSetRasterizationSamplesEXT-commandBuffer-recording commandBuffer must be in the recording state
- VUID-vkCmdSetRasterizationSamplesEXT-commandBuffer-cmdpool The VkCommandPool that commandBuffer was allocated from must support graphics operations
- VUID-vkCmdSetRasterizationSamplesEXT-videocoding This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

<table>
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<tr>
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<td>Graphics</td>
<td>State</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Each sample in a fragment is also assigned a unique coverage index $j$ in the range $[0, n \times \text{rasterizationSamples})$, where $n$ is the number of sets in the fragment. If the fragment contains a single set of samples, the coverage index is always equal to the sample index. If a shading rate image is used and a fragment covers multiple pixels, the coverage index is determined as defined by VkPipelineViewportCoarseSampleOrderStateCreateInfoNV or vkCmdSetCoarseSampleOrderNV.

If the fragment shading rate is set, the coverage index $j$ is determined as a function of the pixel index $p$, the sample index $i$, and the number of rasterization samples $r$ as:

$$j = i + r \times ((f_w \times f_h) - 1 - p)$$

where the pixel index $p$ is determined as a function of the pixel's framebuffer location $(x, y)$ and the fragment size $(f_w, f_h)$:
\[ p_x = x \mod f_w \]

\[ p_y = y \mod f_h \]

\[ p = p_x + (p_y \times f_w) \]

The table below illustrates the pixel index for multi-pixel fragments:

**Table 35. Pixel indices - 1 wide**

<table>
<thead>
<tr>
<th>1x1</th>
<th>1x2</th>
<th>1x4</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="1x1 Diagram" /></td>
<td><img src="image2" alt="1x2 Diagram" /></td>
<td><img src="image3" alt="1x4 Diagram" /></td>
</tr>
</tbody>
</table>

**Table 36. Pixel indices - 2 wide**

<table>
<thead>
<tr>
<th>2x1</th>
<th>2x2</th>
<th>2x4</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image4" alt="2x1 Diagram" /></td>
<td><img src="image5" alt="2x2 Diagram" /></td>
<td><img src="image6" alt="2x4 Diagram" /></td>
</tr>
</tbody>
</table>

**Table 37. Pixel indices - 4 wide**

<table>
<thead>
<tr>
<th>4x1</th>
<th>4x2</th>
<th>4x4</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image7" alt="4x1 Diagram" /></td>
<td><img src="image8" alt="4x2 Diagram" /></td>
<td><img src="image9" alt="4x4 Diagram" /></td>
</tr>
</tbody>
</table>
The coverage mask includes $B$ bits packed into $W$ words, defined as:

$$B = n \times \text{rasterizationSamples}$$

$$W = \lceil B/32 \rceil$$

Bit $b$ in coverage mask word $w$ is 1 if the sample with coverage index $j = 32 \times w + b$ is covered, and 0 otherwise.

If the `standardSampleLocations` member of `VkPhysicalDeviceLimits` is `VK_TRUE`, then the sample counts `VK_SAMPLE_COUNT_1_BIT`, `VK_SAMPLE_COUNT_2_BIT`, `VK_SAMPLE_COUNT_4_BIT`, `VK_SAMPLE_COUNT_8_BIT`, and `VK_SAMPLE_COUNT_16_BIT` have sample locations as listed in the following table, with the $i$th entry in the table corresponding to sample index $i$. `VK_SAMPLE_COUNT_32_BIT` and `VK_SAMPLE_COUNT_64_BIT` do not have standard sample locations. Locations are defined relative to an origin in the upper left corner of the fragment.
### Table 38. Standard sample locations

<table>
<thead>
<tr>
<th>Sample count</th>
<th>Sample Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VK_SAMPLE_COUNT_1_BIT</strong></td>
<td>(0.5,0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>VK_SAMPLE_COUNT_2_BIT</strong></td>
<td>(0.75,0.75)</td>
</tr>
<tr>
<td></td>
<td>(0.25,0.25)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>VK_SAMPLE_COUNT_4_BIT</strong></td>
<td>(0.375, 0.125)</td>
</tr>
<tr>
<td></td>
<td>(0.875, 0.375)</td>
</tr>
<tr>
<td></td>
<td>(0.125, 0.625)</td>
</tr>
<tr>
<td></td>
<td>(0.625, 0.875)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>VK_SAMPLE_COUNT_8_BIT</strong></td>
<td>(0.5625, 0.3125)</td>
</tr>
<tr>
<td></td>
<td>(0.4375, 0.6875)</td>
</tr>
<tr>
<td></td>
<td>(0.8125, 0.5625)</td>
</tr>
<tr>
<td></td>
<td>(0.3125, 0.1875)</td>
</tr>
<tr>
<td></td>
<td>(0.1875, 0.8125)</td>
</tr>
<tr>
<td></td>
<td>(0.625, 0.4375)</td>
</tr>
<tr>
<td></td>
<td>(0.6875, 0.9375)</td>
</tr>
<tr>
<td></td>
<td>(0.9375, 0.0625)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>VK_SAMPLE_COUNT_16_BIT</strong></td>
<td>(0.5625, 0.5625)</td>
</tr>
<tr>
<td></td>
<td>(0.4375, 0.3125)</td>
</tr>
<tr>
<td></td>
<td>(0.3125, 0.625)</td>
</tr>
<tr>
<td></td>
<td>(0.75, 0.4375)</td>
</tr>
<tr>
<td></td>
<td>(0.1875, 0.375)</td>
</tr>
<tr>
<td></td>
<td>(0.625, 0.8125)</td>
</tr>
<tr>
<td></td>
<td>(0.8125, 0.6875)</td>
</tr>
<tr>
<td></td>
<td>(0.6875, 0.1875)</td>
</tr>
<tr>
<td></td>
<td>(0.375, 0.875)</td>
</tr>
<tr>
<td></td>
<td>(0.5, 0.0625)</td>
</tr>
<tr>
<td></td>
<td>(0.25, 0.125)</td>
</tr>
<tr>
<td></td>
<td>(0.125, 0.75)</td>
</tr>
<tr>
<td></td>
<td>(0.0, 0.5)</td>
</tr>
<tr>
<td></td>
<td>(0.9375, 0.25)</td>
</tr>
<tr>
<td></td>
<td>(0.875, 0.9375)</td>
</tr>
<tr>
<td></td>
<td>(0.0625, 0.0)</td>
</tr>
</tbody>
</table>

Color images created with multiple samples per pixel use a compression technique where there are
two arrays of data associated with each pixel. The first array contains one element per sample where each element stores an index to the second array defining the fragment mask of the pixel. The second array contains one element per color fragment and each element stores a unique color value in the format of the image. With this compression technique it is not always necessary to actually use unique storage locations for each color sample: when multiple samples share the same color value the fragment mask may have two samples referring to the same color fragment. The number of color fragments is determined by the samples member of the VkImageCreateInfo structure used to create the image. The VK_AMD_shader_fragment_mask device extension provides shader instructions enabling the application to get direct access to the fragment mask and the individual color fragment values.

![Figure 19. Fragment Mask]

28.5. Custom Sample Locations

Applications can also control the sample locations used for rasterization.

If the pNext chain of the VkPipelineMultisampleStateCreateInfo structure specified at pipeline creation time includes a VkPipelineSampleLocationsStateCreateInfoEXT structure, then that structure controls the sample locations used when rasterizing primitives with the pipeline.

The VkPipelineSampleLocationsStateCreateInfoEXT structure is defined as:

```c
// Provided by VK_EXT_sample_locations
typedef struct VkPipelineSampleLocationsStateCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkBool32 sampleLocationsEnable;
    VkSampleLocationsInfoEXT sampleLocationsInfo;
} VkPipelineSampleLocationsStateCreateInfoEXT;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **sampleLocationsEnable** controls whether custom sample locations are used. If sampleLocationsEnable is VK_FALSE, the default sample locations are used and the values specified in sampleLocationsInfo are ignored.
- **sampleLocationsInfo** is the sample locations to use during rasterization if sampleLocationsEnable is VK_TRUE and the graphics pipeline is not created with VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT.
Valid Usage (Implicit)

- VUID-VkPipelineSampleLocationsStateCreateInfoEXT-sType-sType
  *sType* must be *VK_STRUCTURE_TYPE_PIPELINE_SAMPLE_LOCATIONS_STATE_CREATE_INFO_EXT*

- VUID-VkPipelineSampleLocationsStateCreateInfoEXT-sampleLocationsInfo-parameter
  *sampleLocationsInfo* must be a valid *VkSampleLocationsInfoEXT* structure

The *VkSampleLocationsInfoEXT* structure is defined as:

```c
// Provided by VK_EXT_sample_locations
typedef struct VkSampleLocationsInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkSampleCountFlagBits sampleLocationsPerPixel;
    VkExtent2D sampleLocationGridSize;
    uint32_t sampleLocationsCount;
    const VkSampleLocationEXT* pSampleLocations;
} VkSampleLocationsInfoEXT;
```

- *sType* is a *VkStructureType* value identifying this structure.
- *pNext* is NULL or a pointer to a structure extending this structure.
- *sampleLocationsPerPixel* is a *VkSampleCountFlagBits* value specifying the number of sample locations per pixel.
- *sampleLocationGridSize* is the size of the sample location grid to select custom sample locations for.
- *sampleLocationsCount* is the number of sample locations in *pSampleLocations*.
- *pSampleLocations* is a pointer to an array of *sampleLocationsCount* *VkSampleLocationEXT* structures.

This structure can be used either to specify the sample locations to be used for rendering or to specify the set of sample locations an image subresource has been last rendered with for the purposes of layout transitions of depth/stencil images created with *VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT*.

The sample locations in *pSampleLocations* specify *sampleLocationsPerPixel* number of sample locations for each pixel in the grid of the size specified in *sampleLocationGridSize*. The sample location for sample *i* at the pixel grid location *(x,y)* is taken from *pSampleLocations*[(x + y × sampleLocationGridSize.width) × sampleLocationsPerPixel + i].

If the render pass has a fragment density map, the implementation will choose the sample locations for the fragment and the contents of *pSampleLocations* may be ignored.
Valid Usage

• VUID-VkSampleLocationsInfoEXT-sampleLocationsPerPixel-01526
  sampleLocationsPerPixel must be a bit value that is set in
  VkPhysicalDeviceSampleLocationsPropertiesEXT::sampleLocationSampleCounts

• VUID-VkSampleLocationsInfoEXT-sampleLocationsCount-01527
  sampleLocationsCount must equal sampleLocationsPerPixel \times sampleLocationGridSize.width \times sampleLocationGridSize.height

Valid Usage (Implicit)

• VUID-VkSampleLocationsInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_SAMPLE_LOCATIONS_INFO_EXT

• VUID-VkSampleLocationsInfoEXT-pSampleLocations-parameter
  If sampleLocationsCount is not 0, pSampleLocations must be a valid pointer to an array of
  sampleLocationsCount VkSampleLocationEXT structures

The VkSampleLocationEXT structure is defined as:

```c
// Provided by VK_EXT_sample_locations
typedef struct VkSampleLocationEXT {
    float x;
    float y;
} VkSampleLocationEXT;
```

• x is the horizontal coordinate of the sample’s location.
• y is the vertical coordinate of the sample’s location.

The domain space of the sample location coordinates has an upper-left origin within the pixel in framebuffer space.

The values specified in a VkSampleLocationEXT structure are always clamped to the implementation-dependent sample location coordinate range \([sampleLocationCoordinateRange[0], sampleLocationCoordinateRange[1]]\) that can be queried using VkPhysicalDeviceSampleLocationsPropertiesEXT.

To dynamically set the sampleLocationsEnable state, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
void vkCmdSetSampleLocationsEnableEXT(
    VkCommandBuffer commandBuffer,
    VkBool32 sampleLocationsEnable);
```

• commandBuffer is the command buffer into which the command will be recorded.
sampleLocationsEnable specifies the sampleLocationsEnable state.

This command sets the sampleLocationsEnable state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT set in VkPipelineDynamicStateCreateInfo::pDynamicStates. Otherwise, this state is specified by the VkPipelineSampleLocationsStateCreateInfo::sampleLocationsEnable value used to create the currently active pipeline.

Valid Usage

- VUID-vkCmdSetSampleLocationsEnableEXT-None-08554
  Either the extendedDynamicState3SampleLocationsEnable feature or the shaderObject feature or both must be enabled

Valid Usage (Implicit)

- VUID-vkCmdSetSampleLocationsEnableEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdSetSampleLocationsEnableEXT-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdSetSampleLocationsEnableEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdSetSampleLocationsEnableEXT-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary, Secondary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics</td>
<td>State</td>
</tr>
</tbody>
</table>

To dynamically set the sample locations used for rasterization, call:
// Provided by VK_EXT_sample_locations
void vkCmdSetSampleLocationsEXT(
    VkCommandBuffer commandBuffer,
    const VkSampleLocationsInfoEXT* pSampleLocationsInfo);

- `commandBuffer` is the command buffer into which the command will be recorded.
- `pSampleLocationsInfo` is the sample locations state to set.

This command sets the custom sample locations for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`, and when the `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` property of the bound graphics pipeline is `VK_TRUE`. Otherwise, this state is specified by the `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsInfo` values used to create the currently active pipeline.

### Valid Usage

- **VUID-vkCmdSetSampleLocationsEXT-variableSampleLocations-01530**
  If `VkPhysicalDeviceSampleLocationsPropertiesEXT::variableSampleLocations` is `VK_FALSE` then the current render pass must have been begun by specifying a `VkRenderPassSampleLocationsBeginInfoEXT` structure whose `pPostSubpassSampleLocations` member contains an element with a `subpassIndex` matching the current subpass index and the `sampleLocationsInfo` member of that element must match the sample locations state pointed to by `pSampleLocationsInfo`.

### Valid Usage (Implicit)

- **VUID-vkCmdSetSampleLocationsEXT-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- **VUID-vkCmdSetSampleLocationsEXT-pSampleLocationsInfo-parameter**
  `pSampleLocationsInfo` must be a valid pointer to a valid `VkSampleLocationsInfoEXT` structure.

- **VUID-vkCmdSetSampleLocationsEXT-commandBuffer-recording**
  `commandBuffer` must be in the recording state.

- **VUID-vkCmdSetSampleLocationsEXT-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations.

- **VUID-vkCmdSetSampleLocationsEXT-videocoding**
  This command must only be called outside of a video coding scope.
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics</td>
<td>State</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

28.6. Fragment Shading Rates

The features advertised by `VkPhysicalDeviceFragmentShadingRateFeaturesKHR` allow an application to control the shading rate of a given fragment shader invocation.

The fragment shading rate strongly interacts with Multisampling, and the set of available rates for an implementation may be restricted by sample rate.

To query available shading rates, call:

```c
// Provided by VK_KHR_fragment_shading_rate
VkResult vkGetPhysicalDeviceFragmentShadingRatesKHR(
    VkPhysicalDevice physicalDevice,  // Provided by VK_KHR_fragment_shading_rate
    uint32_t* pFragmentShadingRateCount, // Provided by VK_KHR_fragment_shading_rate
    VkPhysicalDeviceFragmentShadingRateKHR* pFragmentShadingRates);
```

- `physicalDevice` is the handle to the physical device whose properties will be queried.
- `pFragmentShadingRateCount` is a pointer to an integer related to the number of fragment shading rates available or queried, as described below.
- `pFragmentShadingRates` is either `NULL` or a pointer to an array of `VkPhysicalDeviceFragmentShadingRateKHR` structures.

If `pFragmentShadingRates` is `NULL`, then the number of fragment shading rates available is returned in `pFragmentShadingRateCount`. Otherwise, `pFragmentShadingRateCount` must point to a variable set by the user to the number of elements in the `pFragmentShadingRates` array, and on return the variable is overwritten with the number of structures actually written to `pFragmentShadingRates`. If `pFragmentShadingRateCount` is less than the number of fragment shading rates available, at most `pFragmentShadingRateCount` structures will be written, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available fragment shading rates were returned.
The returned array of fragment shading rates must be ordered from largest \( \text{fragmentSize.width} \) value to smallest, and each set of fragment shading rates with the same \( \text{fragmentSize.width} \) value must be ordered from largest \( \text{fragmentSize.height} \) to smallest. Any two entries in the array must not have the same \( \text{fragmentSize} \) values.

For any entry in the array, the following rules also apply:

- The value of \( \text{fragmentSize.width} \) must be less than or equal to \( \text{maxFragmentSize.width} \).
- The value of \( \text{fragmentSize.width} \) must be greater than or equal to 1.
- The value of \( \text{fragmentSize.width} \) must be a power-of-two.
- The value of \( \text{fragmentSize.height} \) must be less than or equal to \( \text{maxFragmentSize.height} \).
- The value of \( \text{fragmentSize.height} \) must be greater than or equal to 1.
- The value of \( \text{fragmentSize.height} \) must be a power-of-two.
- The highest sample count in \( \text{sampleCounts} \) must be less than or equal to \( \text{maxFragmentShadingRateRasterizationSamples} \).
- The product of \( \text{fragmentSize.width} \), \( \text{fragmentSize.height} \), and the highest sample count in \( \text{sampleCounts} \) must be less than or equal to \( \text{maxFragmentShadingRateCoverageSamples} \).

Implementations must support at least the following shading rates:

<table>
<thead>
<tr>
<th>( \text{sampleCounts} )</th>
<th>( \text{fragmentSize} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_SAMPLE_COUNT_1_BIT</td>
<td>2,2</td>
</tr>
<tr>
<td>VK_SAMPLE_COUNT_4_BIT</td>
<td>2,1</td>
</tr>
<tr>
<td>~0</td>
<td>1,1</td>
</tr>
</tbody>
</table>

If \( \text{framebufferColorSampleCounts} \), includes VK\_SAMPLE\_COUNT\_2\_BIT, the required rates must also include VK\_SAMPLE\_COUNT\_2\_BIT.

Note

Including the \( \{1,1\} \) fragment size is done for completeness; it has no actual effect on the support of rendering without setting the fragment size. All sample counts and render pass transforms are supported for this rate.

The returned set of fragment shading rates must be returned in the native (rotated) coordinate system. For rasterization using render pass transform not equal to VK\_SURFACE\_TRANSFORM\_IDENTITY\_BIT\_KHR, the application must transform the returned fragment shading rates into the current (unrotated) coordinate system to get the supported rates for that transform.

Note

For example, consider an implementation returning support for 4x2, but not 2x4 in the set of supported fragment shading rates. This means that for transforms VK\_SURFACE\_TRANSFORM\_ROTATE\_90\_BIT\_KHR and VK\_SURFACE\_TRANSFORM\_ROTATE\_270\_BIT\_KHR, 2x4 is a supported rate, but 4x2 is an
Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceFragmentShadingRatesKHR-physicalDevice-parameter
  physicalDevice must be a valid VkPhysicalDevice handle

- VUID-vkGetPhysicalDeviceFragmentShadingRatesKHR-pFragmentShadingRateCount-parameter
  pFragmentShadingRateCount must be a valid pointer to a uint32_t value

- VUID-vkGetPhysicalDeviceFragmentShadingRatesKHR-pFragmentShadingRates-parameter
  If the value referenced by pFragmentShadingRateCount is not 0, and pFragmentShadingRates is not NULL, pFragmentShadingRates must be a valid pointer to an array of pFragmentShadingRateCount VkPhysicalDeviceFragmentShadingRateKHR structures

Return Codes

Success
- VK_SUCCESS
- VK_INCOMPLETE

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY

The VkPhysicalDeviceFragmentShadingRateKHR structure is defined as

```c
// Provided by VK_KHR_fragment_shading_rate
typedef struct VkPhysicalDeviceFragmentShadingRateKHR {
    VkStructureType sType;
    void* pNext;
    VkSampleCountFlags sampleCounts;
    VkExtent2D fragmentSize;
} VkPhysicalDeviceFragmentShadingRateKHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- sampleCounts is a bitmask of sample counts for which the shading rate described by fragmentSize is supported.
- fragmentSize is a VkExtent2D describing the width and height of a supported shading rate.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceFragmentShadingRateKHR-sType-sType
Fragment shading rates can be set at three points, with the three rates combined to determine the final shading rate.

### 28.6.1. Pipeline Fragment Shading Rate

The pipeline fragment shading rate can be set on a per-draw basis by either setting the rate in a graphics pipeline, or dynamically via `vkCmdSetFragmentShadingRateKHR`.

The `VkPipelineFragmentShadingRateStateCreateInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_fragment_shading_rate
typedef struct VkPipelineFragmentShadingRateStateCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkExtent2D fragmentSize;
    VkFragmentShadingRateCombinerOpKHR combinerOps[2];
} VkPipelineFragmentShadingRateStateCreateInfoKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **fragmentSize** specifies a `VkExtent2D` structure containing the fragment size used to define the pipeline fragment shading rate for drawing commands using this pipeline.
- **combinerOps** specifies a `VkFragmentShadingRateCombinerOpKHR` value determining how the pipeline, primitive, and attachment shading rates are combined for fragments generated by drawing commands using the created pipeline.

If the `pNext` chain of `VkGraphicsPipelineCreateInfo` includes a `VkPipelineFragmentShadingRateStateCreateInfoKHR` structure, then that structure includes parameters controlling the pipeline fragment shading rate.

If this structure is not present, **fragmentSize** is considered to be equal to (1,1), and both elements of **combinerOps** are considered to be equal to `VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR`.

#### Valid Usage (Implicit)

- **VUID-VkPipelineFragmentShadingRateStateCreateInfoKHR-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_FRAGMENT_SHADING_RATE_STATE_CREATE_INFO_KHR`

To dynamically set the pipeline fragment shading rate and combiner operation, call:

```c
// Provided by VK_KHR_fragment_shading_rate
```
void vkCmdSetFragmentShadingRateKHR(
    VkCommandBuffer commandBuffer,
    const VkExtent2D* pFragmentSize,
    const VkFragmentShadingRateCombinerOpKHR combinerOps[2]);

• commandBuffer is the command buffer into which the command will be recorded.
• pFragmentSize specifies the pipeline fragment shading rate for subsequent drawing commands.
• combinerOps specifies a VkFragmentShadingRateCombinerOpKHR determining how the pipeline, primitive, and attachment shading rates are combined for fragments generated by subsequent drawing commands.

This command sets the pipeline fragment shading rate and combiner operation for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR set in VkPipelineDynamicStateCreateInfo::pDynamicStates. Otherwise, this state is specified by the VkPipelineFragmentShadingRateStateCreateInfoKHR values used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetFragmentShadingRateKHR-pipelineFragmentShadingRate-04507
  If pipelineFragmentShadingRate is not enabled, pFragmentSize->width must be 1

- VUID-vkCmdSetFragmentShadingRateKHR-primitiveFragmentShadingRate-04508
  If primitiveFragmentShadingRate is not enabled, pFragmentSize->height must be 1

- VUID-vkCmdSetFragmentShadingRateKHR-attachmentFragmentShadingRate-04509
  One of pipelineFragmentShadingRate, primitiveFragmentShadingRate, or attachmentFragmentShadingRate must be enabled

- VUID-vkCmdSetFragmentShadingRateKHR-attachmentFragmentShadingRateCombinerOp-04510
  If the primitiveFragmentShadingRate feature is not enabled, combinerOps[0] must be VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR

- VUID-vkCmdSetFragmentShadingRateKHR-attachmentFragmentShadingRateCombinerOp-04511
  If the attachmentFragmentShadingRate feature is not enabled, combinerOps[1] must be VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR

- VUID-vkCmdSetFragmentShadingRateKHR-fragmentSizeNonTrivialCombinerOps-04512
  If the fragmentSizeNonTrivialCombinerOps limit is not supported, elements of combinerOps must be either VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR or VK_FRAGMENT_SHADING_RATE_COMBINER_OP_REPLACE_KHR

- VUID-vkCmdSetFragmentShadingRateKHR-pFragmentSize-04513
  pFragmentSize->width must be greater than or equal to 1

- VUID-vkCmdSetFragmentShadingRateKHR-pFragmentSize-04514
  pFragmentSize->height must be greater than or equal to 1

- VUID-vkCmdSetFragmentShadingRateKHR-pFragmentSize-04515
  pFragmentSize->width must be a power-of-two value
• VUID-vkCmdSetFragmentShadingRateKHR-pFragmentSize-04516
  *pFragmentSize->height* must be a power-of-two value

• VUID-vkCmdSetFragmentShadingRateKHR-pFragmentSize-04517
  *pFragmentSize->width* must be less than or equal to 4

• VUID-vkCmdSetFragmentShadingRateKHR-pFragmentSize-04518
  *pFragmentSize->height* must be less than or equal to 4

**Valid Usage (Implicit)**

• VUID-vkCmdSetFragmentShadingRateKHR-commandBuffer-parameter
  *commandBuffer* must be a valid `VkCommandBuffer` handle

• VUID-vkCmdSetFragmentShadingRateKHR-pFragmentSize-parameter
  *pFragmentSize* must be a valid pointer to a valid `VkExtent2D` structure

• VUID-vkCmdSetFragmentShadingRateKHR-combinerOps-parameter
  Each element of *combinerOps* must be a valid `VkFragmentShadingRateCombinerOpKHR` value

• VUID-vkCmdSetFragmentShadingRateKHR-commandBuffer-recording
  *commandBuffer* must be in the recording state

• VUID-vkCmdSetFragmentShadingRateKHR-commandBuffer-cmdpool
  The `VkCommandPool` that *commandBuffer* was allocated from must support graphics operations

• VUID-vkCmdSetFragmentShadingRateKHR-videocoding
  This command must only be called outside of a video coding scope

**Host Synchronization**

• Host access to *commandBuffer* must be externally synchronized

• Host access to the `VkCommandPool` that *commandBuffer* was allocated from must be externally synchronized

**Command Properties**

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
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</tr>
</thead>
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<tr>
<td>Primary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics</td>
<td>State</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**28.6.2. Primitive Fragment Shading Rate**

The *primitive fragment shading rate* can be set via the `PrimitiveShadingRateKHR` built-in in the last
active pre-rasterization shader stage. If the last pre-rasterization shader stage is using the MeshEXT Execution Model, the rate associated with a given primitive is sourced from the value written to the per-primitive PrimitiveShadingRateKHR. Otherwise the rate associated with a given primitive is sourced from the value written to PrimitiveShadingRateKHR by that primitive’s provoking vertex.

28.6.3. Attachment Fragment Shading Rate

The attachment shading rate can be set by including VkFragmentShadingRateAttachmentInfoKHR in a subpass to define a fragment shading rate attachment. Each pixel in the framebuffer is assigned an attachment fragment shading rate by the corresponding texel in the fragment shading rate attachment, according to:

\[
x' = \text{floor}(x / \text{region}_x) \\
y' = \text{floor}(y / \text{region}_y)
\]

where \(x'\) and \(y'\) are the coordinates of a texel in the fragment shading rate attachment, \(x\) and \(y\) are the coordinates of the pixel in the framebuffer, and \(\text{region}_x\) and \(\text{region}_y\) are the size of the region each texel corresponds to, as defined by the shadingRateAttachmentTexelSize member of VkFragmentShadingRateAttachmentInfoKHR.

If multiview is enabled and the shading rate attachment has multiple layers, the shading rate attachment texel is selected from the layer determined by the ViewIndex built-in. If multiview is disabled, and both the shading rate attachment and the framebuffer have multiple layers, the shading rate attachment texel is selected from the layer determined by the Layer built-in. Otherwise, the texel is unconditionally selected from the first layer of the attachment.

The fragment size is encoded into the first component of the identified texel as follows:

\[
s_{\text{w}} = 2^{((\text{texel} / 4) \& 3)} \\
s_{\text{h}} = 2^{(\text{texel} \& 3)}
\]

where texel is the value in the first component of the identified texel, and \(s_{\text{w}}\) and \(s_{\text{h}}\) are the width and height of the fragment size, decoded from the texel.

If no fragment shading rate attachment is specified, this size is calculated as \(s_{\text{w}} = s_{\text{h}} = 1\). Applications must not specify a width or height greater than 4 by this method.

The Fragment Shading Rate enumeration in SPIR-V adheres to the above encoding.

28.6.4. Combining the Fragment Shading Rates

The final rate \((C_{xy}')\) used for fragment shading must be one of the rates returned by vkGetPhysicalDeviceFragmentShadingRatesKHR for the sample count and render pass transform
used by rasterization.

If any of the following conditions are met, $C_{xy}$ must be set to $\{1,1\}$:

- If Sample Shading is enabled.
- The `fragmentShadingRateWithSampleMask` limit is not supported, and `VkPipelineMultisampleStateCreateInfo::pSampleMask` contains a zero value in any bit used by fragment operations.
- The `fragmentShadingRateWithShaderSampleMask` is not supported, and the fragment shader has `SampleMask` in the input or output interface.
- The `fragmentShadingRateWithShaderDepthStencilWrites` limit is not supported, and the fragment shader declares the `FragDepth` or `FragStencilRefEXT` built-in.
- The `fragmentShadingRateWithConservativeRasterization` limit is not supported, and `VkPipelineRasterizationConservativeStateCreateInfoEXT::conservativeRasterizationMode` is not `VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT`.
- The `fragmentShadingRateWithFragmentShaderInterlock` limit is not supported, and the fragment shader declares any of the `fragment shader interlock` execution modes.
- The `fragmentShadingRateWithCustomSampleLocations` limit is not supported, and `VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable` is `VK_TRUE`.
- The fragment shader declares any of the `TileImageColorReadAccessEXT`, `TileImageDepthReadAccessEXT`, or `TileImageStencilReadAccessEXT` capabilities.

Otherwise, each of the specified shading rates are combined and then used to derive the value of $C_{xy}$. As there are three ways to specify shading rates, two combiner operations are specified - between the pipeline and primitive shading rates, and between the result of that and the attachment shading rate.

The equation used for each combiner operation is defined by `VkFragmentShadingRateCombinerOpKHR`:

```c
// Provided by VK_KHR_fragment_shading_rate
typedef enum VkFragmentShadingRateCombinerOpKHR {
    VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR = 0,
    VK_FRAGMENT_SHADING_RATE_COMBINER_OP_REPLACE_KHR = 1,
    VK_FRAGMENT_SHADING_RATE_COMBINER_OP_MIN_KHR = 2,
    VK_FRAGMENT_SHADING_RATE_COMBINER_OP_MAX_KHR = 3,
    VK_FRAGMENT_SHADING_RATE_COMBINER_OP_MUL_KHR = 4,
} VkFragmentShadingRateCombinerOpKHR;
```

- `VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR` specifies a combiner operation of $\text{combine}(A_{xy}, B_{xy}) = A_{xy}$.
- `VK_FRAGMENT_SHADING_RATE_COMBINER_OP_REPLACE_KHR` specifies a combiner operation of $\text{combine}(A_{xy}, B_{xy}) = B_{xy}$.
- `VK_FRAGMENT_SHADING_RATE_COMBINER_OP_MIN_KHR` specifies a combiner operation of $\text{combine}(A_{xy}, B_{xy}) = \min(A_{xy}, B_{xy})$. 

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• **VK_FRAGMENT_SHADING_RATE_COMBINER_OP_MAX_KHR** specifies a combiner operation of \( \text{combine}(A_{xy},B_{xy}) = \max(A_{xy},B_{xy}) \).

• **VK_FRAGMENT_SHADING_RATE_COMBINER_OP_MUL_KHR** specifies a combiner operation of \( \text{combine}(A_{xy},B_{xy}) = A_{xy} \cdot B_{xy} \).

where \( \text{combine}(A_{xy},B_{xy}) \) is the combine operation, and \( A_{xy} \) and \( B_{xy} \) are the inputs to the operation.

If \( \text{fragmentShadingRateStrictMultiplyCombiner} \) is \( \text{VK_FALSE} \), using **VK_FRAGMENT_SHADING_RATE_COMBINER_OP_MUL_KHR** with values of 1 for both \( A \) and \( B \) in the same dimension results in the value 2 being produced for that dimension. See the definition of **fragmentShadingRateStrictMultiplyCombiner** for more information.

These operations are performed in a component-wise fashion.

This is used to generate a combined fragment area using the equation:

\[
C_{xy} = \text{combine}(A_{xy},B_{xy})
\]

where \( C_{xy} \) is the combined fragment area result, and \( A_{xy} \) and \( B_{xy} \) are the fragment areas of the fragment shading rates being combined.

Two combine operations are performed, first with \( A_{xy} \) equal to the pipeline fragment shading rate and \( B_{xy} \) equal to the primitive fragment shading rate, with the combine() operation selected by combinerOps[0]. A second combination is then performed, with \( A_{xy} \) equal to the result of the first combination and \( B_{xy} \) equal to the attachment fragment shading rate, with the combine() operation selected by combinerOps[1]. The result of the second combination is used as the final fragment shading rate, reported via the **ShadingRateKHR** built-in.

Implementations should clamp the inputs to the combiner operations \( A_{xy} \) and \( B_{xy} \), and must clamp the result of the second combiner operation.

A fragment shading rate \( R_{xy} \) representing any of \( A_{xy}, B_{xy} \) or \( C_{xy} \) is clamped as follows. If \( R_{xy} \) is one of the rates returned by **vkGetPhysicalDeviceFragmentShadingRatesKHR** for the sample count and render pass transform used by rasterization, the clamped shading rate \( R_{xy}' \) is \( R_{xy} \). Otherwise, the clamped shading rate is selected from the rates returned by **vkGetPhysicalDeviceFragmentShadingRatesKHR** for the sample count and render pass transform used by rasterization. From this list of supported rates, the following steps are applied in order, to select a single value:

1. Keep only rates where \( R_{x}' \leq R_x \) and \( R_{y}' \leq R_y \).
   * Implementations may also keep rates where \( R_{x}' \leq R_y \) and \( R_{y}' \leq R_x \).
2. Keep only rates with the highest area (\( R_x' \times R_y' \)).
3. Keep only rates with the lowest aspect ratio (\( R_x' + R_y' \)).
4. In cases where a wide (e.g. 4x1) and tall (e.g. 1x4) rate remain, the implementation may choose either rate. However, it must choose this rate consistently for the same shading rates, render pass transform, and combiner operations for the lifetime of the **VkDevice**.
28.6.5. Extended Fragment Shading Rates

The features advertised by `VkPhysicalDeviceFragmentShadingRateEnumsFeaturesNV` provide support for additional fragment shading rates beyond those specifying one fragment shader invocation covering all pixels in a fragment whose size is indicated by the fragment shading rate.

If the `fragmentShadingRateEnums` feature is enabled, fragment shading rates may be specified using the `VkFragmentShadingRateNV` enumerated type defined as:

```c
// Provided by VK_NV_fragment_shading_rateEnums
typedef enum VkFragmentShadingRateNV {
    VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_PIXEL_NV = 0,
    VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_1X2_PIXELS_NV = 1,
    VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_2X1_PIXELS_NV = 4,
    VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_2X2_PIXELS_NV = 5,
    VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_2X4_PIXELS_NV = 6,
    VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_4X2_PIXELS_NV = 9,
    VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_4X4_PIXELS_NV = 10,
    VK_FRAGMENT_SHADING_RATE_2_INVOCATIONS_PER_PIXEL_NV = 11,
    VK_FRAGMENT_SHADING_RATE_4_INVOCATIONS_PER_PIXEL_NV = 12,
    VK_FRAGMENT_SHADING_RATE_8_INVOCATIONS_PER_PIXEL_NV = 13,
    VK_FRAGMENT_SHADING_RATE_16_INVOCATIONS_PER_PIXEL_NV = 14,
    VK_FRAGMENT_SHADING_RATE_NO_INVOCATIONS_NV = 15,
} VkFragmentShadingRateNV;
```

- `VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_PIXEL_NV` specifies a fragment size of 1x1 pixels.
- `VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_1X2_PIXELS_NV` specifies a fragment size of 1x2 pixels.
- `VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_2X1_PIXELS_NV` specifies a fragment size of 2x1 pixels.
- `VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_2X2_PIXELS_NV` specifies a fragment size of 2x2 pixels.
- `VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_2X4_PIXELS_NV` specifies a fragment size of 2x4 pixels.
- `VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_4X2_PIXELS_NV` specifies a fragment size of 4x2 pixels.
- `VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_4X4_PIXELS_NV` specifies a fragment size of 4x4 pixels.
- `VK_FRAGMENT_SHADING_RATE_2_INVOCATIONS_PER_PIXEL_NV` specifies a fragment size of 1x1 pixels, with two fragment shader invocations per fragment.
- `VK_FRAGMENT_SHADING_RATE_4_INVOCATIONS_PER_PIXEL_NV` specifies a fragment size of 1x1 pixels, with four fragment shader invocations per fragment.
- `VK_FRAGMENT_SHADING_RATE_8_INVOCATIONS_PER_PIXEL_NV` specifies a fragment size of 1x1 pixels, with eight fragment shader invocations per fragment.
• **VK_FRAGMENT_SHADING_RATE_16_INVOCATIONS_PER_PIXEL_NV** specifies a fragment size of 1x1 pixels, with sixteen fragment shader invocations per fragment.

• **VK_FRAGMENT_SHADING_RATE_NO_INVOCATIONS_NV** specifies that any portions of a primitive that use that shading rate should be discarded without invoking any fragment shader.

To use the shading rates **VK_FRAGMENT_SHADING_RATE_2_INVOCATIONS_PER_PIXEL_NV**, **VK_FRAGMENT_SHADING_RATE_4_INVOCATIONS_PER_PIXEL_NV**, **VK_FRAGMENT_SHADING_RATE_8_INVOCATIONS_PER_PIXEL_NV**, and **VK_FRAGMENT_SHADING_RATE_16_INVOCATIONS_PER_PIXEL_NV** as a pipeline, primitive, or attachment shading rate, the **supersampleFragmentShadingRates** feature must be enabled. To use the shading rate **VK_FRAGMENT_SHADING_RATE_NO_INVOCATIONS_NV** as a pipeline, primitive, or attachment shading rate, the **noInvocationFragmentShadingRates** feature must be enabled.

When using fragment shading rate enums, the pipeline fragment shading rate can be set on a per-draw basis by either setting the rate in a graphics pipeline, or dynamically via **vkCmdSetFragmentShadingRateEnumNV**.

The **VkPipelineFragmentShadingRateEnumStateCreateInfoNV** structure is defined as:

```
// Provided by VK_NV_fragment_shading_rateEnums
typedef struct VkPipelineFragmentShadingRateEnumStateCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkFragmentShadingRateTypeNV shadingRateType;
    VkFragmentShadingRateNV shadingRate;
    VkFragmentShadingRateCombinerOpKHR combinerOps[2];
} VkPipelineFragmentShadingRateEnumStateCreateInfoNV;
```

• **sType** is a **VkStructureType** value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **shadingRateType** specifies a **VkFragmentShadingRateTypeNV** value indicating whether fragment shading rates are specified using fragment sizes or **VkFragmentShadingRateNV** enums.

• **shadingRate** specifies a **VkFragmentShadingRateNV** value indicating the pipeline fragment shading rate.

• **combinerOps** specifies **VkFragmentShadingRateCombinerOpKHR** values determining how the pipeline, primitive, and attachment shading rates are combined for fragments generated by drawing commands using the created pipeline.

If the **pNext** chain of **VkGraphicsPipelineCreateInfo** includes a **VkPipelineFragmentShadingRateEnumStateCreateInfoNV** structure, then that structure includes parameters controlling the pipeline fragment shading rate.

If this structure is not present, **shadingRateType** is considered to be equal to **VK_FRAGMENT_SHADING_RATE_TYPE_FRAGMENT_SIZE_NV**, **shadingRate** is considered to be equal to **VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_PIXEL_NV**, and both elements of **combinerOps** are considered to be equal to **VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR**.
Valid Usage (Implicit)

- VUID-VkPipelineFragmentShadingRateEnumStateCreateInfoNV-sType-sType must be VK_STRUCTURE_TYPE_PIPELINE_FRAGMENT_SHADING_RATE_ENUM_STATE_CREATE_INFO_NV

The VkFragmentShadingRateTypeNV enumerated type specifies whether a graphics pipeline gets its pipeline fragment shading rates and combiners from the VkPipelineFragmentShadingRateEnumStateCreateInfoNV structure or the VkPipelineFragmentShadingRateStateCreateInfoKHR structure.

// Provided by VK_NV_fragment_shading_rateEnums
typedef enum VkFragmentShadingRateTypeNV {
    VK_FRAGMENT_SHADING_RATE_TYPE_FRAGMENT_SIZE_NV = 0,
    VK_FRAGMENT_SHADING_RATE_TYPE_ENUMS_NV = 1,
} VkFragmentShadingRateTypeNV;

- VK_FRAGMENT_SHADING_RATE_TYPE_FRAGMENT_SIZE_NV specifies that a graphics pipeline should obtain its pipeline fragment shading rate and shading rate combiner state from the VkPipelineFragmentShadingRateStateCreateInfoKHR structure and that any state specified by the VkPipelineFragmentShadingRateEnumStateCreateInfoNV structure should be ignored.

- VK_FRAGMENT_SHADING_RATE_TYPE_ENUMS_NV specifies that a graphics pipeline should obtain its pipeline fragment shading rate and shading rate combiner state from the VkPipelineFragmentShadingRateEnumStateCreateInfoNV structure and that any state specified by the VkPipelineFragmentShadingRateStateCreateInfoKHR structure should be ignored.

To dynamically set the pipeline fragment shading rate and combiner operation, call:

// Provided by VK_NV_fragment_shading_rateEnums
void vkCmdSetFragmentShadingRateEnumNV(
    VkCommandBuffer commandBuffer,
    VkFragmentShadingRateNV shadingRate,
    const VkFragmentShadingRateCombinerOpKHR combinerOps[2]);

- commandBuffer is the command buffer into which the command will be recorded.

- shadingRate specifies a VkFragmentShadingRateNV enum indicating the pipeline fragment shading rate for subsequent drawing commands.

- combinerOps specifies a VkFragmentShadingRateCombinerOpKHR determining how the pipeline, primitive, and attachment shading rates are combined for fragments generated by subsequent drawing commands.

This command sets the pipeline fragment shading rate and combiner operation for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR set in VkPipelineDynamicStateCreateInfo::pDynamicStates. Otherwise, this state is specified by the
VkPipelineFragmentShadingRateEnumStateCreateInfoNV values used to create the currently active pipeline.

**Note**

This command allows specifying additional shading rates beyond those supported by `vkCmdSetFragmentShadingRateKHR`. For more information, refer to the `VK_NV_fragment_shading_rate Enums` appendix.

---

**Valid Usage**

- **VUID-vkCmdSetFragmentShadingRateEnumNV-pipelineFragmentShadingRate-04576**
  
  If `pipelineFragmentShadingRate` is not enabled, `shadingRate` must be `VK_FRAGMENT_SHADING_RATE_1_INVOCATION_PER_PIXEL_NV`.

- **VUID-vkCmdSetFragmentShadingRateEnumNV-supersampleFragmentShadingRates-04577**
  
  If `supersampleFragmentShadingRates` is not enabled, `shadingRate` must not be `VK_FRAGMENT_SHADING_RATE_2_INVOCATIONS_PER_PIXEL_NV`, `VK_FRAGMENT_SHADING_RATE_4_INVOCATIONS_PER_PIXEL_NV`, `VK_FRAGMENT_SHADING_RATE_8_INVOCATIONS_PER_PIXEL_NV`, or `VK_FRAGMENT_SHADING_RATE_16_INVOCATIONS_PER_PIXEL_NV`.

- **VUID-vkCmdSetFragmentShadingRateEnumNV-noInvocationFragmentShadingRates-04578**
  
  If `noInvocationFragmentShadingRates` is not enabled, `shadingRate` must not be `VK_FRAGMENT_SHADING_RATE_NO_INVOCATIONS_NV`.

- **VUID-vkCmdSetFragmentShadingRateEnumNV-fragmentShadingRateEnums-04579**

  The `fragmentShadingRateEnums` feature must be enabled.

- **VUID-vkCmdSetFragmentShadingRateEnumNV-pipelineFragmentShadingRate-04580**

  One of the `pipelineFragmentShadingRate`, `primitiveFragmentShadingRate`, or `attachmentFragmentShadingRate` features must be enabled.

- **VUID-vkCmdSetFragmentShadingRateEnumNV-primitiveFragmentShadingRate-04581**

  If the `primitiveFragmentShadingRate` feature is not enabled, `combinerOps[0]` must be `VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR`.

- **VUID-vkCmdSetFragmentShadingRateEnumNV-attachmentFragmentShadingRate-04582**

  If the `attachmentFragmentShadingRate` feature is not enabled, `combinerOps[1]` must be `VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR`.

- **VUID-vkCmdSetFragmentShadingRateEnumNV-fragmentSizeNonTrivialCombinerOps-04583**

  If the `fragmentSizeNonTrivialCombinerOps` limit is not supported, elements of `combinerOps` must be either `VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR` or `VK_FRAGMENT_SHADING_RATE_COMBINER_OP_REPLACE_KHR`.
Valid Usage (Implicit)

- VUID-vkCmdSetFragmentShadingRateEnumNV-commandBuffer-parameter
  
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdSetFragmentShadingRateEnumNV-shadingRate-parameter
  
  shadingRate must be a valid VkFragmentShadingRateNV value

- VUID-vkCmdSetFragmentShadingRateEnumNV-combinerOps-parameter
  
  Each element of combinerOps must be a valid VkFragmentShadingRateCombinerOpKHR value

- VUID-vkCmdSetFragmentShadingRateEnumNV-commandBuffer-recording
  
  commandBuffer must be in the recording state

- VUID-vkCmdSetFragmentShadingRateEnumNV-commandBuffer-cmdpool
  
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdSetFragmentShadingRateEnumNV-videocoding
  
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

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When the supersampleFragmentShadingRates or noInvocationFragmentShadingRates features are enabled, the behavior of the shading rate combiner operations is extended to support the shading rates enabled by those features. Primitive and attachment shading rate values are interpreted as VkFragmentShadingRateNV values and the behavior of the combiners is modified as follows:

- For VK_FRAGMENT_SHADING_RATE_COMBINER_OP_MIN_KHR, VK_FRAGMENT_SHADING_RATE_COMBINER_OP_MAX_KHR, and VK_FRAGMENT_SHADING_RATE_COMBINER_OP_MUL_KHR, if either Axy or Bxy is VK_FRAGMENT_SHADING_RATE_NO_INVOCATIONS_NV, combine(Axy, Bxy) produces a shading rate of VK_FRAGMENT_SHADING_RATE_NO_INVOCATIONS_NV, regardless of the other input shading rate.

- For VK_FRAGMENT_SHADING_RATE_COMBINER_OP_MIN_KHR, combine(Axy, Bxy) produces a shading rate
whose fragment size is the smaller of the fragment sizes of $A_{xy}$ and $B_{xy}$ and whose invocation count is the larger of the invocation counts of $A_{xy}$ and $B_{xy}$.

- For `VK_FRAGMENT_SHADING_RATE_COMBINER_OP_MAX_KHR`, combine($A_{xy}$,$B_{xy}$) produces a shading rate whose fragment size is the larger of the fragment sizes of $A_{xy}$ and $B_{xy}$ and whose invocation count is the smaller of the invocation counts of $A_{xy}$ and $B_{xy}$.

- For `VK_FRAGMENT_SHADING_RATE_COMBINER_OP_MUL_KHR`, combine($A_{xy}$,$B_{xy}$) produces a shading rate whose fragment size and invocation count is the product of the fragment sizes and invocation counts, respectively, of $A_{xy}$ and $B_{xy}$. If the resulting shading rate has both multiple pixels and multiple invocations per fragment, an implementation may adjust the shading rate by reducing both the pixel and invocation counts.

If the final shading rate from the combiners is `VK_FRAGMENT_SHADING_RATE_NO_INVOCATIONS_NV`, no fragments will be generated for any portion of a primitive using that shading rate.

If the final shading rate from the combiners specifies multiple fragment shader invocations per fragment, the fragment will be processed with multiple unique samples as in sample shading, where the total number the total number of invocations is taken from the shading rate and then clamped to `rasterizationSamples` and `maxFragmentShadingRateInvocationCount`.

### 28.7. Shading Rate Image

The `shadingRateImage` feature allows pipelines to use a shading rate image to control the fragment area and the minimum number of fragment shader invocations launched for each fragment. When the shading rate image is enabled, the rasterizer determines a base shading rate for each region of the framebuffer covered by a primitive by fetching a value from the shading rate image and translating it to a shading rate using a per-viewport shading rate palette. This base shading rate is then adjusted to derive a final shading rate. The final shading rate specifies the fragment area and fragment shader invocation count to use for fragments generated in the region.

If the `pNext` chain of `VkPipelineViewportStateCreateInfo` includes a `VkPipelineViewportShadingRateImageStateCreateInfoNV` structure, then that structure includes parameters controlling the shading rate.

The `VkPipelineViewportShadingRateImageStateCreateInfoNV` structure is defined as:

```c
// Provided by VK_NV_shading_rate_image
typedef struct VkPipelineViewportShadingRateImageStateCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkBool32 shadingRateImageEnable;
    uint32_t viewportCount;
    const VkShadingRatePaletteNV* pShadingRatePalettes;
} VkPipelineViewportShadingRateImageStateCreateInfoNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
• shadingRateImageEnable specifies whether shading rate image and palettes are used during rasterization.

• viewportCount specifies the number of per-viewport palettes used to translate values stored in shading rate images.

• pShadingRatePalettes is a pointer to an array of VkShadingRatePaletteNV structures defining the palette for each viewport. If the shading rate palette state is dynamic, this member is ignored.

If this structure is not present, shadingRateImageEnable is considered to be VK_FALSE, and the shading rate image and palettes are not used.

Valid Usage

• VUID-VkPipelineViewportShadingRateImageStateCreateInfoNV-viewportCount-02054
If the multiViewport feature is not enabled, viewportCount must be 0 or 1

• VUID-VkPipelineViewportShadingRateImageStateCreateInfoNV-viewportCount-02055
viewportCount must be less than or equal to VkPhysicalDeviceLimits::maxViewports

• VUID-VkPipelineViewportShadingRateImageStateCreateInfoNV-shadingRateImageEnable-02056
If shadingRateImageEnable is VK_TRUE, viewportCount must be greater or equal to the viewportCount member of VkPipelineViewportStateCreateInfo

Valid Usage (Implicit)

• VUID-VkPipelineViewportShadingRateImageStateCreateInfoNV-sType-sType
sType must be VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_SHADING_RATE_IMAGE_STATE_CREATE_INFO_NV

When shading rate image usage is enabled in the bound pipeline, the pipeline uses a shading rate image specified by the command:

```c
void vkCmdBindShadingRateImageNV(
    VkCommandBuffer commandBuffer, 
    VkImageView imageView, 
    VkImageLayout imageLayout);
```

• commandBuffer is the command buffer into which the command will be recorded.

• imageView is an image view handle specifying the shading rate image. imageView may be set to VK_NULL_HANDLE, which is equivalent to specifying a view of an image filled with zero values.

• imageLayout is the layout that the image subresources accessible from imageView will be in when the shading rate image is accessed.
Valid Usage

- VUID-vkCmdBindShadingRateImageNV-None-02058
  The shadingRateImage feature **must** be enabled

- VUID-vkCmdBindShadingRateImageNV-imageView-02059
  If imageView is not VK_NULL_HANDLE, it **must** be a valid VkImageView handle of type VK_IMAGE_VIEW_TYPE_2D or VK_IMAGE_VIEW_TYPE_2D_ARRAY

- VUID-vkCmdBindShadingRateImageNV-imageView-02060
  If imageView is not VK_NULL_HANDLE, it **must** be a valid VkImageView handle of type VK_IMAGE_VIEW_TYPE_2D or VK_IMAGE_VIEW_TYPE_2D_ARRAY

- VUID-vkCmdBindShadingRateImageNV-imageView-02061
  If imageView is not VK_NULL_HANDLE, it **must** have a format of VK_FORMAT_R8_UINT

- VUID-vkCmdBindShadingRateImageNV-imageView-02062
  If imageView is not VK_NULL_HANDLE, it **must** have been created with a usage value including VK_IMAGE_USAGE_SHADING_RATE_IMAGE_BIT_NV

- VUID-vkCmdBindShadingRateImageNV-imageView-02063
  If imageView is not VK_NULL_HANDLE, it **must** have imageLayout match the actual VkImageLayout of each subresource accessible from imageView at the time the subresource is accessed

- VUID-vkCmdBindShadingRateImageNV-imageView-02064
  If imageView is not VK_NULL_HANDLE, imageLayout **must** be VK_IMAGE_LAYOUT_SHADING_RATE_OPTIMAL_NV or VK_IMAGE_LAYOUT_GENERAL

Valid Usage (Implicit)

- VUID-vkCmdBindShadingRateImageNV-commandBuffer-parameter
  commandBuffer **must** be a valid VkCommandBuffer handle

- VUID-vkCmdBindShadingRateImageNV-imageView-parameter
  If imageView is not VK_NULL_HANDLE, imageView **must** be a valid VkImageView handle

- VUID-vkCmdBindShadingRateImageNV-imageLayout-parameter
  imageLayout **must** be a valid VkImageLayout value

- VUID-vkCmdBindShadingRateImageNV-commandBuffer-recording
  commandBuffer **must** be in the recording state

- VUID-vkCmdBindShadingRateImageNV-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from **must** support graphics operations

- VUID-vkCmdBindShadingRateImageNV-videocoding
  This command **must** only be called outside of a video coding scope

- VUID-vkCmdBindShadingRateImageNV-commonparent
  Both of commandBuffer, and imageView that are valid handles of non-ignored parameters **must** have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

- Host access to commandBuffer **must** be externally synchronized
Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized.

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</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics</td>
<td>State</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

When the shading rate image is enabled in the current pipeline, rasterizing a primitive covering the pixel with coordinates \((x,y)\) will fetch a shading rate index value from the shading rate image bound by `vkCmdBindShadingRateImageNV`. If the shading rate image view has a type of `VK_IMAGE_VIEW_TYPE_2D`, the lookup will use texel coordinates \((u,v)\) where \(u = \lfloor \frac{x}{\text{tw} \times \text{th}} \rfloor\), \(v = \lfloor \frac{y}{\text{th}} \rfloor\), and \(\text{tw} \times \text{th}\) are the width and height of the implementation-dependent shading rate texel size. If the shading rate image view has a type of `VK_IMAGE_VIEW_TYPE_2D_ARRAY`, the lookup will use texel coordinates \((u,v)\) to extract a texel from the layer \(l\), where \(l\) is the layer of the framebuffer being rendered to. If \(l\) is greater than or equal to the number of layers in the image view, layer zero will be used.

If the bound shading rate image view is not `VK_NULL_HANDLE` and contains a texel with coordinates \((u,v)\) in layer \(l\) (if applicable), the single unsigned integer component for that texel will be used as the shading rate index. If the \((u,v)\) coordinate is outside the extents of the subresource used by the shading rate image view, or if the image view is `VK_NULL_HANDLE`, the shading rate index is zero. If the shading rate image view has multiple mipmap levels, the base level identified by `VkImageSubresourceRange::baseMipLevel` will be used.

A shading rate index is mapped to a base shading rate using a lookup table called the shading rate image palette. There is a separate palette for each viewport. The number of entries in each palette is given by the implementation-dependent shading rate image palette size.

To dynamically set the `shadingRateImageEnable` state, call:

```c
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_shading_rate_image,
// VK_EXT_shader_object with VK_NV_shading_rate_image
void vkCmdSetShadingRateImageEnableNV(
    VkCommandBuffer commandBuffer,
    VkBool32 shadingRateImageEnable);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `shadingRateImageEnable` specifies the `shadingRateImageEnable` state.

This command sets the `shadingRateImageEnable` state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV` set in `VkPipelineDynamicStateCreateInfo`.
Otherwise, this state is specified by the `VkPipelineViewportShadingRateImageStateCreateInfoNV::shadingRateImageEnable` value used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetShadingRateImageEnableNV-None-08556
  Either the `extendedDynamicState3ShadingRateImageEnable` feature or the `shaderObject` feature or both must be enabled

### Valid Usage (Implicit)

- VUID-vkCmdSetShadingRateImageEnableNV-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetShadingRateImageEnableNV-commandBuffer-recording
  `commandBuffer` must be in the recording state
- VUID-vkCmdSetShadingRateImageEnableNV-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations
- VUID-vkCmdSetShadingRateImageEnableNV-videocoding
  This command must only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

### Command Properties

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<thead>
<tr>
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<td></td>
</tr>
</tbody>
</table>

To **dynamically set** the per-viewport shading rate image palettes, call:

// Provided by VK_NV_shading_rate_image

```c
void vkCmdSetViewportShadingRatePaletteNV(
    VkCommandBuffer commandBuffer,
    uint32_t firstViewport,
);```
This command sets the per-viewport shading rate image palettes for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV set in VkPipelineDynamicStateCreateInfo::pDynamicStates. Otherwise, this state is specified by the VkPipelineViewportShadingRateImageStateCreateInfoNV::pShadingRatePalettes values used to create the currently active pipeline.

**Valid Usage**

- VUID-vkCmdSetViewportShadingRatePaletteNV-None-02064
  The shadingRateImage feature must be enabled

- VUID-vkCmdSetViewportShadingRatePaletteNV-firstViewport-02067
  The sum of firstViewport and viewportCount must be between 1 and VkPhysicalDeviceLimits::maxViewports, inclusive

- VUID-vkCmdSetViewportShadingRatePaletteNV-firstViewport-02068
  If the multiViewport feature is not enabled, firstViewport must be 0

- VUID-vkCmdSetViewportShadingRatePaletteNV-viewportCount-02069
  If the multiViewport feature is not enabled, viewportCount must be 1

**Valid Usage (Implicit)**

- VUID-vkCmdSetViewportShadingRatePaletteNV-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdSetViewportShadingRatePaletteNV-pShadingRatePalettes-parameter
  pShadingRatePalettes must be a valid pointer to an array of viewportCount valid VkShadingRatePaletteNV structures

- VUID-vkCmdSetViewportShadingRatePaletteNV-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdSetViewportShadingRatePaletteNV-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

Command Properties

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</tbody>
</table>

The `VkShadingRatePaletteNV` structure specifies the contents of a single shading rate image palette and is defined as:

```c
// Provided by VK_NV_shading_rate_image
typedef struct VkShadingRatePaletteNV {
    uint32_t shadingRatePaletteEntryCount;
    const VkShadingRatePaletteEntryNV* pShadingRatePaletteEntries;
} VkShadingRatePaletteNV;
```

- `shadingRatePaletteEntryCount` specifies the number of entries in the shading rate image palette.
- `pShadingRatePaletteEntries` is a pointer to an array of `VkShadingRatePaletteEntryNV` enums defining the shading rate for each palette entry.

Valid Usage

- VUID-VkShadingRatePaletteNV-shadingRatePaletteEntryCount-02071
  
  `shadingRatePaletteEntryCount` must be between 1 and `VkPhysicalDeviceShadingRateImagePropertiesNV::shadingRatePaletteSize`, inclusive.

Valid Usage (Implicit)

- VUID-VkShadingRatePaletteNV-pShadingRatePaletteEntries-parameter
  
  `pShadingRatePaletteEntries` must be a valid pointer to an array of
shadingRatePaletteEntryCount valid VkShadingRatePaletteEntryNV values

- VUID-VkShadingRatePaletteNV-shadingRatePaletteEntryCount-arraylength
shadingRatePaletteEntryCount must be greater than 0

To determine the base shading rate image, a shading rate index \( i \) is mapped to array element \( i \) in the array pShadingRatePaletteEntries for the palette corresponding to the viewport used for the fragment. If \( i \) is greater than or equal to the palette size shadingRatePaletteEntryCount, the base shading rate is undefined.

The supported shading rate image palette entries are defined by VkShadingRatePaletteEntryNV:

```c
// Provided by VK_NV_shading_rate_image
typedef enum VkShadingRatePaletteEntryNV {
    VK_SHADING_RATE_PALETTE_ENTRY_NO_INVOCATIONS_NV = 0,
    VK_SHADING_RATE_PALETTE_ENTRY_16_INVOCATIONS_PER_PIXEL_NV = 1,
    VK_SHADING_RATE_PALETTE_ENTRY_8_INVOCATIONS_PER_PIXEL_NV = 2,
    VK_SHADING_RATE_PALETTE_ENTRY_4_INVOCATIONS_PER_PIXEL_NV = 3,
    VK_SHADING_RATE_PALETTE_ENTRY_2_INVOCATIONS_PER_PIXEL_NV = 4,
    VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_PIXEL_NV = 5,
    VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_2X1_PIXELS_NV = 6,
    VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_1X2_PIXELS_NV = 7,
    VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_2X2_PIXELS_NV = 8,
    VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_4X2_PIXELS_NV = 9,
    VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_2X4_PIXELS_NV = 10,
    VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_4X4_PIXELS_NV = 11,
} VkShadingRatePaletteEntryNV;
```

The following table indicates the width and height (in pixels) of each fragment generated using the indicated shading rate, as well as the maximum number of fragment shader invocations launched for each fragment. When processing regions of a primitive that have a shading rate of VK_SHADING_RATE_PALETTE_ENTRY_NO_INVOCATIONS_NV, no fragments will be generated in that region.

<table>
<thead>
<tr>
<th>Shading Rate</th>
<th>Width</th>
<th>Height</th>
<th>Invocations</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_SHADING_RATE_PALETTE_ENTRY_NO_INVOCATIONS_NV</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>VK_SHADING_RATE_PALETTE_ENTRY_16_INVOCATIONS_PER_PIXEL_NV</td>
<td>1</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>VK_SHADING_RATE_PALETTE_ENTRY_8_INVOCATIONS_PER_PIXEL_NV</td>
<td>1</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>VK_SHADING_RATE_PALETTE_ENTRY_4_INVOCATIONS_PER_PIXEL_NV</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>VK_SHADING_RATE_PALETTE_ENTRY_2_INVOCATIONS_PER_PIXEL_NV</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
### Shading Rate

<table>
<thead>
<tr>
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<tr>
<td>VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_PIXEL_NV</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_2X1_PIXELS_NV</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_1X2_PIXELS_NV</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_2X2_PIXELS_NV</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_4X2_PIXELS_NV</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_2X4_PIXELS_NV</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_4X4_PIXELS_NV</td>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

When the shading rate image is disabled, a shading rate of VK_SHADING_RATE_PALETTE_ENTRY_1_INVOCATION_PER_PIXEL_NV will be used as the base shading rate.

Once a base shading rate has been established, it is adjusted to produce a final shading rate. First, if the base shading rate uses multiple pixels for each fragment, the implementation may reduce the fragment area to ensure that the total number of coverage samples for all pixels in a fragment does not exceed an implementation-dependent maximum.

If sample shading is active in the current pipeline and would result in processing \( n (n > 1) \) unique samples per fragment when the shading rate image is disabled, the shading rate is adjusted in an implementation-dependent manner to increase the number of fragment shader invocations spawned by the primitive. If the shading rate indicates \( f_s \) pixels per fragment and \( f_s \) is greater than \( n \), the fragment area is adjusted so each fragment has approximately \( f_s \frac{f}{n} \) pixels. Otherwise, if the shading rate indicates \( ipf \) invocations per fragment, the fragment area will be adjusted to a single pixel with approximately \( ipf \times \frac{f}{n} \) invocations per fragment.

If sample shading occurs due to the use of a fragment shader input variable decorated with SampleId or SamplePosition, the shading rate is ignored. Each fragment will have a single pixel and will spawn up to rasterizationSamples fragment shader invocations, as when using sample shading without a shading rate image.

Finally, if the shading rate specifies multiple fragment shader invocations per fragment, the total number of invocations in the shading rate is clamped to be no larger than rasterizationSamples.

When the final shading rate for a primitive covering pixel \((x,y)\) has a fragment area of \( fw \times fh \), the fragment for that pixel will cover all pixels with coordinates \((x',y')\) that satisfy the equations:
This combined fragment is considered to have multiple coverage samples; the total number of samples in this fragment is given by \( \text{samples} = \frac{fw \times fh \times rs}{f} \) where \( rs \) indicates the value of \text{VkPipelineMultisampleStateCreateInfo::rasterizationSamples} specified at pipeline creation time. The set of coverage samples in the fragment is the union of the per-pixel coverage samples in each of the fragment’s pixels. The location and order of coverage samples within each pixel in the combined fragment are assigned as described in Multisampling and Custom Sample Locations. Each coverage sample in the set of pixels belonging to the combined fragment is assigned a unique coverage index in the range \([0, \text{samples}-1]\). If the shadingRateCoarseSampleOrder feature is supported, the order of coverage samples can be specified for each combination of fragment area and coverage sample count. If this feature is not supported, the sample order is implementation-dependent.

If the \text{pNext} chain of \text{VkPipelineViewportStateCreateInfo} includes a \text{VkPipelineViewportCoarseSampleOrderStateCreateInfoNV} structure, then that structure includes parameters controlling the order of coverage samples in fragments larger than one pixel.

The \text{VkPipelineViewportCoarseSampleOrderStateCreateInfoNV} structure is defined as:

```c
typedef struct VkPipelineViewportCoarseSampleOrderStateCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkCoarseSampleOrderTypeNV sampleOrderType;
    uint32_t customSampleOrderCount;
    const VkCoarseSampleOrderCustomNV* pCustomSampleOrders;
} VkPipelineViewportCoarseSampleOrderStateCreateInfoNV;
```

- \text{sType} is a \text{VkStructureType} value identifying this structure.
- \text{pNext} is NULL or a pointer to a structure extending this structure.
- \text{sampleOrderType} specifies the mechanism used to order coverage samples in fragments larger than one pixel.
- \text{customSampleOrderCount} specifies the number of custom sample orderings to use when ordering coverage samples.
- \text{pCustomSampleOrders} is a pointer to an array of \text{customSampleOrderCount} \text{VkCoarseSampleOrderCustomNV} structures, each structure specifying the coverage sample order for a single combination of fragment area and coverage sample count.

If this structure is not present, \text{sampleOrderType} is considered to be \text{VK_COARSE_SAMPLE_ORDER_TYPE_DEFAULT_NV}.

If \text{sampleOrderType} is \text{VK_COARSE_SAMPLE_ORDER_TYPE_CUSTOM_NV}, the coverage sample order used for any combination of fragment area and coverage sample count not enumerated in
pCustomSampleOrders will be identical to that used for VK_COARSE_SAMPLE_ORDER_TYPE_DEFAULT_NV.

If the pipeline was created with VK_DYNAMIC_STATE_VIEWPORT_COARSE_SAMPLE_ORDER_NV, the contents of this structure (if present) are ignored, and the coverage sample order is instead specified by 
vkCmdSetCoarseSampleOrderNV.

### Valid Usage

- VUID-VkPipelineViewportCoarseSampleOrderStateCreateInfoNV-sampleOrderType-02072
  If sampleOrderType is not VK_COARSE_SAMPLE_ORDER_TYPE_CUSTOM_NV, customSamplerOrderCount must be 0

- VUID-VkPipelineViewportCoarseSampleOrderStateCreateInfoNV-pCustomSampleOrders-02234
  The array pCustomSampleOrders must not contain two structures with matching values for both the shadingRate and sampleCount members

### Valid Usage (Implicit)

- VUID-VkPipelineViewportCoarseSampleOrderStateCreateInfoNV-sType-sType must be VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_COARSE_SAMPLE_ORDER_STATE_CREATE_INFO_NV

- VUID-VkPipelineViewportCoarseSampleOrderStateCreateInfoNV-sampleOrderType-parameter sampleOrderType must be a valid VkCoarseSampleOrderTypeNV value

- VUID-VkPipelineViewportCoarseSampleOrderStateCreateInfoNV-pCustomSampleOrders-parameter If customSampleOrderCount is not 0, pCustomSampleOrders must be a valid pointer to an array of customSampleOrderCount valid VkCoarseSampleOrderCustomNV structures

The type VkCoarseSampleOrderTypeNV specifies the technique used to order coverage samples in fragments larger than one pixel, and is defined as:

```c
// Provided by VK_NV_shading_rate_image
typedef enum VkCoarseSampleOrderTypeNV {
    VK_COARSE_SAMPLE_ORDER_TYPE_DEFAULT_NV = 0,
    VK_COARSE_SAMPLE_ORDER_TYPE_CUSTOM_NV = 1,
    VK_COARSE_SAMPLE_ORDER_TYPE_PIXEL_MAJOR_NV = 2,
    VK_COARSE_SAMPLE_ORDER_TYPE_SAMPLE_MAJOR_NV = 3,
} VkCoarseSampleOrderTypeNV;
```

- VK_COARSE_SAMPLE_ORDER_TYPE_DEFAULT_NV specifies that coverage samples will be ordered in an implementation-dependent manner.

- VK_COARSE_SAMPLE_ORDER_TYPE_CUSTOM_NV specifies that coverage samples will be ordered according to the array of custom orderings provided in either the pCustomSampleOrders member
of VkPipelineViewportCoarseSampleOrderStateCreateInfoNV or the pCustomSampleOrders member of vkCmdSetCoarseSampleOrderNV.

- **VK_COARSE_SAMPLE_ORDER_TYPE_PIXEL_MAJOR_NV** specifies that coverage samples will be ordered sequentially, sorted first by pixel coordinate (in row-major order) and then by sample index.
- **VK_COARSE_SAMPLE_ORDER_TYPE_SAMPLE_MAJOR_NV** specifies that coverage samples will be ordered sequentially, sorted first by sample index and then by pixel coordinate (in row-major order).

When using a coarse sample order of **VK_COARSE_SAMPLE_ORDER_TYPE_PIXEL_MAJOR_NV** for a fragment with an upper-left corner of \((fx, fy)\) with a width of \(fw \times fh\) and \(fsc\) samples per pixel, coverage index \(cs\) of the fragment will be assigned to sample index \(fs\) of pixel \((px, py)\) as follows:

\[
px = fx + \left\lfloor \frac{\lfloor c \frac{s}{fsc} \% f w \}}{s} \right\rfloor \\
py = fy + \left\lfloor \frac{x}{w} \% f h \right\rfloor \\
fs = cs \% fsc
\]

When using a coarse sample order of **VK_COARSE_SAMPLE_ORDER_TYPE_SAMPLE_MAJOR_NV**, coverage index \(cs\) will be assigned as follows:

\[
px = fx + cs \% fw \\
py = fy + \left\lfloor \frac{x}{w} \% fh \right\rfloor \\
fs = \left\lfloor c \frac{s}{fw \times fh} \right\rfloor
\]

The **VkCoarseSampleOrderCustomNV** structure is used with a coverage sample ordering type of **VK_COARSE_SAMPLE_ORDER_TYPE_CUSTOM_NV** to specify the order of coverage samples for one combination of fragment width, fragment height, and coverage sample count.

```c
// Provided by VK_NV_shading_rate_image
typedef struct VkCoarseSampleOrderCustomNV {
    VkShadingRatePaletteEntryNV shadingRate;
    uint32_t sampleCount;
    uint32_t sampleLocationCount;
    const VkCoarseSampleLocationNV* pSampleLocations;
} VkCoarseSampleOrderCustomNV;
```

- **shadingRate** is a shading rate palette entry that identifies the fragment width and height for the combination of fragment area and per-pixel coverage sample count to control.
- **sampleCount** identifies the per-pixel coverage sample count for the combination of fragment area and coverage sample count to control.
- **sampleLocationCount** specifies the number of sample locations in the custom ordering.
- **pSampleLocations** is a pointer to an array of **VkCoarseSampleLocationNV** structures specifying the location of each sample in the custom ordering.
When using a custom sample ordering, element $j$ in $p\text{SampleLocations}$ specifies a specific pixel location and sample index that corresponds to coverage index $j$ in the multi-pixel fragment.

### Valid Usage

- **VUID-VkCoarseSampleOrderCustomNV-shadingRate-02073**
  
  shadingRate must be a shading rate that generates fragments with more than one pixel

- **VUID-VkCoarseSampleOrderCustomNV-sampleCount-02074**
  
  sampleCount must correspond to a sample count enumerated in $\text{VkSampleCountFlags}$ whose corresponding bit is set in $\text{VkPhysicalDeviceLimits::framebufferNoAttachmentsSampleCounts}$

- **VUID-VkCoarseSampleOrderCustomNV-sampleLocationCount-02075**
  
  sampleLocationCount must be equal to the product of sampleCount, the fragment width for shadingRate, and the fragment height for shadingRate

- **VUID-VkCoarseSampleOrderCustomNV-sampleLocationCount-02076**
  
  sampleLocationCount must be less than or equal to the value of $\text{VkPhysicalDeviceShadingRateImagePropertiesNV::shadingRateMaxCoarseSamples}$

- **VUID-VkCoarseSampleOrderCustomNV-pSampleLocations-02077**
  
  The array $p\text{SampleLocations}$ must contain exactly one entry for every combination of valid values for pixelX, pixelY, and sample in the structure $\text{VkCoarseSampleOrderCustomNV}$

### Valid Usage (Implicit)

- **VUID-VkCoarseSampleOrderCustomNV-shadingRate-parameter**
  
  shadingRate must be a valid $\text{VkShadingRatePaletteEntryNV}$ value

- **VUID-VkCoarseSampleOrderCustomNV-pSampleLocations-parameter**
  
  $p\text{SampleLocations}$ must be a valid pointer to an array of sampleLocationCount $\text{VkCoarseSampleLocationNV}$ structures

- **VUID-VkCoarseSampleOrderCustomNV-sampleLocationCount-arraylength**
  
  sampleLocationCount must be greater than 0

The $\text{VkCoarseSampleLocationNV}$ structure identifies a specific pixel and sample index for one of the coverage samples in a fragment that is larger than one pixel. This structure is defined as:

```c
// Provided by VK_NV_shading_rate_image
typedef struct VkCoarseSampleLocationNV {
    uint32_t pixelX;
    uint32_t pixelY;
    uint32_t sample;
} VkCoarseSampleLocationNV;
```

- pixelX is added to the x coordinate of the upper-leftmost pixel of each fragment to identify the pixel containing the coverage sample.
• `pixelY` is added to the y coordinate of the upper-leftmost pixel of each fragment to identify the pixel containing the coverage sample.

• `sample` is the number of the coverage sample in the pixel identified by `pixelX` and `pixelY`.

**Valid Usage**

- VUID-VkCoarseSampleLocationNV-pixelX-02078
  `pixelX` **must** be less than the width (in pixels) of the fragment

- VUID-VkCoarseSampleLocationNV-pixelY-02079
  `pixelY` **must** be less than the height (in pixels) of the fragment

- VUID-VkCoarseSampleLocationNV-sample-02080
  `sample` **must** be less than the number of coverage samples in each pixel belonging to the fragment

To **dynamically set** the order of coverage samples in fragments larger than one pixel, call:

```c
// Provided by VK_NV_shading_rate_image
void vkCmdSetCoarseSampleOrderNV(
    VkCommandBuffer commandBuffer,
    VkCoarseSampleOrderTypeNV sampleOrderType,
    uint32_t customSampleOrderCount,
    const VkCoarseSampleOrderCustomNV* pCustomSampleOrders);
```

- `commandBuffer` is the command buffer into which the command will be recorded.

- `sampleOrderType` specifies the mechanism used to order coverage samples in fragments larger than one pixel.

- `customSampleOrderCount` specifies the number of custom sample orderings to use when ordering coverage samples.

- `pCustomSampleOrders` is a pointer to an array of `VkCoarseSampleOrderCustomNV` structures, each structure specifying the coverage sample order for a single combination of fragment area and coverage sample count.

If `sampleOrderType` is `VK_COARSE_SAMPLE_ORDER_TYPE_CUSTOM_NV`, the coverage sample order used for any combination of fragment area and coverage sample count not enumerated in `pCustomSampleOrders` will be identical to that used for `VK_COARSE_SAMPLE_ORDER_TYPE_DEFAULT_NV`.

This command sets the order of coverage samples for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_VIEWPORT_COARSE_SAMPLE_ORDER_NV` set in `VkPipelineDynamicStateCreateInfo`::`pDynamicStates`. Otherwise, this state is specified by the `VkPipelineViewportCoarseSampleOrderStateCreateInfoNV` values used to create the currently active pipeline.
Valid Usage

• VUID-vkCmdSetCoarseSampleOrderNV-sampleOrderType-02081
  If `sampleOrderType` is not `VK_COARSE_SAMPLE_ORDER_TYPE_CUSTOM_NV`, `customSamplerOrderCount` must be 0

• VUID-vkCmdSetCoarseSampleOrderNV-pCustomSampleOrders-02235
  The array `pCustomSampleOrders` must not contain two structures with matching values for both the `shadingRate` and `sampleCount` members

Valid Usage (Implicit)

• VUID-vkCmdSetCoarseSampleOrderNV-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

• VUID-vkCmdSetCoarseSampleOrderNV-sampleOrderType-parameter
  `sampleOrderType` must be a valid `VkCoarseSampleOrderTypeNV` value

• VUID-vkCmdSetCoarseSampleOrderNV-pCustomSampleOrders-parameter
  If `customSampleOrderCount` is not 0, `pCustomSampleOrders` must be a valid pointer to an array of `customSampleOrderCount` valid `VkCoarseSampleOrderCustomNV` structures

• VUID-vkCmdSetCoarseSampleOrderNV-commandBuffer-recording
  `commandBuffer` must be in the `recording state`

• VUID-vkCmdSetCoarseSampleOrderNV-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations

• VUID-vkCmdSetCoarseSampleOrderNV-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

• Host access to `commandBuffer` must be externally synchronized

• Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
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</thead>
<tbody>
<tr>
<td>Primary Secondary</td>
<td>Both</td>
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</tr>
</tbody>
</table>

If the final shading rate for a primitive covering pixel \((x,y)\) results in \(n\) invocations per pixel \((n > 1)\),
Each coverage sample in the fragment will be assigned to one of the \( n \) fragment shader invocations in an implementation-dependent manner. The outputs from the fragment output interface of each shader invocation will be broadcast to all of the framebuffer samples associated with the invocation. If none of the coverage samples associated with a fragment shader invocation is covered by a primitive, the implementation may discard the fragment shader invocation for those samples.

If the final shading rate for a primitive covering pixel \((x, y)\) results in a fragment containing multiple pixels, a single set of fragment shader invocations will be generated for all pixels in the combined fragment. Outputs from the fragment output interface will be broadcast to all covered framebuffer samples belonging to the fragment. If the fragment shader executes code discarding the fragment, none of the samples of the fragment will be updated.

### 28.8. Sample Shading

Sample shading can be used to specify a minimum number of unique samples to process for each fragment. If sample shading is enabled, an implementation must invoke the fragment shader at least \( \text{max} (\lceil \text{VkPipelineMultisampleStateCreateInfo::minSampleShading} \times \text{VkPipelineMultisampleStateCreateInfo::rasterizationSamples} \rceil, 1) \) times per fragment. If \text{VkPipelineMultisampleStateCreateInfo::sampleShadingEnable} is set to \text{VK_TRUE}, sample shading is enabled.

If a fragment shader entry point statically uses an input variable decorated with a BuiltIn of SampleId or SamplePosition, sample shading is enabled and a value of 1.0 is used instead of minSampleShading. If a fragment shader entry point statically uses an input variable decorated with Sample, sample shading may be enabled and a value of 1.0 will be used instead of minSampleShading if it is. If the VK_AMD_mixed_attachment_samples extension is enabled and the subpass uses color attachments, the samples value used to create each color attachment is used instead of rasterizationSamples.

#### Note

If a shader decorates an input variable with Sample and that value meaningfully impacts the output of a shader, sample shading will be enabled to ensure that the input is in fact interpolated per-sample. This is inherent to the specification and not spelled out here - if an application simply declares such a variable it is implementation-defined whether sample shading is enabled or not. It is possible to see the effects of this by using atomics in the shader or using a pipeline statistics query to query the number of fragment invocations, even if the shader itself does not use any per-sample variables.

If there are fewer fragment invocations than covered samples, implementations may include those samples in fragment shader invocations in any manner as long as covered samples are all shaded at least once, and each invocation that is not a helper invocation covers at least one sample.

### 28.9. Barycentric Interpolation

When the fragmentShaderBarycentric feature is enabled, the PerVertexKHR interpolation decoration
can be used with fragment shader inputs to indicate that the decorated inputs do not have associated data in the fragment. Such inputs can only be accessed in a fragment shader using an array index whose value (0, 1, or 2) identifies one of the vertices of the primitive that produced the fragment. Reads of per-vertex values for missing vertices, such as the third vertex of a line primitive, will return values from the valid vertex with the highest index. This means that the per-vertex values of indices 1 and 2 for point primitives will be equal to those of index 0, and the per-vertex values of index 2 for line primitives will be equal to those of index 1.

When tessellation, geometry shading, and mesh shading are not active, fragment shader inputs decorated with PerVertexKHR will take values from one of the vertices of the primitive that produced the fragment, identified by the extra index provided in SPIR-V code accessing the input. If the \( n \) vertices passed to a draw call are numbered 0 through \( n-1 \), and the point, line, and triangle primitives produced by the draw call are numbered with consecutive integers beginning with zero, the following table indicates the original vertex numbers used when the provoking vertex mode is VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT for index values of 0, 1, and 2. If an input decorated with PerVertexKHR is accessed with any other vertex index value, or is accessed while rasterizing a polygon when the VkPipelineRasterizationStateCreateInfo::polygonMode property of the currently active pipeline is not VK_POLYGON_MODE_FILL, an undefined value is returned.

<table>
<thead>
<tr>
<th>Primitive Topology</th>
<th>Vertex 0</th>
<th>Vertex 1</th>
<th>Vertex 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_POINT_LIST</td>
<td>( i )</td>
<td>( i )</td>
<td>( i )</td>
</tr>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_LINE_LIST</td>
<td>( 2i )</td>
<td>( 2i+1 )</td>
<td>( 2i+1 )</td>
</tr>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_LINE_STRIP</td>
<td>( i )</td>
<td>( i+1 )</td>
<td>( i+1 )</td>
</tr>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST</td>
<td>( 3i )</td>
<td>( 3i+1 )</td>
<td>( 3i+2 )</td>
</tr>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP (even)</td>
<td>( i )</td>
<td>( i+1 )</td>
<td>( i+2 )</td>
</tr>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP (odd)</td>
<td>( i )</td>
<td>( i+2 )</td>
<td>( i+1 )</td>
</tr>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN</td>
<td>( i+1 )</td>
<td>( i+2 )</td>
<td>( 0 )</td>
</tr>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_LINE_LIST_WITH_ADJACENCY</td>
<td>( 4i+1 )</td>
<td>( 4i+2 )</td>
<td>( 4i+2 )</td>
</tr>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_LINE_STRIP_WITH_ADJACENCY</td>
<td>( i+1 )</td>
<td>( i+2 )</td>
<td>( i+2 )</td>
</tr>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST_WITH_ADJACENCY</td>
<td>( 6i )</td>
<td>( 6i+2 )</td>
<td>( 6i+4 )</td>
</tr>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP_WITH_ADJACENCY (even)</td>
<td>( 2i )</td>
<td>( 2i+2 )</td>
<td>( 2i+4 )</td>
</tr>
<tr>
<td>Primitive Topology</td>
<td>Vertex 0</td>
<td>Vertex 1</td>
<td>Vertex 2</td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP_WITH_ADJACENCY (odd)</td>
<td>2i</td>
<td>2i+4</td>
<td>2i+2</td>
</tr>
</tbody>
</table>

When the provoking vertex mode is VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT, the original vertex numbers used are the same as above except as indicated in the table below.

<table>
<thead>
<tr>
<th>Primitive Topology</th>
<th>Vertex 0</th>
<th>Vertex 1</th>
<th>Vertex 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP (odd, and triStripVertexOrderIndependentOfProvokingVertex of VkPhysicalDeviceFragmentShaderBarycentricPropertiesKHR is VK_FALSE)</td>
<td>i+1</td>
<td>i</td>
<td>i+2</td>
</tr>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN</td>
<td>0</td>
<td>i+1</td>
<td>i+2</td>
</tr>
<tr>
<td>VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP_WITH_ADJACENCY (odd)</td>
<td>2i+2</td>
<td>2i</td>
<td>2i+4</td>
</tr>
</tbody>
</table>

When geometry or mesh shading is active, primitives processed by fragment shaders are assembled from the vertices emitted by the geometry or mesh shader. In this case, the vertices used for fragment shader inputs decorated with PerVertexKHR are derived by treating the primitives produced by the shader as though they were specified by a draw call and consulting the table above.

When using tessellation without geometry shading, the tessellator produces primitives in an implementation-dependent manner. While there is no defined vertex ordering for inputs decorated with PerVertexKHR, the vertex ordering used in this case will be consistent with the ordering used to derive the values of inputs decorated with BaryCoordKHR or BaryCoordNoPerspKHR.

Fragment shader inputs decorated with BaryCoordKHR or BaryCoordNoPerspKHR hold three-component vectors with barycentric weights that indicate the location of the fragment relative to the screen-space locations of vertices of its primitive. For point primitives, such variables are always assigned the value (1,0,0). For line primitives, the built-ins are obtained by interpolating an attribute whose values for the vertices numbered 0 and 1 are (1,0,0) and (0,1,0), respectively. For polygon primitives, the built-ins are obtained by interpolating an attribute whose values for the vertices numbered 0, 1, and 2 are (1,0,0), (0,1,0), and (0,0,1), respectively. For BaryCoordKHR, the values are obtained using perspective interpolation. For BaryCoordNoPerspKHR, the values are obtained using linear interpolation. The values of BaryCoordKHR and BaryCoordNoPerspKHR are undefined while rasterizing a polygon when the VkPipelineRasterizationStateCreateInfo::polygonMode property of the currently active pipeline is not VK_POLYGON_MODE_FILL.
28.10. Points

A point is drawn by generating a set of fragments in the shape of a square centered around the vertex of the point. Each vertex has an associated point size controlling the width/height of that square. The point size is taken from the (potentially clipped) shader built-in PointSize written by:

- the geometry shader, if active;
- the tessellation evaluation shader, if active and no geometry shader is active;
- the vertex shader, otherwise

and clamped to the implementation-dependent point size range \([\text{pointSizeRange}[0], \text{pointSizeRange}[1]]\). The value written to PointSize **must** be greater than zero. If maintenance5 is enabled, and a value is not written to PointSize, the point size takes a default value of 1.0.

Not all point sizes need be supported, but the size 1.0 **must** be supported. The range of supported sizes and the size of evenly-spaced gradations within that range are implementation-dependent. The range and gradations are obtained from the pointSizeRange and pointSizeGranularity members of VkPhysicalDeviceLimits. If, for instance, the size range is from 0.1 to 2.0 and the gradation size is 0.1, then the sizes 0.1, 0.2, ..., 1.9, 2.0 are supported. Additional point sizes may also be supported. There is no requirement that these sizes be equally spaced. If an unsupported size is requested, the nearest supported size is used instead.

Further, if the render pass has a fragment density map attachment, point size may be rounded by the implementation to a multiple of the fragment's width or height.

28.10.1. Basic Point Rasterization

Point rasterization produces a fragment for each fragment area group of framebuffer pixels with one or more sample points that intersect a region centered at the point’s \((x_f,y_f)\). This region is a square with side equal to the current point size. Coverage bits that correspond to sample points that intersect the region are 1, other coverage bits are 0. All fragments produced in rasterizing a point are assigned the same associated data, which are those of the vertex corresponding to the point. However, the fragment shader built-in PointCoord contains point sprite texture coordinates. The s and t point sprite texture coordinates vary from zero to one across the point horizontally left-to-right and vertically top-to-bottom, respectively. The following formulas are used to evaluate s and t:

\[
\begin{align*}
    s &= \frac{1}{2} + \frac{(x_p - x_f)}{\text{size}} \\
    t &= \frac{1}{2} + \frac{(y_p - y_f)}{\text{size}}
\end{align*}
\]

where size is the point’s size; \((x_p,y_p)\) is the location at which the point sprite coordinates are evaluated - this may be the framebuffer coordinates of the fragment center, or the location of a sample; and \((x_f,y_f)\) is the exact, unrounded framebuffer coordinate of the vertex for the point.
28.11. Line Segments

Line segment rasterization options are controlled by the 
VkPipelineRasterizationLineStateCreateInfoEXT structure.

The `VkPipelineRasterizationLineStateCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_line_rasterization
typedef struct VkPipelineRasterizationLineStateCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkLineRasterizationModeEXT lineRasterizationMode;
    VkBool32 stippledLineEnable;
    uint32_t lineStippleFactor;
    uint16_t lineStipplePattern;
} VkPipelineRasterizationLineStateCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `lineRasterizationMode` is a `VkLineRasterizationModeEXT` value selecting the style of line rasterization.
- `stippledLineEnable` enables stippled line rasterization.
- `lineStippleFactor` is the repeat factor used in stippled line rasterization.
- `lineStipplePattern` is the bit pattern used in stippled line rasterization.

If `stippledLineEnable` is `VK_FALSE`, the values of `lineStippleFactor` and `lineStipplePattern` are ignored.

### Valid Usage

- VUID-VkPipelineRasterizationLineStateCreateInfoEXT-lineRasterizationMode-02768
  If `lineRasterizationMode` is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT`, then the `rectangularLines` feature **must** be enabled

- VUID-VkPipelineRasterizationLineStateCreateInfoEXT-lineRasterizationMode-02769
  If `lineRasterizationMode` is `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT`, then the `bresenhamLines` feature **must** be enabled

- VUID-VkPipelineRasterizationLineStateCreateInfoEXT-lineRasterizationMode-02770
  If `lineRasterizationMode` is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT`, then the `smoothLines` feature **must** be enabled

- VUID-VkPipelineRasterizationLineStateCreateInfoEXT-stippledLineEnable-02771
  If `stippledLineEnable` is `VK_TRUE` and `lineRasterizationMode` is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT`, then the `stippledRectangularLines` feature **must** be enabled

- VUID-VkPipelineRasterizationLineStateCreateInfoEXT-stippledLineEnable-02772
If `stippledLineEnable` is `VK_TRUE` and `lineRasterizationMode` is `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT`, then the `stippledBresenhamLines` feature must be enabled

- VUID-VkPipelineRasterizationLineStateCreateInfoEXT-stippledLineEnable-02773
  If `stippledLineEnable` is `VK_TRUE` and `lineRasterizationMode` is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT`, then the `stippledSmoothLines` feature must be enabled

- VUID-VkPipelineRasterizationLineStateCreateInfoEXT-stippledLineEnable-02774
  If `stippledLineEnable` is `VK_TRUE` and `lineRasterizationMode` is `VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT`, then the `stippledRectangularLines` feature must be enabled and `VkPhysicalDeviceLimits::strictLines` must be `VK_TRUE`

**Valid Usage (Implicit)**

- VUID-VkPipelineRasterizationLineStateCreateInfoEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_LINE_STATE_CREATE_INFO_EXT`

- VUID-VkPipelineRasterizationLineStateCreateInfoEXT-lineRasterizationMode-parameter
  `lineRasterizationMode` must be a valid `VkLineRasterizationModeEXT` value

Possible values of `VkPipelineRasterizationLineStateCreateInfoEXT::lineRasterizationMode` are:

```c
// Provided by VK_EXT_line_rasterization
typedef enum VkLineRasterizationModeEXT {
    VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT = 0,
    VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT = 1,
    VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT = 2,
    VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT = 3,
} VkLineRasterizationModeEXT;
```

- `VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT` is equivalent to `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT` if `VkPhysicalDeviceLimits::strictLines` is `VK_TRUE`, otherwise lines are drawn as non-strictLines parallelograms. Both of these modes are defined in Basic Line Segment Rasterization.

- `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT` specifies lines drawn as if they were rectangles extruded from the line

- `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT` specifies lines drawn by determining which pixel diamonds the line intersects and exits, as defined in Bresenham Line Segment Rasterization.

- `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT` specifies lines drawn if they were rectangles extruded from the line, with alpha falloff, as defined in Smooth Lines.

To dynamically set the `lineRasterizationMode` state, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
```
void vkCmdSetLineRasterizationModeEXT(
    VkCommandBuffer commandBuffer,
    VkLineRasterizationModeEXT lineRasterizationMode);

- `commandBuffer` is the command buffer into which the command will be recorded.
- `lineRasterizationMode` specifies the `lineRasterizationMode` state.

This command sets the `lineRasterizationMode` state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` set in `VkPipelineDynamicStateCreateInfo` ::`pDynamicStates`. Otherwise, this state is specified by the `VkPipelineRasterizationLineStateCreateInfoEXT` ::`lineRasterizationMode` value used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetLineRasterizationModeEXT-None-08558
  Either the extendedDynamicState3LineRasterizationMode feature or the shaderObject feature or both must be enabled

- VUID-vkCmdSetLineRasterizationModeEXT-lineRasterizationMode-07418
  If `lineRasterizationMode` is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT`, then the rectangularLines feature must be enabled

- VUID-vkCmdSetLineRasterizationModeEXT-lineRasterizationMode-07419
  If `lineRasterizationMode` is `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT`, then the brendamhlines feature must be enabled

- VUID-vkCmdSetLineRasterizationModeEXT-lineRasterizationMode-07420
  If `lineRasterizationMode` is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT`, then the smoothlines feature must be enabled

### Valid Usage (Implicit)

- VUID-vkCmdSetLineRasterizationModeEXT-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdSetLineRasterizationModeEXT-lineRasterizationMode-parameter
  `lineRasterizationMode` must be a valid `VkLineRasterizationModeEXT` value

- VUID-vkCmdSetLineRasterizationModeEXT-commandBuffer-recording
  `commandBuffer` must be in the recording state

- VUID-vkCmdSetLineRasterizationModeEXT-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations

- VUID-vkCmdSetLineRasterizationModeEXT-videocoding
  This command must only be called outside of a video coding scope
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

### Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics</td>
<td>State</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To dynamically set the `stippledLineEnable` state, call:

```c
void vkCmdSetLineStippleEnableEXT(
    VkCommandBuffer commandBuffer,
    VkBool32 stippledLineEnable);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `stippledLineEnable` specifies the `stippledLineEnable` state.

This command sets the `stippledLineEnable` state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineRasterizationLineStateCreateInfoEXT::stippledLineEnable` value used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetLineStippleEnableEXT-None-08560
  Either the `extendedDynamicState3LineStippleEnable` feature or the `shaderObject` feature or both must be enabled

### Valid Usage (Implicit)

- VUID-vkCmdSetLineStippleEnableEXT-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetLineStippleEnableEXT-commandBuffer-recording
  `commandBuffer` must be in the recording state
The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations.

This command must only be called outside of a video coding scope.

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

**Command Properties**

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics</td>
<td>State</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To dynamically set the line width, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdSetLineWidth(
    VkCommandBuffer commandBuffer,
    float lineWidth);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `lineWidth` is the width of rasterized line segments.

This command sets the line width for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_LINE_WIDTH` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineRasterizationStateCreateInfo::lineWidth` value used to create the currently active pipeline.

**Valid Usage**

- VUID-vkCmdSetLineWidth-lineWidth-00788
  - If the `wideLines` feature is not enabled, `lineWidth` must be `1.0`
Valid Usage (Implicit)

- VUID-vkCmdSetLineWidth-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle
- VUID-vkCmdSetLineWidth-commandBuffer-recording
  commandBuffer must be in the recording state
- VUID-vkCmdSetLineWidth-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations
- VUID-vkCmdSetLineWidth-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
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<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Secondary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics</td>
<td>State</td>
</tr>
</tbody>
</table>

Not all line widths need be supported for line segment rasterization, but width 1.0 antialiased segments must be provided. The range and gradations are obtained from the lineWidthRange and lineWidthGranularity members of VkPhysicalDeviceLimits. If, for instance, the size range is from 0.1 to 2.0 and the gradation size is 0.1, then the sizes 0.1, 0.2, ..., 1.9, 2.0 are supported. Additional line widths may also be supported. There is no requirement that these widths be equally spaced. If an unsupported width is requested, the nearest supported width is used instead.

Further, if the render pass has a fragment density map attachment, line width may be rounded by the implementation to a multiple of the fragment’s width or height.

28.11.1. Basic Line Segment Rasterization

If the lineRasterizationMode member of VkPipelineRasterizationLineStateCreateInfoEXT is VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT, rasterized line segments produce fragments which intersect a rectangle centered on the line segment. Two of the edges are parallel to the specified line segment; each is at a distance of one-half the current width from that segment in directions perpendicular to the direction of the line. The other two edges pass through the line endpoints and...
are perpendicular to the direction of the specified line segment. Coverage bits that correspond to sample points that intersect the rectangle are 1, other coverage bits are 0.

Next we specify how the data associated with each rasterized fragment are obtained. Let \( p_r = (x_d, y_d) \) be the framebuffer coordinates at which associated data are evaluated. This may be the center of a fragment or the location of a sample within the fragment. When \( \text{rasterizationSamples} \) is \( \text{VK\_SAMPLE\_COUNT\_1\_BIT} \), the fragment center must be used. Let \( p_a = (x_a, y_a) \) and \( p_b = (x_b, y_b) \) be initial and final endpoints of the line segment, respectively. Set

\[
t = \frac{(p_r - p_a) \cdot (p_b - p_a)}{||p_b - p_a||^2}
\]

(Note that \( t = 0 \) at \( p_a \) and \( t = 1 \) at \( p_b \). Also note that this calculation projects the vector from \( p_a \) to \( p_r \) onto the line, and thus computes the normalized distance of the fragment along the line.)

If \( \text{strictLines} \) is \( \text{VK\_TRUE} \), line segments are rasterized using perspective or linear interpolation.

**Perspective interpolation** for a line segment interpolates two values in a manner that is correct when taking the perspective of the viewport into consideration, by way of the line segment's clip coordinates. An interpolated value \( f \) can be determined by

\[
f = \frac{(1 - t)f_a / w_a + tf_b / w_b}{(1 - t) / w_a + t / w_b}
\]

where \( f_a \) and \( f_b \) are the data associated with the starting and ending endpoints of the segment, respectively; \( w_a \) and \( w_b \) are the clip w coordinates of the starting and ending endpoints of the segment, respectively.

**Linear interpolation** for a line segment directly interpolates two values, and an interpolated value \( f \) can be determined by

\[
f = (1 - t)f_a + tf_b
\]

where \( f_a \) and \( f_b \) are the data associated with the starting and ending endpoints of the segment, respectively.

The clip coordinate \( w \) for a sample is determined using perspective interpolation. The depth value \( z \) for a sample is determined using linear interpolation. Interpolation of fragment shader input values are determined by **Interpolation decorations**.

The above description documents the preferred method of line rasterization, and must be used when \( \text{lineRasterizationMode} \) is \( \text{VK\_LINE\_RASTERIZATION\_MODE\_RECTANGULAR\_EXT} \).

By default, when \( \text{strictLines} \) is \( \text{VK\_FALSE} \), and when the \( \text{lineRasterizationMode} \) is \( \text{VK\_LINE\_RASTERIZATION\_MODE\_DEFAULT\_EXT} \), the edges of the lines are generated as a parallelogram surrounding the original line. The major axis is chosen by noting the axis in which there is the greatest distance between the line start and end points. If the difference is equal in both directions then the X axis is chosen as the major axis. Edges 2 and 3 are aligned to the minor axis and are centered on the endpoints of the line as in **Non strict lines**, and each is \( \text{lineWidth} \) long. Edges 0 and 1
are parallel to the line and connect the endpoints of edges 2 and 3. Coverage bits that correspond to sample points that intersect the parallelogram are 1, other coverage bits are 0.

Samples that fall exactly on the edge of the parallelogram follow the polygon rasterization rules.

Interpolation occurs as if the parallelogram was decomposed into two triangles where each pair of vertices at each end of the line has identical attributes.

![Parallelogram Diagram](image)

*Figure 20. Non strict lines*

Only when `strictLines` is `VK_FALSE` implementations may deviate from the non-strict line algorithm described above in the following ways:

- Implementations may instead interpolate each fragment according to the formula in [Basic Line Segment Rasterization](#) using the original line segment endpoints.
- Rasterization of non-antialiased non-strict line segments may be performed using the rules defined in [Bresenham Line Segment Rasterization](#).

If `VkPhysicalDeviceMaintenance5PropertiesKHR::nonStrictSinglePixelWideLinesUseParallelogram` is `VK_TRUE`, the `lineRasterizationMode` is `VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT`, and `strictLines` is `VK_FALSE`, non-strict lines of width 1.0 are rasterized as parallelograms, otherwise they are rasterized using Bresenham’s algorithm.

If `VkPhysicalDeviceMaintenance5PropertiesKHR::nonStrictWideLinesUseParallelogram` is `VK_TRUE`, the `lineRasterizationMode` is `VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT`, and `strictLines` is `VK_FALSE`, non-strict lines of width greater than 1.0 are rasterized as parallelograms, otherwise they are rasterized using Bresenham’s algorithm.

### 28.11.2. Bresenham Line Segment Rasterization

If `lineRasterizationMode` is `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT`, then the following rules replace the line rasterization rules defined in [Basic Line Segment Rasterization](#).

Non-strict lines may also follow these rasterization rules for non-antialiased lines.
Line segment rasterization begins by characterizing the segment as either *x-major* or *y-major*. *x-major* line segments have slope in the closed interval [-1,1]; all other line segments are *y-major* (slope is determined by the segment’s endpoints). We specify rasterization only for *x-major* segments except in cases where the modifications for *y-major* segments are not self-evident.

Ideally, Vulkan uses a *diamond-exit* rule to determine those fragments that are produced by rasterizing a line segment. For each fragment *f* with center at framebuffer coordinates *x_f* and *y_f*, define a diamond-shaped region that is the intersection of four half planes:

\[ R_f = \{(x, y) \mid |x - x_f| + |y - y_f| < \frac{1}{2}\} \]

Essentially, a line segment starting at *p_a* and ending at *p_b* produces those fragments *f* for which the segment intersects *R_f*, except if *p_b* is contained in *R_f*.

![Figure 21. Visualization of Bresenham's algorithm](image)

To avoid difficulties when an endpoint lies on a boundary of *R_f* we (in principle) perturb the supplied endpoints by a tiny amount. Let *p_a* and *p_b* have framebuffer coordinates (*x_a*, *y_a*) and (*x_b*, *y_b*), respectively. Obtain the perturbed endpoints *p_a'* given by (*x_a*, *y_a*) - (*ε*, *ε*) and *p_b'* given by (*x_b*, *y_b*) - (*ε*, *ε*). Rasterizing the line segment starting at *p_a'* and ending on *p_b'* produces those fragments *f* for which the segment starting at *p_a'* and ending on *p_b'* intersects *R_f*, except if *p_b'* is contained in *R_f*. *ε* is chosen to be so small that rasterizing the line segment produces the same fragments when *δ* is substituted for *ε* for any 0 < *δ* ≤ *ε*.

When *p_a* and *p_b* lie on fragment centers, this characterization of fragments reduces to Bresenham’s algorithm with one modification: lines produced in this description are “half-open”, meaning that the final fragment (corresponding to *p_b*) is not drawn. This means that when rasterizing a series of connected line segments, shared endpoints will be produced only once rather than twice (as would
Implementations may use other line segment rasterization algorithms, subject to the following rules:

- The coordinates of a fragment produced by the algorithm must not deviate by more than one unit in either x or y framebuffer coordinates from a corresponding fragment produced by the diamond-exit rule.
- The total number of fragments produced by the algorithm must not differ from that produced by the diamond-exit rule by no more than one.
- For an x-major line, two fragments that lie in the same framebuffer-coordinate column must not be produced (for a y-major line, two fragments that lie in the same framebuffer-coordinate row must not be produced).
- If two line segments share a common endpoint, and both segments are either x-major (both left-to-right or both right-to-left) or y-major (both bottom-to-top or both top-to-bottom), then rasterizing both segments must not produce duplicate fragments. Fragments also must not be omitted so as to interrupt continuity of the connected segments.

The actual width \( w \) of Bresenham lines is determined by rounding the line width to the nearest integer, clamping it to the implementation-dependent lineWidthRange (with both values rounded to the nearest integer), then clamping it to be no less than 1.

Bresenham line segments of width other than one are rasterized by offsetting them in the minor direction (for an x-major line, the minor direction is y, and for a y-major line, the minor direction is x) and producing a row or column of fragments in the minor direction. If the line segment has endpoints given by \((x_0, y_0)\) and \((x_1, y_1)\) in framebuffer coordinates, the segment with endpoints \((x_0, y_0 - \frac{w-1}{2})\) and \((x_1, y_1 - \frac{w-1}{2})\) is rasterized, but instead of a single fragment, a column of fragments of height \( w \) (a row of fragments of length \( w \) for a y-major segment) is produced at each \( x \) (y for y-major) location. The lowest fragment of this column is the fragment that would be produced by rasterizing the segment of width 1 with the modified coordinates.

The preferred method of attribute interpolation for a wide line is to generate the same attribute values for all fragments in the row or column described above, as if the adjusted line was used for interpolation and those values replicated to the other fragments, except for FragCoord which is interpolated as usual. Implementations may instead interpolate each fragment according to the formula in Basic Line Segment Rasterization, using the original line segment endpoints.

When Bresenham lines are being rasterized, sample locations may all be treated as being at the pixel center (this may affect attribute and depth interpolation).

\[ \text{Note} \]

The sample locations described above are not used for determining coverage, they are only used for things like attribute interpolation. The rasterization rules that determine coverage are defined in terms of whether the line intersects pixels, as opposed to the point sampling rules used for other primitive types. So these rules are independent of the sample locations. One consequence of this is that Bresenham lines cover the same pixels regardless of the number of rasterization
samples, and cover all samples in those pixels (unless masked out or killed).

28.11.3. Line Stipple

If the `stippledLineEnable` member of `VkPipelineRasterizationLineStateCreateInfoEXT` is `VK_TRUE`, then lines are rasterized with a line stipple determined by `lineStippleFactor` and `lineStipplePattern`. `lineStipplePattern` is an unsigned 16-bit integer that determines which fragments are to be drawn or discarded when the line is rasterized. `lineStippleFactor` is a count that is used to modify the effective line stipple by causing each bit in `lineStipplePattern` to be used `lineStippleFactor` times.

Line stippling discards certain fragments that are produced by rasterization. The masking is achieved using three parameters: the 16-bit line stipple pattern $p$, the line stipple factor $r$, and an integer stipple counter $s$. Let

$$b = \left\lfloor \frac{s}{r} \right\rfloor \mod 16$$

Then a fragment is produced if the $b$'th bit of $p$ is 1, and discarded otherwise. The bits of $p$ are numbered with 0 being the least significant and 15 being the most significant.

The initial value of $s$ is zero. For `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT` lines, $s$ is incremented after production of each fragment of a line segment (fragments are produced in order, beginning at the starting point and working towards the ending point). For `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT` and `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT` lines, the rectangular region is subdivided into adjacent unit-length rectangles, and $s$ is incremented once for each rectangle. Rectangles with a value of $s$ such that the $b$'th bit of $p$ is zero are discarded. If the last rectangle in a line segment is shorter than unit-length, then the remainder may carry over to the next line segment in the line strip using the same value of $s$ (this is the preferred behavior, for the stipple pattern to appear more consistent through the strip).

$s$ is reset to 0 at the start of each strip (for line strips), and before every line segment in a group of independent segments.

If the line segment has been clipped, then the value of $s$ at the beginning of the line segment is implementation-dependent.

To dynamically set the line stipple state, call:

```c
// Provided by VK_EXT_line_rasterization
void vkCmdSetLineStippleEXT(
    VkCommandBuffer commandBuffer,  // commandBuffer is the command buffer into which the command will be recorded.
    uint32_t lineStippleFactor,     // lineStippleFactor is the repeat factor used in stippled line rasterization.
    uint16_t lineStipplePattern);
```
• **lineStipplePattern** is the bit pattern used in stippled line rasterization.

This command sets the line stipple state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with **VK_DYNAMIC_STATE_LINE_STIPPLE_EXT** set in **VkPipelineDynamicStateCreateInfo::pDynamicStates**. Otherwise, this state is specified by the **VkPipelineRasterizationLineStateCreateInfoEXT::lineStippleFactor** and **VkPipelineRasterizationLineStateCreateInfoEXT::lineStipplePattern** values used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetLineStippleEXT-lineStippleFactor-02776
  - **lineStippleFactor** must be in the range [1,256]

### Valid Usage (Implicit)

- VUID-vkCmdSetLineStippleEXT-commandBuffer-parameter
  - **commandBuffer** must be a valid **VkCommandBuffer** handle
- VUID-vkCmdSetLineStippleEXT-commandBuffer-recording
  - **commandBuffer** must be in the recording state
- VUID-vkCmdSetLineStippleEXT-commandBuffer-cmdpool
  - The **VkCommandPool** that **commandBuffer** was allocated from must support graphics operations
- VUID-vkCmdSetLineStippleEXT-videocoding
  - This command must only be called outside of a video coding scope

### Host Synchronization

- Host access to **commandBuffer** must be externally synchronized
- Host access to the **VkCommandPool** that **commandBuffer** was allocated from must be externally synchronized

### Command Properties

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28.11.4. Smooth Lines

If the `lineRasterizationMode` member of `VkPipelineRasterizationLineStateCreateInfoEXT` is
`VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT`, then lines are considered to be rectangles
using the same geometry as for `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT` lines. The rules for
determining which pixels are covered are implementation-dependent, and may include nearby
pixels where no sample locations are covered or where the rectangle does not intersect the pixel at
all. For each pixel that is considered covered, the fragment computes a coverage value that
approximates the area of the intersection of the rectangle with the pixel square, and this coverage
value is multiplied into the color location 0's alpha value after fragment shading, as described in
Multisample Coverage.

Note

The details of the rasterization rules and area calculation are left intentionally
vague, to allow implementations to generate coverage and values that are
aesthetically pleasing.

28.12. Polygons

A polygon results from the decomposition of a triangle strip, triangle fan or a series of independent
triangles. Like points and line segments, polygon rasterization is controlled by several variables in
the `VkPipelineRasterizationStateCreateInfo` structure.

28.12.1. Basic Polygon Rasterization

The first step of polygon rasterization is to determine whether the triangle is back-facing or front-
facing. This determination is made based on the sign of the (clipped or unclipped) polygon's area
computed in framebuffer coordinates. One way to compute this area is:

\[
\text{a} = -\frac{1}{2} \sum_{i=0}^{n-1} x_i f y_i f^t - x_i f^t y_i f
\]

where \(x_i\) and \(y_i\) are the x and y framebuffer coordinates of the ith vertex of the n-vertex polygon
(verticies are numbered starting at zero for the purposes of this computation) and \(i \oplus 1\) is \((i + 1) \mod n\).

The interpretation of the sign of \(a\) is determined by the `VkPipelineRasterizationStateCreateInfo`:
::frontFace property of the currently active pipeline. Possible values are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkFrontFace {
    VK_FRONT_FACE_COUNTER_CLOCKWISE = 0,
    VK_FRONT_FACE_CLOCKWISE = 1,
} VkFrontFace;
```

- `VK_FRONT_FACE_COUNTER_CLOCKWISE` specifies that a triangle with positive area is considered front-
facing.
• **VK_FRONT_FACE_CLOCKWISE** specifies that a triangle with negative area is considered front-facing.

Any triangle which is not front-facing is back-facing, including zero-area triangles.

To **dynamically set** the front face orientation, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdSetFrontFace(
    VkCommandBuffer commandBuffer,
    VkFrontFace frontFace);
```

or the equivalent command

```c
// Provided by VK_EXT_extended_dynamic_state, VK_EXT_shader_object
void vkCmdSetFrontFaceEXT(
    VkCommandBuffer commandBuffer,
    VkFrontFace frontFace);
```

• **commandBuffer** is the command buffer into which the command will be recorded.

• **frontFace** is a **VkFrontFace** value specifying the front-facing triangle orientation to be used for culling.

This command sets the front face orientation for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with **VK_DYNAMIC_STATE_FRONT_FACE** set in **VkPipelineDynamicStateCreateInfo::pDynamicStates**. Otherwise, this state is specified by the **VkPipelineRasterizationStateCreateInfo::frontFace** value used to create the currently active pipeline.

### Valid Usage

- **VUID-vkCmdSetFrontFace-None-08971**
  At least one of the following must be true:
  - the **extendedDynamicState** feature is enabled
  - the **shaderObject** feature is enabled
  - the value of **VkApplicationInfo::apiVersion** used to create the **VkInstance** parent of **commandBuffer** is greater than or equal to Version 1.3

### Valid Usage (Implicit)

- **VUID-vkCmdSetFrontFace-commandBuffer-parameter**
  **commandBuffer** must be a valid **VkCommandBuffer** handle

- **VUID-vkCmdSetFrontFace-frontFace-parameter**
  **frontFace** must be a valid **VkFrontFace** value
VUID-vkCmdSetFrontFace-commandBuffer-recording

commandBuffer must be in the recording state

VUID-vkCmdSetFrontFace-commandBuffer-cmdpool

The VkCommandPool that commandBuffer was allocated from must support graphics operations

VUID-vkCmdSetFrontFace-videcoding

This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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Once the orientation of triangles is determined, they are culled according to the VkPipelineRasterizationStateCreateInfo::cullMode property of the currently active pipeline. Possible values are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkCullModeFlagBits {
    VK_CULL_MODE_NONE = 0,
    VK_CULL_MODE_FRONT_BIT = 0x00000001,
    VK_CULL_MODE_BACK_BIT = 0x00000002,
    VK_CULL_MODE_FRONT_AND_BACK = 0x00000003,
} VkCullModeFlagBits;
```

- **VK_CULL_MODE_NONE** specifies that no triangles are discarded
- **VK_CULL_MODE_FRONT_BIT** specifies that front-facing triangles are discarded
- **VK_CULL_MODE_BACK_BIT** specifies that back-facing triangles are discarded
- **VK_CULL_MODE_FRONT_AND_BACK** specifies that all triangles are discarded.

Following culling, fragments are produced for any triangles which have not been discarded.

```c
// Provided by VK_VERSION_1_0
```
typedef VkFlags VkCullModeFlags;

VkCullModeFlags is a bitmask type for setting a mask of zero or more VkCullModeFlagBits.

To dynamically set the cull mode, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdSetCullMode(
    VkCommandBuffer commandBuffer,
    VkCullModeFlags cullMode);
```
or the equivalent command

```c
// Provided by VK_EXT_extended_dynamic_state, VK_EXT_shader_object
void vkCmdSetCullModeEXT(
    VkCommandBuffer commandBuffer,
    VkCullModeFlags cullMode);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `cullMode` specifies the cull mode property to use for drawing.

This command sets the cull mode for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_CULL_MODE` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineRasterizationStateCreateInfo::cullMode` value used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetCullMode-None-08971
  At least one of the following **must** be true:
  - the `extendedDynamicState` feature is enabled
  - the `shaderObject` feature is enabled
  - the value of `VkApplicationInfo::apiVersion` used to create the `VkInstance` parent of `commandBuffer` is greater than or equal to Version 1.3

### Valid Usage (Implicit)

- VUID-vkCmdSetCullMode-commandBuffer-parameter
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- VUID-vkCmdSetCullMode-cullMode-parameter
  `cullMode` **must** be a valid combination of `VkCullModeFlagBits` values

- VUID-vkCmdSetCullMode-commandBuffer-recording
  `commandBuffer` **must** be in the **recording state**
Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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The rule for determining which fragments are produced by polygon rasterization is called point sampling. The two-dimensional projection obtained by taking the x and y framebuffer coordinates of the polygon’s vertices is formed. Fragments are produced for any fragment area groups of pixels for which any sample points lie inside of this polygon. Coverage bits that correspond to sample points that satisfy the point sampling criteria are 1, other coverage bits are 0. Special treatment is given to a sample whose sample location lies on a polygon edge. In such a case, if two polygons lie on either side of a common edge (with identical endpoints) on which a sample point lies, then exactly one of the polygons must result in a covered sample for that fragment during rasterization. As for the data associated with each fragment produced by rasterizing a polygon, we begin by specifying how these values are produced for fragments in a triangle.

Barycentric coordinates are a set of three numbers, a, b, and c, each in the range [0,1], with $a + b + c = 1$. These coordinates uniquely specify any point p within the triangle or on the triangle’s boundary as

$$p = a \, p_a + b \, p_b + c \, p_c,$$

where $p_a$, $p_b$, and $p_c$ are the vertices of the triangle. a, b, and c are determined by:

$$a = \frac{A(p \, p_b \, p_c)}{A(p_a \, p_b \, p_c)}, \quad b = \frac{A(p \, p_a \, p_c)}{A(p_a \, p_b \, p_c)}, \quad c = \frac{A(p \, p_a \, p_b)}{A(p_a \, p_b \, p_c)},$$

where $A(lmn)$ denotes the area in framebuffer coordinates of the triangle with vertices l, m, and n.

Denote an associated datum at $p_a$, $p_b$, or $p_c$ as $f_a$, $f_b$, or $f_c$, respectively.
Perspective interpolation for a triangle interpolates three values in a manner that is correct when taking the perspective of the viewport into consideration, by way of the triangle’s clip coordinates. An interpolated value \( f \) can be determined by

\[
f = \frac{af_a / w_a + bf_b / w_b + cf_c / w_c}{a / w_a + b / w_b + c / w_c}
\]

where \( w_a, w_b \) and \( w_c \) are the clip \( w \) coordinates of \( p_a, p_b \), and \( p_c \), respectively. \( a, b \), and \( c \) are the barycentric coordinates of the location at which the data are produced.

Linear interpolation for a triangle directly interpolates three values, and an interpolated value \( f \) can be determined by

\[
f = a f_a + b f_b + c f_c
\]

where \( f_a, f_b \), and \( f_c \) are the data associated with \( p_a, p_b \), and \( p_c \), respectively.

The clip coordinate \( w \) for a sample is determined using perspective interpolation. The depth value \( z \) for a sample is determined using linear interpolation. Interpolation of fragment shader input values are determined by Interpolation decorations.

For a polygon with more than three edges, such as are produced by clipping a triangle, a convex combination of the values of the datum at the polygon’s vertices must be used to obtain the value assigned to each fragment produced by the rasterization algorithm. That is, it must be the case that at every fragment

\[
f = \sum_{i=1}^{n} a_i f_i
\]

where \( n \) is the number of vertices in the polygon and \( f_i \) is the value of \( f \) at vertex \( i \). For each \( i \), \( 0 \leq a_i \leq 1 \) and \( \sum_{i=1}^{n} a_i = 1 \). The values of \( a_i \) may differ from fragment to fragment, but at vertex \( i \), \( a_i = 1 \) and \( a_j = 0 \) for \( j \neq i \).

Note

One algorithm that achieves the required behavior is to triangulate a polygon (without adding any vertices) and then treat each triangle individually as already discussed. A scan-line rasterizer that linearly interpolates data along each edge and then linearly interpolates data across each horizontal span from edge to edge also satisfies the restrictions (in this case the numerator and denominator of perspective interpolation are iterated independently, and a division is performed for each fragment).

28.12.2. Polygon Mode

Possible values of the \texttt{VkPipelineRasterizationStateCreateInfo::polygonMode} property of the currently active pipeline, specifying the method of rasterization for polygons, are:

// Provided by VK_VERSION_1_0
typedef enum VkPolygonMode {
    VK_POLYGON_MODE_FILL = 0,
    VK_POLYGON_MODE_LINE = 1,
    VK_POLYGON_MODE_POINT = 2,
    // Provided by VK_NV_fill_rectangle
    VK_POLYGON_MODE_FILL_RECTANGLE_NV = 1000153000,
} VkPolygonMode;

- **VK_POLYGON_MODE_POINT** specifies that polygon vertices are drawn as points.
- **VK_POLYGON_MODE_LINE** specifies that polygon edges are drawn as line segments.
- **VK_POLYGON_MODE_FILL** specifies that polygons are rendered using the polygon rasterization rules in this section.
- **VK_POLYGON_MODE_FILL_RECTANGLE_NV** specifies that polygons are rendered using polygon rasterization rules, modified to consider a sample within the primitive if the sample location is inside the axis-aligned bounding box of the triangle after projection. Note that the barycentric weights used in attribute interpolation can extend outside the range [0,1] when these primitives are shaded. Special treatment is given to a sample position on the boundary edge of the bounding box. In such a case, if two rectangles lie on either side of a common edge (with identical endpoints) on which a sample position lies, then exactly one of the triangles must produce a fragment that covers that sample during rasterization.

Polygons rendered in **VK_POLYGON_MODE_FILL_RECTANGLE_NV** mode may be clipped by the frustum or by user clip planes. If clipping is applied, the triangle is culled rather than clipped.

Area calculation and facingness are determined for **VK_POLYGON_MODE_FILL_RECTANGLE_NV** mode using the triangle’s vertices.

These modes affect only the final rasterization of polygons: in particular, a polygon’s vertices are shaded and the polygon is clipped and possibly culled before these modes are applied.

If **VkPhysicalDeviceMaintenance5PropertiesKHR::polygonModePointSize** is set to **VK_TRUE**, the point size of the final rasterization of polygons is taken from **PointSize** when **polygon mode** is **VK_POLYGON_MODE_POINT**.

Otherwise, if **VkPhysicalDeviceMaintenance5PropertiesKHR::polygonModePointSize** is set to **VK_FALSE**, the point size of the final rasterization of polygons is **1.0** when **polygon mode** is **VK_POLYGON_MODE_POINT**.

To dynamically set the polygon mode, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
void vkCmdSetPolygonModeEXT(
    VkCommandBuffer commandBuffer,  // commandBuffer is the command buffer into which the command will be recorded.
    VkPolygonMode polygonMode);    // polygonMode specifies polygon mode.
```
This command sets the polygon mode for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with VK_DYNAMIC_STATE_POLYGON_MODE_EXT set in VkPipelineDynamicStateCreateInfo::pDynamicStates. Otherwise, this state is specified by the VkPipelineRasterizationStateCreateInfo::polygonMode value used to create the currently active pipeline.

Valid Usage

- VUID-vkCmdSetPolygonModeEXT-None-08566
  Either the extendedDynamicState3PolygonMode feature or the shaderObject feature or both must be enabled

- VUID-vkCmdSetPolygonModeEXT-fillModeNonSolid-07424
  If the fillModeNonSolid feature is not enabled, polygonMode must be VK_POLYGON_MODE_FILL or VK_POLYGON_MODE_FILL_RECTANGLE_NV

- VUID-vkCmdSetPolygonModeEXT-polygonMode-07425
  If the VK_NV_fill_rectangle extension is not enabled, polygonMode must not be VK_POLYGON_MODE_FILL_RECTANGLE_NV

Valid Usage (Implicit)

- VUID-vkCmdSetPolygonModeEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdSetPolygonModeEXT-polygonMode-parameter
  polygonMode must be a valid VkPolygonMode value

- VUID-vkCmdSetPolygonModeEXT-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdSetPolygonModeEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdSetPolygonModeEXT-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
**Command Properties**

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### 28.12.3. Depth Bias

The depth values of all fragments generated by the rasterization of a polygon can be biased (offset) by a single depth bias value \( \delta \) that is computed for that polygon.

**Depth Bias Enable**

The depth bias computation is enabled by the `depthBiasEnable` set with `vkCmdSetDepthBiasEnable` and `vkCmdSetDepthBiasEnableEXT`, or the corresponding `VkPipelineRasterizationStateCreateInfo::depthBiasEnable` value used to create the currently active pipeline. If the depth bias enable is `VK_FALSE`, no bias is applied and the fragment's depth values are unchanged.

To dynamically enable whether to bias fragment depth values, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdSetDepthBiasEnable(
    VkCommandBuffer commandBuffer,
    VkBool32 depthBiasEnable);
```

or the equivalent command

```c
// Provided by VK_EXT_extended_dynamic_state2, VK_EXT_shader_object
void vkCmdSetDepthBiasEnableEXT(
    VkCommandBuffer commandBuffer,
    VkBool32 depthBiasEnable);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `depthBiasEnable` controls whether to bias fragment depth values.

This command sets the depth bias enable for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineRasterizationStateCreateInfo::depthBiasEnable` value used to create the currently active pipeline.
Valid Usage

- VUID-vkCmdSetDepthBiasEnable-None-08970
  At least one of the following must be true:
  - the `extendedDynamicState2` feature is enabled
  - the `shaderObject` feature is enabled
  - the value of `VkApplicationInfo::apiKeyVersion` used to create the `VkInstance` parent of `commandBuffer` is greater than or equal to Version 1.3

Valid Usage (Implicit)

- VUID-vkCmdSetDepthBiasEnable-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetDepthBiasEnable-commandBuffer-recording
  `commandBuffer` must be in the recording state
- VUID-vkCmdSetDepthBiasEnable-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations
- VUID-vkCmdSetDepthBiasEnable-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

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Depth Bias Computation

The depth bias depends on three parameters:

- `depthBiasSlopeFactor` scales the maximum depth slope $m$ of the polygon
- `depthBiasConstantFactor` scales the parameter $r$ of the depth attachment
• the scaled terms are summed to produce a value which is then clamped to a minimum or
maximum value specified by depthBiasClamp

depthBiasSlopeFactor, depthBiasConstantFactor, and depthBiasClamp can each be positive, negative,
or zero. These parameters are set as described for vkCmdSetDepthBias and
vkCmdSetDepthBias2EXT below.

The maximum depth slope of a triangle is

\[ m = \sqrt{\left(\frac{\partial z_f}{\partial x_f}\right)^2 + \left(\frac{\partial z_f}{\partial y_f}\right)^2} \]

where \((x_f, y_f, z_f)\) is a point on the triangle. \(m\) may be approximated as

\[ m = \max\left(\left|\frac{\partial z_f}{\partial x_f}\right|, \left|\frac{\partial z_f}{\partial y_f}\right|\right). \]

In a pipeline with a depth bias representation of VK_DEPTH_BIAS_REPRESENTATION_FLOAT_EXT, \(r\), for the
given primitive is defined as

\[ r = 1 \]

Otherwise \(r\) is the minimum resolvable difference that depends on the depth attachment
representation. If VkDepthBiasRepresentationInfoEXT::depthBiasExact is VK_FALSE it is the smallest
difference in framebuffer coordinate \(z\) values that is guaranteed to remain distinct throughout
polygon rasterization and in the depth attachment. All pairs of fragments generated by the
rasterization of two polygons with otherwise identical vertices, but \(z\) values that differ by \(r\), will
have distinct depth values.

For fixed-point depth attachment representations, or in a pipeline with a depth bias representation
of VK_DEPTH_BIAS_REPRESENTATION_LEAST_REPRESENTABLE_VALUE_FORCE_UNORM_EXT, \(r\) is constant
throughout the range of the entire depth attachment. If VkDepthBiasRepresentationInfoEXT
::depthBiasExact is VK_TRUE, then its value must be

\[ r = 2^n \]

Otherwise its value is implementation-dependent but must be at most

\[ r = 2 \times 2^n \]

where \(n\) is the number of bits used for the depth aspect when using a fixed-point attachment, or the
number of mantissa bits plus one when using a floating-point attachment.

Otherwise for floating-point depth attachment, there is no single minimum resolvable difference. In
this case, the minimum resolvable difference for a given polygon is dependent on the maximum
exponent, \(e\), in the range of \(z\) values spanned by the primitive. If \(n\) is the number of bits in the
floating-point mantissa, the minimum resolvable difference, \(r\), for the given primitive is defined as
If a triangle is rasterized using the `VK_POLYGON_MODE_FILL_RECTANGLE_NV` polygon mode, then this minimum resolvable difference may not be resolvable for samples outside of the triangle, where the depth is extrapolated.

If no depth attachment is present, \( r \) is undefined.

The bias value \( o \) for a polygon is

\[
o = \text{dbclamp}(m \times \text{depthBiasSlopeFactor} + r \times \text{depthBiasConstantFactor})
\]

where \( \text{dbclamp}(x) = \begin{cases} 
  x & \text{depthBiasClamp} = 0 \text{ or } \text{NaN} \\
  \min(x, \text{depthBiasClamp}) & \text{depthBiasClamp} > 0 \\
  \max(x, \text{depthBiasClamp}) & \text{depthBiasClamp} < 0
\end{cases} \)

\( m \) is computed as described above. If the depth attachment uses a fixed-point representation, \( m \) is a function of depth values in the range \([0,1]\), and \( o \) is applied to depth values in the same range.

Depth bias is applied to triangle topology primitives received by the rasterizer regardless of polygon mode. Depth bias may also be applied to line and point topology primitives received by the rasterizer.

To dynamically set the depth bias parameters, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdSetDepthBias(
    VkCommandBuffer commandBuffer,
    float depthBiasConstantFactor,
    float depthBiasClamp,
    float depthBiasSlopeFactor);
```

- \( \text{commandBuffer} \) is the command buffer into which the command will be recorded.
- \( \text{depthBiasConstantFactor} \) is a scalar factor controlling the constant depth value added to each fragment.
- \( \text{depthBiasClamp} \) is the maximum (or minimum) depth bias of a fragment.
- \( \text{depthBiasSlopeFactor} \) is a scalar factor applied to a fragment's slope in depth bias calculations.

This command sets the depth bias parameters for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_DEPTH_BIAS` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the corresponding `VkPipelineRasterizationStateCreateInfo::depthBiasConstantFactor`, `depthBiasClamp`, and `depthBiasSlopeFactor` values used to create the currently active pipeline.

Calling this function is equivalent to calling `vkCmdSetDepthBias2EXT` without a `VkDepthBiasRepresentationInfoEXT` in the pNext chain of `VkDepthBiasInfoEXT`.
Valid Usage

- VUID-vkCmdSetDepthBias-depthBiasClamp-00790
  If the depthBiasClamp feature is not enabled, depthBiasClamp must be 0.0

Valid Usage (Implicit)

- VUID-vkCmdSetDepthBias-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle
- VUID-vkCmdSetDepthBias-commandBuffer-recording
  commandBuffer must be in the recording state
- VUID-vkCmdSetDepthBias-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations
- VUID-vkCmdSetDepthBias-videoencoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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The VkDepthBiasRepresentationInfoEXT structure is defined as:

```c
// Provided by VK_EXT_depth_bias_control
typedef struct VkDepthBiasRepresentationInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkDepthBiasRepresentationEXT depthBiasRepresentation;
    VkBool32 depthBiasExact;
} VkDepthBiasRepresentationInfoEXT;
```
• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **depthBiasRepresentation** is a `VkDepthBiasRepresentationEXT` value specifying the depth bias representation.

• **depthBiasExact** specifies that the implementation is not allowed to scale the depth bias value to ensure a minimum resolvable distance.

### Valid Usage

- **VUID-VkDepthBiasRepresentationInfoEXT-leastRepresentableValueForceUnormRepresentation-08947**
  
  If the `leastRepresentableValueForceUnormRepresentation` feature is not enabled, `depthBiasRepresentation` must not be `VK_DEPTH_BIAS_REPRESENTATION_LEAST_REPRESENTABLE_VALUE_FORCE_UNORM_EXT`

- **VUID-VkDepthBiasRepresentationInfoEXT-floatRepresentation-08948**
  
  If the `floatRepresentation` feature is not enabled, `depthBiasRepresentation` must not be `VK_DEPTH_BIAS_REPRESENTATION_FLOAT_EXT`

- **VUID-VkDepthBiasRepresentationInfoEXT-depthBiasExact-08949**
  
  If the `depthBiasExact` feature is not enabled, `depthBiasExact` must be `VK_FALSE`

### Valid Usage (Implicit)

- **VUID-VkDepthBiasRepresentationInfoEXT-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_DEPTH_BIAS_REPRESENTATION_INFO_EXT`

- **VUID-VkDepthBiasRepresentationInfoEXT-depthBiasRepresentation-parameter**
  
  `depthBiasRepresentation` must be a valid `VkDepthBiasRepresentationEXT` value

Possible values of `VkDepthBiasRepresentationInfoEXT::depthBiasRepresentation`, specifying the depth bias representation are:

```c
// Provided by VK_EXT_depth_bias_control
typedef enum VkDepthBiasRepresentationEXT {
    VK_DEPTH_BIAS_REPRESENTATION_LEAST_REPRESENTABLE_VALUE_FORMAT_EXT = 0,
    VK_DEPTH_BIAS_REPRESENTATION_LEAST_REPRESENTABLE_VALUE_FORCE_UNORM_EXT = 1,
    VK_DEPTH_BIAS_REPRESENTATION_FLOAT_EXT = 2,
} VkDepthBiasRepresentationEXT;
```

- **`VK_DEPTH_BIAS_REPRESENTATION_LEAST_REPRESENTABLE_VALUE_FORMAT_EXT`** specifies that the depth bias representation is a factor of the format's `r` as described in **Depth Bias Computation**.

- **`VK_DEPTH_BIAS_REPRESENTATION_LEAST_REPRESENTABLE_VALUE_FORCE_UNORM_EXT`** specifies that the depth bias representation is a factor of a constant `r` defined by the bit-size or mantissa of the format as described in **Depth Bias Computation**.
VK_DEPTH_BIAS_REPRESENTATION_FLOAT_EXT specifies that the depth bias representation is a factor of constant \( r \) equal to 1.

The VkDepthBiasInfoEXT structure is defined as:

```c
// Provided by VK_EXT_depth_bias_control
typedef struct VkDepthBiasInfoEXT {
    VkStructureType sType;
    const void* pNext;
    float depthBiasConstantFactor;
    float depthBiasClamp;
    float depthBiasSlopeFactor;
} VkDepthBiasInfoEXT;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **depthBiasConstantFactor** is a scalar factor controlling the constant depth value added to each fragment.
- **depthBiasClamp** is the maximum (or minimum) depth bias of a fragment.
- **depthBiasSlopeFactor** is a scalar factor applied to a fragment’s slope in depth bias calculations.

If **pNext** does not contain a VkDepthBiasRepresentationInfoEXT structure, then this command is equivalent to including a VkDepthBiasRepresentationInfoEXT with depthBiasExact set to VK_FALSE and depthBiasRepresentation set to VK_DEPTH_BIAS_REPRESENTATION_LEAST_REPRESENTABLE_VALUE_FORMAT_EXT.

### Valid Usage

- VUID-VkDepthBiasInfoEXT-depthBiasClamp-08950
  If the depthBiasClamp feature is not enabled, depthBiasClamp must be 0.0

### Valid Usage (Implicit)

- VUID-VkDepthBiasInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_DEPTH_BIAS_INFO_EXT

- VUID-VkDepthBiasInfoEXT-pNext-pNext
  pNext must be NULL or a pointer to a valid instance of VkDepthBiasRepresentationInfoEXT

- VUID-VkDepthBiasInfoEXT-sType-unique
  The sType value of each struct in the pNext chain must be unique

To dynamically set the depth bias parameters, call:

```c
// Provided by VK_EXT_depth_bias_control
```
```c
void vkCmdSetDepthBias2EXT(
    VkCommandBuffer commandBuffer,
    const VkDepthBiasInfoEXT* pDepthBiasInfo);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `pDepthBiasInfo` is a pointer to a `VkDepthBiasInfoEXT` structure specifying depth bias parameters.

This command is functionally identical to `vkCmdSetDepthBias`, but includes extensible sub-structures that include `sType` and `pNext` parameters, allowing them to be more easily extended.

**Valid Usage (Implicit)**

- VUID-vkCmdSetDepthBias2EXT-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetDepthBias2EXT-pDepthBiasInfo-parameter
  `pDepthBiasInfo` must be a valid pointer to a valid `VkDepthBiasInfoEXT` structure
- VUID-vkCmdSetDepthBias2EXT-commandBuffer-recording
  `commandBuffer` must be in the recording state
- VUID-vkCmdSetDepthBias2EXT-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations
- VUID-vkCmdSetDepthBias2EXT-videocoding
  This command must only be called outside of a video coding scope

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

**Command Properties**

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**28.12.4. Conservative Rasterization**

If the `pNext` chain of `VkPipelineRasterizationStateCreateInfo` includes a
VkPipelineRasterizationConservativeStateCreateInfoEXT structure, then that structure includes parameters controlling conservative rasterization.

VkPipelineRasterizationConservativeStateCreateInfoEXT is defined as:

```c
// Provided by VK_EXT_conservative_rasterization
typedef struct VkPipelineRasterizationConservativeStateCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkPipelineRasterizationConservativeStateCreateFlagsEXT flags;
    VkConservativeRasterizationModeEXT conservativeRasterizationMode;
    float extraPrimitiveOverestimationSize;
} VkPipelineRasterizationConservativeStateCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `flags` is reserved for future use.
- `conservativeRasterizationMode` is the conservative rasterization mode to use.
- `extraPrimitiveOverestimationSize` is the extra size in pixels to increase the generating primitive during conservative rasterization at each of its edges in X and Y equally in screen space beyond the base overestimation specified in `VkPhysicalDeviceConservativeRasterizationPropertiesEXT::primitiveOverestimationSize`. If `conservativeRasterizationMode` is not `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`, this value is ignored.

If this structure is not included in the `pNext` chain, `conservativeRasterizationMode` is considered to be `VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT`, and and conservative rasterization is disabled.

Polygon rasterization can be made conservative by setting `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT` or `VK_CONSERVATIVE_RASTERIZATION_MODE_UNDERESTIMATE_EXT` in `VkPipelineRasterizationConservativeStateCreateInfoEXT`.

**Note**

If `conservativePointAndLineRasterization` is supported, conservative rasterization can be applied to line and point primitives, otherwise it must be disabled.

**Valid Usage**

- `VUID-VkPipelineRasterizationConservativeStateCreateInfoEXT-extraPrimitiveOverestimationSize-01769` `extraPrimitiveOverestimationSize` must be in the range of 0.0 to `VkPhysicalDeviceConservativeRasterizationPropertiesEXT::maxExtraPrimitiveOverestimationSize` inclusive.
Valid Usage (Implicit)

- VUID-VkPipelineRasterizationConservativeStateCreateInfoEXT-sType-sType must be 
  VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_CONSERVATIVE_STATE_CREATE_INFO_EXT
- VUID-VkPipelineRasterizationConservativeStateCreateInfoEXT-flags-zerobitmask
  flags must be 0
- VUID-VkPipelineRasterizationConservativeStateCreateInfoEXT-
  conservativeRasterizationMode-parameter
  conservativeRasterizationMode must be a valid VkConservativeRasterizationModeEXT value

// Provided by VK_EXT_conservative_rasterization
typedef VkFlags VkPipelineRasterizationConservativeStateCreateFlagsEXT;

VkPipelineRasterizationConservativeStateCreateFlagsEXT is a bitmask type for setting a mask, but is currently reserved for future use.

Possible values of VkPipelineRasterizationConservativeStateCreateInfoEXT::conservativeRasterizationMode, specifying the conservative rasterization mode are:

// Provided by VK_EXT_conservative_rasterization
typedef enum VkConservativeRasterizationModeEXT {
  VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT = 0,
  VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT = 1,
  VK_CONSERVATIVE_RASTERIZATION_MODE_UNDERESTIMATE_EXT = 2,
} VkConservativeRasterizationModeEXT;

- VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT specifies that conservative rasterization is disabled and rasterization proceeds as normal.
- VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT specifies that conservative rasterization is enabled in overestimation mode.
- VK_CONSERVATIVE_RASTERIZATION_MODE_UNDERESTIMATE_EXT specifies that conservative rasterization is enabled in underestimation mode.

To dynamically set the conservativeRasterizationMode, call:

// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
void vkCmdSetConservativeRasterizationModeEXT(
  VkCommandBuffer commandBuffer,
  VkConservativeRasterizationModeEXT conservativeRasterizationMode);

- commandBuffer is the command buffer into which the command will be recorded.
conservativeRasterizationMode specifies the conservativeRasterizationMode state.

This command sets the conservativeRasterizationMode state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT set in VkPipelineDynamicStateCreateInfo::pDynamicStates. Otherwise, this state is specified by the VkPipelineRasterizationConservativeStateCreateInfoEXT::conservativeRasterizationMode value used to create the currently active pipeline.

Valid Usage

- VUID-vkCmdSetConservativeRasterizationModeEXT-None-08570
  Either the extendedDynamicState3ConservativeRasterizationMode feature or the shaderObject feature or both must be enabled

Valid Usage (Implicit)

- VUID-vkCmdSetConservativeRasterizationModeEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle
- VUID-vkCmdSetConservativeRasterizationModeEXT-conservativeRasterizationMode-parameter
  conservativeRasterizationMode must be a valid VkConservativeRasterizationModeEXT value
- VUID-vkCmdSetConservativeRasterizationModeEXT-commandBuffer-recording
  commandBuffer must be in the recording state
- VUID-vkCmdSetConservativeRasterizationModeEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations
- VUID-vkCmdSetConservativeRasterizationModeEXT-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
To dynamically set the `extraPrimitiveOverestimationSize`, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
void vkCmdSetExtraPrimitiveOverestimationSizeEXT(
    VkCommandBuffer commandBuffer, 
    float extraPrimitiveOverestimationSize);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `extraPrimitiveOverestimationSize` specifies the `extraPrimitiveOverestimationSize`.

This command sets the `extraPrimitiveOverestimationSize` for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineRasterizationConservativeStateCreateInfoEXT::extraPrimitiveOverestimationSize` value used to create the currently active pipeline.

### Valid Usage

- **VUID-vkCmdSetExtraPrimitiveOverestimationSizeEXT-None-08572**
  Either the `extendedDynamicState3ExtraPrimitiveOverestimationSize` feature or the `shaderObject` feature or both must be enabled

- **VUID-vkCmdSetExtraPrimitiveOverestimationSizeEXT-extraPrimitiveOverestimationSize-07428**
  `extraPrimitiveOverestimationSize` must be in the range of 0.0 to `VkPhysicalDeviceConservativeRasterizationPropertiesEXT::maxExtraPrimitiveOverestimationSize` inclusive

### Valid Usage (Implicit)

- **VUID-vkCmdSetExtraPrimitiveOverestimationSizeEXT-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- **VUID-vkCmdSetExtraPrimitiveOverestimationSizeEXT-commandBuffer-recording**
  `commandBuffer` must be in the recording state

- **VUID-vkCmdSetExtraPrimitiveOverestimationSizeEXT-commandBuffer-cmdpool**
The \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from \textbf{must} support graphics operations.

- VUID-vkCmdSetExtraPrimitiveOverestimationSizeEXT-videocoding
  This command \textbf{must} only be called outside of a video coding scope.

### Host Synchronization

- Host access to \texttt{commandBuffer} \textbf{must} be externally synchronized.
- Host access to the \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from \textbf{must} be externally synchronized.

### Command Properties

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When overestimate conservative rasterization is enabled, rather than evaluating coverage at individual sample locations, a determination is made whether any portion of the pixel (including its edges and corners) is covered by the primitive. If any portion of the pixel is covered, then all bits of the \textit{coverage mask} for the fragment corresponding to that pixel are enabled. If the render pass has a fragment density map attachment and any bit of the \textit{coverage mask} for the fragment is enabled, then all bits of the \textit{coverage mask} for the fragment are enabled.

For the purposes of evaluating which pixels are covered by the primitive, implementations \textbf{can} increase the size of the primitive by up to \texttt{VkPhysicalDeviceConservativeRasterizationPropertiesEXT::primitiveOverestimationSize} pixels at each of the primitive edges. This \textbf{may} increase the number of fragments generated by this primitive and represents an overestimation of the pixel coverage.

This overestimation size can be increased further by setting the \texttt{extraPrimitiveOverestimationSize} value above \texttt{0.0} in steps of \texttt{VkPhysicalDeviceConservativeRasterizationPropertiesEXT::extraPrimitiveOverestimationSizeGranularity} up to and including \texttt{VkPhysicalDeviceConservativeRasterizationPropertiesEXT::extraPrimitiveOverestimationSize}. This \textbf{may} further increase the number of fragments generated by this primitive.

The actual precision of the overestimation size used for conservative rasterization \textbf{may} vary between implementations and produce results that only approximate the \texttt{primitiveOverestimationSize} and \texttt{extraPrimitiveOverestimationSizeGranularity} properties. Implementations \textbf{may} especially vary these approximations when the render pass has a fragment density map and the fragment area covers multiple pixels.

For triangles if \texttt{VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT} is enabled, fragments will be generated if the primitive area covers any portion of any pixel inside the fragment area, including...
their edges or corners. The tie-breaking rule described in Basic Polygon Rasterization does not apply during conservative rasterization and coverage is set for all fragments generated from shared edges of polygons. Degenerate triangles that evaluate to zero area after rasterization, even for pixels containing a vertex or edge of the zero-area polygon, will be culled if VkPhysicalDeviceConservativeRasterizationPropertiesEXT::degenerateTrianglesRasterized is VK_FALSE or will generate fragments if degenerateTrianglesRasterized is VK_TRUE. The fragment input values for these degenerate triangles take their attribute and depth values from the provoking vertex. Degenerate triangles are considered back-facing and the application can enable backface culling if desired. Triangles that are zero area before rasterization may be culled regardless.

For lines if VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT is enabled, and the implementation sets VkPhysicalDeviceConservativeRasterizationPropertiesEXT::conservativePointAndLineRasterization to VK_TRUE, fragments will be generated if the line covers any portion of any pixel inside the fragment area, including their edges or corners. Degenerate lines that evaluate to zero length after rasterization will be culled if VkPhysicalDeviceConservativeRasterizationPropertiesEXT::degenerateLinesRasterized is VK_FALSE or will generate fragments if degenerateLinesRasterized is VK_TRUE. The fragments input values for these degenerate lines take their attribute and depth values from the provoking vertex. Lines that are zero length before rasterization may be culled regardless.

For points if VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT is enabled, and the implementation sets VkPhysicalDeviceConservativeRasterizationPropertiesEXT::conservativePointAndLineRasterization to VK_TRUE, fragments will be generated if the point square covers any portion of any pixel inside the fragment area, including their edges or corners.

When underestimate conservative rasterization is enabled, rather than evaluating coverage at individual sample locations, a determination is made whether all of the pixel (including its edges and corners) is covered by the primitive. If the entire pixel is covered, then a fragment is generated with all bits of its coverage mask corresponding to the pixel enabled, otherwise the pixel is not considered covered even if some portion of the pixel is covered. The fragment is discarded if no pixels inside the fragment area are considered covered. If the render pass has a fragment density map attachment and any pixel inside the fragment area is not considered covered, then the fragment is discarded even if some pixels are considered covered.

For triangles, if VK_CONSERVATIVE_RASTERIZATION_MODE_UNDERESTIMATE_EXT is enabled, fragments will only be generated if any pixel inside the fragment area is fully covered by the generating primitive, including its edges and corners.

For lines, if VK_CONSERVATIVE_RASTERIZATION_MODE_UNDERESTIMATE_EXT is enabled, fragments will be generated if any pixel inside the fragment area, including its edges and corners, are entirely covered by the line.

For points, if VK_CONSERVATIVE_RASTERIZATION_MODE_UNDERESTIMATE_EXT is enabled, fragments will only be generated if the point square covers the entirety of any pixel square inside the fragment area, including its edges or corners.

If the render pass has a fragment density map and VK_CONSERVATIVE_RASTERIZATION_MODE_UNDERESTIMATE_EXT is enabled, fragments will only be generated if the entirety of all pixels inside the fragment area are covered by the generating primitive, line, or...
point.

For both overestimate and underestimate conservative rasterization modes a fragment has all of its pixel squares fully covered by the generating primitive must set `FullyCoveredEXT` to `VK_TRUE` if the implementation enables the `VkPhysicalDeviceConservativeRasterizationPropertiesEXT`::`fullyCoveredFragmentShaderInputVariable` feature.

When the use of a shaded rate image or setting the fragment shading rate results in fragments covering multiple pixels, coverage for conservative rasterization is still evaluated on a per-pixel basis and may result in fragments with partial coverage. For fragment shader inputs decorated with `FullyCoveredEXT`, a fragment is considered fully covered if and only if all pixels in the fragment are fully covered by the generating primitive.
Chapter 29. Fragment Operations

Fragments produced by rasterization go through a number of operations to determine whether or how values produced by fragment shading are written to the framebuffer.

The following fragment operations adhere to rasterization order, and are typically performed in this order:

1. Discard rectangles test
2. Scissor test
3. Exclusive scissor test
4. Sample mask test
5. Certain Fragment shading operations:
   - Sample Mask Accesses
   - Tile Image Reads
   - Depth Replacement
   - Stencil Reference Replacement
   - Interlocked Operations
6. Multisample coverage
7. Depth bounds test
8. Stencil test
9. Depth test
10. Representative fragment test
11. Sample counting
12. Coverage to color
13. Coverage reduction
14. Coverage modulation

The coverage mask generated by rasterization describes the initial coverage of each sample covered by the fragment. Fragment operations will update the coverage mask to add or subtract coverage where appropriate. If a fragment operation results in all bits of the coverage mask being 0, the fragment is discarded, and no further operations are performed. Fragments can also be programmatically discarded in a fragment shader by executing one of

- `OpTerminateInvocation`
- `OpDemoteToHelperInvocationEXT`
- `OpKill`.

When one of the fragment operations in this chapter is described as “replacing” a fragment shader output, that output is replaced unconditionally, even if no fragment shader previously wrote to that output.
If there is a fragment shader and it declares the PostDepthCoverage execution mode, the sample mask test is instead performed after the depth test.

If VkPhysicalDeviceMaintenance5PropertiesKHR::earlyFragmentMultisampleCoverageAfterSampleCounting is set to VK_TRUE and there is a fragment shader which declares the EarlyFragmentTests execution mode, fragment shading and multisample coverage operations must be performed after sample counting.

Otherwise, if VkPhysicalDeviceMaintenance5PropertiesKHR::earlyFragmentMultisampleCoverageAfterSampleCounting is set to VK_FALSE and there is a fragment shader which declares the EarlyFragmentTests execution mode, fragment shading and multisample coverage operations should instead be performed after sample counting, but may be performed before sample counting.

If VkPhysicalDeviceMaintenance5PropertiesKHR::earlyFragmentSampleMaskTestBeforeSampleCounting is set to VK_TRUE and there is a fragment shader which declares the EarlyFragmentTests execution mode, sample mask test operations must follow the order of fragment operations from above.

Otherwise, if VkPhysicalDeviceMaintenance5PropertiesKHR::earlyFragmentSampleMaskTestBeforeSampleCounting is set to VK_FALSE and there is a fragment shader which declares the EarlyFragmentTests execution mode, sample mask test operations should follow the order of fragment operations from above but may instead be performed after sample counting.

If there is a fragment shader which declares the EarlyAndLateFragmentTestsAMD execution mode, and it does not declare the DepthReplacing or StencilRefReplacingEXT execution mode, fragment shading and multisample coverage operations are instead be performed after sample counting.

For a pipeline with the following properties:

- a fragment shader is specified
- the fragment shader either specifies EarlyAndLateFragmentTestsAMD or does not write to storage resources;
- the fragment shader specifies the StencilRefReplacingEXT execution mode;
- either
  - the fragment shader specifies the StencilRefUnchangedFrontAMD execution mode;
  - the fragment shader specifies the StencilRefLessFrontAMD execution mode and the pipeline uses a VkPipelineDepthStencilStateCreateInfo::front.compareOp of VK_COMPARE_OP_GREATER or VK_COMPARE_OP_GREATER_OR_EQUAL; or
  - the fragment shader specifies the StencilRefGreaterFrontAMD execution mode and the pipeline uses a VkPipelineDepthStencilStateCreateInfo::front.compareOp of VK_COMPARE_OP_LESS or VK_COMPARE_OP_LESS_OR_EQUAL; and
- either
  - the fragment shader specifies the StencilRefUnchangedBackAMD execution mode;
  - the fragment shader specifies the StencilRefLessBackAMD execution mode and the pipeline uses a VkPipelineDepthStencilStateCreateInfo::back.compareOp of VK_COMPARE_OP_GREATER or VK_COMPARE_OP_GREATER_OR_EQUAL; or
the fragment shader specifies the `StencilRefGreaterBackAMD` execution mode and the pipeline uses a `VkPipelineDepthStencilStateCreateInfo::back.compareOp` of `VK_COMPARE_OP_LESS` or `VK_COMPARE_OP_LESS_OR_EQUAL`.

An additional stencil test may be performed before fragment shading, using the stencil reference value specified by `VkPipelineDepthStencilStateCreateInfo::front.reference` or `VkPipelineDepthStencilStateCreateInfo::back.reference`.

For a pipeline with the following properties:

- a fragment shader is specified
- the fragment shader either specifies `EarlyAndLateFragmentTestsAMD` or does not write to storage resources;
- the fragment shader specifies the `DepthReplacing` execution mode; and
- either
  - the fragment shader specifies the `DepthUnchanged` execution mode;
  - the fragment shader specifies the `DepthLess` execution mode and the pipeline uses a `VkPipelineDepthStencilStateCreateInfo::depthCompareOp` of `VK_COMPARE_OP_GREATER` or `VK_COMPARE_OP_GREATER_OR_EQUAL`; or
  - the fragment shader specifies the `DepthGreater` execution mode and the pipeline uses a `VkPipelineDepthStencilStateCreateInfo::depthCompareOp` of `VK_COMPARE_OP_LESS` or `VK_COMPARE_OP_LESS_OR_EQUAL`.

The implementation may perform depth bounds test before fragment shading and perform an additional depth test immediately after that using the interpolated depth value generated by rasterization.

Once all fragment operations have completed, fragment shader outputs for covered color attachment samples pass through framebuffer operations.

### 29.1. Discard Rectangles Test

The discard rectangle test compares the framebuffer coordinates \((x_f, y_f)\) of each sample covered by a fragment against a set of discard rectangles.

Each discard rectangle is defined by a `VkRect2D`. These values are either set by the `VkPipelineDiscardRectangleStateCreateInfoEXT` structure during pipeline creation, or dynamically by the `vkCmdSetDiscardRectangleEXT` command.

A given sample is considered inside a discard rectangle if the \(x_i\) is in the range \([VkRect2D::offset.x, VkRect2D::offset.x + VkRect2D::extent.x]\), and \(y_i\) is in the range \([VkRect2D::offset.y, VkRect2D::offset.y + VkRect2D::extent.y]\). If the test is set to be inclusive, samples that are not inside any of the discard rectangles will have their coverage set to 0. If the test is set to be exclusive, samples that are inside any of the discard rectangles will have their coverage set to 0.

If no discard rectangles are specified, the coverage mask is unmodified by this operation.
The `VkPipelineDiscardRectangleStateCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_discard_rectangles
typedef struct VkPipelineDiscardRectangleStateCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkPipelineDiscardRectangleStateCreateInfoFlagsEXT flags;
    VkDiscardRectangleModeEXT discardRectangleMode;
    uint32_t discardRectangleCount;
    const VkRect2D* pDiscardRectangles;
} VkPipelineDiscardRectangleStateCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is reserved for future use.
- `discardRectangleMode` is a `VkDiscardRectangleModeEXT` value determining whether the discard rectangle test is inclusive or exclusive.
- `discardRectangleCount` is the number of discard rectangles to use.
- `pDiscardRectangles` is a pointer to an array of `VkRect2D` structures defining discard rectangles.

If the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` dynamic state is enabled for a pipeline, the `pDiscardRectangles` member is ignored. If the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT` dynamic state is not enabled for the pipeline the presence of this structure in the `VkGraphicsPipelineCreateInfo` chain, and a `discardRectangleCount` greater than zero, implicitly enables discard rectangles in the pipeline, otherwise discard rectangles **must** enabled or disabled by `vkCmdSetDiscardRectangleEnableEXT`. If the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT` dynamic state is enabled for the pipeline, the `discardRectangleMode` member is ignored, and the discard rectangle mode **must** be set by `vkCmdSetDiscardRectangleModeEXT`.

When this structure is included in the `pNext` chain of `VkGraphicsPipelineCreateInfo`, it defines parameters of the discard rectangle test. If the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` dynamic state is not enabled, and this structure is not included in the `pNext` chain, it is equivalent to specifying this structure with a `discardRectangleCount` of 0.

### Valid Usage

- VUID-VkPipelineDiscardRectangleStateCreateInfoEXT-discardRectangleCount-00582
  
  `discardRectangleCount` **must** be less than or equal to `VkPhysicalDeviceDiscardRectanglePropertiesEXT::maxDiscardRectangles`

### Valid Usage (Implicit)

- VUID-VkPipelineDiscardRectangleStateCreateInfoEXT-sType-sType
  
  `sType` **must** be `VK_STRUCTURE_TYPE_PIPELINE_DISCARD_RECTANGLE_STATE_CREATE_INFO_EXT`
• VUID-VkPipelineDiscardRectangleStateCreateInfoEXT-flags-zerobitmask
  flags must be 0

• VUID-VkPipelineDiscardRectangleStateCreateInfoEXT-discardRectangleMode-parameter
discardRectangleMode must be a valid VkDiscardRectangleModeEXT value

// Provided by VK_EXT_discard_rectangles
typedef VkFlags VkPipelineDiscardRectangleStateCreateFlagsEXT;

VkPipelineDiscardRectangleStateCreateFlagsEXT is a bitmask type for setting a mask, but is currently reserved for future use.

VkDiscardRectangleModeEXT values are:

// Provided by VK_EXT_discard_rectangles
typedef enum VkDiscardRectangleModeEXT {
  VK_DISCARD_RECTANGLE_MODE_INCLUSIVE_EXT = 0,
  VK_DISCARD_RECTANGLE_MODE_EXCLUSIVE_EXT = 1,
} VkDiscardRectangleModeEXT;

• VK_DISCARD_RECTANGLE_MODE_INCLUSIVE_EXT specifies that the discard rectangle test is inclusive.
• VK_DISCARD_RECTANGLE_MODE_EXCLUSIVE_EXT specifies that the discard rectangle test is exclusive.

To dynamically set the discard rectangles, call:

// Provided by VK_EXT_discard_rectangles
void vkCmdSetDiscardRectangleEXT(
  VkCommandBuffer commandBuffer,
  uint32_t firstDiscardRectangle,
  uint32_t discardRectangleCount,
  const VkRect2D* pDiscardRectangles);

• commandBuffer is the command buffer into which the command will be recorded.
• firstDiscardRectangle is the index of the first discard rectangle whose state is updated by the command.
• discardRectangleCount is the number of discard rectangles whose state are updated by the command.
• pDiscardRectangles is a pointer to an array of VkRect2D structures specifying discard rectangles.

The discard rectangle taken from element i of pDiscardRectangles replace the current state for the discard rectangle at index firstDiscardRectangle + i, for i in [0, discardRectangleCount).

This command sets the discard rectangles for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT set in VkPipelineDynamicStateCreateInfo::pDynamicStates.
Otherwise, this state is specified by the `VkPipelineDiscardRectangleStateCreateInfoEXT::pDiscardRectangles` values used to create the currently active pipeline.

**Valid Usage**

- **VUID-vkCmdSetDiscardRectangleEXT-firstDiscardRectangle-00585**
  The sum of `firstDiscardRectangle` and `discardRectangleCount` must be less than or equal to `VkPhysicalDeviceDiscardRectanglePropertiesEXT::maxDiscardRectangles`

- **VUID-vkCmdSetDiscardRectangleEXT-x-00587**
  The x and y member of `offset` in each `VkRect2D` element of `pDiscardRectangles` must be greater than or equal to 0

- **VUID-vkCmdSetDiscardRectangleEXT-offset-00588**
  Evaluation of `(offset.x + extent.width)` in each `VkRect2D` element of `pDiscardRectangles` must not cause a signed integer addition overflow

- **VUID-vkCmdSetDiscardRectangleEXT-offset-00589**
  Evaluation of `(offset.y + extent.height)` in each `VkRect2D` element of `pDiscardRectangles` must not cause a signed integer addition overflow

- **VUID-vkCmdSetDiscardRectangleEXT-viewportScissor2D-04788**
  If this command is recorded in a secondary command buffer with `VkCommandBufferInheritanceViewportScissorInfoNV::viewportScissor2D` enabled, then this function must not be called

**Valid Usage (Implicit)**

- **VUID-vkCmdSetDiscardRectangleEXT-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- **VUID-vkCmdSetDiscardRectangleEXT-pDiscardRectangles-parameter**
  `pDiscardRectangles` must be a valid pointer to an array of `discardRectangleCount` `VkRect2D` structures

- **VUID-vkCmdSetDiscardRectangleEXT-commandBuffer-recording**
  `commandBuffer` must be in the recording state

- **VUID-vkCmdSetDiscardRectangleEXT-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations

- **VUID-vkCmdSetDiscardRectangleEXT-videocoding**
  This command must only be called outside of a video coding scope

- **VUID-vkCmdSetDiscardRectangleEXT-discardRectangleCount-arraylength**
  `discardRectangleCount` must be greater than 0

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized


• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

### Command Properties

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To dynamically set whether discard rectangles are enabled, call:

```c
// Provided by VK_EXT_discard_rectangles
void vkCmdSetDiscardRectangleEnableEXT(
    VkCommandBuffer commandBuffer,  
    VkBool32 discardRectangleEnable);
```

- commandBuffer is the command buffer into which the command will be recorded.
- discardRectangleEnable specifies whether discard rectangles are enabled or not.

This command sets the discard rectangle enable for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is implied by the `VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount` value used to create the currently active pipeline, where a non-zero `discardRectangleCount` implicitly enables discard rectangles, otherwise they are disabled.

### Valid Usage

- VUID-vkCmdSetDiscardRectangleEnableEXT-specVersion-07851
  The `VK_EXT_discard_rectangles` extension must be enabled, and the implementation must support at least `specVersion 2` of this extension

### Valid Usage (Implicit)

- VUID-vkCmdSetDiscardRectangleEnableEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdSetDiscardRectangleEnableEXT-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdSetDiscardRectangleEnableEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

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To dynamically set the discard rectangle mode, call:

```c
// Provided by VK_EXT_discard_rectangles
void vkCmdSetDiscardRectangleModeEXT(
    VkCommandBuffer commandBuffer,
    VkDiscardRectangleModeEXT discardRectangleMode);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `discardRectangleMode` specifies the discard rectangle mode for all discard rectangles, either inclusive or exclusive.

This command sets the discard rectangle mode for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleMode` value used to create the currently active pipeline.

Valid Usage

- `VUID-vkCmdSetDiscardRectangleModeEXT-specVersion-07852`
  The `VK_EXT_discard_rectangles` extension must be enabled, and the implementation must support at least `specVersion 2` of this extension
Valid Usage (Implicit)

- VUID-vkCmdSetDiscardRectangleModeEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdSetDiscardRectangleModeEXT-discardRectangleMode-parameter
  discardRectangleMode must be a valid VkDiscardRectangleModeEXT value

- VUID-vkCmdSetDiscardRectangleModeEXT-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdSetDiscardRectangleModeEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdSetDiscardRectangleModeEXT-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

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29.2. Scissor Test

The scissor test compares the framebuffer coordinates \((x_f, y_f)\) of each sample covered by a fragment against a scissor rectangle at the index equal to the fragment’s ViewportIndex.

Each scissor rectangle is defined by a VkRect2D. These values are either set by the VkPipelineViewportStateCreateInfo structure during pipeline creation, or dynamically by the vkCmdSetScissor command.

A given sample is considered inside a scissor rectangle if \(x_f\) is in the range \([VkRect2D::offset.x, VkRect2D::offset.x + VkRect2D::extent.x)\), and \(y_f\) is in the range \([VkRect2D::offset.y, VkRect2D::offset.y + VkRect2D::extent.y)\). Samples with coordinates outside the scissor rectangle at the corresponding ViewportIndex will have their coverage set to 0.

If a render pass transform is enabled, the \((offset.x\) and \(offset.y\) and \(extent.width\) and \(extent.height\) of the scissor test rectangle must be transformed using the render pass transform matrix before being compared against the framebuffer coordinates.
`extent.height` values are transformed as described in render pass transform before participating in the scissor test.

To dynamically set the scissor rectangles, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdSetScissor(
    VkCommandBuffer commandBuffer,
    uint32_t firstScissor,
    uint32_t scissorCount,
    const VkRect2D* pScissors);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `firstScissor` is the index of the first scissor whose state is updated by the command.
- `scissorCount` is the number of scissors whose rectangles are updated by the command.
- `pScissors` is a pointer to an array of `VkRect2D` structures defining scissor rectangles.

The scissor rectangles taken from element `i` of `pScissors` replace the current state for the scissor index `firstScissor + i`, for `i` in `[0, scissorCount)`.

This command sets the scissor rectangles for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_SCISSOR` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineViewportStateCreateInfo::pScissors` values used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetScissor-firstScissor-00592
  The sum of `firstScissor` and `scissorCount` must be between 1 and `VkPhysicalDeviceLimits::maxViewports`, inclusive

- VUID-vkCmdSetScissor-firstScissor-00593
  If the multiViewport feature is not enabled, `firstScissor` must be 0

- VUID-vkCmdSetScissor-scissorCount-00594
  If the multiViewport feature is not enabled, `scissorCount` must be 1

- VUID-vkCmdSetScissor-x-00595
  The `x` and `y` members of `offset` member of any element of `pScissors` must be greater than or equal to 0

- VUID-vkCmdSetScissor-offset-00596
  Evaluation of `(offset.x + extent.width)` must not cause a signed integer addition overflow for any element of `pScissors`

- VUID-vkCmdSetScissor-offset-00597
  Evaluation of `(offset.y + extent.height)` must not cause a signed integer addition overflow for any element of `pScissors`

- VUID-vkCmdSetScissor-viewportScissor2D-04789
If this command is recorded in a secondary command buffer with `VkCommandBufferInheritanceViewportScissorInfoNV::viewportScissor2D` enabled, then this function must not be called.

**Valid Usage (Implicit)**

- VUID-vkCmdSetScissor-commandBuffer-parameter
  
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- VUID-vkCmdSetScissor-pScissors-parameter
  
  `pScissors` must be a valid pointer to an array of `scissorCount` `VkRect2D` structures.

- VUID-vkCmdSetScissor-commandBuffer-recording
  
  `commandBuffer` must be in the recording state.

- VUID-vkCmdSetScissor-commandBuffer-cmdpool
  
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations.

- VUID-vkCmdSetScissor-videocoding
  
  This command must only be called outside of a video coding scope.

- VUID-vkCmdSetScissor-scissorCount-arraylength
  
  `scissorCount` must be greater than 0.

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized.

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

**Command Properties**

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<tr>
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<td>Both</td>
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**29.3. Exclusive Scissor Test**

The exclusive scissor test compares the framebuffer coordinates \((x_f, y_f)\) of each sample covered by a fragment against an exclusive scissor rectangle at the index equal to the fragment's `ViewportIndex`.

Each exclusive scissor rectangle is defined by a `VkRect2D`. These values are either set by the `VkPipelineViewportExclusiveScissorStateCreateInfoNV` structure during pipeline creation, or
dynamically by the `vkCmdSetExclusiveScissorNV` command.

A given sample is considered inside an exclusive scissor rectangle if \( x \) is in the range \([\text{VkRect2D}::\text{offset.x}, \text{VkRect2D}::\text{offset.x} + \text{VkRect2D}::\text{extent.x})\), and \( y \) is in the range \([\text{VkRect2D}::\text{offset.y}, \text{VkRect2D}::\text{offset.y} + \text{VkRect2D}::\text{extent.y})\). Samples with coordinates inside the exclusive scissor rectangle at the corresponding `ViewportIndex` will have their coverage set to 0.

If no exclusive scissor rectangles are specified, the coverage mask is unmodified by this operation.

The `VkPipelineViewportExclusiveScissorStateCreateInfoNV` structure is defined as:

```c
// Provided by VK_NV_scissor_exclusive
typedef struct VkPipelineViewportExclusiveScissorStateCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    uint32_t exclusiveScissorCount;
    const VkRect2D* pExclusiveScissors;
} VkPipelineViewportExclusiveScissorStateCreateInfoNV;
```

- *sType* is a `VkStructureType` value identifying this structure.
- *pNext* is NULL or a pointer to a structure extending this structure.
- *exclusiveScissorCount* is the number of exclusive scissor rectangles.
- *pExclusiveScissors* is a pointer to an array of `VkRect2D` structures defining exclusive scissor rectangles.

If the `VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV` dynamic state is enabled for a pipeline, the *pExclusiveScissors* member is ignored.

When this structure is included in the *pNext* chain of `VkGraphicsPipelineCreateInfo`, it defines parameters of the exclusive scissor test. If this structure is not included in the *pNext* chain, it is equivalent to specifying this structure with a `exclusiveScissorCount` of 0.

### Valid Usage

- VUID-VkPipelineViewportExclusiveScissorStateCreateInfoNV-exclusiveScissorCount-02027
  If the `multiViewport` feature is not enabled, `exclusiveScissorCount` must be 0 or 1
- VUID-VkPipelineViewportExclusiveScissorStateCreateInfoNV-exclusiveScissorCount-02028
  `exclusiveScissorCount` must be less than or equal to `VkPhysicalDeviceLimits::maxViewports`
- VUID-VkPipelineViewportExclusiveScissorStateCreateInfoNV-exclusiveScissorCount-02029
  `exclusiveScissorCount` must be 0 or greater than or equal to the `viewportCount` member of `VkPipelineViewportStateCreateInfo`
Valid Usage (Implicit)

- VUID-VkPipelineViewportExclusiveScissorStateCreateInfoNV-sType-sType must be
  VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_EXCLUSIVE_SCISSOR_STATE_CREATE_INFO_NV

To dynamically set the exclusive scissor rectangles, call:

```c
// Provided by VK_NV_scissor_exclusive
void vkCmdSetExclusiveScissorNV(
    VkCommandBuffer commandBuffer,
    uint32_t firstExclusiveScissor,
    uint32_t exclusiveScissorCount,
    const VkRect2D* pExclusiveScissors);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `firstExclusiveScissor` is the index of the first exclusive scissor rectangle whose state is updated
  by the command.
- `exclusiveScissorCount` is the number of exclusive scissor rectangles updated by the command.
- `pExclusiveScissors` is a pointer to an array of `VkRect2D` structures defining exclusive scissor
  rectangles.

The scissor rectangles taken from element i of `pExclusiveScissors` replace the current state for the
scissor index `firstExclusiveScissor + i`, for i in `[0, exclusiveScissorCount)`.

This command sets the exclusive scissor rectangles for subsequent drawing commands when
drawing using shader objects, or when the graphics pipeline is created with
`VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`.
Otherwise, this state is specified by the `VkPipelineViewportExclusiveScissorStateCreateInfoNV`:
`pExclusiveScissors` values used to create the currently active pipeline.

Valid Usage

- VUID-vkCmdSetExclusiveScissorNV-None-02031
  The `exclusiveScissor` feature must be enabled

- VUID-vkCmdSetExclusiveScissorNV-firstExclusiveScissor-02034
  The sum of `firstExclusiveScissor` and `exclusiveScissorCount` must be between 1 and
  `VkPhysicalDeviceLimits::maxViewports`, inclusive

- VUID-vkCmdSetExclusiveScissorNV-firstExclusiveScissor-02035
  If the `multiViewport` feature is not enabled, `firstExclusiveScissor` must be 0

- VUID-vkCmdSetExclusiveScissorNV-exclusiveScissorCount-02036
  If the `multiViewport` feature is not enabled, `exclusiveScissorCount` must be 1

- VUID-vkCmdSetExclusiveScissorNV-x-02037
The x and y members of offset in each member of pExclusiveScissors must be greater than or equal to 0

- VUID-vkCmdSetExclusiveScissorNV-offset-02038
  Evaluation of (offset.x + extent.width) for each member of pExclusiveScissors must not cause a signed integer addition overflow

- VUID-vkCmdSetExclusiveScissorNV-offset-02039
  Evaluation of (offset.y + extent.height) for each member of pExclusiveScissors must not cause a signed integer addition overflow

Valid Usage (Implicit)

- VUID-vkCmdSetExclusiveScissorNV-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdSetExclusiveScissorNV-pExclusiveScissors-parameter
  pExclusiveScissors must be a valid pointer to an array of exclusiveScissorCount VkRect2D structures

- VUID-vkCmdSetExclusiveScissorNV-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdSetExclusiveScissorNV-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdSetExclusiveScissorNV-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdSetExclusiveScissorNV-exclusiveScissorCount-arraylength
  exclusiveScissorCount must be greater than 0

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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To dynamically set whether an exclusive scissor is enabled or not, call:
void vkCmdSetExclusiveScissorEnableNV(
    VkCommandBuffer commandBuffer,
    uint32_t firstExclusiveScissor,
    uint32_t exclusiveScissorCount,
    const VkBool32* pExclusiveScissorEnables);

- **commandBuffer** is the command buffer into which the command will be recorded.
- **firstExclusiveScissor** is the index of the first exclusive scissor rectangle whose state is updated by the command.
- **exclusiveScissorCount** is the number of exclusive scissor rectangles updated by the command.
- **pExclusiveScissorEnables** is a pointer to an array of `VkBool32` values defining whether the exclusive scissor is enabled.

The exclusive scissor enables taken from element `i` of `pExclusiveScissorEnables` replace the current state for the scissor index `firstExclusiveScissor + i`, for `i` in `[0, exclusiveScissorCount)`. This command sets the exclusive scissor enable for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is implied by the `VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount` value used to create the currently active pipeline, where all `exclusiveScissorCount` exclusive scissors are implicitly enabled and the remainder up to `VkPhysicalDeviceLimits::maxViewports` are implicitly disabled.

### Valid Usage

- **VUID-vkCmdSetExclusiveScissorEnableNV-exclusiveScissor-07853**
  The `exclusiveScissor` feature **must** be enabled, and the implementation **must** support at least specVersion 2 of the `VK_NV_scissor_exclusive` extension

### Valid Usage (Implicit)

- **VUID-vkCmdSetExclusiveScissorEnableNV-commandBuffer-parameter**
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- **VUID-vkCmdSetExclusiveScissorEnableNV-pExclusiveScissorEnables-parameter**
  `pExclusiveScissorEnables` **must** be a valid pointer to an array of `exclusiveScissorCount` `VkBool32` values

- **VUID-vkCmdSetExclusiveScissorEnableNV-commandBuffer-recording**
  `commandBuffer` **must** be in the recording state

- **VUID-vkCmdSetExclusiveScissorEnableNV-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics operations
29.4. Sample Mask Test

The sample mask test compares the coverage mask for a fragment with the sample mask defined by `VkPipelineMultisampleStateCreateInfo::pSampleMask`.

To dynamically set the sample mask, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
void vkCmdSetSampleMaskEXT(
    VkCommandBuffer commandBuffer,
    VkSampleCountFlagBits samples,
    const VkSampleMask* pSampleMask);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `samples` specifies the number of sample bits in the `pSampleMask`.
- `pSampleMask` is a pointer to an array of `VkSampleMask` values, where the array size is based on the `samples` parameter.

This command sets the sample mask for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineMultisampleStateCreateInfo::pSampleMask` value used to create the currently active pipeline.
Valid Usage

- VUID-vkCmdSetSampleMaskEXT-None-08504
  Either the `extendedDynamicState3SampleMask` feature or the `shaderObject` feature or both must be enabled.

Valid Usage (Implicit)

- VUID-vkCmdSetSampleMaskEXT-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- VUID-vkCmdSetSampleMaskEXT-samples-parameter
  `samples` must be a valid `VkSampleCountFlagBits` value.

- VUID-vkCmdSetSampleMaskEXT-psampleMask-parameter
  `pSampleMask` must be a valid pointer to an array of \( \frac{s_{amps}}{32} \) `VkSampleMask` values.

- VUID-vkCmdSetSampleMaskEXT-commandBuffer-recording
  `commandBuffer` must be in the recording state.

- VUID-vkCmdSetSampleMaskEXT-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations.

- VUID-vkCmdSetSampleMaskEXT-videocoding
  This command must only be called outside of a video coding scope.

Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

Command Properties

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<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
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</tr>
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</table>

Each bit of the coverage mask is associated with a sample index as described in the `rasterization chapter`. If the bit in `VkPipelineMultisampleStateCreateInfo::pSampleMask` which is associated with that same sample index is set to 0, the coverage mask bit is set to 0.
29.5. Fragment Shading

Fragment shaders are invoked for each fragment, or as helper invocations.

Most operations in the fragment shader are not performed in rasterization order, with exceptions called out in the following sections.

For fragment shaders invoked by fragments, the following rules apply:

- A fragment shader must not be executed if a fragment operation that executes before fragment shading discards the fragment.
- A fragment shader may not be executed if:
  - An implementation determines that another fragment shader, invoked by a subsequent primitive in primitive order, overwrites all results computed by the shader (including writes to storage resources).
  - Any other fragment operation discards the fragment, and the shader does not write to any storage resources.
- Otherwise, at least one fragment shader must be executed.
  - If sample shading is enabled and multiple invocations per fragment are required, additional invocations must be executed as specified.
  - If a shading rate image is used and multiple invocations per fragment are required, additional invocations must be executed as specified.
  - Each covered sample must be included in at least one fragment shader invocation.

If no fragment shader is included in the pipeline, no fragment shader is executed, and undefined values may be written to all color attachment outputs during this fragment operation.

Note

Multiple fragment shader invocations may be executed for the same fragment for any number of implementation-dependent reasons. When there is more than one fragment shader invocation per fragment, the association of samples to invocations is implementation-dependent. Stores and atomics performed by these additional invocations have the normal effect.

For example, if the subpass includes multiple views in its view mask, a fragment shader may be invoked separately for each view.

Similarly, if the render pass has a fragment density map attachment, more than one fragment shader invocation may be invoked for each covered sample. Such additional invocations are only produced if VkPhysicalDeviceFragmentDensityMapPropertiesEXT::fragmentDensityInvocations is VK_TRUE. Implementations may generate these additional fragment shader invocations in order to make transitions between fragment areas with different fragment densities more smooth.
29.5.1. Sample Mask

Reading from the `SampleMask` built-in in the `Input` storage class will return the coverage mask for the current fragment as calculated by fragment operations that executed prior to fragment shading.

If `sample shading` is enabled, fragment shaders will only see values of 1 for samples being shaded - other bits will be 0.

Each bit of the coverage mask is associated with a sample index as described in the `rasterization chapter`. If the bit in `SampleMask` which is associated with that same sample index is set to 0, that coverage mask bit is set to 0.

Values written to the `SampleMask` built-in in the `Output` storage class will be used by the `multisample coverage` operation, with the same encoding as the input built-in.

29.5.2. Fragment Shader Tile Image Reads

If the `VK_EXT_shader_tile_image` extension is enabled, implementations divide the framebuffer into a grid of tiles. A `tile image` is a view of a framebuffer attachment tile for fragments with locations within the tile.

Within a render pass instance initiated by `vkCmdBeginRenderingKHR`, fragment shader invocations can read the framebuffer color, depth, and stencil values at the fragment location via tile images.

```markdown
Note
Even though fragment shader invocation can only read from the corresponding fragment location, the abstraction of a tile image is introduced for the following reasons:

- Tile dimensions will be exposed in a future extension
- Future functionality such as executing compute dispatches within render passes via tile shaders can leverage tile images.
```

Enabling `shaderTileImageColorReadAccess`, `shaderTileImageDepthReadAccess`, `shaderTileImageStencilReadAccess` enables fragment shader invocations to read from color, depth, and stencil, respectively.

Color values are read from tile image variables with `OpColorAttachmentReadEXT`. Tile image variables are linked to specific color attachments using `Location` decoration. See `Fragment Tile Image Interface` for more details.

Depth values are read with `OpDepthAttachmentReadEXT`.

Stencil values are read with `OpStencilAttachmentReadEXT`.

The sample to read is specified by a `sample index` value specified as the `Sample` operand to `OpColorAttachmentReadEXT`, `OpDepthAttachmentReadEXT`, or `OpStencilAttachmentReadEXT`.

If `sample shading` is disabled, a fragment invocation can read from all sample locations associated
with the fragment regardless of the fragment’s coverage. This functionality is supported for \text{VkPipelineMultisampleStateCreateInfo::rasterizationSamples} > 1 when \text{VkPhysicalDeviceShaderTileImagePropertiesEXT::shaderTileImageReadSampleFromPixelRateInvocation} is VK_TRUE.

If \text{sample shading} is enabled, and \text{minSampleShading} is 1.0, a fragment invocation \textbf{must} only read from the \text{coverage index} sample. Tile image access \textbf{must} not be used if the value of \text{minSampleShading} is not 1.0.

If the \text{fragment shader} declares the \text{EarlyFragmentTests} execution mode, depth reads are allowed only if depth writes are disabled and stencil reads are allowed only if stencil writes are disabled.

If \text{VkPhysicalDeviceShaderTileImagePropertiesEXT::shaderTileImageReadFromHelperInvocation} is VK_FALSE, values read from helper invocations are undefined otherwise the values read are subject to the coherency guarantees described below.

\text{OpDepthAttachmentReadEXT} returns an undefined value if no depth attachment is present. \text{OpStencilAttachmentReadEXT} returns an undefined value if no stencil attachment is present.

Tile image reads from color, depth and stencil attachments are said to be coherent when the accesses happen in raster order and without \text{data race} with respect to accesses to the attachments from framebuffer-space pipeline stages. The samples which qualify for coherent access and the enabling conditions are described below.

- Let \text{Rc} be the set of components being read from an attachment \text{A} in a draw call
- Let \text{Wc} be the set of components being written to \text{A} by the draw call

The samples which qualify for coherent tile image reads from an attachment \text{A} are:

- All samples in a pixel when \text{Rc} is disjoint with \text{Wc}.
- The samples with coverage in a fragment when \text{Rc} is not disjoint with \text{Wc}. The samples with coverage are determined by the coverage mask for the fragment as calculated by fragment operations that executed prior to fragment shading, including early fragment tests if enabled for the draw call.

A fragment shader \textbf{can} declare \text{NonCoherentColorAttachmentReadEXT}, \text{NonCoherentDepthAttachmentReadEXT}, or \text{NonCoherentStencilAttachmentReadEXT} execution modes to enable non-coherent tile image reads which requires explicit tile image synchronization for the writes to an attachment to be made visible via tile image reads.

When \text{VkPhysicalDeviceShaderTileImagePropertiesEXT::shaderTileImageCoherentReadAccelerated} is VK_TRUE, the implementation prefers that coherent tile image reads are used, otherwise the implementation prefers that non-coherent tile image reads are used.

\textit{Note}

In practice, the most common tile image reads usage patterns fall under one of the following:

- Programmable blending - each fragment reads from a single sample
At its location. Per-sample shading is typically enabled when multisampled render targets are used.

- G-buffer generation and shading in one render pass - in the shading phase a fragment reads from a single sample at its location.
- Programmatic resolve - a fragment reads from all samples at its location (per-sample shading is disabled). This requires the use of a "full-screen triangle" instead of a rectangle composed of two triangles in order to avoid data races along the shared edge of the triangles.
- 1:1 texturing with LOD - in use cases such a deferred screen space decals a fragment reads a single sample (SampleID) from depth buffer, but requires being able to read from helper threads to derive the texture LOD. This use case is supported as long as the attachment components being read are not overwritten by color, depth, or stencil attachment writes.

All of the above use cases are supported by coherent tile image reads, but only the latter three are supported when non-coherent reads are used as there is no mechanism to synchronize non-coherent reads with writes within a draw call.

### 29.5.3. Depth Replacement

Writing to the `FragDepth` built-in will replace the fragment’s calculated depth values for each sample in the input `SampleMask`. Depth testing performed after the fragment shader for this fragment will use this new value as $z_f$.

### 29.5.4. Stencil Reference Replacement

Writing to the `FragStencilRefEXT` built-in will replace the fragment’s stencil reference value for each sample in the input `SampleMask`. Stencil testing performed after the fragment shader for this fragment will use this new value as $s_r$.

### 29.5.5. Interlocked Operations

`OpBeginInvocationInterlockEXT` and `OpEndInvocationInterlockEXT` define a section of a fragment shader which imposes additional ordering constraints on operations performed within them. These operations are defined as interlocked operations. How interlocked operations are ordered against other fragment shader invocations depends on the specified execution modes.

If the `ShadingRateInterlockOrderedEXT` execution mode is specified, any interlocked operations in a fragment shader must happen before interlocked operations in fragment shader invocations that execute later in rasterization order and cover at least one sample in the same fragment area, and must happen after interlocked operations in a fragment shader that executes earlier in rasterization order and cover at least one sample in the same fragment area.

If the `ShadingRateInterlockUnorderedEXT` execution mode is specified, any interlocked operations in a fragment shader must happen before or after interlocked operations in fragment shader invocations that execute earlier or later in rasterization order and cover at least one sample in the same fragment area.
If the `PixelInterlockOrderedEXT` execution mode is specified, any interlocked operations in a fragment shader **must** happen before interlocked operations in fragment shader invocations that execute later in **rasterization order** and cover at least one sample in the same pixel, and **must** happen after interlocked operations in a fragment shader that executes earlier in **rasterization order** and cover at least one sample in the same pixel.

If the `PixelInterlockUnorderedEXT` execution mode is specified, any interlocked operations in a fragment shader **must** happen before or after interlocked operations in fragment shader invocations that execute earlier or later in **rasterization order** and cover at least one sample in the same pixel.

If the `SampleInterlockOrderedEXT` execution mode is specified, any interlocked operations in a fragment shader **must** happen before interlocked operations in fragment shader invocations that execute later in **rasterization order** and cover at least one of the same samples, and **must** happen after interlocked operations in a fragment shader that executes earlier in **rasterization order** and cover at least one of the same samples.

If the `SampleInterlockUnorderedEXT` execution mode is specified, any interlocked operations in a fragment shader **must** happen before or after interlocked operations in fragment shader invocations that execute earlier or later in **rasterization order** and cover at least one of the same samples.

### 29.6. Multisample Coverage

If a fragment shader is active and its entry point’s interface includes a built-in output variable decorated with `SampleMask`, but not `OverrideCoverageNV`, the coverage mask is **ANDed** with the bits of the `SampleMask` built-in to generate a new coverage mask. If the `SampleMask` built-in is also decorated with `OverrideCoverageNV`, the coverage mask is replaced with the mask bits set in the shader. If **sample shading** is enabled, bits written to `SampleMask` corresponding to samples that are not being shaded by the fragment shader invocation are ignored. If no fragment shader is active, or if the active fragment shader does not include `SampleMask` in its interface, the coverage mask is not modified.

Next, the fragment alpha value and coverage mask are modified based on the line coverage factor if the `lineRasterizationMode` member of the `VkPipelineRasterizationStateCreateInfo` structure is `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT`, and the `alphaToCoverageEnable` and `alphaToOneEnable` members of the `VkPipelineMultisampleStateCreateInfo` structure.

To **dynamically set** the `alphaToCoverageEnable` state, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
void vkCmdSetAlphaToCoverageEnableEXT(
    VkCommandBuffer commandBuffer, commandBuffer,
    VkBool32 alphaToCoverageEnable);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `alphaToCoverageEnable` specifies the `alphaToCoverageEnable` state.
This command sets the `alphaToCoverageEnable` state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineMultisampleStateCreateInfo::alphaToCoverageEnable` value used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetAlphaToCoverageEnableEXT-None-08506
  Either the `extendedDynamicState3AlphaToCoverageEnable` feature or the `shaderObject` feature or both must be enabled

### Valid Usage (Implicit)

- VUID-vkCmdSetAlphaToCoverageEnableEXT-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetAlphaToCoverageEnableEXT-commandBuffer-recording
  `commandBuffer` must be in the recording state
- VUID-vkCmdSetAlphaToCoverageEnableEXT-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations
- VUID-vkCmdSetAlphaToCoverageEnableEXT-videocoding
  This command must only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

### Command Properties

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To dynamically set the `alphaToOneEnable` state, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
void vkCmdSetAlphaToOneEnableEXT(
```
• `commandBuffer` is the command buffer into which the command will be recorded.
• `alphaToOneEnable` specifies the `alphaToOneEnable` state.

This command sets the `alphaToOneEnable` state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineMultisampleStateCreateInfo::alphaToOneEnable` value used to create the currently active pipeline.

### Valid Usage

- **VUID-vkCmdSetAlphaToOneEnableEXT-None-08508**
  Either the `extendedDynamicState3AlphaToOneEnable` feature or the `shaderObject` feature or both must be enabled

- **VUID-vkCmdSetAlphaToOneEnableEXT-alphaToOne-07607**
  If the `alphaToOne` feature is not enabled, `alphaToOneEnable` must be `VK_FALSE`

### Valid Usage (Implicit)

- **VUID-vkCmdSetAlphaToOneEnableEXT-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- **VUID-vkCmdSetAlphaToOneEnableEXT-commandBuffer-recording**
  `commandBuffer` must be in the recording state

- **VUID-vkCmdSetAlphaToOneEnableEXT-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations

- **VUID-vkCmdSetAlphaToOneEnableEXT-videocoding**
  This command must only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized
All alpha values in this section refer only to the alpha component of the fragment shader output that has a Location and Index decoration of zero (see the Fragment Output Interface section). If that shader output has an integer or unsigned integer type, then these operations are skipped.

If the lineRasterizationMode member of the VkPipelineRasterizationStateCreateInfo structure is VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT and the fragment came from a line segment, then the alpha value is replaced by multiplying it by the coverage factor for the fragment computed during smooth line rasterization.

If alphaToCoverageEnable is enabled, a temporary coverage mask is generated where each bit is determined by the fragment's alpha value, which is ANDed with the fragment coverage mask.

No specific algorithm is specified for converting the alpha value to a temporary coverage mask. It is intended that the number of 1's in this value be proportional to the alpha value (clamped to [0,1]), with all 1's corresponding to a value of 1.0 and all 0's corresponding to 0.0. The algorithm may be different at different framebuffer coordinates.

Note
Using different algorithms at different framebuffer coordinates may help to avoid artifacts caused by regular coverage sample locations.

Finally, if alphaToOneEnable is enabled, each alpha value is replaced by the maximum representable alpha value for fixed-point color attachments, or by 1.0 for floating-point attachments. Otherwise, the alpha values are not changed.

## 29.7. Depth and Stencil Operations

Pipeline state controlling the depth bounds tests, stencil test, and depth test is specified through the members of the VkPipelineDepthStencilStateCreateInfo structure.

The VkPipelineDepthStencilStateCreateInfo structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPipelineDepthStencilStateCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkPipelineDepthStencilStateCreateFlags flags;
    VkBool32 depthTestEnable;
    VkBool32 depthWriteEnable;
    VkBool32 stencilTestEnable;
} VkPipelineDepthStencilStateCreateInfo;
```
VkCompareOp
depthCompareOp;
VkBool32
depthBoundsTestEnable;
VkBool32
stencilTestEnable;
VkStencilOpState
front;
VkStencilOpState
back;
float
minDepthBounds;
float
maxDepthBounds;
}
VkPipelineDepthStencilStateCreateInfo;

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **flags** is a bitmask of **VkPipelineDepthStencilStateCreateFlagBits** specifying additional depth/stencil state information.
- **depthTestEnable** controls whether **depth testing** is enabled.
- **depthWriteEnable** controls whether **depth writes** are enabled when **depthTestEnable** is **VK_TRUE**. Depth writes are always disabled when **depthTestEnable** is **VK_FALSE**.
- **depthCompareOp** is a **VkCompareOp** value specifying the comparison operator to use in the **Depth Comparison** step of the **depth test**.
- **depthBoundsTestEnable** controls whether **depth bounds testing** is enabled.
- **stencilTestEnable** controls whether **stencil testing** is enabled.
- **front** and **back** are **VkStencilOpState** values controlling the corresponding parameters of the **stencil test**.
- **minDepthBounds** is the minimum depth bound used in the **depth bounds test**.
- **maxDepthBounds** is the maximum depth bound used in the **depth bounds test**.

**Valid Usage**

- **VUID-VkPipelineDepthStencilStateCreateInfo-depthBoundsTestEnable-00598**
  If the **depthBounds** feature is not enabled, **depthBoundsTestEnable** must be **VK_FALSE**.

- **VUID-VkPipelineDepthStencilStateCreateInfo-separateStencilMaskRef-04453**
  If the **VK_KHR_portability_subset** extension is enabled, and the value of **VkPipelineDepthStencilStateCreateInfo::stencilTestEnable** is **VK_TRUE**, and the value of **VkPipelineRasterizationStateCreateInfo::cullMode** is **VK_CULL_MODE_NONE**, the value of **reference** in each of the **VkStencilOpState** structs in **front** and **back** must be the same.

- **VUID-VkPipelineDepthStencilStateCreateInfo-rasterizationOrderDepthAttachmentAccess-06463**
  If the **rasterizationOrderDepthAttachmentAccess** feature is not enabled, **flags** must not include **VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT**.

- **VUID-VkPipelineDepthStencilStateCreateInfo-rasterizationOrderStencilAttachmentAccess-**
If the `rasterizationOrderStencilAttachmentAccess` feature is not enabled, flags **must** not include

`VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT`

---

### Valid Usage (Implicit)

- **VUID-VkPipelineDepthStencilStateCreateInfo-sType-sType**
  
  *sType* **must** be `VK_STRUCTURE_TYPE_PIPELINE_DEPTH_STENCIL_STATE_CREATE_INFO`

- **VUID-VkPipelineDepthStencilStateCreateInfo-pNext-pNext**
  
  *pNext* **must** be `NULL`

- **VUID-VkPipelineDepthStencilStateCreateInfo-flags-parameter**
  
  *flags* **must** be a valid combination of `VkPipelineDepthStencilStateCreateFlagBits` values

- **VUID-VkPipelineDepthStencilStateCreateInfo-depthCompareOp-parameter**
  
  *depthCompareOp* **must** be a valid `VkCompareOp` value

- **VUID-VkPipelineDepthStencilStateCreateInfo-front-parameter**
  
  *front* **must** be a valid `VkStencilOpState` structure

- **VUID-VkPipelineDepthStencilStateCreateInfo-back-parameter**
  
  *back* **must** be a valid `VkStencilOpState` structure

---

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkPipelineDepthStencilStateCreateFlags;
```

`VkPipelineDepthStencilStateCreateFlags` is a bitmask type for setting a mask of zero or more `VkPipelineDepthStencilStateCreateFlagBits`

Bits which **can** be set in the `VkPipelineDepthStencilStateCreateInfo::flags` parameter are:

```c
// Provided by VK_EXT_rasterization_order_attachment_access
typedef enum VkPipelineDepthStencilStateCreateFlagBits {
  // Provided by VK_EXT_rasterization_order_attachment_access

  VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT = 0x00000001,
  // Provided by VK_EXT_rasterization_order_attachment_access

  VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT = 0x00000002,
  // Provided by VK_ARM_rasterization_order_attachment_access

  VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_ARM =
  VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT

```
• **VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT** indicates that access to the depth aspects of depth/stencil and input attachments will have implicit framebuffer-local memory dependencies.

• **VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT** indicates that access to the stencil aspects of depth/stencil and input attachments will have implicit framebuffer-local memory dependencies.

When **VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT** is included in a pipeline, it forms a framebuffer-local memory dependency for each fragment generated by draw commands for that pipeline with the following scopes:

• The first **synchronization scope** includes **VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT** and **VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT** pipeline stages executed by all previous fragments (as defined by **primitive order**) in the corresponding **framebuffer regions** including those generated by the same draw command.

• The second **synchronization scope** includes **VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT** and **VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT** pipeline stages executed by the generated fragment.

• The first **access scope** includes all writes to the depth aspect of depth/stencil attachments.

• The second **access scope** includes all reads from the depth aspect of input attachments.

When **VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT** is included in a pipeline, it forms a framebuffer-local memory dependency for each fragment generated by draw commands for that pipeline with the following scopes:

• The first **synchronization scope** includes **VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT** and **VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT** pipeline stages executed by all previous fragments (as defined by **primitive order**) in the corresponding **framebuffer regions** including those generated by the same draw command.

• The second **synchronization scope** includes **VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT** and **VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT** pipeline stages executed by the generated fragment.

• The first **access scope** includes all writes to the stencil aspect of depth/stencil attachments.

• The second **access scope** includes all reads from the stencil aspect of input attachments.
29.8. Depth Bounds Test

The depth bounds test compares the depth value $z_a$ in the depth/stencil attachment at each sample’s framebuffer coordinates $(x_f, y_f)$ and sample index $i$ against a set of depth bounds.

The depth bounds are determined by two floating point values defining a minimum ($\text{minDepthBounds}$) and maximum ($\text{maxDepthBounds}$) depth value. These values are either set by the VkPipelineDepthStencilStateCreateInfo structure during pipeline creation, or dynamically by vkCmdSetDepthBoundsTestEnable and vkCmdSetDepthBounds.

A given sample is considered within the depth bounds if $z_a$ is in the range $[\text{minDepthBounds}, \text{maxDepthBounds}]$. Samples with depth attachment values outside of the depth bounds will have their coverage set to 0.

If the depth bounds test is disabled, or if there is no depth attachment, the coverage mask is unmodified by this operation.

To dynamically enable or disable the depth bounds test, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdSetDepthBoundsTestEnable(
    VkCommandBuffer commandBuffer,       // Provided by VK_VERSION_1_3
    VkBool32 depthBoundsTestEnable);     // Provided by VK_VERSION_1_3
```

or the equivalent command

```c
// Provided by VK_EXT_extended_dynamic_state, VK_EXT_shader_object
void vkCmdSetDepthBoundsTestEnableEXT(
    VkCommandBuffer commandBuffer,       // Provided by VK_EXT_extended_dynamic_state, VK_EXT_shader_object
    VkBool32 depthBoundsTestEnable);     // Provided by VK_EXT_extended_dynamic_state, VK_EXT_shader_object
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `depthBoundsTestEnable` specifies if the depth bounds test is enabled.

This command sets the depth bounds enable for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE set in VkPipelineDynamicStateCreateInfo::pDynamicStates. Otherwise, this state is specified by the VkPipelineDepthStencilStateCreateInfo::depthBoundsTestEnable value used to create the currently active pipeline.

**Valid Usage**

- VUID-vkCmdSetDepthBoundsTestEnable-None-08971
  At least one of the following must be true:
  - the extendedDynamicState feature is enabled
  - the shaderObject feature is enabled
the value of \texttt{VkApplicationInfo::apiVersion} used to create the \texttt{VkInstance} parent of \texttt{commandBuffer} is greater than or equal to Version 1.3

**Valid Usage (Implicit)**

- \textbf{VUID-vkCmdSetDepthBoundsTestEnable-commandBuffer-parameter} \texttt{commandBuffer} \textbf{must} be a valid \texttt{VkCommandBuffer} handle
- \textbf{VUID-vkCmdSetDepthBoundsTestEnable-commandBuffer-recording} \texttt{commandBuffer} \textbf{must} be in the \textit{recording} state
- \textbf{VUID-vkCmdSetDepthBoundsTestEnable-commandBuffer-cmdpool} The \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from \textbf{must} support graphics operations
- \textbf{VUID-vkCmdSetDepthBoundsTestEnable-videocoding} This command \textbf{must} only be called outside of a video coding scope

**Host Synchronization**

- Host access to \texttt{commandBuffer} \textbf{must} be externally synchronized
- Host access to the \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from \textbf{must} be externally synchronized

**Command Properties**

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<thead>
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<tr>
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</tr>
<tr>
<td>Secondary</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

To \textit{dynamically set} the depth bounds range, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdSetDepthBounds(
    VkCommandBuffer commandBuffer,
    float minDepthBounds,
    float maxDepthBounds);
```

- \texttt{commandBuffer} is the command buffer into which the command will be recorded.
- \texttt{minDepthBounds} is the minimum depth bound.
- \texttt{maxDepthBounds} is the maximum depth bound.
This command sets the depth bounds range for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with \texttt{VK_DYNAMIC_STATE_DEPTH_BOUNDS} set in \texttt{VkPipelineDynamicStateCreateInfo::pDynamicStates}. Otherwise, this state is specified by the \texttt{VkPipelineDepthStencilStateCreateInfo::minDepthBounds} and \texttt{VkPipelineDepthStencilStateCreateInfo::maxDepthBounds} values used to create the currently active pipeline.

### Valid Usage

- **VUID-vkCmdSetDepthBounds-minDepthBounds-00600**
  If the \texttt{VK_EXT_depth_range_unrestricted} extension is not enabled, \texttt{minDepthBounds} must be between 0.0 and 1.0, inclusive.

- **VUID-vkCmdSetDepthBounds-maxDepthBounds-00601**
  If the \texttt{VK_EXT_depth_range_unrestricted} extension is not enabled, \texttt{maxDepthBounds} must be between 0.0 and 1.0, inclusive.

### Valid Usage (Implicit)

- **VUID-vkCmdSetDepthBounds-commandBuffer-parameter**
  \texttt{commandBuffer} must be a valid \texttt{VkCommandBuffer} handle.

- **VUID-vkCmdSetDepthBounds-commandBuffer-recording**
  \texttt{commandBuffer} must be in the recording state.

- **VUID-vkCmdSetDepthBounds-commandBuffer-cmdpool**
  The \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from must support graphics operations.

- **VUID-vkCmdSetDepthBounds-videocoding**
  This command must only be called outside of a video coding scope.

### Host Synchronization

- Host access to \texttt{commandBuffer} must be externally synchronized.

- Host access to the \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from must be externally synchronized.

### Command Properties

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</tr>
</tbody>
</table>
29.9. Stencil Test

The stencil test compares the stencil attachment value \( s_a \) in the depth/stencil attachment at each sample’s framebuffer coordinates \((x_f, y_f)\) and sample index \( i \) against a stencil reference value.

If the render pass has a fragment density map attachment and the fragment covers multiple pixels, there is an implementation-dependent association of coverage samples to stencil attachment samples within the fragment. However, if all samples in the fragment are covered, and the stencil attachment value is updated as a result of this test, all stencil attachment samples will be updated.

If the stencil test is not enabled, as specified by \( \text{vkCmdSetStencilTestEnable} \) or \( \text{VkPipelineDepthStencilStateCreateInfo::stencilTestEnable} \), or if there is no stencil attachment, the coverage mask is unmodified by this operation.

The stencil test is controlled by one of two sets of stencil-related state, the front stencil state and the back stencil state. Stencil tests and writes use the back stencil state when processing fragments generated by back-facing polygons, and the front stencil state when processing fragments generated by front-facing polygons or any other primitives.

The comparison operation performed is determined by the \( \text{VkCompareOp} \) value set by \( \text{vkCmdSetStencilOp::compareOp} \), or by \( \text{VkStencilOpState::compareOp} \) during pipeline creation.

The compare mask \( s_c \) and stencil reference value \( s_r \) of the front or the back stencil state set determine arguments of the comparison operation. \( s_c \) is set by the \( \text{VkPipelineDepthStencilStateCreateInfo} \) structure during pipeline creation, or by the \( \text{vkCmdSetStencilCompareMask} \) command. \( s_r \) is set by \( \text{VkPipelineDepthStencilStateCreateInfo} \) or by \( \text{vkCmdSetStencilReference} \).

\( s_r \) and \( s_a \) are each independently combined with \( s_c \) using a bitwise AND operation to create masked reference and attachment values \( s'_r \) and \( s'_a \). \( s'_r \) and \( s'_a \) are used as the reference and test values, respectively, in the operation specified by the \( \text{VkCompareOp} \).

If the comparison evaluates to false, the coverage for the sample is set to 0.

A new stencil value \( s_g \) is generated according to a stencil operation defined by \( \text{VkStencilOp} \) parameters set by \( \text{vkCmdSetStencilOp} \) or \( \text{VkPipelineDepthStencilStateCreateInfo} \). If the stencil test fails, \( \text{failOp} \) defines the stencil operation used. If the stencil test passes however, the stencil op used is based on the depth test - if it passes, \( \text{VkPipelineDepthStencilStateCreateInfo::passOp} \) is used, otherwise \( \text{VkPipelineDepthStencilStateCreateInfo::depthFailOp} \) is used.

The stencil attachment value \( s_a \) is then updated with the generated stencil value \( s_g \) according to the write mask \( s_w \) defined by writeMask in \( \text{VkPipelineDepthStencilStateCreateInfo::front} \) and \( \text{VkPipelineDepthStencilStateCreateInfo::back} \) as:

\[
s_a = (s_a \& \neg s_w) \mid (s_g \& s_w)
\]

To dynamically enable or disable the stencil test, call:
// Provided by VK_VERSION_1_3
void vkCmdSetStencilTestEnable(
    VkCommandBuffer commandBuffer,
    VkBool32 stencilTestEnable);

or the equivalent command

// Provided by VK_EXT_extended_dynamic_state, VK_EXT_shader_object
void vkCmdSetStencilTestEnableEXT(
    VkCommandBuffer commandBuffer,
    VkBool32 stencilTestEnable);

• commandBuffer is the command buffer into which the command will be recorded.
• stencilTestEnable specifies if the stencil test is enabled.

This command sets the stencil test enable for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE set in VkPipelineDynamicStateCreateInfo::pDynamicStates. Otherwise, this state is specified by the VkPipelineDepthStencilStateCreateInfo::stencilTestEnable value used to create the currently active pipeline.

Valid Usage

• VUID-vkCmdSetStencilTestEnable-None-08971
  At least one of the following must be true:
  ◦ the extendedDynamicState feature is enabled
  ◦ the shaderObject feature is enabled
  ◦ the value of VkApplicationInfo::apiVersion used to create the VkInstance parent of commandBuffer is greater than or equal to Version 1.3

Valid Usage (Implicit)

• VUID-vkCmdSetStencilTestEnable-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

• VUID-vkCmdSetStencilTestEnable-commandBuffer-recording
  commandBuffer must be in the recording state

• VUID-vkCmdSetStencilTestEnable-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

• VUID-vkCmdSetStencilTestEnable-videocoding
  This command must only be called outside of a video coding scope
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

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<td>Secondary</td>
<td></td>
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</tr>
</tbody>
</table>

To dynamically set the stencil operation, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdSetStencilOp(
    VkCommandBuffer
    commandBuffer,       
    VkStencilFaceFlags
    faceMask, 
    VkStencilOp
    failOp, 
    VkStencilOp
    passOp, 
    VkStencilOp
    depthFailOp, 
    VkCompareOp
    compareOp); 
```

or the equivalent command

```c
// Provided by VK_EXT_extended_dynamic_state, VK_EXT_shader_object
void vkCmdSetStencilOpEXT(
    VkCommandBuffer
    commandBuffer,       
    VkStencilFaceFlags
    faceMask, 
    VkStencilOp
    failOp, 
    VkStencilOp
    passOp, 
    VkStencilOp
    depthFailOp, 
    VkCompareOp
    compareOp); 
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `faceMask` is a bitmask of `VkStencilFaceFlagBits` specifying the set of stencil state for which to update the stencil operation.
- `failOp` is a `VkStencilOp` value specifying the action performed on samples that fail the stencil test.
- `passOp` is a `VkStencilOp` value specifying the action performed on samples that pass both the depth and stencil tests.
• **depthFailOp** is a [VkStencilOp](https://vulkan.khronos.org/standards/v1.3/vulkan-core.html#VkStencilOp) value specifying the action performed on samples that pass the stencil test and fail the depth test.

• **compareOp** is a [VkCompareOp](https://vulkan.khronos.org/standards/v1.3/vulkan-core.html#VkCompareOp) value specifying the comparison operator used in the stencil test.

This command sets the stencil operation for subsequent drawing commands when when drawing using [shader objects](https://vulkan.khronos.org/standards/v1.3/vulkan-core.html#_shader_objects), or when the graphics pipeline is created with `VK_DYNAMIC_STATE_STENCIL_OP` set in [VkPipelineDynamicStateCreateInfo](https://vulkan.khronos.org/standards/v1.3/vulkan-core.html#VkPipelineDynamicStateCreateInfo)::pDynamicStates. Otherwise, this state is specified by the corresponding [VkPipelineDepthStencilStateCreateInfo](https://vulkan.khronos.org/standards/v1.3/vulkan-core.html#VkPipelineDepthStencilStateCreateInfo)::failOp, passOp, depthFailOp, and compareOp values used to create the currently active pipeline, for both front and back faces.

**Valid Usage**

- VUID-vkCmdSetStencilOp-None-08971
  At least one of the following **must** be true:
    - the extendedDynamicState feature is enabled
    - the shaderObject feature is enabled
    - the value of VkApplicationInfo::apiVersion used to create the VkInstance parent of commandBuffer is greater than or equal to Version 1.3

**Valid Usage (Implicit)**

- VUID-vkCmdSetStencilOp-commandBuffer-parameter
  commandBuffer **must** be a valid VkCommandBuffer handle

- VUID-vkCmdSetStencilOp-faceMask-parameter
  faceMask **must** be a valid combination of VkStencilFaceFlagBits values

- VUID-vkCmdSetStencilOp-faceMask-requiredbitsetmask
  faceMask **must** not be 0

- VUID-vkCmdSetStencilOp-failOp-parameter
  failOp **must** be a valid VkStencilOp value

- VUID-vkCmdSetStencilOp-passOp-parameter
  passOp **must** be a valid VkStencilOp value

- VUID-vkCmdSetStencilOp-depthFailOp-parameter
  depthFailOp **must** be a valid VkStencilOp value

- VUID-vkCmdSetStencilOp-compareOp-parameter
  compareOp **must** be a valid VkCompareOp value

- VUID-vkCmdSetStencilOp-commandBuffer-recording
  commandBuffer **must** be in the recording state

- VUID-vkCmdSetStencilOp-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from **must** support graphics operations

- VUID-vkCmdSetStencilOp-videocoding
This command **must** only be called outside of a video coding scope

---

**Host Synchronization**

- Host access to **commandBuffer** **must** be externally synchronized
- Host access to the **VkCommandPool** that **commandBuffer** was allocated from **must** be externally synchronized

---

**Command Properties**

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</tr>
</tbody>
</table>

The **VkStencilOpState** structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkStencilOpState {
    VkStencilOp failOp;
    VkStencilOp passOp;
    VkStencilOp depthFailOp;
    VkCompareOp compareOp;
    uint32_t compareMask;
    uint32_t writeMask;
    uint32_t reference;
} VkStencilOpState;
```

- **failOp** is a **VkStencilOp** value specifying the action performed on samples that fail the stencil test.
- **passOp** is a **VkStencilOp** value specifying the action performed on samples that pass both the depth and stencil tests.
- **depthFailOp** is a **VkStencilOp** value specifying the action performed on samples that pass the stencil test and fail the depth test.
- **compareOp** is a **VkCompareOp** value specifying the comparison operator used in the stencil test.
- **compareMask** selects the bits of the unsigned integer stencil values participating in the stencil test.
- **writeMask** selects the bits of the unsigned integer stencil values updated by the stencil test in the stencil framebuffer attachment.
- **reference** is an integer stencil reference value that is used in the unsigned stencil comparison.
To dynamically set the stencil compare mask, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdSetStencilCompareMask(
    VkCommandBuffer commandBuffer,
    VkStencilFaceFlags faceMask,
    uint32_t compareMask);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `faceMask` is a bitmask of `VkStencilFaceFlagBits` specifying the set of stencil state for which to update the compare mask.
- `compareMask` is the new value to use as the stencil compare mask.

This command sets the stencil compare mask for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkStencilOpState::compareMask` value used to create the currently active pipeline, for both front and back faces.
operations

- VUID-vkCmdSetStencilCompareMask-videocoding
  This command **must** only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` **must** be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized

### Command Properties

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</table>

`VkStencilFaceFlagBits` values are:

```cpp
// Provided by VK_VERSION_1_0
typedef enum VkStencilFaceFlagBits {
    VK_STENCIL_FACE_FRONT_BIT = 0x00000001,
    VK_STENCIL_FACE_BACK_BIT = 0x00000002,
    VK_STENCIL_FACE_FRONT_AND_BACK = 0x00000003,
    VK_STENCIL_FRONT_AND_BACK = VK_STENCIL_FACE_FRONT_AND_BACK,
} VkStencilFaceFlagBits;
```

- **VK_STENCIL_FACE_FRONT_BIT** specifies that only the front set of stencil state is updated.
- **VK_STENCIL_FACE_BACK_BIT** specifies that only the back set of stencil state is updated.
- **VK_STENCIL_FACE_FRONT_AND_BACK** is the combination of **VK_STENCIL_FACE_FRONT_BIT** and **VK_STENCIL_FACE_BACK_BIT**, and specifies that both sets of stencil state are updated.

```cpp
// Provided by VK_VERSION_1_0
typedef VkFlags VkStencilFaceFlags;
```

`VkStencilFaceFlags` is a bitmask type for setting a mask of zero or more `VkStencilFaceFlagBits`.

To **dynamically set** the stencil write mask, call:

```cpp
// Provided by VK_VERSION_1_0
void vkCmdSetStencilWriteMask(
```
VkCommandBuffer commandBuffer, VkStencilFaceFlags faceMask, uint32_t writeMask);

- **commandBuffer** is the command buffer into which the command will be recorded.
- **faceMask** is a bitmask of *VkStencilFaceFlagBits* specifying the set of stencil state for which to update the write mask, as described above for *vkCmdSetStencilCompareMask*.
- **writeMask** is the new value to use as the stencil write mask.

This command sets the stencil write mask for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_STENCIL_WRITE_MASK` set in *VkPipelineDynamicStateCreateInfo::pDynamicStates*. Otherwise, this state is specified by the `writeMask` value used to create the currently active pipeline, for both *VkPipelineDepthStencilStateCreateInfo::front* and *VkPipelineDepthStencilStateCreateInfo::back* faces.

### Valid Usage (Implicit)

- **VUID-vkCmdSetStencilWriteMask-commandBuffer-parameter**
  - `commandBuffer` must be a valid *VkCommandBuffer* handle
- **VUID-vkCmdSetStencilWriteMask-faceMask-parameter**
  - `faceMask` must be a valid combination of *VkStencilFaceFlagBits* values
- **VUID-vkCmdSetStencilWriteMask-faceMask-requiredbitmask**
  - `faceMask` must not be 0
- **VUID-vkCmdSetStencilWriteMask-commandBuffer-recording**
  - `commandBuffer` must be in the recording state
- **VUID-vkCmdSetStencilWriteMask-commandBuffer-cmdpool**
The *VkCommandPool* that `commandBuffer` was allocated from must support graphics operations
- **VUID-vkCmdSetStencilWriteMask-videocoding**
  - This command must only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the *VkCommandPool* that `commandBuffer` was allocated from must be externally synchronized
To **dynamically set** the stencil reference value, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdSetStencilReference(
    VkCommandBuffer commandBuffer,
    VkStencilFaceFlags faceMask,
    uint32_t reference);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `faceMask` is a bitmask of `VkStencilFaceFlagBits` specifying the set of stencil state for which to update the reference value, as described above for `vkCmdSetStencilCompareMask`.
- `reference` is the new value to use as the stencil reference value.

This command sets the stencil reference value for subsequent drawing commands when drawing using *shader objects*, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_STENCIL_REFERENCE` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineDepthStencilStateCreateInfo::reference` value used to create the currently active pipeline, for both front and back faces.

**Valid Usage (Implicit)**

- VUID-vkCmdSetStencilReference-commandBuffer-parameter
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetStencilReference-faceMask-parameter
  `faceMask` **must** be a valid combination of `VkStencilFaceFlagBits` values
- VUID-vkCmdSetStencilReference-faceMask-required bitmask
  `faceMask` **must** not be 0
- VUID-vkCmdSetStencilReference-commandBuffer-recording
  `commandBuffer` **must** be in the recording state
- VUID-vkCmdSetStencilReference-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics operations
- VUID-vkCmdSetStencilReference-vidcoding
  This command **must** only be called outside of a video coding scope
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

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Possible values of the `failOp`, `passOp`, and `depthFailOp` members of `VkStencilOpState`, specifying what happens to the stored stencil value if this or certain subsequent tests fail or pass, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkStencilOp {  
    VK_STENCIL_OP_KEEP = 0,  
    VK_STENCIL_OP_ZERO = 1,  
    VK_STENCIL_OP_REPLACE = 2,  
    VK_STENCIL_OP_INCREMENT_AND_CLAMP = 3,  
    VK_STENCIL_OP_DECREMENT_AND_CLAMP = 4,  
    VK_STENCIL_OP_INVERT = 5,  
    VK_STENCIL_OP_INCREMENT_AND_WRAP = 6,  
    VK_STENCIL_OP_DECREMENT_AND_WRAP = 7,  
} VkStencilOp;
```

- `VK_STENCIL_OP_KEEP` keeps the current value.
- `VK_STENCIL_OP_ZERO` sets the value to 0.
- `VK_STENCIL_OP_REPLACE` sets the value to reference.
- `VK_STENCIL_OP_INCREMENT_AND_CLAMP` increments the current value and clamps to the maximum representable unsigned value.
- `VK_STENCIL_OP_DECREMENT_AND_CLAMP` decrements the current value and clamps to 0.
- `VK_STENCIL_OP_INVERT` bitwise-inverts the current value.
- `VK_STENCIL_OP_INCREMENT_AND_WRAP` increments the current value and wraps to 0 when the maximum value would have been exceeded.
- `VK_STENCIL_OP_DECREMENT_AND_WRAP` decrements the current value and wraps to the maximum possible value when the value would go below 0.

For purposes of increment and decrement, the stencil bits are considered as an unsigned integer.
29.10. Depth Test

The depth test compares the depth value \( z_a \) in the depth/stencil attachment at each sample's framebuffer coordinates \((x_f, y_f)\) and sample index \(i\) against the sample's depth value \(z_f\). If there is no depth attachment then the depth test is skipped.

If the render pass has a fragment density map attachment and the fragment covers multiple pixels, there is an implementation-dependent association of rasterization samples to depth attachment samples within the fragment. However, if all samples in the fragment are covered, and the depth attachment value is updated as a result of this test, all depth attachment samples will be updated.

The depth test occurs in three stages, as detailed in the following sections.

29.10.1. Depth Clamping and Range Adjustment

If \( \text{VkPipelineRasterizationStateCreateInfo}::\text{depthClampEnable} \) is enabled, \(z_f\) is clamped to \([z_{\text{min}}, z_{\text{max}}]\), where \(z_{\text{min}} = \min(n,f)\), \(z_{\text{max}} = \max(n,f)\), and \(n\) and \(f\) are the \(\text{minDepth}\) and \(\text{maxDepth}\) depth range values of the viewport used by this fragment, respectively.

If \( \text{VkPhysicalDeviceDepthClampZeroOneFeaturesEXT}::\text{depthClampZeroOne} \) is enabled:

- If the depth attachment has a floating-point format and \(\text{VK_EXT_depth_range_unrestricted}\) is enabled then \(z_f\) is unchanged.

- Otherwise, \(z_f\) is clamped to the range \([0, 1]\).

Otherwise:

- If \(z_f\) is not in the range \([z_{\text{min}}, z_{\text{max}}]\), then \(z_f\) is undefined following this step.

- If the depth attachment has a fixed-point format and \(z_f\) is not in the range \([0, 1]\), then \(z_f\) is undefined following this step.

29.10.2. Depth Comparison

If the depth test is not enabled, as specified by \(\text{vkCmdSetDepthTestEnable}\) or \(\text{VkPipelineDepthStencilStateCreateInfo}::\text{depthTestEnable}\), then this step is skipped.

The comparison operation performed is determined by the \(\text{VkCompareOp}\) value set by \(\text{vkCmdSetDepthCompareOp}\), or by \(\text{VkPipelineDepthStencilStateCreateInfo}::\text{depthCompareOp}\) during pipeline creation. \(z_f\) and \(z_a\) are used as the \textit{reference} and \textit{test} values, respectively, in the operation specified by the \(\text{VkCompareOp}\).

If the comparison evaluates to false, the coverage for the sample is set to \(\theta\).

29.10.3. Depth Attachment Writes

If depth writes are enabled, as specified by \(\text{vkCmdSetDepthWriteEnable}\) or \(\text{VkPipelineDepthStencilStateCreateInfo}::\text{depthWriteEnable}\), and the comparison evaluated to true, the depth attachment value \(z_a\) is set to the sample's depth value \(z_f\). If there is no depth attachment, no value is written.
To dynamically enable or disable the depth test, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdSetDepthTestEnable(
    VkCommandBuffer commandBuffer,
    VkBool32 depthTestEnable);
```

or the equivalent command

```c
// Provided by VK_EXT_extended_dynamic_state, VK_EXT_shader_object
void vkCmdSetDepthTestEnableEXT(
    VkCommandBuffer commandBuffer,
    VkBool32 depthTestEnable);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `depthTestEnable` specifies if the depth test is enabled.

This command sets the depth test enable for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineDepthStencilStateCreateInfo::depthTestEnable` value used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetDepthTestEnable-None-08971
  At least one of the following must be true:
  - the extendedDynamicState feature is enabled
  - the shaderObject feature is enabled
  - the value of `VkApplicationInfo::apiVersion` used to create the `VkInstance` parent of `commandBuffer` is greater than or equal to Version 1.3

### Valid Usage (Implicit)

- VUID-vkCmdSetDepthTestEnable-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetDepthTestEnable-commandBuffer-recording
  `commandBuffer` must be in the recording state
- VUID-vkCmdSetDepthTestEnable-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations
- VUID-vkCmdSetDepthTestEnable-videocoding
This command **must** only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` **must** be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized

### Command Properties

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To **dynamically set** the depth compare operator, call:

```c
// Provided by VK_VERSION_1_3
void vkCmdSetDepthCompareOp(
    VkCommandBuffer commandBuffer,
    VkCompareOp depthCompareOp);
```

or the equivalent command

```c
// Provided by VK_EXT_extended_dynamic_state, VK_EXT_shader_object
void vkCmdSetDepthCompareOpEXT(
    VkCommandBuffer commandBuffer,
    VkCompareOp depthCompareOp);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `depthCompareOp` is a `VkCompareOp` value specifying the comparison operator used for the **Depth Comparison** step of the **depth test**.

This command sets the depth comparison operator for subsequent drawing commands when drawing using **shader objects**, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineDepthStencilStateCreateInfo::depthCompareOp` value used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetDepthCompareOp-None-08971
At least one of the following must be true:

- the extendedDynamicState feature is enabled
- the shaderObject feature is enabled
- the value of VkApplicationInfo::apiVersion used to create the VkInstance parent of commandBuffer is greater than or equal to Version 1.3

Valid Usage (Implicit)

- VUID-vkCmdSetDepthCompareOp-commandBuffer-parameter commandBuffer must be a valid VkCommandBuffer handle
- VUID-vkCmdSetDepthCompareOp-depthCompareOp-parameter depthCompareOp must be a valid VkCompareOp value
- VUID-vkCmdSetDepthCompareOp-commandBuffer-recording commandBuffer must be in the recording state
- VUID-vkCmdSetDepthCompareOp-commandBuffer-cmdpool The VkCommandPool that commandBuffer was allocated from must support graphics operations
- VUID-vkCmdSetDepthCompareOp-videocoding This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

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To dynamically set the depth write enable, call:

```c
// Provided by VK_VERSION_1_3
def void vkCmdSetDepthWriteEnable(
      VkCommandBuffer commandBuffer,
      VkBool32 depthWriteEnable);
```
This command sets the depth write enable for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineDepthStencilStateCreateInfo::depthWriteEnable` value used to create the currently active pipeline.

### Valid Usage

- **VUID-vkCmdSetDepthWriteEnable-None-08971**
  At least one of the following **must** be true:
  - the `extendedDynamicState` feature is enabled
  - the `shaderObject` feature is enabled
  - the value of `VkApplicationInfo::apiVersion` used to create the `VkInstance` parent of `commandBuffer` is greater than or equal to Version 1.3

### Valid Usage (Implicit)

- **VUID-vkCmdSetDepthWriteEnable-commandBuffer-parameter**
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- **VUID-vkCmdSetDepthWriteEnable-commandBuffer-recording**
  `commandBuffer` **must** be in the recording state

- **VUID-vkCmdSetDepthWriteEnable-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics operations

- **VUID-vkCmdSetDepthWriteEnable-videocoding**
  This command **must** only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` **must** be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized
29.11. Representative Fragment Test

The representative fragment test allows implementations to reduce the amount of rasterization and fragment processing work performed for each point, line, or triangle primitive. For any primitive that produces one or more fragments that pass all prior early fragment tests, the implementation may choose one or more “representative” fragments for processing and discard all other fragments. For draw calls rendering multiple points, lines, or triangles arranged in lists, strips, or fans, the representative fragment test is performed independently for each of those primitives. The set of fragments discarded by the representative fragment test is implementation-dependent. In some cases, the representative fragment test may not discard any fragments for a given primitive.

If the `pNext` chain of `VkGraphicsPipelineCreateInfo` includes a `VkPipelineRepresentativeFragmentTestStateCreateInfoNV` structure, then that structure includes parameters controlling the representative fragment test.

The `VkPipelineRepresentativeFragmentTestStateCreateInfoNV` structure is defined as:

```c
// Provided by VK_NV_representative_fragment_test
typedef struct VkPipelineRepresentativeFragmentTestStateCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkBool32 representativeFragmentTestEnable;
} VkPipelineRepresentativeFragmentTestStateCreateInfoNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `representativeFragmentTestEnable` controls whether the representative fragment test is enabled.

If this structure is not included in the `pNext` chain, `representativeFragmentTestEnable` is considered to be `VK_FALSE`, and the representative fragment test is disabled.

If the active fragment shader does not specify the `EarlyFragmentTests` execution mode, the representative fragment shader test has no effect, even if enabled.

**Valid Usage (Implicit)**

- `VUID-VkPipelineRepresentativeFragmentTestStateCreateInfoNV-sType-sType` must be
To **dynamically set** the `representativeFragmentTestEnable` state, call:

```c
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_representative_fragment_test,
// VK_EXT_shader_object with VK_NV_representative_fragment_test
void vkCmdSetRepresentativeFragmentTestEnableNV(
    VkCommandBuffer commandBuffer,
    VkBool32 representativeFragmentTestEnable);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `representativeFragmentTestEnable` specifies the `representativeFragmentTestEnable` state.

This command sets the `representativeFragmentTestEnable` state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineRepresentativeFragmentTestStateCreateInfoNV::representativeFragmentTestEnable` value used to create the currently active pipeline.

**Valid Usage**

- VUID-vkCmdSetRepresentativeFragmentTestEnableNV-None-08522
  Either the `extendedDynamicState3RepresentativeFragmentTestEnable` feature or the `shaderObject` feature or both **must** be enabled

**Valid Usage (Implicit)**

- VUID-vkCmdSetRepresentativeFragmentTestEnableNV-commandBuffer-parameter
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetRepresentativeFragmentTestEnableNV-commandBuffer-recording
  `commandBuffer` **must** be in the recording state
- VUID-vkCmdSetRepresentativeFragmentTestEnableNV-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics operations
- VUID-vkCmdSetRepresentativeFragmentTestEnableNV-videocoding
  This command **must** only be called outside of a video coding scope

**Host Synchronization**

- Host access to `commandBuffer` **must** be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally...
# Command Properties

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## 29.12. Sample Counting

Occlusion queries use query pool entries to track the number of samples that pass all the per-fragment tests. The mechanism of collecting an occlusion query value is described in [Occlusion Queries](#).

The occlusion query sample counter increments by one for each sample with a coverage value of 1 in each fragment that survives all the per-fragment tests, including scissor, exclusive scissor, sample mask, alpha to coverage, stencil, and depth tests.

## 29.13. Fragment Coverage To Color

The `VkPipelineCoverageToColorStateCreateInfoNV` structure is defined as:

```c
// Provided by VK_NV_fragment_coverage_to_color
typedef struct VkPipelineCoverageToColorStateCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkPipelineCoverageToColorStateCreateFlagsNV flags;
    VkBool32 coverageToColorEnable;
    uint32_t coverageToColorLocation;
} VkPipelineCoverageToColorStateCreateInfoNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is reserved for future use.
- `coverageToColorEnable` controls whether the fragment coverage value replaces a fragment color output.
- `coverageToColorLocation` controls which fragment shader color output value is replaced.

If the `pNext` chain of `VkPipelineMultisampleStateCreateInfo` includes a `VkPipelineCoverageToColorStateCreateInfoNV` structure, then that structure controls whether the fragment coverage is substituted for a fragment color output and, if so, which output is replaced.
If `coverageToColorEnable` is `VK_TRUE`, the coverage mask replaces the first component of the color value corresponding to the fragment shader output location with `Location` equal to `coverageToColorLocation` and `Index` equal to zero. If the color attachment format has fewer bits than the coverage mask, the low bits of the sample coverage mask are taken without any clamping. If the color attachment format has more bits than the coverage mask, the high bits of the sample coverage mask are filled with zeros.

If `coverageToColorEnable` is `VK_FALSE`, these operations are skipped. If this structure is not included in the `pNext` chain, it is as if `coverageToColorEnable` is `VK_FALSE`.

### Valid Usage

- VUID-VkPipelineCoverageToColorStateCreateInfoNV-coverageToColorEnable-01404
  
  If `coverageToColorEnable` is `VK_TRUE`, then the render pass subpass indicated by `VkGraphicsPipelineCreateInfo::renderPass` and `VkGraphicsPipelineCreateInfo::subpass` must have a color attachment at the location selected by `coverageToColorLocation`, with a `VkFormat` of `VK_FORMAT_R8_UINT`, `VK_FORMAT_R8_SINT`, `VK_FORMAT_R16_UINT`, `VK_FORMAT_R16_SINT`, `VK_FORMAT_R32_UINT`, or `VK_FORMAT_R32_SINT`.

### Valid Usage (Implicit)

- VUID-VkPipelineCoverageToColorStateCreateInfoNV-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_COVERAGE_TO_COLOR_STATE_CREATE_INFO_NV`.

- VUID-VkPipelineCoverageToColorStateCreateInfoNV-flags-zerobitmask
  
  `flags` must be `0`.

```c
typedef VkFlags VkPipelineCoverageToColorStateCreateFlagsNV;

// Provided by VK_NV_fragment_coverage_to_color
VkPipelineCoverageToColorStateCreateFlagsNV
```

`VkPipelineCoverageToColorStateCreateFlagsNV` is a bitmask type for setting a mask, but is currently reserved for future use.

To dynamically set the `coverageToColorEnable` state, call:

```c
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_fragment_coverage_to_color,
// VK_EXT_shader_object with VK_NV_fragment_coverage_to_color
void vkCmdSetCoverageToColorEnableNV(
  VkCommandBuffer commandBuffer,
  VkBool32 coverageToColorEnable);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `coverageToColorEnable` specifies the `coverageToColorEnable` state.

This command sets the `coverageToColorEnable` state for subsequent drawing commands when
drawing using shader objects, or when the graphics pipeline is created with

\texttt{VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV} set in \texttt{VkPipelineDynamicStateCreateInfo::pDynamicStates}. Otherwise, this state is specified by the \texttt{VkPipelineCoverageToColorStateCreateInfoNV::coverageToColorEnable} value used to create the currently active pipeline.

### Valid Usage

- \texttt{VUID-vkCmdSetCoverageToColorEnableNV-None-08524}
  
  Either the \texttt{extendedDynamicState3CoverageToColorEnable} feature or the \texttt{shaderObject} feature or both \textbf{must} be enabled

### Valid Usage (Implicit)

- \texttt{VUID-vkCmdSetCoverageToColorEnableNV-commandBuffer-parameter}
  
  \texttt{commandBuffer} \textbf{must} be a valid \texttt{VkCommandBuffer} handle

- \texttt{VUID-vkCmdSetCoverageToColorEnableNV-commandBuffer-recording}
  
  \texttt{commandBuffer} \textbf{must} be in the \texttt{recording state}

- \texttt{VUID-vkCmdSetCoverageToColorEnableNV-commandBuffer-cmdpool}
  
  The \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from \textbf{must} support graphics operations

- \texttt{VUID-vkCmdSetCoverageToColorEnableNV-videocoding}
  
  This command \textbf{must} only be called outside of a video coding scope

### Host Synchronization

- Host access to \texttt{commandBuffer} \textbf{must} be externally synchronized

- Host access to the \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from \textbf{must} be externally synchronized

### Command Properties

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</tr>
</tbody>
</table>

To \textbf{dynamically set} the \texttt{coverageToColorLocation} state, call:

```
// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_fragment_coverage_to_color,
// VK_EXT_shader_object with VK_NV_fragment_coverage_to_color
```
```c
void vkCmdSetCoverageToColorLocationNV(
    VkCommandBuffer commandBuffer,
    uint32_t coverageToColorLocation);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `coverageToColorLocation` specifies the `coverageToColorLocation` state.

This command sets the `coverageToColorLocation` state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` set in `VkPipelineDynamicStateCreateInfo`'s `pDynamicStates`. Otherwise, this state is specified by the `VkPipelineCoverageToColorStateCreateInfoNV`'s `coverageToColorLocation` value used to create the currently active pipeline.

**Valid Usage**

- **VUID-vkCmdSetCoverageToColorLocationNV-None-08526**
  Either the `extendedDynamicState3CoverageToColorLocation` feature or the `shaderObject` feature or both must be enabled

**Valid Usage (Implicit)**

- **VUID-vkCmdSetCoverageToColorLocationNV-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- **VUID-vkCmdSetCoverageToColorLocationNV-commandBuffer-recording**
  `commandBuffer` must be in the recording state
- **VUID-vkCmdSetCoverageToColorLocationNV-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations
- **VUID-vkCmdSetCoverageToColorLocationNV-videocoding**
  This command must only be called outside of a video coding scope

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Coverage reduction takes the coverage information for a fragment and converts that to a boolean coverage value for each color sample in each pixel covered by the fragment.

29.14.1. Pixel Coverage

Coverage for each pixel is first extracted from the total fragment coverage mask. This consists of `rasterizationSamples` unique coverage samples for each pixel in the fragment area, each with a unique sample index. If the fragment only contains a single pixel, coverage for the pixel is equivalent to the fragment coverage.

If the render pass has a fragment density map attachment and the fragment covers multiple pixels, pixel coverage is generated in an implementation-dependent manner. If all samples in the fragment are covered, all samples will be covered in each pixel coverage.

If a shading rate image is used, and the fragment covers multiple pixels, each pixel's coverage consists of the coverage samples corresponding to that pixel, and each sample retains its unique sample index.

If the fragment shading rate is set, and the fragment covers multiple pixels, each pixel's coverage consists of the coverage samples with a pixel index matching that pixel, and each sample retains its unique sample index.

29.14.2. Color Sample Coverage

Once pixel coverage is determined, coverage for each individual color sample corresponding to that pixel is determined.

If the number of `rasterizationSamples` is identical to the number of samples in the color attachments, a color sample is covered if the pixel coverage sample with the same sample index is covered.

Otherwise, the coverage for each color sample is computed from the pixel coverage as follows.

If the `VK_AMD_mixed_attachment_samples` extension is enabled, for color samples present in the color attachments, a color sample is covered if the pixel coverage sample with the same sample index is covered; additional pixel coverage samples are discarded.

If the `pNext` chain of `VkSubpassDescription2` or `VkRenderingInfo` includes a
VkMultisampledRenderToSingleSampledInfoEXT structure with the multisampledRenderToSingleSampledEnable field equal to VK_TRUE, sample coverage is calculated as if the attachment has VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples samples.

When the VK_NV_coverage_reduction_mode extension is enabled, the pipeline state controlling coverage reduction is specified through the members of the VkPipelineCoverageReductionStateCreateInfoNV structure.

The VkPipelineCoverageReductionStateCreateInfoNV structure is defined as:

```c
// Provided by VK_NV_coverage_reduction_mode
typedef struct VkPipelineCoverageReductionStateCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkPipelineCoverageReductionStateCreateFlagsNV flags;
    VkCoverageReductionModeNV coverageReductionMode;
} VkPipelineCoverageReductionStateCreateInfoNV;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **coverageReductionMode** is a VkCoverageReductionModeNV value controlling how color sample coverage is generated from pixel coverage.

If this structure is not included in the pNext chain, or if the extension is not enabled, the default coverage reduction mode is inferred as follows:

- If the VK_NV_framebuffer_mixed_samples extension is enabled, then it is as if the coverageReductionMode is VK_COVERAGE_REDUCTION_MODE_MERGE_NV.
- If the VK_AMD_mixed_attachment_samples extension is enabled, then it is as if the coverageReductionMode is VK_COVERAGE_REDUCTION_MODE_TRUNCATE_NV.
- If both VK_NV_framebuffer_mixed_samples and VK_AMD_mixed_attachment_samples are enabled, then the default coverage reduction mode is implementation-dependent.

**Valid Usage (Implicit)**

- VUID-VkPipelineCoverageReductionStateCreateInfoNV-sType-sType
  **sType** must be VK_STRUCTURE_TYPE_PIPELINE_COVERAGE_REDUCTION_STATE_CREATE_INFO_NV
- VUID-VkPipelineCoverageReductionStateCreateInfoNV-flags-zerobitmask
  **flags** must be 0
- VUID-VkPipelineCoverageReductionStateCreateInfoNV-coverageReductionMode-parameter
  **coverageReductionMode** must be a valid VkCoverageReductionModeNV value
typedef VkFlags VkPipelineCoverageReductionStateCreateFlagsNV;

VkPipelineCoverageReductionStateCreateFlagsNV is a bitmask type for setting a mask, but is currently reserved for future use.

Possible values of VkPipelineCoverageReductionStateCreateInfoNV::coverageReductionMode, specifying how color sample coverage is generated from pixel coverage, are:

typedef enum VkCoverageReductionModeNV {
    VK_COVERAGE_REDUCTION_MODE_MERGE_NV = 0,
    VK_COVERAGE_REDUCTION_MODE_TRUNCATE_NV = 1,
} VkCoverageReductionModeNV;

- **VK_COVERAGE_REDUCTION_MODE_MERGE_NV** specifies that each color sample will be associated with an implementation-dependent subset of samples in the pixel coverage. If any of those associated samples are covered, the color sample is covered.

- **VK_COVERAGE_REDUCTION_MODE_TRUNCATE_NV** specifies that for color samples present in the color attachments, a color sample is covered if the pixel coverage sample with the same sample index i is covered; other pixel coverage samples are discarded.

To **dynamically set** the **coverageReductionMode** state, call:

void vkCmdSetCoverageReductionModeNV(
    VkCommandBuffer commandBuffer,
    VkCoverageReductionModeNV coverageReductionMode);

- **commandBuffer** is the command buffer into which the command will be recorded.
- **coverageReductionMode** specifies the **coverageReductionMode** state.

This command sets the **coverageReductionMode** state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV set in VkPipelineDynamicStateCreateInfo::pDynamicStates. Otherwise, this state is specified by the VkPipelineCoverageReductionStateCreateInfoNV::coverageReductionMode value used to create the currently active pipeline.

**Valid Usage**

- VUID-vkCmdSetCoverageReductionModeNV-None-08528
  Either the extendedDynamicState3CoverageReductionMode feature or the shaderObject feature or both **must** be enabled.
Valid Usage (Implicit)

- VUID-vkCmdSetCoverageReductionModeNV-commandBuffer-parameter
  
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdSetCoverageReductionModeNV-coverageReductionMode-parameter
  
  `coverageReductionMode` must be a valid `VkCoverageReductionModeNV` value

- VUID-vkCmdSetCoverageReductionModeNV-commandBuffer-recording
  
  `commandBuffer` must be in the recording state

- VUID-vkCmdSetCoverageReductionModeNV-commandBuffer-cmdpool
  
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations

- VUID-vkCmdSetCoverageReductionModeNV-videocoding
  
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to `commandBuffer` must be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

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</table>

To query the set of mixed sample combinations of coverage reduction mode, rasterization samples and color, depth, stencil attachment sample counts that are supported by a physical device, call:

```c
// Provided by VK_NV_coverage_reduction_mode
VkResult vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV(
    VkPhysicalDevice physicalDevice,  // physicalDevice is the physical device from which to query the set of combinations.
    uint32_t* pCombinationCount,      // pCombinationCount is a pointer to an integer related to the number of combinations available or queried, as described below.
    VkFramebufferMixedSamplesCombinationNV* pCombinations); // pCombinations is either NULL or a pointer to an array of
```
VkFramebufferMixedSamplesCombinationNV values, indicating the supported combinations of coverage reduction mode, rasterization samples, and color, depth, stencil attachment sample counts.

If pCombinations is NULL, then the number of supported combinations for the given physicalDevice is returned in pCombinationCount. Otherwise, pCombinationCount must point to a variable set by the user to the number of elements in the pCombinations array, and on return the variable is overwritten with the number of values actually written to pCombinations. If the value of pCombinationCount is less than the number of combinations supported for the given physicalDevice, at most pCombinationCount values will be written to pCombinations, and VK_INCOMPLETE will be returned instead of VK_SUCCESS, to indicate that not all the supported values were returned.

Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV-physicalDevice-parameter physicalDevice must be a valid VkPhysicalDevice handle
- VUID-vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV-pCombinationCount-parameter pCombinationCount must be a valid pointer to a uint32_t value
- VUID-vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV-pCombinations-parameter If the value referenced by pCombinationCount is not 0, and pCombinations is not NULL, pCombinations must be a valid pointer to an array of pCombinationCount VkFramebufferMixedSamplesCombinationNV structures

Return Codes

Success
- VK_SUCCESS
- VK_INCOMPLETE

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkFramebufferMixedSamplesCombinationNV structure is defined as:

```c
// Provided by VK_NV_coverage_reduction_mode
typedef struct VkFramebufferMixedSamplesCombinationNV {
    VkStructureType sType;
    void* pNext;
    VkCoverageReductionModeNV coverageReductionMode;
    VkSampleCountFlagBits rasterizationSamples;
    VkSampleCountFlags depthStencilSamples;
} VkFramebufferMixedSamplesCombinationNV;
```
VkSampleCountFlags colorSamples;
} VkFramebufferMixedSamplesCombinationNV;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• coverageReductionMode is a VkCoverageReductionModeNV value specifying the coverage reduction mode.
• rasterizationSamples is a VkSampleCountFlagBits specifying the number of rasterization samples in the supported combination.
• depthStencilSamples specifies the number of samples in the depth stencil attachment in the supported combination. A value of 0 indicates the combination does not have a depth stencil attachment.
• colorSamples specifies the number of color samples in a color attachment in the supported combination. A value of 0 indicates the combination does not have a color attachment.

Valid Usage (Implicit)

• VUID-VkFramebufferMixedSamplesCombinationNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_FRAMEBUFFER_MIXED_SAMPLES_COMBINATION_NV
• VUID-VkFramebufferMixedSamplesCombinationNV-pNext-pNext
  pNext must be NULL

29.14.3. Coverage Modulation

As part of coverage reduction, fragment color values can also be modulated (multiplied) by a value that is a function of fraction of covered rasterization samples associated with that color sample.

Pipeline state controlling coverage modulation is specified through the members of the VkPipelineCoverageModulationStateCreateInfoNV structure.

The VkPipelineCoverageModulationStateCreateInfoNV structure is defined as:

```c
// Provided by VK_NV_framebuffer_mixed_samples
typedef struct VkPipelineCoverageModulationStateCreateInfoNV {
  VkStructureType sType;
  const void* pNext;
  VkPipelineCoverageModulationStateCreateFlagsNV flags;
  VkCoverageModulationModeNV coverageModulationMode;
  VkBool32 coverageModulationTableEnable;
  uint32_t coverageModulationTableCount;
  const float* coverageModulationTable;
} VkPipelineCoverageModulationStateCreateInfoNV;
```

• sType is a VkStructureType value identifying this structure.
• `pNext` is NULL or a pointer to a structure extending this structure.

• `flags` is reserved for future use.

• `coverageModulationMode` is a `VkCoverageModulationModeNV` value controlling which color components are modulated.

• `coverageModulationTableEnable` controls whether the modulation factor is looked up from a table in `pCoverageModulationTable`.

• `coverageModulationTableCount` is the number of elements in `pCoverageModulationTable`.

• `pCoverageModulationTable` is a table of modulation factors containing a value for each number of covered samples.

If `coverageModulationTableEnable` is `VK_FALSE`, then for each color sample the associated bits of the pixel coverage are counted and divided by the number of associated bits to produce a modulation factor `R` in the range (0,1] (a value of zero would have been killed due to a color coverage of 0). Specifically:

• `N = value of rasterizationSamples`

• `M = value of VkAttachmentDescription::samples for any color attachments`

• `R = popcount(associated coverage bits) / (N / M)`

If `coverageModulationTableEnable` is `VK_TRUE`, the value `R` is computed using a programmable lookup table. The lookup table has `N / M` elements, and the element of the table is selected by:

• `R = pCoverageModulationTable[popcount(associated coverage bits)-1]`

Note that the table does not have an entry for `popcount(associated coverage bits) = 0`, because such samples would have been killed.

The values of `pCoverageModulationTable` may be rounded to an implementation-dependent precision, which is at least as fine as `1 / N`, and clamped to [0,1].

For each color attachment with a floating point or normalized color format, each fragment output color value is replicated to `M` values which can each be modulated (multiplied) by that color sample’s associated value of `R`. Which components are modulated is controlled by `coverageModulationMode`.

If this structure is not included in the `pNext` chain, it is as if `coverageModulationMode` is `VK_COVERAGE_MODULATION_MODE_NONE_NV`.

If the coverage reduction mode is `VK_COVERAGE_REDUCTION_MODE_TRUNCATE_NV`, each color sample is associated with only a single coverage sample. In this case, it is as if `coverageModulationMode` is `VK_COVERAGE_MODULATION_MODE_NONE_NV`.

Valid Usage

• VUID-VkPipelineCoverageModulationStateCreateInfoNV-coverageModulationTableEnable-01405
  If `coverageModulationTableEnable` is `VK_TRUE`, `coverageModulationTableCount` must be equal
to the number of rasterization samples divided by the number of color samples in the subpass

### Valid Usage (Implicit)

- **VUID-VkPipelineCoverageModulationStateCreateInfoNV-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_COVERAGE_MODULATION_STATE_CREATE_INFO_NV`

- **VUID-VkPipelineCoverageModulationStateCreateInfoNV-flags-zerobitmask**
  - `flags` must be 0

- **VUID-VkPipelineCoverageModulationStateCreateInfoNV-coverageModulationMode-parameter**
  - `coverageModulationMode` must be a valid `VkCoverageModulationModeNV` value

// Provided by VK_NV_framebuffer_mixed_samples

```c
typedef VkFlags VkPipelineCoverageModulationStateCreateFlagsNV;
```

`VkPipelineCoverageModulationStateCreateFlagsNV` is a bitmask type for setting a mask, but is currently reserved for future use.

Possible values of `VkPipelineCoverageModulationStateCreateInfoNV::coverageModulationMode`, specifying which color components are modulated, are:

// Provided by VK_NV_framebuffer_mixed_samples

```c
typedef enum VkCoverageModulationModeNV {
    VK_COVERAGE_MODULATION_MODE_NONE_NV = 0,
    VK_COVERAGE_MODULATION_MODE_RGB_NV = 1,
    VK_COVERAGE_MODULATION_MODE_ALPHA_NV = 2,
    VK_COVERAGE_MODULATION_MODE_RGBA_NV = 3,
} VkCoverageModulationModeNV;
```

- **VK_COVERAGE_MODULATION_MODE_NONE_NV** specifies that no components are multiplied by the modulation factor.
- **VK_COVERAGE_MODULATION_MODE_RGB_NV** specifies that the red, green, and blue components are multiplied by the modulation factor.
- **VK_COVERAGE_MODULATION_MODE_ALPHA_NV** specifies that the alpha component is multiplied by the modulation factor.
- **VK_COVERAGE_MODULATION_MODE_RGBA_NV** specifies that all components are multiplied by the modulation factor.

To **dynamically set** the `coverageModulationMode` state, call:

// Provided by VK_EXT_extended_dynamic_state3 with VK_NV_framebuffer_mixed_samples,
// VK_EXT_shader_object with VK_NV_framebuffer_mixed_samples
void vkCmdSetCoverageModulationModeNV(
    VkCommandBuffer commandBuffer,
    VkCoverageModulationModeNV coverageModulationMode);

- `commandBuffer` is the command buffer into which the command will be recorded.
- `coverageModulationMode` specifies the `coverageModulationMode` state.

This command sets the `coverageModulationMode` state for subsequent drawing commands when drawing using shader objects, or the graphics pipeline is created with `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineCoverageModulationStateCreateInfoNV::coverageModulationMode` value used to create the currently active pipeline.

### Valid Usage

- **VUID-vkCmdSetCoverageModulationModeNV-None-08530**
  
  Either the `extendedDynamicState3CoverageModulationMode` feature or the `shaderObject` feature or both **must** be enabled

### Valid Usage (Implicit)

- **VUID-vkCmdSetCoverageModulationModeNV-commandBuffer-parameter**
  
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- **VUID-vkCmdSetCoverageModulationModeNV-coverageModulationMode-parameter**
  
  `coverageModulationMode` **must** be a valid `VkCoverageModulationModeNV` value

- **VUID-vkCmdSetCoverageModulationModeNV-commandBuffer-recording**
  
  `commandBuffer` **must** be in the recording state

- **VUID-vkCmdSetCoverageModulationModeNV-commandBuffer-cmdpool**
  
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics operations

- **VUID-vkCmdSetCoverageModulationModeNV-videocoding**
  
  This command **must** only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` **must** be externally synchronized

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized
Command Properties

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To **dynamically set** the `coverageModulationTableEnable` state, call:

```c
void vkCmdSetCoverageModulationTableEnableNV(
    VkCommandBuffer commandBuffer,
    VkBool32 coverageModulationTableEnable);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `coverageModulationTableEnable` specifies the `coverageModulationTableEnable` state.

This command sets the `coverageModulationTableEnable` state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineCoverageModulationStateCreateInfoNV::coverageModulationTableEnable` value used to create the currently active pipeline.

**Valid Usage**

- VUID-vkCmdSetCoverageModulationTableEnableNV-None-08532
  
  Either the `extendedDynamicState3CoverageModulationTableEnable` feature or the `shaderObject` feature or both **must** be enabled

**Valid Usage (Implicit)**

- VUID-vkCmdSetCoverageModulationTableEnableNV-commandBuffer-parameter
  
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- VUID-vkCmdSetCoverageModulationTableEnableNV-commandBuffer-recording
  
  `commandBuffer` **must** be in the `recording` state

- VUID-vkCmdSetCoverageModulationTableEnableNV-commandBuffer-cmdpool
  
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support graphics operations

- VUID-vkCmdSetCoverageModulationTableEnableNV-videocoding
  
  This command **must** only be called outside of a video coding scope
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

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<td></td>
</tr>
</tbody>
</table>

To dynamically set the `pCoverageModulationTable` state, call:

```c
void vkCmdSetCoverageModulationTableNV(
    VkCommandBuffer commandBuffer,
    uint32_t coverageModulationTableCount,
    const float* pCoverageModulationTable);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `coverageModulationTableCount` specifies the number of elements in `pCoverageModulationTable`.
- `pCoverageModulationTable` specifies the table of modulation factors containing a value for each number of covered samples.

This command sets the table of modulation factors for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineCoverageModulationStateCreateInfoNV::coverageModulationTableCount`, and `VkPipelineCoverageModulationStateCreateInfoNV::pCoverageModulationTable` values used to create the currently active pipeline.

Valid Usage

- VUID-vkCmdSetCoverageModulationTableNV-None-08534
  Either the extendedDynamicState3CoverageModulationTable feature or the shaderObject feature or both must be enabled
Valid Usage (Implicit)

- VUID-vkCmdSetCoverageModulationTableNV-commandBuffer-parameter
  \texttt{commandBuffer} must be a valid \texttt{VkCommandBuffer} handle

- VUID-vkCmdSetCoverageModulationTableNV-pCoverageModulationTable-parameter
  \texttt{pCoverageModulationTable} must be a valid pointer to an array of \textit{coverageModulationTableCount float} values

- VUID-vkCmdSetCoverageModulationTableNV-commandBuffer-recording
  \texttt{commandBuffer} must be in the recording state

- VUID-vkCmdSetCoverageModulationTableNV-commandBuffer-cmdpool
  The \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from must support graphics operations

- VUID-vkCmdSetCoverageModulationTableNV-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdSetCoverageModulationTableNV-coverageModulationTableCount-arraylength
  \texttt{coverageModulationTableCount} must be greater than 0

Host Synchronization

- Host access to \texttt{commandBuffer} must be externally synchronized

- Host access to the \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from must be externally synchronized

Command Properties

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Chapter 30. The Framebuffer

30.1. Blending

Blending combines the incoming source fragment’s R, G, B, and A values with the destination R, G, B, and A values of each sample stored in the framebuffer at the fragment’s \((x_f, y_f)\) location. Blending is performed for each color sample covered by the fragment, rather than just once for each fragment.

Source and destination values are combined according to the blend operation, quadruplets of source and destination weighting factors determined by the blend factors, and a blend constant, to obtain a new set of R, G, B, and A values, as described below.

Blending is computed and applied separately to each color attachment used by the subpass, with separate controls for each attachment.

Prior to performing the blend operation, signed and unsigned normalized fixed-point color components undergo an implied conversion to floating-point as specified by Conversion from Normalized Fixed-Point to Floating-Point. Blending computations are treated as if carried out in floating-point, and basic blend operations are performed with a precision and dynamic range no lower than that used to represent destination components. Advanced blending operations are performed with a precision and dynamic range no lower than the smaller of that used to represent destination components or that used to represent 16-bit floating-point values.

Note

Blending is only defined for floating-point, UNORM, SNORM, and sRGB formats. Within those formats, the implementation may only support blending on some subset of them. Which formats support blending is indicated by VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT.

The pipeline blend state is included in the VkPipelineColorBlendStateCreateInfo structure during graphics pipeline creation:

The VkPipelineColorBlendStateCreateInfo structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPipelineColorBlendStateCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkPipelineColorBlendStateCreateFlags flags;
    VkBool32 logicOpEnable;
    VkLogicOp logicOp;
    uint32_t attachmentCount;
    const VkPipelineColorBlendAttachmentState* pAttachments;
    float blendConstants[4];
} VkPipelineColorBlendStateCreateInfo;
```

- `sType` is a VkStructureType value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.

• **flags** is a bitmask of VkPipelineColorBlendStateCreateFlagBits specifying additional color blending information.

• **logicOpEnable** controls whether to apply Logical Operations.

• **logicOp** selects which logical operation to apply.

• **attachmentCount** is the number of VkPipelineColorBlendAttachmentState elements in pAttachments. It is ignored if the pipeline is created with VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT, VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT, and VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT dynamic states set, and either VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT set or advancedBlendCoherentOperations is not enabled on the device.

• **pAttachments** is a pointer to an array of VkPipelineColorBlendAttachmentState structures defining blend state for each color attachment. It is ignored if the pipeline is created with VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT, VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT, and VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT dynamic states set, and either VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT set or advancedBlendCoherentOperations is not enabled on the device.

• **blendConstants** is a pointer to an array of four values used as the R, G, B, and A components of the blend constant that are used in blending, depending on the blend factor.

---

### Valid Usage

• **VUID-VkPipelineColorBlendStateCreateInfo-pAttachments-00605**  
  If the independentBlend feature is not enabled, all elements of pAttachments must be identical

• **VUID-VkPipelineColorBlendStateCreateInfo-logicOpEnable-00606**  
  If the logicOp feature is not enabled, logicOpEnable must be VK_FALSE

• **VUID-VkPipelineColorBlendStateCreateInfo-logicOpEnable-00607**  
  If logicOpEnable is VK_TRUE, logicOp must be a valid VkLogicOp value

• **VUID-VkPipelineColorBlendStateCreateInfo-rasterizationOrderColorAttachmentAccess-06465**  
  If the rasterizationOrderColorAttachmentAccess feature is not enabled, flags must not include VK_PIPELINE_COLOR_BLEND_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_BIT_EXT

• **VUID-VkPipelineColorBlendStateCreateInfo-pAttachments-07353**  
  If attachmentCount is not 0, and any of VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT, VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT, VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT, or VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT are not set, pAttachments must be a valid pointer to an array of attachmentCount valid VkPipelineColorBlendAttachmentState structures
Valid Usage (Implicit)

- **VUID-VkPipelineColorBlendStateCreateInfo-sType-sType**
  
  The `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_COLOR_BLEND_STATE_CREATE_INFO`.

- **VUID-VkPipelineColorBlendStateCreateInfo-pNext-pNext**
  
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkPipelineColorBlendAdvancedStateCreateInfoEXT` or `VkPipelineColorWriteCreateInfoEXT`.

- **VUID-VkPipelineColorBlendStateCreateInfo-sType-unique**
  
  The `sType` value of each struct in the `pNext` chain must be unique.

- **VUID-VkPipelineColorBlendStateCreateInfo-flags-parameter**
  
  The `flags` must be a valid combination of `VkPipelineColorBlendStateCreateFlagBits` values.

- **VUID-VkPipelineColorBlendStateCreateInfo-pAttachments-parameter**
  
  If `attachmentCount` is not 0, and `pAttachments` is not `NULL`, `pAttachments` must be a valid pointer to an array of `attachmentCount` valid `VkPipelineColorBlendAttachmentState` structures.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkPipelineColorBlendStateCreateFlags;

VkPipelineColorBlendStateCreateFlags is a bitmask type for setting a mask of zero or more `VkPipelineColorBlendStateCreateFlagBits`.

Bits which can be set in the `VkPipelineColorBlendStateCreateInfo::flags` parameter are:

```c
// Provided by VK_EXT_rasterization_order_attachment_access
typedef enum VkPipelineColorBlendStateCreateFlagBits {
    // Provided by VK_EXT_rasterization_order_attachment_access
    VK_PIPELINE_COLOR_BLEND_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_BIT_EXT = 0x00000001,
    // Provided by VK_ARM_rasterization_order_attachment_access
    VK_PIPELINE_COLOR_BLEND_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_BIT_ARM = VK_PIPELINE_COLOR_BLEND_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_BIT_EXT,
} VkPipelineColorBlendStateCreateFlagBits;
```

- **VK_PIPELINE_COLOR_BLEND_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_BIT_EXT** indicates that access to color and input attachments will have implicit framebuffer-local memory dependencies, allowing applications to express custom blending operations in a fragment shader.

When **VK_PIPELINE_COLOR_BLEND_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_BIT_EXT** is included in a pipeline, it forms a framebuffer-local memory dependency for each fragment generated by draw commands for that pipeline with the following scopes:
The first synchronization scope includes the VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT pipeline stage executed by all previous fragments (as defined by primitive order) in the corresponding framebuffer regions including those generated by the same draw command.

The second synchronization scope includes the VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT pipeline stage executed by the generated fragment.

The first access scope includes all writes to color attachments.

The second access scope includes all reads from input attachments.

The VkPipelineColorBlendAttachmentState structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPipelineColorBlendAttachmentState {
    VkBool32 blendEnable;
    VkBlendFactor srcColorBlendFactor;
    VkBlendFactor dstColorBlendFactor;
    VkBlendOp colorBlendOp;
    VkBlendFactor srcAlphaBlendFactor;
    VkBlendFactor dstAlphaBlendFactor;
    VkBlendOp alphaBlendOp;
    VkColorComponentFlags colorWriteMask;
} VkPipelineColorBlendAttachmentState;
```

- **blendEnable** controls whether blending is enabled for the corresponding color attachment. If blending is not enabled, the source fragment’s color for that attachment is passed through unmodified.

- **srcColorBlendFactor** selects which blend factor is used to determine the source factors \((S_r, S_g, S_b)\).

- **dstColorBlendFactor** selects which blend factor is used to determine the destination factors \((D_r, D_g, D_b)\).

- **colorBlendOp** selects which blend operation is used to calculate the RGB values to write to the color attachment.

- **srcAlphaBlendFactor** selects which blend factor is used to determine the source factor \(S_a\).

- **dstAlphaBlendFactor** selects which blend factor is used to determine the destination factor \(D_a\).

- **alphaBlendOp** selects which blend operation is used to calculate the alpha values to write to the color attachment.

- **colorWriteMask** is a bitmask of VkColorComponentFlagBits specifying which of the R, G, B, and/or A components are enabled for writing, as described for the Color Write Mask.

**Valid Usage**

- VUID-VkPipelineColorBlendAttachmentState-srcColorBlendFactor-00608
  If the dualSrcBlend feature is not enabled, srcColorBlendFactor must not be
  VK_BLEND_FACTOR_SRC1_COLOR, VK_BLEND_FACTOR_ONE_MINUS_SRC1_COLOR,
  VK_BLEND_FACTOR_SRC1_ALPHA, or VK_BLEND_FACTOR_ONE_MINUS_SRC1_ALPHA
If the dualSrcBlend feature is not enabled, dstColorBlendFactor must not be
VK_BLEND_FACTOR_SRC1_COLOR, VK_BLEND_FACTOR_ONE_MINUS_SRC1_COLOR, 
VK_BLEND_FACTOR_SRC1_ALPHA, or VK_BLEND_FACTOR_ONE_MINUS_SRC1_ALPHA

If the dualSrcBlend feature is not enabled, srcAlphaBlendFactor must not be
VK_BLEND_FACTOR_SRC1_COLOR, VK_BLEND_FACTOR_ONE_MINUS_SRC1_COLOR, 
VK_BLEND_FACTOR_SRC1_ALPHA, or VK_BLEND_FACTOR_ONE_MINUS_SRC1_ALPHA

If the dualSrcBlend feature is not enabled, dstAlphaBlendFactor must not be
VK_BLEND_FACTOR_SRC1_COLOR, VK_BLEND_FACTOR_ONE_MINUS_SRC1_COLOR, 
VK_BLEND_FACTOR_SRC1_ALPHA, or VK_BLEND_FACTOR_ONE_MINUS_SRC1_ALPHA

If either of colorBlendOp or alphaBlendOp is an advanced blend operation, then 
colorBlendOp must equal alphaBlendOp

If VkPhysicalDeviceBlendOperationAdvancedPropertiesEXT::advancedBlendIndependentBlend is VK_FALSE and colorBlendOp is an advanced blend operation, then colorBlendOp must be the same for all attachments

If VkPhysicalDeviceBlendOperationAdvancedPropertiesEXT::advancedBlendIndependentBlend is VK_FALSE and alphaBlendOp is an advanced blend operation, then alphaBlendOp must be the same for all attachments

If VkPhysicalDeviceBlendOperationAdvancedPropertiesEXT::advancedBlendAllOperations is VK_FALSE, then colorBlendOp must not be VK_BLEND_OP_ZERO_EXT, VK_BLEND_OP_SRC_EXT, 
VK_BLEND_OP_DST_EXT, VK_BLEND_OP_SRC_OVER_EXT, VK_BLEND_OP_DST_OVER_EXT, 
VK_BLEND_OP_SRC_IN_EXT, VK_BLEND_OP_DST_IN_EXT, VK_BLEND_OP_SRC_ATOP_EXT, VK_BLEND_OP_DST_ATOP_EXT, 
VK_BLEND_OP_XOR_EXT, VK_BLEND_OP_INVERT_EXT, VK_BLEND_OP_INVERT_RGB_EXT, 
VK_BLEND_OP_LINEARDODGE_EXT, VK_BLEND_OP_LINEARBURN_EXT, VK_BLEND_OP_VIVIDLIGHT_EXT, 
VK_BLEND_OP_LINEARLIGHT_EXT, VK_BLEND_OP_PINLIGHT_EXT, VK_BLEND_OP_HARDMIX_EXT, 
VK_BLEND_OP_PLUS_EXT, VK_BLEND_OP_PLUS_CLAMPED_EXT, VK_BLEND_OP_PLUS_CLAMPED_ALPHA_EXT, 
VK_BLEND_OP_PLUS_DARKER_EXT, VK_BLEND_OP_MINUS_EXT, VK_BLEND_OP_MINUS_CLAMPED_EXT, 
VK_BLEND_OP_CONTRAST_EXT, VK_BLEND_OP_INVERT_OVG_EXT, VK_BLEND_OP_RED_EXT, 
VK_BLEND_OP_GREEN_EXT, or VK_BLEND_OP_BLUE_EXT

If colorBlendOp or alphaBlendOp is an advanced blend operation, then colorAttachmentCount of the subpass this pipeline is compiled against must be less than or equal to VkPhysicalDeviceBlendOperationAdvancedPropertiesEXT::advancedBlendMaxColorAttachments

If the VK_KHR_portability_subset extension is enabled, and 
VkPhysicalDevicePortabilitySubsetFeaturesKHR::constantAlphaColorBlendFactors is VK_FALSE, srcColorBlendFactor must not be VK_BLEND_FACTOR_CONSTANT_ALPHA or
If the `VK_KHR_portability_subset` extension is enabled, and `VkPhysicalDevicePortabilitySubsetFeaturesKHR::constantAlphaColorBlendFactors` is `VK_FALSE`, `dstColorBlendFactor must not` be `VK_BLEND_FACTOR_CONSTANT_ALPHA` or `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA`.

### Valid Usage (Implicit)

- **VUID-VkPipelineColorBlendAttachmentState-srcColorBlendFactor-parameter**
  - `srcColorBlendFactor must` be a valid `VkBlendFactor` value
- **VUID-VkPipelineColorBlendAttachmentState-dstColorBlendFactor-parameter**
  - `dstColorBlendFactor must` be a valid `VkBlendFactor` value
- **VUID-VkPipelineColorBlendAttachmentState-colorBlendOp-parameter**
  - `colorBlendOp must` be a valid `VkBlendOp` value
- **VUID-VkPipelineColorBlendAttachmentState-srcAlphaBlendFactor-parameter**
  - `srcAlphaBlendFactor must` be a valid `VkBlendFactor` value
- **VUID-VkPipelineColorBlendAttachmentState-dstAlphaBlendFactor-parameter**
  - `dstAlphaBlendFactor must` be a valid `VkBlendFactor` value
- **VUID-VkPipelineColorBlendAttachmentState-alphaBlendOp-parameter**
  - `alphaBlendOp must` be a valid `VkBlendOp` value
- **VUID-VkPipelineColorBlendAttachmentState-colorWriteMask-parameter**
  - `colorWriteMask must` be a valid combination of `VkColorComponentFlagBits` values

To **dynamically set** `blendEnable`, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
void vkCmdSetColorBlendEnableEXT(
  VkCommandBuffer commandBuffer,
  uint32_t firstAttachment,
  uint32_t attachmentCount,
  const VkBool32* pColorBlendEnables);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `firstAttachment` the first color attachment the color blending enable applies.
- `attachmentCount` the number of color blending enables in the `pColorBlendEnables` array.
- `pColorBlendEnables` an array of booleans to indicate whether color blending is enabled for the corresponding attachment.

This command sets the color blending enable of the specified color attachments for subsequent drawing commands when drawing using **shader objects**, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` set in `VkPipelineDynamicStateCreateInfo`.
To dynamically set color blend factors and operations, call:

```markdown
2650
```
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object

```c
void vkCmdSetColorBlendEquationEXT(
    VkCommandBuffer commandBuffer,
    uint32_t firstAttachment,
    uint32_t attachmentCount,
    const VkColorBlendEquationEXT* pColorBlendEquations);
```

- **commandBuffer** is the command buffer into which the command will be recorded.
- **firstAttachment** is the first color attachment the color blend factors and operations apply to.
- **attachmentCount** is the number of `VkColorBlendEquationEXT` elements in the `pColorBlendEquations` array.
- **pColorBlendEquations** is an array of `VkColorBlendEquationEXT` structs that specify the color blend factors and operations for the corresponding attachments.

This command sets the color blending factors and operations of the specified attachments for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineColorBlendAttachmentState::srcColorBlendFactor`, `VkPipelineColorBlendAttachmentState::dstColorBlendFactor`, `VkPipelineColorBlendAttachmentState::colorBlendOp`, `VkPipelineColorBlendAttachmentState::srcAlphaBlendFactor`, `VkPipelineColorBlendAttachmentState::dstAlphaBlendFactor`, and `VkPipelineColorBlendAttachmentState::alphaBlendOp` values used to create the currently active pipeline.

**Valid Usage**

- **VUID-vkCmdSetColorBlendEquationEXT-None-08538**
  Either the `extendedDynamicState3ColorBlendEquation` feature or the `shaderObject` feature or both must be enabled

**Valid Usage ( Implicit )**

- **VUID-vkCmdSetColorBlendEquationEXT-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- **VUID-vkCmdSetColorBlendEquationEXT-pColorBlendEquations-parameter**
  `pColorBlendEquations` must be a valid pointer to an array of `attachmentCount` valid `VkColorBlendEquationEXT` structures
- **VUID-vkCmdSetColorBlendEquationEXT-commandBuffer-recording**
  `commandBuffer` must be in the recording state
- **VUID-vkCmdSetColorBlendEquationEXT-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations
• VUID-vkCmdSetColorBlendEquationEXT-videocoding
  This command must only be called outside of a video coding scope
• VUID-vkCmdSetColorBlendEquationEXT-attachmentCount-arraylength
  attachmentCount must be greater than 0

**Host Synchronization**

• Host access to commandBuffer must be externally synchronized
• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

**Command Properties**

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<tr>
<th>Command Buffer Levels</th>
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<th>Video Coding Scope</th>
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<th>Command Type</th>
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<td>Outside</td>
<td>Graphics</td>
<td>State</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The VkColorBlendEquationEXT structure is defined as:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
typedef struct VkColorBlendEquationEXT {
    VkBlendFactor srcColorBlendFactor;
    VkBlendFactor dstColorBlendFactor;
    VkBlendOp colorBlendOp;
    VkBlendFactor srcAlphaBlendFactor;
    VkBlendFactor dstAlphaBlendFactor;
    VkBlendOp alphaBlendOp;
} VkColorBlendEquationEXT;
```

• `srcColorBlendFactor` selects which blend factor is used to determine the source factors \((S_r, S_g, S_b)\).
• `dstColorBlendFactor` selects which blend factor is used to determine the destination factors \((D_r, D_g, D_b)\).
• `colorBlendOp` selects which blend operation is used to calculate the RGB values to write to the color attachment.
• `srcAlphaBlendFactor` selects which blend factor is used to determine the source factor \(S_a\).
• `dstAlphaBlendFactor` selects which blend factor is used to determine the destination factor \(D_a\).
• `alphaBlendOp` selects which blend operation is use to calculate the alpha values to write to the color attachment.
Valid Usage

- **VUID-VkColorBlendEquationEXT-dualSrcBlend-07357**
  If the dualSrcBlend feature is not enabled, `srcColorBlendFactor` must not be
  `VK_BLEND_FACTOR_SRC1_COLOR`, `VK_BLEND_FACTOR_ONE_MINUS_SRC1_COLOR`, `VK_BLEND_FACTOR_SRC1_ALPHA`, or `VK_BLEND_FACTOR_ONE_MINUS_SRC1_ALPHA`.

- **VUID-VkColorBlendEquationEXT-dualSrcBlend-07358**
  If the dualSrcBlend feature is not enabled, `dstColorBlendFactor` must not be
  `VK_BLEND_FACTOR_SRC1_COLOR`, `VK_BLEND_FACTOR_ONE_MINUS_SRC1_COLOR`, `VK_BLEND_FACTOR_SRC1_ALPHA`, or `VK_BLEND_FACTOR_ONE_MINUS_SRC1_ALPHA`.

- **VUID-VkColorBlendEquationEXT-dualSrcBlend-07359**
  If the dualSrcBlend feature is not enabled, `srcAlphaBlendFactor` must not be
  `VK_BLEND_FACTOR_SRC1_COLOR`, `VK_BLEND_FACTOR_ONE_MINUS_SRC1_COLOR`, `VK_BLEND_FACTOR_SRC1_ALPHA`, or `VK_BLEND_FACTOR_ONE_MINUS_SRC1_ALPHA`.

- **VUID-VkColorBlendEquationEXT-dualSrcBlend-07360**
  If the dualSrcBlend feature is not enabled, `dstAlphaBlendFactor` must not be
  `VK_BLEND_FACTOR_SRC1_COLOR`, `VK_BLEND_FACTOR_ONE_MINUS_SRC1_COLOR`, `VK_BLEND_FACTOR_SRC1_ALPHA`, or `VK_BLEND_FACTOR_ONE_MINUS_SRC1_ALPHA`.

- **VUID-VkColorBlendEquationEXT-colorBlendOp-07361**

- **VUID-VkColorBlendEquationEXT-constantAlphaColorBlendFactors-07362**
  If the `VK_KHR_portability_subset` extension is enabled, and `VkPhysicalDevicePortabilitySubsetFeaturesKHR::constantAlphaColorBlendFactors` is `VK_FALSE`, `srcColorBlendFactor` must not be `VK_BLEND_FACTOR_CONSTANT_ALPHA` or `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA`.

- **VUID-VkColorBlendEquationEXT-constantAlphaColorBlendFactors-07363**
  If the `VK_KHR_portability_subset` extension is enabled, and `VkPhysicalDevicePortabilitySubsetFeaturesKHR::constantAlphaColorBlendFactors` is `VK_FALSE`, `dstColorBlendFactor` must not be `VK_BLEND_FACTOR_CONSTANT_ALPHA` or `VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA`.
Valid Usage (Implicit)

- `VUID-VkColorBlendEquationEXT-srcColorBlendFactor-parameter srcColorBlendFactor must be a valid VkBlendFactor value`
- `VUID-VkColorBlendEquationEXT-dstColorBlendFactor-parameter dstColorBlendFactor must be a valid VkBlendFactor value`
- `VUID-VkColorBlendEquationEXT-colorBlendOp-parameter colorBlendOp must be a valid VkBlendOp value`
- `VUID-VkColorBlendEquationEXT-srcAlphaBlendFactor-parameter srcAlphaBlendFactor must be a valid VkBlendFactor value`
- `VUID-VkColorBlendEquationEXT-dstAlphaBlendFactor-parameter dstAlphaBlendFactor must be a valid VkBlendFactor value`
- `VUID-VkColorBlendEquationEXT-alphaBlendOp-parameter alphaBlendOp must be a valid VkBlendOp value`

To dynamically set the color write masks, call:

```c
void vkCmdSetColorWriteMaskEXT(
    VkCommandBuffer commandBuffer, 
    uint32_t firstAttachment, 
    uint32_t attachmentCount, 
    const VkColorComponentFlags* pColorWriteMasks);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `firstAttachment` the first color attachment the color write masks apply to.
- `attachmentCount` the number of VkColorComponentFlags values in the `pColorWriteMasks` array.
- `pColorWriteMasks` an array of VkColorComponentFlags values that specify the color write masks of the corresponding attachments.

This command sets the color write masks of the specified attachments for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineColorBlendAttachmentState::colorWriteMask` values used to create the currently active pipeline.

**Note**

Formats with bits that are shared between components specified by `VkColorComponentFlagBits`, such as `VK_FORMAT_E5B9G9R9_UFLOAT_PACK32`, cannot have their channels individually masked by this functionality; either all components that share bits have to be enabled, or none of them.
Valid Usage

• VUID-vkCmdSetColorWriteMaskEXT-None-08540
  Either the extendedDynamicState3ColorWriteMask feature or the shaderObject feature or both must be enabled

Valid Usage (Implicit)

• VUID-vkCmdSetColorWriteMaskEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

• VUID-vkCmdSetColorWriteMaskEXT-pColorWriteMasks-parameter
  pColorWriteMasks must be a valid pointer to an array of attachmentCount valid combinations of VkColorComponentFlagBits values

• VUID-vkCmdSetColorWriteMaskEXT-commandBuffer-recording
  commandBuffer must be in the recording state

• VUID-vkCmdSetColorWriteMaskEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

• VUID-vkCmdSetColorWriteMaskEXT-videocoding
  This command must only be called outside of a video coding scope

• VUID-vkCmdSetColorWriteMaskEXT-attachmentCount-arraylength
  attachmentCount must be greater than 0

Host Synchronization

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

30.1.1. Blend Factors

The source and destination color and alpha blending factors are selected from the enum:
typedef enum VkBlendFactor {
    VK_BLEND_FACTOR_ZERO = 0,
    VK_BLEND_FACTOR_ONE = 1,
    VK_BLEND_FACTOR_SRC_COLOR = 2,
    VK_BLEND_FACTOR_ONE_MINUS_SRC_COLOR = 3,
    VK_BLEND_FACTOR_DST_COLOR = 4,
    VK_BLEND_FACTOR_ONE_MINUS_DST_COLOR = 5,
    VK_BLEND_FACTOR_SRC_ALPHA = 6,
    VK_BLEND_FACTOR_ONE_MINUS_SRC_ALPHA = 7,
    VK_BLEND_FACTOR_DST_ALPHA = 8,
    VK_BLEND_FACTOR_ONE_MINUS_DST_ALPHA = 9,
    VK_BLEND_FACTOR_CONSTANT_COLOR = 10,
    VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR = 11,
    VK_BLEND_FACTOR_CONSTANT_ALPHA = 12,
    VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA = 13,
    VK_BLEND_FACTOR_SRC_ALPHA_SATURATE = 14,
    VK_BLEND_FACTOR_SRC1_COLOR = 15,
    VK_BLEND_FACTOR_ONE_MINUS_SRC1_COLOR = 16,
    VK_BLEND_FACTOR_SRC1_ALPHA = 17,
    VK_BLEND_FACTOR_ONE_MINUS_SRC1_ALPHA = 18,
} VkBlendFactor;

The semantics of the enum values are described in the table below:

<table>
<thead>
<tr>
<th>VkBlendFactor</th>
<th>RGB Blend Factors (S&lt;sub&gt;r&lt;/sub&gt;,S&lt;sub&gt;g&lt;/sub&gt;,S&lt;sub&gt;b&lt;/sub&gt;)</th>
<th>Alpha Blend Factor (S&lt;sub&gt;a&lt;/sub&gt; or D&lt;sub&gt;a&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_BLEND_FACTOR_ZERO</td>
<td>(0,0,0)</td>
<td>0</td>
</tr>
<tr>
<td>VK_BLEND_FACTOR_ONE</td>
<td>(1,1,1)</td>
<td>1</td>
</tr>
<tr>
<td>VK_BLEND_FACTOR_SRC_COLOR</td>
<td>(R&lt;sub&gt;s0&lt;/sub&gt;,G&lt;sub&gt;s0&lt;/sub&gt;,B&lt;sub&gt;s0&lt;/sub&gt;)</td>
<td>A&lt;sub&gt;s0&lt;/sub&gt;</td>
</tr>
<tr>
<td>VK_BLEND_FACTOR_ONE_MINUS_SRC_COLOR</td>
<td>(1-R&lt;sub&gt;s0&lt;/sub&gt;,1-G&lt;sub&gt;s0&lt;/sub&gt;,1-B&lt;sub&gt;s0&lt;/sub&gt;)</td>
<td>1-A&lt;sub&gt;s0&lt;/sub&gt;</td>
</tr>
<tr>
<td>VK_BLEND_FACTOR_DST_COLOR</td>
<td>(R&lt;sub&gt;d&lt;/sub&gt;,G&lt;sub&gt;d&lt;/sub&gt;,B&lt;sub&gt;d&lt;/sub&gt;)</td>
<td>A&lt;sub&gt;d&lt;/sub&gt;</td>
</tr>
<tr>
<td>VK_BLEND_FACTOR_ONE_MINUS_DST_COLOR</td>
<td>(1-R&lt;sub&gt;d&lt;/sub&gt;,1-G&lt;sub&gt;d&lt;/sub&gt;,1-B&lt;sub&gt;d&lt;/sub&gt;)</td>
<td>1-A&lt;sub&gt;d&lt;/sub&gt;</td>
</tr>
<tr>
<td>VK_BLEND_FACTOR_SRC_ALPHA</td>
<td>(A&lt;sub&gt;s0&lt;/sub&gt;,A&lt;sub&gt;s0&lt;/sub&gt;,A&lt;sub&gt;s0&lt;/sub&gt;)</td>
<td>A&lt;sub&gt;s0&lt;/sub&gt;</td>
</tr>
<tr>
<td>VK_BLEND_FACTOR_ONE_MINUS_SRC_ALPHA</td>
<td>(1-A&lt;sub&gt;s0&lt;/sub&gt;,1-A&lt;sub&gt;s0&lt;/sub&gt;,1-A&lt;sub&gt;s0&lt;/sub&gt;)</td>
<td>1-A&lt;sub&gt;s0&lt;/sub&gt;</td>
</tr>
<tr>
<td>VK_BLEND_FACTOR_DST_ALPHA</td>
<td>(A&lt;sub&gt;d&lt;/sub&gt;,A&lt;sub&gt;d&lt;/sub&gt;,A&lt;sub&gt;d&lt;/sub&gt;)</td>
<td>A&lt;sub&gt;d&lt;/sub&gt;</td>
</tr>
<tr>
<td>VK_BLEND_FACTOR_ONE_MINUS_DST_ALPHA</td>
<td>(1-A&lt;sub&gt;d&lt;/sub&gt;,1-A&lt;sub&gt;d&lt;/sub&gt;,1-A&lt;sub&gt;d&lt;/sub&gt;)</td>
<td>1-A&lt;sub&gt;d&lt;/sub&gt;</td>
</tr>
<tr>
<td>VK_BLEND_FACTOR_CONSTANT_COLOR</td>
<td>(R&lt;sub&gt;c&lt;/sub&gt;,G&lt;sub&gt;c&lt;/sub&gt;,B&lt;sub&gt;c&lt;/sub&gt;)</td>
<td>A&lt;sub&gt;c&lt;/sub&gt;</td>
</tr>
<tr>
<td>VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR</td>
<td>(1-R&lt;sub&gt;c&lt;/sub&gt;,1-G&lt;sub&gt;c&lt;/sub&gt;,1-B&lt;sub&gt;c&lt;/sub&gt;)</td>
<td>1-A&lt;sub&gt;c&lt;/sub&gt;</td>
</tr>
<tr>
<td>VK_BLEND_FACTOR_CONSTANT_ALPHA</td>
<td>(A&lt;sub&gt;c&lt;/sub&gt;,A&lt;sub&gt;c&lt;/sub&gt;,A&lt;sub&gt;c&lt;/sub&gt;)</td>
<td>A&lt;sub&gt;c&lt;/sub&gt;</td>
</tr>
</tbody>
</table>
**VkBlendFactor** | **RGB Blend Factors** \((S_r,S_g,S_b)\) or \((D_r,D_g,D_b)\) | **Alpha Blend Factor** \((S_a\text{ or } D_a)\)  
--- | --- | ---  
**VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA** | \((1-A_c,1-A_c,1-A_c)\) | \(1-A_c\)  
**VK_BLEND_FACTOR_SRC_ALPHA_SATURATE** | \((f,f); f = \min(A_s0,1-A_d)\) | \(1\)  
**VK_BLEND_FACTOR_SRC1_COLOR** | \((R_s1,G_s1,B_s1)\) | \(A_s1\)  
**VK_BLEND_FACTOR_ONE_MINUS_SRC1_COLOR** | \((1-R_s1,1-G_s1,1-B_s1)\) | \(1-A_s1\)  
**VK_BLEND_FACTOR_SRC1_ALPHA** | \((A_s1,A_s1,A_s1)\) | \(A_s1\)  
**VK_BLEND_FACTOR_ONE_MINUS_SRC1_ALPHA** | \((1-A_s1,1-A_s1,1-A_s1)\) | \(1-A_s1\)

In this table, the following conventions are used:

- \(R_{s0},G_{s0},B_{s0}\) and \(A_{s0}\) represent the first source color R, G, B, and A components, respectively, for the fragment output location corresponding to the color attachment being blended.

- \(R_{s1},G_{s1},B_{s1}\) and \(A_{s1}\) represent the second source color R, G, B, and A components, respectively, used in dual source blending modes, for the fragment output location corresponding to the color attachment being blended.

- \(R_{d},G_{d},B_{d}\) and \(A_{d}\) represent the R, G, B, and A components of the destination color. That is, the color currently in the corresponding color attachment for this fragment/sample.

- \(R_{c},G_{c},B_{c}\) and \(A_{c}\) represent the blend constant R, G, B, and A components, respectively.

To **dynamically set and change** the blend constants, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdSetBlendConstants(
    VkCommandBuffer commandBuffer,  
    const float blendConstants[4]);
```

- **commandBuffer** is the command buffer into which the command will be recorded.

- **blendConstants** is a pointer to an array of four values specifying the \(R_c, G_c, B_c\), and \(A_c\) components of the blend constant color used in blending, depending on the **blend factor**.

This command sets blend constants for subsequent drawing commands when when drawing using **shader objects**, or the graphics pipeline is created with **VK_DYNAMIC_STATE_BLEND_CONSTANTS** set in **VkPipelineDynamicStateCreateInfo::pDynamicStates**. Otherwise, this state is specified by the **VkPipelineColorBlendStateCreateInfo::blendConstants** values used to create the currently active pipeline.

---

**Valid Usage (Implicit)**

- VUID-vkCmdSetBlendConstants-commandBuffer-parameter  
  **commandBuffer** must be a valid **VkCommandBuffer** handle
• VUID-vkCmdSetBlendConstants-commandBuffer-recording
commandBuffer must be in the recording state

• VUID-vkCmdSetBlendConstants-commandBuffer-cmdpool
The VkCommandPool that commandBuffer was allocated from must support graphics operations

• VUID-vkCmdSetBlendConstants-videocoding
This command must only be called outside of a video coding scope

Host Synchronization

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics</td>
<td>State</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

30.1.2. Dual-Source Blending

Blend factors that use the secondary color input \((R_{s1}, G_{s1}, B_{s1}, A_{s1})\) (\texttt{VK_BLEND_FACTOR_SRC1_COLOR, VK_BLEND_FACTOR_ONE_MINUS_SRC1_COLOR, VK_BLEND_FACTOR_SRC1_ALPHA,} and \texttt{VK_BLEND_FACTOR_ONE_MINUS_SRC1_ALPHA}) may consume implementation resources that could otherwise be used for rendering to multiple color attachments. Therefore, the number of color attachments that can be used in a framebuffer may be lower when using dual-source blending.

Dual-source blending is only supported if the dualSrcBlend feature is enabled.

The maximum number of color attachments that can be used in a subpass when using dual-source blending functions is implementation-dependent and is reported as the maxFragmentDualSrcAttachments member of VkPhysicalDeviceLimits.

Color outputs can be bound to the first and second inputs of the blender using the Index decoration, as described in Fragment Output Interface. If the second color input to the blender is not written in the shader, or if no output is bound to the second input of a blender, the value of the second input is undefined.

30.1.3. Blend Operations

Once the source and destination blend factors have been selected, they along with the source and destination components are passed to the blending operations. RGB and alpha components can use
different operations. Possible values of `VkBlendOp`, specifying the operations, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkBlendOp {
    VK_BLEND_OP_ADD = 0,
    VK_BLEND_OP_SUBTRACT = 1,
    VK_BLEND_OP_REVERSE_SUBTRACT = 2,
    VK_BLEND_OP_MIN = 3,
    VK_BLEND_OP_MAX = 4,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_ZERO_EXT = 1000148000,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_SRC_EXT = 1000148001,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_DST_EXT = 1000148002,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_SRC_OVER_EXT = 1000148003,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_DST_OVER_EXT = 1000148004,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_SRC_IN_EXT = 1000148005,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_DST_IN_EXT = 1000148006,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_SRC_ATOP_EXT = 1000148009,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_DST_ATOP_EXT = 1000148010,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_XOR_EXT = 1000148011,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_MULTIPLY_EXT = 1000148012,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_SCREEN_EXT = 1000148013,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_OVERLAY_EXT = 1000148014,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_DARKEN_EXT = 1000148015,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_LIGHTEN_EXT = 1000148016,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_COLORDODGE_EXT = 1000148017,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_COLORBURN_EXT = 1000148018,
    // Provided by VK_EXT_blend_operation_advanced
    VK_BLEND_OP_HARDLIGHT_EXT = 1000148019,
};
```
VK_BLEND_OP_SOFTLIGHT_EXT = 1000148020,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_DIFFERENCE_EXT = 1000148021,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_EXCLUSION_EXT = 1000148022,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_INVERT_EXT = 1000148023,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_INVERT_RGB_EXT = 1000148024,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_LINEARDODGE_EXT = 1000148025,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_LINEARBURN_EXT = 1000148026,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_VIVIDLIGHT_EXT = 1000148027,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_LINEARLIGHT_EXT = 1000148028,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_PINLIGHT_EXT = 1000148029,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_HARDMIX_EXT = 1000148030,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_HSL_HUE_EXT = 1000148031,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_HSL_SATURATION_EXT = 1000148032,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_HSL_COLOR_EXT = 1000148033,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_HSL_LUMINOSITY_EXT = 1000148034,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_PLUS_EXT = 1000148035,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_PLUS_CLAMPED_EXT = 1000148036,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_PLUS_CLAMPED_ALPHA_EXT = 1000148037,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_PLUS_DARKER_EXT = 1000148038,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_MINUS_EXT = 1000148039,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_MINUS_CLAMPED_EXT = 1000148040,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_CONTRAST_EXT = 1000148041,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_INVERT_OVG_EXT = 1000148042,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_RED_EXT = 1000148043,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_GREEN_EXT = 1000148044,
// Provided by VK_EXT_blend_operation_advanced
VK_BLEND_OP_BLUE_EXT = 1000148045,
} VkBlendOp;
The semantics of the basic blend operations are described in the table below:

<table>
<thead>
<tr>
<th>VkBlendOp</th>
<th>RGB Components</th>
<th>Alpha Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_BLEND_OP_ADD</td>
<td>( R = R_s \times S_r + R_d \times D_r )</td>
<td>( A = A_s \times S_a + A_d \times D_a )</td>
</tr>
<tr>
<td></td>
<td>( G = G_s \times S_g + G_d \times D_g )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( B = B_s \times S_b + B_d \times D_b )</td>
<td></td>
</tr>
<tr>
<td>VK_BLEND_OP_SUBTRACT</td>
<td>( R = R_s \times S_r - R_d \times D_r )</td>
<td>( A = A_s \times S_a - A_d \times D_a )</td>
</tr>
<tr>
<td></td>
<td>( G = G_s \times S_g - G_d \times D_g )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( B = B_s \times S_b - B_d \times D_b )</td>
<td></td>
</tr>
<tr>
<td>VK_BLEND_OP_REVERSE_SUBTRACT</td>
<td>( R = R_d \times D_r - R_s \times S_r )</td>
<td>( A = A_d \times D_a - A_s \times S_a )</td>
</tr>
<tr>
<td></td>
<td>( G = G_d \times D_g - G_s \times S_g )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( B = B_d \times D_b - B_s \times S_b )</td>
<td></td>
</tr>
<tr>
<td>VK_BLEND_OP_MIN</td>
<td>( R = \min(R_s, R_d) )</td>
<td>( A = \min(A_s, A_d) )</td>
</tr>
<tr>
<td></td>
<td>( G = \min(G_s, G_d) )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( B = \min(B_s, B_d) )</td>
<td></td>
</tr>
<tr>
<td>VK_BLEND_OP_MAX</td>
<td>( R = \max(R_s, R_d) )</td>
<td>( A = \max(A_s, A_d) )</td>
</tr>
<tr>
<td></td>
<td>( G = \max(G_s, G_d) )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( B = \max(B_s, B_d) )</td>
<td></td>
</tr>
</tbody>
</table>

In this table, the following conventions are used:

- \( R_s, G_s, B_s \) and \( A_s \) represent the first source color R, G, B, and A components, respectively.
- \( R_d, G_d, B_d \) and \( A_d \) represent the R, G, B, and A components of the destination color. That is, the color currently in the corresponding color attachment for this fragment/sample.
- \( S_r, S_g, S_b \) and \( S_a \) represent the source blend factor R, G, B, and A components, respectively.
- \( D_r, D_g, D_b \) and \( D_a \) represent the destination blend factor R, G, B, and A components, respectively.

The blending operation produces a new set of values R, G, B, and A, which are written to the framebuffer attachment. If blending is not enabled for this attachment, then R, G, B and A are assigned \( R_s, G_s, B_s \) and \( A_s \), respectively.

If the color attachment is fixed-point, the components of the source and destination values and blend factors are each clamped to \([0,1]\) or \([-1,1]\) respectively for an unsigned normalized or signed normalized color attachment prior to evaluating the blend operations. If the color attachment is floating-point, no clamping occurs.

If the numeric format of a framebuffer attachment uses sRGB encoding, the R, G, and B destination color values (after conversion from fixed-point to floating-point) are considered to be encoded for the sRGB color space and hence are linearized prior to their use in blending. Each R, G, and B component is converted from nonlinear to linear as described in the “sRGB EOTF” section of the Khronos Data Format Specification. If the format is not sRGB, no linearization is performed.

If the numeric format of a framebuffer attachment uses sRGB encoding, then the final R, G and B values are converted into the nonlinear sRGB representation before being written to the framebuffer attachment as described in the “sRGB EOTF” section of the Khronos Data Format Specification.
Specification.

If the numeric format of a framebuffer color attachment is not sRGB encoded then the resulting c values for R, G and B are unmodified. The value of A is never sRGB encoded. That is, the alpha component is always stored in memory as linear.

If the framebuffer color attachment is VK_ATTACHMENT_UNUSED, no writes are performed through that attachment. Writes are not performed to framebuffer color attachments greater than or equal to the VkSubpassDescription::colorAttachmentCount or VkSubpassDescription2::colorAttachmentCount value.

30.1.4. Advanced Blend Operations

The advanced blend operations are those listed in tables f/X/Y/Z Advanced Blend Operations, Hue-Saturation-Luminosity Advanced Blend Operations, and Additional RGB Blend Operations.

If the pNext chain of VkPipelineColorBlendStateCreateInfo includes a VkPipelineColorBlendAdvancedStateCreateInfoEXT structure, then that structure includes parameters that affect advanced blend operations.

The VkPipelineColorBlendAdvancedStateCreateInfoEXT structure is defined as:

```c
// Provided by VK_EXT_blend_operation_advanced
typedef struct VkPipelineColorBlendAdvancedStateCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkBool32 srcPremultiplied;
    VkBool32 dstPremultiplied;
    VkBlendOverlapEXT blendOverlap;
} VkPipelineColorBlendAdvancedStateCreateInfoEXT;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **srcPremultiplied** specifies whether the source color of the blend operation is treated as premultiplied.
- **dstPremultiplied** specifies whether the destination color of the blend operation is treated as premultiplied.
- **blendOverlap** is a VkBlendOverlapEXT value specifying how the source and destination sample's coverage is correlated.

If this structure is not present, srcPremultiplied and dstPremultiplied are both considered to be VK_TRUE, and blendOverlap is considered to be VK_BLEND_OVERLAP_UNCORRELATED_EXT.

**Valid Usage**

- VUID-VkPipelineColorBlendAdvancedStateCreateInfoEXT-srcPremultiplied-01424
  If the non-premultiplied source color property is not supported, srcPremultiplied must be
If the non-premultiplied destination color property is not supported, `dstPremultiplied` must be `VK_TRUE`.

If the correlated overlap property is not supported, `blendOverlap` must be `VK_BLEND_OVERLAP_UNCORRELATED_EXT`.

Valid Usage (Implicit)

- `sType` must be `VK_STRUCTURE_TYPE_PIPELINE_COLOR_BLEND_ADVANCED_STATE_CREATE_INFO_EXT`.
- `blendOverlap` must be a valid `VkBlendOverlapEXT` value.

To dynamically set the advanced blend state, call:

```c
void vkCmdSetColorBlendAdvancedEXT(
    VkCommandBuffer commandBuffer,
    uint32_t firstAttachment,
    uint32_t attachmentCount,
    const VkColorBlendAdvancedEXT* pColorBlendAdvanced);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `firstAttachment` the first color attachment the advanced blend parameters apply to.
- `attachmentCount` the number of `VkColorBlendAdvancedEXT` elements in the `pColorBlendAdvanced` array.
- `pColorBlendAdvanced` an array of `VkColorBlendAdvancedEXT` structs that specify the advanced color blend parameters for the corresponding attachments.

This command sets the advanced blend operation parameters of the specified attachments for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineColorBlendAdvancedStateCreateInfoEXT::srcPremultiplied`, `VkPipelineColorBlendAdvancedStateCreateInfoEXT::dstPremultiplied`, and `VkPipelineColorBlendAdvancedStateCreateInfoEXT::blendOverlap` values used to create the currently active pipeline.

Valid Usage

- `VUID-vkCmdSetColorBlendAdvancedEXT-None-08592`
Either the extendedDynamicState3ColorBlendAdvanced feature or the shaderObject feature or both must be enabled.

### Valid Usage (Implicit)

- VUID-vkCmdSetColorBlendAdvancedEXT-commandBuffer-parameter
  
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdSetColorBlendAdvancedEXT-pColorBlendAdvanced-parameter
  
  pColorBlendAdvanced must be a valid pointer to an array of attachmentCount valid VkColorBlendAdvancedEXT structures

- VUID-vkCmdSetColorBlendAdvancedEXT-commandBuffer-recording
  
  commandBuffer must be in the recording state

- VUID-vkCmdSetColorBlendAdvancedEXT-commandBuffer-cmdpool
  
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdSetColorBlendAdvancedEXT-videocoding
  
  This command must only be called outside of a video coding scope

- VUID-vkCmdSetColorBlendAdvancedEXT-attachmentCount-arraylength
  
  attachmentCount must be greater than 0

### Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

### Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics</td>
<td>State</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The VkColorBlendAdvancedEXT structure is defined as:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
typedef struct VkColorBlendAdvancedEXT {
    VkBlendOp advancedBlendOp;
    VkBool32 srcPremultiplied;
    VkBool32 dstPremultiplied;
    VkBlendOverlapEXT blendOverlap;
};
```
 VkBool32 clampResults;
} VkColorBlendAdvancedEXT;

- **advancedBlendOp** selects which blend operation is used to calculate the RGB values to write to the color attachment.
- **srcPremultiplied** specifies whether the source color of the blend operation is treated as premultiplied.
- **dstPremultiplied** specifies whether the destination color of the blend operation is treated as premultiplied.
- **blendOverlap** is a VkBlendOverlapEXT value specifying how the source and destination sample’s coverage is correlated.
- **clampResults** specifies the results must be clamped to the [0,1] range before writing to the attachment, which is useful when the attachment format is not normalized fixed-point.

### Valid Usage

- **VUID-VkColorBlendAdvancedEXT-srcPremultiplied-07505**
  If the non-premultiplied source color property is not supported, **srcPremultiplied** must be **VK_TRUE**

- **VUID-VkColorBlendAdvancedEXT-dstPremultiplied-07506**
  If the non-premultiplied destination color property is not supported, **dstPremultiplied** must be **VK_TRUE**

- **VUID-VkColorBlendAdvancedEXT-blendOverlap-07507**
  If the correlated overlap property is not supported, **blendOverlap** must be **VK_BLEND_OVERLAP_UNCORRELATED_EXT**

### Valid Usage (Implicit)

- **VUID-VkColorBlendAdvancedEXT-advancedBlendOp-parameter**
  **advancedBlendOp** must be a valid VkBlendOp value

- **VUID-VkColorBlendAdvancedEXT-blendOverlap-parameter**
  **blendOverlap** must be a valid VkBlendOverlapEXT value

When using one of the operations in table f/X/Y/Z Advanced Blend Operations or Hue-Saturation-Luminosity Advanced Blend Operations, blending is performed according to the following equations:

\[
egin{align*}
R &= f(R_s', R_d') \cdot p_0(A_s, A_d) + Y \cdot R_s' \cdot p_1(A_s, A_d) + Z \cdot R_d' \cdot p_2(A_s, A_d) \\
G &= f(G_s', G_d') \cdot p_0(A_s, A_d) + Y \cdot G_s' \cdot p_1(A_s, A_d) + Z \cdot G_d' \cdot p_2(A_s, A_d) \\
B &= f(B_s', B_d') \cdot p_0(A_s, A_d) + Y \cdot B_s' \cdot p_1(A_s, A_d) + Z \cdot B_d' \cdot p_2(A_s, A_d) \\
A &= X \cdot p_0(A_s, A_d) + Y \cdot p_1(A_s, A_d) + Z \cdot p_2(A_s, A_d)
\end{align*}
\]

where the function \(f\) and terms \(X, Y, \text{ and } Z\) are specified in the table. The R, G, and B components of
the source color used for blending are derived according to srcPremultiplied. If srcPremultiplied is set to VK_TRUE, the fragment color components are considered to have been premultiplied by the A component prior to blending. The base source color \((R_s', G_s', B_s')\) is obtained by dividing through by the A component:

\[
(R_s', G_s', B_s') = \begin{cases} 
(0, 0, 0) & A_s = 0 \\
\left( \frac{R_s}{A_s'}, \frac{G_s}{A_s'}, \frac{B_s}{A_s} \right) & \text{otherwise}
\end{cases}
\]

If srcPremultiplied is VK_FALSE, the fragment color components are used as the base color:

\[
(R_s', G_s', B_s') = (R_s, G_s, B_s)
\]

The R, G, and B components of the destination color used for blending are derived according to dstPremultiplied. If dstPremultiplied is set to VK_TRUE, the destination components are considered to have been premultiplied by the A component prior to blending. The base destination color \((R_d', G_d', B_d')\) is obtained by dividing through by the A component:

\[
(R_d', G_d', B_d') = \begin{cases} 
(0, 0, 0) & A_d = 0 \\
\left( \frac{R_d}{A_d'}, \frac{G_d}{A_d'}, \frac{B_d}{A_d} \right) & \text{otherwise}
\end{cases}
\]

If dstPremultiplied is VK_FALSE, the destination color components are used as the base color:

\[
(R_d', G_d', B_d') = (R_d, G_d, B_d)
\]

When blending using advanced blend operations, we expect that the R, G, and B components of premultiplied source and destination color inputs be stored as the product of non-premultiplied R, G, and B component values and the A component of the color. If any R, G, or B component of a premultiplied input color is non-zero and the A component is zero, the color is considered ill-formed, and the corresponding component of the blend result is undefined.

All of the advanced blend operation formulas in this chapter compute the result as a premultiplied color. If dstPremultiplied is VK_FALSE, that result color’s R, G, and B components are divided by the A component before being written to the framebuffer. If any R, G, or B component of the color is non-zero and the A component is zero, the result is considered ill-formed, and the corresponding component of the blend result is undefined. If all components are zero, that value is unchanged.

If the A component of any input or result color is less than zero, the color is considered ill-formed, and all components of the blend result are undefined.

The weighting functions \(p_0\), \(p_1\), and \(p_2\) are defined in table Advanced Blend Overlap Modes. In these functions, the A components of the source and destination colors are taken to indicate the portion of the pixel covered by the fragment (source) and the fragments previously accumulated in the pixel (destination). The functions \(p_0\), \(p_1\), and \(p_2\) approximate the relative portion of the pixel covered by the intersection of the source and destination, covered only by the source, and covered only by the destination, respectively.
Possible values of `VkPipelineColorBlendAdvancedStateCreateInfoEXT::blendOverlap`, specifying the blend overlap functions, are:

```c
// Provided by VK_EXT_blend_operation_advanced
typedef enum VkBlendOverlapEXT {
    VK_BLEND_OVERLAP_UNCORRELATED_EXT = 0,
    VK_BLEND_OVERLAP_DISJOINT_EXT = 1,
    VK_BLEND_OVERLAP_CONJOINT_EXT = 2,
} VkBlendOverlapEXT;
```

- **VK_BLEND_OVERLAP_UNCORRELATED_EXT** specifies that there is no correlation between the source and destination coverage.
- **VK_BLEND_OVERLAP_CONJOINT_EXT** specifies that the source and destination coverage are considered to have maximal overlap.
- **VK_BLEND_OVERLAP_DISJOINT_EXT** specifies that the source and destination coverage are considered to have minimal overlap.

---

**Table 41. Advanced Blend Overlap Modes**

<table>
<thead>
<tr>
<th>Overlap Mode</th>
<th>Weighting Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_BLEND_OVERLAP_UNCORRELATED_EXT</td>
<td>$p_0(A_s, A_d) = A_s A_d$</td>
</tr>
<tr>
<td></td>
<td>$p_1(A_s, A_d) = A_s (1 - A_d)$</td>
</tr>
<tr>
<td></td>
<td>$p_2(A_s, A_d) = A_d (1 - A_s)$</td>
</tr>
<tr>
<td>VK_BLEND_OVERLAP_CONJOINT_EXT</td>
<td>$p_0(A_s, A_d) = \min(A_s, A_d)$</td>
</tr>
<tr>
<td></td>
<td>$p_1(A_s, A_d) = \max(A_s - A_d, 0)$</td>
</tr>
<tr>
<td></td>
<td>$p_2(A_s, A_d) = \max(A_d - A_s, 0)$</td>
</tr>
<tr>
<td>VK_BLEND_OVERLAP_DISJOINT_EXT</td>
<td>$p_0(A_s, A_d) = \max(A_s + A_d - 1, 0)$</td>
</tr>
<tr>
<td></td>
<td>$p_1(A_s, A_d) = \min(A_s, 1 - A_d)$</td>
</tr>
<tr>
<td></td>
<td>$p_2(A_s, A_d) = \min(A_d, 1 - A_s)$</td>
</tr>
</tbody>
</table>

**Table 42. f/X/Y/Z Advanced Blend Operations**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Blend Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_BLEND_OP_ZERO_EXT</td>
<td>($X, Y, Z) = (0, 0, 0)$</td>
</tr>
<tr>
<td></td>
<td>$f(C_s, C_d) = 0$</td>
</tr>
<tr>
<td>VK_BLEND_OP_SRC_EXT</td>
<td>($X, Y, Z) = (1, 1, 0)$</td>
</tr>
<tr>
<td></td>
<td>$f(C_s, C_d) = C_s$</td>
</tr>
<tr>
<td>VK_BLEND_OP_DST_EXT</td>
<td>($X, Y, Z) = (1, 0, 1)$</td>
</tr>
<tr>
<td></td>
<td>$f(C_s, C_d) = C_d$</td>
</tr>
<tr>
<td>VK_BLEND_OP_SRC_OVER_EXT</td>
<td>($X, Y, Z) = (1, 1, 1)$</td>
</tr>
<tr>
<td></td>
<td>$f(C_s, C_d) = C_s$</td>
</tr>
<tr>
<td>Mode</td>
<td>Blend Coefficients</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>--------------------</td>
</tr>
</tbody>
</table>
| VK_BLEND_OP_DST_OVER_EXT           | \((X, Y, Z) = (1, 1, 1)\)  
\(f(C_s, C_d) = C_d\) |
| VK_BLEND_OP_SRC_IN_EXT             | \((X, Y, Z) = (1, 0, 0)\)  
\(f(C_s, C_d) = C_s\) |
| VK_BLEND_OP_DST_IN_EXT             | \((X, Y, Z) = (1, 0, 0)\)  
\(f(C_s, C_d) = C_d\) |
| VK_BLEND_OP_SRC_OUT_EXT            | \((X, Y, Z) = (0, 1, 0)\)  
\(f(C_s, C_d) = 0\) |
| VK_BLEND_OP_DST_OUT_EXT            | \((X, Y, Z) = (0, 0, 1)\)  
\(f(C_s, C_d) = 0\) |
| VK_BLEND_OP_SRC_ATOP_EXT           | \((X, Y, Z) = (1, 0, 1)\)  
\(f(C_s, C_d) = C_s\) |
| VK_BLEND_OP_DST_ATOP_EXT           | \((X, Y, Z) = (1, 1, 0)\)  
\(f(C_s, C_d) = C_d\) |
| VK_BLEND_OP_XOR_EXT                | \((X, Y, Z) = (0, 1, 1)\)  
\(f(C_s, C_d) = 0\) |
| VK_BLEND_OP_MULTIPLY_EXT           | \((X, Y, Z) = (1, 1, 1)\)  
\(f(C_s, C_d) = C_s C_d\) |
| VK_BLEND_OP_SCREEN_EXT             | \((X, Y, Z) = (1, 1, 1)\)  
\(f(C_s, C_d) = C_s + C_d - C_s C_d\) |
| VK_BLEND_OP_OVERLAY_EXT            | \((X, Y, Z) = (1, 1, 1)\)  
\(f(C_s, C_d) = \begin{cases} 2C_s C_d & C_d \leq 0.5 \\ 1 - 2(1 - C_s)(1 - C_d) & \text{otherwise} \end{cases}\) |
| VK_BLEND_OP_DARKEN_EXT             | \((X, Y, Z) = (1, 1, 1)\)  
\(f(C_s, C_d) = \min(C_s, C_d)\) |
| VK_BLEND_OP_LIGHTEN_EXT            | \((X, Y, Z) = (1, 1, 1)\)  
\(f(C_s, C_d) = \max(C_s, C_d)\) |
| VK_BLEND_OP_COLORDOODGE_EXT        | \((X, Y, Z) = (1, 1, 1)\)  
\(f(C_s, C_d) = \begin{cases} 0 & C_d \leq 0 \\ \min(1, \frac{C_d}{1 - C_s}) & C_d > 0 \text{and} C_s < 1 \\ 1 & C_d > 0 \text{and} C_s \geq 1 \end{cases}\) |
| VK_BLEND_OP_COLORBURN_EXT          | \((X, Y, Z) = (1, 1, 1)\)  
\(f(C_s, C_d) = \begin{cases} 1 & C_d \geq 1 \\ 1 - \min(1, \frac{1 - C_d}{C_s}) & C_d < 1 \text{and} C_s > 0 \\ 0 & C_d < 1 \text{and} C_s \leq 0 \end{cases}\) |
| VK_BLEND_OP_HARDLIGHT_EXT          | \((X, Y, Z) = (1, 1, 1)\)  
\(f(C_s, C_d) = \begin{cases} 2C_s C_d & C_s \leq 0.5 \\ 1 - 2(1 - C_s)(1 - C_d) & \text{otherwise} \end{cases}\) |
When using one of the HSL blend operations in table **Hue-Saturation-Luminosity Advanced Blend Operations** as the blend operation, the RGB color components produced by the function \( f \) are effectively obtained by converting both the non-premultiplied source and destination colors to the HSL (hue, saturation, luminosity) color space, generating a new HSL color by selecting \( H, S, \) and \( L \) components from the source or destination according to the blend operation, and then converting the result back to RGB. In the equations below, a blended RGB color is produced according to the following pseudocode:
float minv3(vec3 c) {
    return min(min(c.r, c.g), c.b);
}
float maxv3(vec3 c) {
    return max(max(c.r, c.g), c.b);
}
float lumv3(vec3 c) {
    return dot(c, vec3(0.30, 0.59, 0.11));
}
float satv3(vec3 c) {
    return maxv3(c) - minv3(c);
}

// If any color components are outside [0,1], adjust the color to
// get the components in range.
vec3 ClipColor(vec3 color) {
    float lum = lumv3(color);
    float mincol = minv3(color);
    float maxcol = maxv3(color);
    if (mincol < 0.0) {
        color = lum + ((color-lum)*lum) / (lum-mincol);
    }
    if (maxcol > 1.0) {
        color = lum + ((color-lum)*(1-lum)) / (maxcol-lum);
    }
    return color;
}

// Take the base RGB color <cbase> and override its luminosity
// with that of the RGB color <clum>.
vec3 SetLum(vec3 cbase, vec3 clum) {
    float lbase = lumv3(cbase);
    float llum = lumv3(clum);
    float ldiff = llum - lbase;
    vec3 color = cbase + vec3(ldiff);
    return ClipColor(color);
}

// Take the base RGB color <cbase> and override its saturation with
// that of the RGB color <csat>. The override the luminosity of the
// result with that of the RGB color <clum>.
vec3 SetLumSat(vec3 cbase, vec3 csat, vec3 clum)
{
    float minbase = minv3(cbase);
    float sbase = satv3(cbase);
    float ssat = satv3(csat);
    vec3 color;
    if (sbase > 0) {
        // Equivalent (modulo rounding errors) to setting the
        // smallest (R,G,B) component to 0, the largest to <ssat>,
        // etc.
    }
}
// and interpolating the "middle" component based on its
// original value relative to the smallest/largest.
    color = (cbase - minbase) * ssat / sbase;
  } else {
    color = vec3(0.0);
  }
  return SetLum(color, clum);
}

Table 43. Hue-Saturation-Luminosity Advanced Blend Operations

<table>
<thead>
<tr>
<th>Mode</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_BLEND_OP_HSL_HUE_EXT</td>
<td>((X, Y, Z) = (1, 1, 1))</td>
</tr>
<tr>
<td></td>
<td>(f(C_s, C_d) = \text{SetLumSat}(C_s, C_d, C_d))</td>
</tr>
<tr>
<td>VK_BLEND_OP_HSL_SATURATION_EXT</td>
<td>((X, Y, Z) = (1, 1, 1))</td>
</tr>
<tr>
<td></td>
<td>(f(C_s, C_d) = \text{SetLumSat}(C_d, C_s, C_d))</td>
</tr>
<tr>
<td>VK_BLEND_OP_HSL_COLOR_EXT</td>
<td>((X, Y, Z) = (1, 1, 1))</td>
</tr>
<tr>
<td></td>
<td>(f(C_s, C_d) = \text{SetLum}(C_s, C_d))</td>
</tr>
<tr>
<td>VK_BLEND_OP_HSL_LUMINOSITY_EXT</td>
<td>((X, Y, Z) = (1, 1, 1))</td>
</tr>
<tr>
<td></td>
<td>(f(C_s, C_d) = \text{SetLum}(C_d, C_s))</td>
</tr>
</tbody>
</table>

When using one of the operations in table Additional RGB Blend Operations as the blend operation, the source and destination colors used by these blending operations are interpreted according to srcPremultiplied and dstPremultiplied. The blending operations below are evaluated where the RGB source and destination color components are both considered to have been premultiplied by the corresponding A component.

\[
(R_s', G_s', B_s') = \begin{cases} 
(R_s, G_s, B_s) & \text{if srcPremultiplied is VK_TRUE} \\
(R_s A_s, G_s A_s, B_s A_s) & \text{if srcPremultiplied is VK_FALSE}
\end{cases}
\]

\[
(R_d', G_d', B_d') = \begin{cases} 
(R_d, G_d, B_d) & \text{if dstPremultiplied is VK_TRUE} \\
(R_d A_d, G_d A_d, B_d A_d) & \text{if dstPremultiplied is VK_FALSE}
\end{cases}
\]

Table 44. Additional RGB Blend Operations

<table>
<thead>
<tr>
<th>Mode</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_BLEND_OP_PLUS_EXT</td>
<td>((R, G, B, A) = (R_s' + R_d', G_s' + G_d', B_s' + B_d', A_s + A_d))</td>
</tr>
<tr>
<td>VK_BLEND_OP_PLUS_CLAMPED_EXT</td>
<td>((R, G, B, A) = (\min(1, R_s' + R_d'), \min(1, G_s' + G_d'), \min(1, B_s' + B_d'), \min(1, A_s + A_d)))</td>
</tr>
<tr>
<td>Mode</td>
<td>Result</td>
</tr>
<tr>
<td>------</td>
<td>--------</td>
</tr>
<tr>
<td>VK_BLEND_OP_PLUS_CLAMPED_ALPHA_EXT</td>
<td>((R, G, B, A) = (\min(\min(1, A_s + A_d), R_s ' + R_d '), \min(\min(1, A_s + A_d), G_s ' + G_d '), \min(\min(1, A_s + A_d), B_s ' + B_d '), \min(1, A_s + A_d)))</td>
</tr>
<tr>
<td>VK_BLEND_OP_PLUS_DARKER_EXT</td>
<td>((R, G, B, A) = (\max(0, R_d ' - R_s '), \max(0, G_d ' - G_s '), \max(0, B_d ' - B_s '), \max(0, A_d - A_s)))</td>
</tr>
<tr>
<td>VK_BLEND_OP_MINUS_EXT</td>
<td>((R, G, B, A) = (R_d ' - R_s ', G_d ' - G_s ', B_d ' - B_s ', A_d - A_s))</td>
</tr>
<tr>
<td>VK_BLEND_OP_MINUS_CLAMPED_EXT</td>
<td>((R, G, B, A) = (\max(0, R_d ' - R_s '), \max(0, G_d ' - G_s '), \max(0, B_d ' - B_s '), \max(0, A_d - A_s)))</td>
</tr>
<tr>
<td>VK_BLEND_OP_CONTRAST_EXT</td>
<td>((R, G, B, A) = (\frac{A_d}{2} + 2(R_d ' - \frac{A_d}{2})(R_s ' - \frac{A_s}{2}), \frac{A_d}{2} + 2(G_d ' - \frac{A_d}{2})(G_s ' - \frac{A_s}{2}), \frac{A_d}{2} + 2(B_d ' - \frac{A_d}{2})(B_s ' - \frac{A_s}{2}), A_d))</td>
</tr>
<tr>
<td>VK_BLEND_OP_INVERT_OVG_EXT</td>
<td>((R, G, B, A) = (A_d(1 - R_d ') + (1 - A_s)R_d ', A_d(1 - G_d ') + (1 - A_s)G_d ', A_d(1 - B_d ') + (1 - A_s)B_d ', A_s + A_d - A_s A_d))</td>
</tr>
<tr>
<td>VK_BLEND_OP_RED_EXT</td>
<td>((R, G, B, A) = (R_s ', G_d ', B_d ', A_d))</td>
</tr>
<tr>
<td>VK_BLEND_OP_GREEN_EXT</td>
<td>((R, G, B, A) = (R_d ', G_s ', B_d ', A_d))</td>
</tr>
<tr>
<td>VK_BLEND_OP_BLUE_EXT</td>
<td>((R, G, B, A) = (R_d ', G_d ', B_s ', A_d))</td>
</tr>
</tbody>
</table>

### 30.2. Logical Operations

The application can enable a logical operation between the fragment’s color values and the existing value in the framebuffer attachment. This logical operation is applied prior to updating the framebuffer attachment. Logical operations are applied only for signed and unsigned integer and normalized integer framebuffers. Logical operations are not applied to floating-point or sRGB format color attachments.

Logical operations are controlled by the `logicOpEnable` and `logicOp` members of `VkPipelineColorBlendStateCreateInfo`. The `logicOpEnable` state can also be controlled by `vkCmdSetLogicOpEnableEXT` if graphics pipeline is created with `VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. The `logicOp` state can also be controlled by `vkCmdSetLogicOpEXT` if graphics pipeline is created with `VK_DYNAMIC_STATE_LOGIC_OP_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. If `logicOpEnable` is `VK_TRUE`, then a logical operation selected by `logicOp` is applied between each color attachment and the fragment’s corresponding output value, and blending of all attachments is treated as if it were disabled. Any attachments using color formats for which logical operations are not supported simply pass through the color values unmodified. The logical operation is applied...
independently for each of the red, green, blue, and alpha components. The `logicOp` is selected from the following operations:

```c
// Provided by VK_VERSION_1_0
typedef enum VkLogicOp {
    VK_LOGIC_OP_CLEAR = 0,
    VK_LOGIC_OP_AND = 1,
    VK_LOGIC_OP_AND.Reverse = 2,
    VK_LOGIC_OP_COPY = 3,
    VK_LOGIC_OP_AND.INVERTED = 4,
    VK_LOGIC_OP_NO_OP = 5,
    VK_LOGIC_OP_XOR = 6,
    VK_LOGIC_OP_OR = 7,
    VK_LOGIC_OP_NOR = 8,
    VK_LOGIC_OP_Equivalent = 9,
    VK_LOGIC_OP_INVERT = 10,
    VK_LOGIC_OP_OR.Reverse = 11,
    VK_LOGIC_OP_COPY.INVERTED = 12,
    VK_LOGIC_OP_OR.INVERTED = 13,
    VK_LOGIC_OP_NAND = 14,
    VK_LOGIC_OP_SET = 15,
} VkLogicOp;
```
The logical operations supported by Vulkan are summarized in the following table in which

- \( \neg \) is bitwise invert,
- \( \& \) is bitwise and,
- \( \lor \) is bitwise or,
- \( \oplus \) is bitwise exclusive or,
- \( s \) is the fragment’s R\(_{s0}\), G\(_{s0}\), B\(_{s0}\) or A\(_{s0}\) component value for the fragment output corresponding to the color attachment being updated, and
- \( d \) is the color attachment’s R, G, B or A component value:

<table>
<thead>
<tr>
<th>Mode</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_LOGIC_OP_CLEAR</td>
<td>0</td>
</tr>
<tr>
<td>VK_LOGIC_OP_AND</td>
<td>( s &amp; d )</td>
</tr>
<tr>
<td>VK_LOGIC_OP_AND_REVERSE</td>
<td>( s &amp; \neg d )</td>
</tr>
<tr>
<td>VK_LOGIC_OP_COPY</td>
<td>( s )</td>
</tr>
<tr>
<td>VK_LOGIC_OP_AND_INVERTED</td>
<td>( \neg s &amp; d )</td>
</tr>
<tr>
<td>VK_LOGIC_OP_NO_OP</td>
<td>( d )</td>
</tr>
<tr>
<td>VK_LOGIC_OP_XOR</td>
<td>( s \oplus d )</td>
</tr>
<tr>
<td>VK_LOGIC_OP_OR</td>
<td>( s \lor d )</td>
</tr>
<tr>
<td>VK_LOGIC_OP_NOR</td>
<td>( \neg (s \lor d) )</td>
</tr>
<tr>
<td>VK_LOGIC_OP_EQUIVALENT</td>
<td>( \neg (s \oplus d) )</td>
</tr>
<tr>
<td>VK_LOGIC_OP_INVERT</td>
<td>( \neg d )</td>
</tr>
<tr>
<td>VK_LOGIC_OP_OR_REVERSE</td>
<td>( s \lor \neg d )</td>
</tr>
<tr>
<td>VK_LOGIC_OP_COPY_INVERTED</td>
<td>( \neg s )</td>
</tr>
<tr>
<td>VK_LOGIC_OP_OR_INVERTED</td>
<td>( \neg s \lor d )</td>
</tr>
<tr>
<td>VK_LOGIC_OP_NAND</td>
<td>( \neg (s \lor d) )</td>
</tr>
<tr>
<td>VK_LOGIC_OP_SET</td>
<td>all 1s</td>
</tr>
</tbody>
</table>

The result of the logical operation is then written to the color attachment as controlled by the component write mask, described in Blend Operations.

To dynamically set whether logical operations are enabled, call:

```c
// Provided by VK_EXT_extended_dynamic_state3, VK_EXT_shader_object
def void vkCmdSetLogicOpEnableEXT(
    VkCommandBuffer commandBuffer,
    VkBool32 logicOpEnable);
```
• **commandBuffer** is the command buffer into which the command will be recorded.
• **logicOpEnable** specifies whether logical operations are enabled.

This command sets whether logical operations are enabled for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineColorBlendStateCreateInfo::logicOpEnable` value used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetLogicOpEnableEXT-None-08542
  Either the `extendedDynamicState3LogicOpEnable` feature or the `shaderObject` feature or both must be enabled
- VUID-vkCmdSetLogicOpEnableEXT-logicOp-07366
  If the `logicOp` feature is not enabled, `logicOpEnable` must be `VK_FALSE`

### Valid Usage (Implicit)

- VUID-vkCmdSetLogicOpEnableEXT-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetLogicOpEnableEXT-commandBuffer-recording
  `commandBuffer` must be in the recording state
- VUID-vkCmdSetLogicOpEnableEXT-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations
- VUID-vkCmdSetLogicOpEnableEXT-videocoding
  This command must only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

### Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Secondary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics</td>
<td>State</td>
</tr>
</tbody>
</table>
To *dynamically set* the logical operation to apply for blend state, call:

```c
// Provided by VK_EXT_extended_dynamic_state2, VK_EXT_shader_object
void vkCmdSetLogicOpEXT(
    VkCommandBuffer commandBuffer,
    VkLogicOp logicOp);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `logicOp` specifies the logical operation to apply for blend state.

This command sets the logical operation for blend state for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with `VK_DYNAMIC_STATE_LOGIC_OP_EXT` set in `VkPipelineDynamicStateCreateInfo::pDynamicStates`. Otherwise, this state is specified by the `VkPipelineColorBlendStateCreateInfo::logicOp` value used to create the currently active pipeline.

### Valid Usage

- VUID-vkCmdSetLogicOpEXT-None-08544
  Either the `extendedDynamicState2LogicOp` feature or the `shaderObject` feature or both must be enabled

### Valid Usage (Implicit)

- VUID-vkCmdSetLogicOpEXT-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetLogicOpEXT-logicOp-parameter
  `logicOp` must be a valid `VkLogicOp` value
- VUID-vkCmdSetLogicOpEXT-commandBuffer-recording
  `commandBuffer` must be in the recording state
- VUID-vkCmdSetLogicOpEXT-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics operations
- VUID-vkCmdSetLogicOpEXT-videocoding
  This command must only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized
30.3. Color Write Mask

Bits which can be set in `VkPipelineColorBlendAttachmentState::colorWriteMask`, determining whether the final color values R, G, B and A are written to the framebuffer attachment, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkColorComponentFlagBits {
    VK_COLOR_COMPONENT_R_BIT = 0x00000001,
    VK_COLOR_COMPONENT_G_BIT = 0x00000002,
    VK_COLOR_COMPONENT_B_BIT = 0x00000004,
    VK_COLOR_COMPONENT_A_BIT = 0x00000008,
} VkColorComponentFlagBits;
```

- `VK_COLOR_COMPONENT_R_BIT` specifies that the R value is written to the color attachment for the appropriate sample. Otherwise, the value in memory is unmodified.
- `VK_COLOR_COMPONENT_G_BIT` specifies that the G value is written to the color attachment for the appropriate sample. Otherwise, the value in memory is unmodified.
- `VK_COLOR_COMPONENT_B_BIT` specifies that the B value is written to the color attachment for the appropriate sample. Otherwise, the value in memory is unmodified.
- `VK_COLOR_COMPONENT_A_BIT` specifies that the A value is written to the color attachment for the appropriate sample. Otherwise, the value in memory is unmodified.

The color write mask operation is applied regardless of whether blending is enabled.

The color write mask operation is applied only if `Color Write Enable` is enabled for the respective attachment. Otherwise the color write mask is ignored and writes to all components of the attachment are disabled.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkColorComponentFlags;
```

`VkColorComponentFlags` is a bitmask type for setting a mask of zero or more `VkColorComponentFlagBits`. 
30.4. Color Write Enable

The VkPipelineColorWriteCreateInfoEXT structure is defined as:

```c
// Provided by VK_EXT_color_write_enable
typedef struct VkPipelineColorWriteCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    uint32_t attachmentCount;
    const VkBool32* pColorWriteEnables;
} VkPipelineColorWriteCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `attachmentCount` is the number of `VkBool32` elements in `pColorWriteEnables`.
- `pColorWriteEnables` is a pointer to an array of per target attachment boolean values specifying whether color writes are enabled for the given attachment.

When this structure is included in the `pNext` chain of `VkPipelineColorBlendStateCreateInfo`, it defines per-attachment color write state. If this structure is not included in the `pNext` chain, it is equivalent to specifying this structure with `attachmentCount` equal to the `attachmentCount` member of `VkPipelineColorBlendStateCreateInfo`, and `pColorWriteEnables` pointing to an array of as many `VK_TRUE` values.

If the `colorWriteEnable` feature is not enabled on the device, all `VkBool32` elements in the `pColorWriteEnables` array must be `VK_TRUE`.

Color Write Enable interacts with the Color Write Mask as follows:

- If `colorWriteEnable` is `VK_TRUE`, writes to the attachment are determined by the `colorWriteMask`.
- If `colorWriteEnable` is `VK_FALSE`, the `colorWriteMask` is ignored and writes to all components of the attachment are disabled. This is equivalent to specifying a `colorWriteMask` of 0.

Valid Usage

- VUID-VkPipelineColorWriteCreateInfoEXT-pAttachments-04801
  If the `colorWriteEnable` feature is not enabled, all elements of `pColorWriteEnables` must be `VK_TRUE`.

- VUID-VkPipelineColorWriteCreateInfoEXT-attachmentCount-07608
  If the pipeline is being created with `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT`, `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT`, `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT`, or `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic states not set, `attachmentCount` must be equal to the `attachmentCount` member of the `VkPipelineColorBlendStateCreateInfo` structure specified during pipeline creation.

- VUID-VkPipelineColorWriteCreateInfoEXT-attachmentCount-06655
attachmentCount must be less than or equal to the maxColorAttachments member of VkPhysicalDeviceLimits

Valid Usage (Implicit)

• VUID-VkPipelineColorWriteCreateInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PIPELINE_COLOR_WRITE_CREATE_INFO_EXT

• VUID-VkPipelineColorWriteCreateInfoEXT-pColorWriteEnables-parameter
  If attachmentCount is not 0, pColorWriteEnables must be a valid pointer to an array of attachmentCount VkBool32 values

To dynamically enable or disable writes to a color attachment, call:

// Provided by VK_EXT_color_write_enable

```c
void vkCmdSetColorWriteEnableEXT(
    VkCommandBuffer commandBuffer,
    uint32_t attachmentCount,
    const VkBool32* pColorWriteEnables);
```

- commandBuffer is the command buffer into which the command will be recorded.
- attachmentCount is the number of VkBool32 elements in pColorWriteEnables.
- pColorWriteEnables is a pointer to an array of per target attachment boolean values specifying whether color writes are enabled for the given attachment.

This command sets the color write enables for subsequent drawing commands when drawing using shader objects, or when the graphics pipeline is created with VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT set in VkPipelineDynamicStateCreateInfo::pDynamicStates. Otherwise, this state is specified by the VkPipelineColorWriteCreateInfoEXT::pColorWriteEnables values used to create the currently active pipeline.

Valid Usage

• VUID-vkCmdSetColorWriteEnableEXT-None-04803
  The colorWriteEnable feature must be enabled

• VUID-vkCmdSetColorWriteEnableEXT-attachmentCount-06656
  attachmentCount must be less than or equal to the maxColorAttachments member of VkPhysicalDeviceLimits

Valid Usage (Implicit)

• VUID-vkCmdSetColorWriteEnableEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle
• VUID-vkCmdSetColorWriteEnableEXT-pColorWriteEnables-parameter
  pColorWriteEnables must be a valid pointer to an array of attachmentCount VkBool32 values

• VUID-vkCmdSetColorWriteEnableEXT-commandBuffer-recording
  commandBuffer must be in the recording state

• VUID-vkCmdSetColorWriteEnableEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

• VUID-vkCmdSetColorWriteEnableEXT-videocoding
  This command must only be called outside of a video coding scope

• VUID-vkCmdSetColorWriteEnableEXT-attachmentCount-arraylength
  attachmentCount must be greater than 0

Host Synchronization

• Host access to commandBuffer must be externally synchronized
• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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</tr>
<tr>
<td>Secondary</td>
<td></td>
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</tr>
</tbody>
</table>

30.5. Framebuffer Query Instructions

To query the tile properties from the attachments in framebuffer, call:

```c
// Provided by VK_QCOM_tile_properties
VkResult vkGetFramebufferTilePropertiesQCOM(
  VkDevice device,
  VkFramebuffer framebuffer,
  uint32_t* pPropertiesCount,
  VkTilePropertiesQCOM* pProperties);
```

• device is a logical device associated with the framebuffer.
• framebuffer is a handle of the framebuffer to query.
• pPropertiesCount is a pointer to an integer related to the number of tile properties available or
queried, as described below.

- `pProperties` is either `NULL` or a pointer to an array of `VkTilePropertiesQCOM` structures.

If `pProperties` is `NULL`, then the number of tile properties available is returned in `pPropertiesCount`. Otherwise, `pPropertiesCount` must point to a variable set by the user to the number of elements in the `pProperties` array, and on return the variable is overwritten with the number of properties actually written to `pProperties`. If `pPropertiesCount` is less than the number of tile properties available, at most `pPropertiesCount` structures will be written, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available properties were returned.

The number of tile properties available is determined by the number of merged subpasses, and each tile property is associated with a merged subpass. There will be at most as many properties as there are subpasses within the render pass. To obtain the tile properties for a given merged subpass, the `pProperties` array can be indexed using the `postMergeIndex` value provided in `VkRenderPassSubpassFeedbackInfoEXT`.

**Valid Usage (Implicit)**

- `VUID-vkGetFramebufferTilePropertiesQCOM-device-parameter`  
  `device` must be a valid `VkDevice` handle

- `VUID-vkGetFramebufferTilePropertiesQCOM-framebuffer-parameter`  
  `framebuffer` must be a valid `VkFramebuffer` handle

- `VUID-vkGetFramebufferTilePropertiesQCOM-pPropertiesCount-parameter`  
  `pPropertiesCount` must be a valid pointer to a `uint32_t` value

- `VUID-vkGetFramebufferTilePropertiesQCOM-pProperties-parameter`  
  If the value referenced by `pPropertiesCount` is not 0, and `pProperties` is not `NULL`,  
  `pProperties` must be a valid pointer to an array of `pPropertiesCount` `VkTilePropertiesQCOM` structures

- `VUID-vkGetFramebufferTilePropertiesQCOM-framebuffer-parent`  
  `framebuffer` must have been created, allocated, or retrieved from `device`

**Return Codes**

**Success**

- `VK_SUCCESS`
- `VK_INCOMPLETE`
Chapter 31. Dispatching Commands

*Dispatching commands* (commands with *Dispatch* in the name) provoke work in a compute pipeline. Dispatching commands are recorded into a command buffer and when executed by a queue, will produce work which executes according to the bound compute pipeline. A compute pipeline must be bound to a command buffer before any dispatching commands are recorded in that command buffer.

To record a dispatch, call:

```c
// Provided by VK_VERSION_1_0
void vkCmdDispatch(
    VkCommandBuffer commandBuffer,
    uint32_t groupCountX,
    uint32_t groupCountY,
    uint32_t groupCountZ);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `groupCountX` is the number of local workgroups to dispatch in the X dimension.
- `groupCountY` is the number of local workgroups to dispatch in the Y dimension.
- `groupCountZ` is the number of local workgroups to dispatch in the Z dimension.

When the command is executed, a global workgroup consisting of \( \text{groupCountX} \times \text{groupCountY} \times \text{groupCountZ} \) local workgroups is assembled.

**Valid Usage**

- VUID-vkCmdDispatch-magFilter-04553
  If a *VkSampler* created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a *VkImageView* as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- VUID-vkCmdDispatch-mipmapMode-04770
  If a *VkSampler* created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a *VkImageView* as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- VUID-vkCmdDispatch-None-06479
  If a *VkImageView* is sampled with depth comparison, the image view’s format features must contain `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT`

- VUID-vkCmdDispatch-None-02691
  If a *VkImageView* is accessed using atomic operations as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT`
If a `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER` descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's `format features` must contain `VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT`.

If a `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`.

If the `VK_EXT_filter_cubic` extension is not enabled and any `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, it must not have a `VkImageViewType` of `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`.

Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` with a reduction mode of either `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering together with minmax filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

If the `cubicRangeClamp` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must not have a `VkSamplerReductionModeCreateInfo` `reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`.

Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`.

Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

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Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.
For any `VkImageView` being written as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view’s format features **must** contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`

• VUID-vkCmdDispatch-OpTypeImage-07028
  For any `VkImageView` being read as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view’s format features **must** contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`

• VUID-vkCmdDispatch-OpTypeImage-07029
  For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view’s buffer features **must** contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`

• VUID-vkCmdDispatch-OpTypeImage-07030
  Any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown` then the view’s buffer features **must** contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`

• VUID-vkCmdDispatch-None-08600
  For each set `n` that is statically used by a bound shader, a descriptor set **must** have been bound to `n` at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set `n`, with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

• VUID-vkCmdDispatch-None-08601
  For each push constant that is statically used by a bound shader, a push constant value **must** have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

• VUID-vkCmdDispatch-maintenance4-08602
  If the `maintenance4` feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value **must** have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

• VUID-vkCmdDispatch-None-08114
  Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, **must** be valid if they are statically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was not created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

• VUID-vkCmdDispatch-None-08115
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` **must** have been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

• VUID-vkCmdDispatch-None-08116
  Descriptors in bound descriptor buffers, specified via
**vkCmdSetDescriptorBufferOffsetsEXT**, **must** be valid if they are dynamically used by the **VkPipeline** bound to the pipeline bind point used by this command and the bound **VkPipeline** was created with **VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT**

- **VUID-vkCmdDispatch-None-08604**
  Descriptors in bound descriptor buffers, specified via **vkCmdSetDescriptorBufferOffsetsEXT**, **must** be valid if they are dynamically used by any **VkShaderEXT** bound to a stage corresponding to the pipeline bind point used by this command

- **VUID-vkCmdDispatch-None-08117**
  If the descriptors used by the **VkPipeline** bound to the pipeline bind point were specified via **vkCmdSetDescriptorBufferOffsetsEXT**, the bound **VkPipeline** **must** have been created with **VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT**

- **VUID-vkCmdDispatch-None-08119**
  If a descriptor is dynamically used with a **VkPipeline** created with **VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT**, the descriptor memory **must** be resident

- **VUID-vkCmdDispatch-None-08605**
  If a descriptor is dynamically used with a **VkShaderEXT** created with a **VkDescriptorSetLayout** that was created with **VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT**, the descriptor memory **must** be resident

- **VUID-vkCmdDispatch-None-08606**
  If the **shaderObject** feature is not enabled, a valid pipeline **must** be bound to the pipeline bind point used by this command

- **VUID-vkCmdDispatch-None-08607**
  If the **shaderObject** is enabled, either a valid pipeline **must** be bound to the pipeline bind point used by this command, or a valid combination of valid and **VK_NULL_HANDLE** shader objects **must** be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- **VUID-vkCmdDispatch-None-08608**
  If a pipeline is bound to the pipeline bind point used by this command, there **must** not have been any calls to dynamic state setting commands for any state not specified as dynamic in the **VkPipeline** object bound to the pipeline bind point used by this command, since that pipeline was bound

- **VUID-vkCmdDispatch-None-08609**
  If the **VkPipeline** object bound to the pipeline bind point used by this command or any **VkShaderEXT** bound to a stage corresponding to the pipeline bind point used by this command accesses a **VkSampler** object that uses unnormalized coordinates, that sampler **must** not be used to sample from any **VkImage** with a **VkImageView** of the type **VK_IMAGE_VIEW_TYPE_3D**, **VK_IMAGE_VIEW_TYPE_CUBE**, **VK_IMAGE_VIEW_TYPE_1D_ARRAY**, **VK_IMAGE_VIEW_TYPE_2D_ARRAY** or **VK_IMAGE_VIEW_TYPE_CUBE_ARRAY**, in any shader stage

- **VUID-vkCmdDispatch-None-08610**
  If the **VkPipeline** object bound to the pipeline bind point used by this command or any **VkShaderEXT** bound to a stage corresponding to the pipeline bind point used by this command accesses a **VkSampler** object that uses unnormalized coordinates, that sampler
must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage

- VUID-vkCmdDispatch-None-08611
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage

- VUID-vkCmdDispatch-uniformBuffers-06935
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDispatch-None-08612
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDispatch-storageBuffers-06936
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDispatch-None-08613
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDispatch-commandBuffer-02707
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource

- VUID-vkCmdDispatch-None-06550
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y’C₆₉₈ conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions

- VUID-vkCmdDispatch-ConstOffset-06551
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y’C₆₉₈ conversion, that object must not use the ConstOffset and Offset operands
If a `VkImageView` is accessed as a result of this command, then the image view’s `viewType` **must** match the `Dim` operand of the `OpTypeImage` as described in Instruction/Sampler/Image View Validation.

If a `VkImageView` is accessed as a result of this command, then the `numeric type` of the image view’s `format` and the `Sampled Type` operand of the `OpTypeImage` **must** match.

If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the image view’s format.

If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have four components.

If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the buffer view’s format.

If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 64.

If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 32.

If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 64.

If a `VkBufferView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 32.

If the `sparseImageInt64Atomics` feature is not enabled, `VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` flag **must** not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag **must** not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.
If `OpImageWeightedSampleQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`.

If `OpImageWeightedSampleQCOM` uses a `VkImageView` as a sample weight image as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`.

If `OpImageBoxFilterQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM`.

If `OpImageBlockMatchSSDQCOM` or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must not have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.
**must** be a single-component format.

- **VUID-vkCmdDispatch-OpImageBlockMatchWindow-09217**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` read from a reference image as result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation

- **VUID-vkCmdDispatch-None-07288**
  Any shader invocation executed by this command **must** terminate

- **VUID-vkCmdDispatch-commandBuffer-02712**
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, any resource written to by the `VkPipeline` object bound to the pipeline bind point used by this command **must** not be an unprotected resource

- **VUID-vkCmdDispatch-commandBuffer-02713**
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, pipeline stages other than the framebuffer-space and compute stages in the `VkPipeline` object bound to the pipeline bind point used by this command **must** not write to any resource

- **VUID-vkCmdDispatch-commandBuffer-04617**
  If any of the shader stages of the `VkPipeline` bound to the pipeline bind point used by this command uses the `RayQueryKHR` capability, then `commandBuffer` **must** not be a protected command buffer

- **VUID-vkCmdDispatch-groupCountX-00386**
  `groupCountX` **must** be less than or equal to `VkPhysicalDeviceLimits::maxComputeWorkGroupCount[0]`

- **VUID-vkCmdDispatch-groupCountY-00387**
  `groupCountY` **must** be less than or equal to `VkPhysicalDeviceLimits::maxComputeWorkGroupCount[1]`

- **VUID-vkCmdDispatch-groupCountZ-00388**
  `groupCountZ` **must** be less than or equal to `VkPhysicalDeviceLimits::maxComputeWorkGroupCount[2]`

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**Valid Usage (Implicit)**

- **VUID-vkCmdDispatch-commandBuffer-parameter**
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- **VUID-vkCmdDispatch-commandBuffer-recording**
  `commandBuffer` **must** be in the recording state

- **VUID-vkCmdDispatch-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from **must** support compute operations

- **VUID-vkCmdDispatch-renderpass**
  This command **must** only be called outside of a render pass instance

- **VUID-vkCmdDispatch-videocoding**
This command **must** only be called outside of a video coding scope.

**Host Synchronization**

- Host access to `commandBuffer` **must** be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized.

**Command Properties**

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To record an indirect dispatching command, call:

```cpp
// Provided by VK_VERSION_1_0
void vkCmdDispatchIndirect(
    VkCommandBuffer commandBuffer,
    VkBuffer buffer,
    VkDeviceSize offset);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `buffer` is the buffer containing dispatch parameters.
- `offset` is the byte offset into `buffer` where parameters begin.

`vkCmdDispatchIndirect` behaves similarly to `vkCmdDispatch` except that the parameters are read by the device from a buffer during execution. The parameters of the dispatch are encoded in a `VkDispatchIndirectCommand` structure taken from `buffer` starting at `offset`.

**Valid Usage**

- **VUID-vkCmdDispatchIndirect-magFilter-04553**
  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view’s format features **must** contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`.

- **VUID-vkCmdDispatchIndirect-mipmapMode-04770**
  If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view’s format features **must** contain.
If a `VkImageView` is sampled with depth comparison, the image view's format features must contain `VK_FORMAT_FEATURE_2SAMPLED_IMAGE_DEPTH_COMPARISON_BIT`.

If a `VkImageView` is accessed using atomic operations as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT`.

If a `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`.

If the `VK_EXT_filter_cubic` extension is not enabled and any `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, it must not have a `VkImageViewType` of `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`.

Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo`: `reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

If the `cubicRangeClamp` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must not have a `VkSamplerReductionModeCreateInfo::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`.

Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.
If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`

- **VUID-vkCmdDispatchIndirect-flags-02696**
  Any `VkImage` created with a `VkCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`

- **VUID-vkCmdDispatchIndirect-OpTypeImage-07027**
  For any `VkImageView` being written as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view's format features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`

- **VUID-vkCmdDispatchIndirect-OpTypeImage-07028**
  For any `VkImageView` being read as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view's format features must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`

- **VUID-vkCmdDispatchIndirect-OpTypeImage-07029**
  For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view's buffer features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`

- **VUID-vkCmdDispatchIndirect-OpTypeImage-07030**
  Any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown` then the view's buffer features must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`

- **VUID-vkCmdDispatchIndirect-None-08600**
  For each set $n$ that is statically used by a bound shader, a descriptor set must have been bound to $n$ at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set $n$, with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

- **VUID-vkCmdDispatchIndirect-None-08601**
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

- **VUID-vkCmdDispatchIndirect-maintenance4-08602**
  If the `maintenance4` feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility

- **VUID-vkCmdDispatchIndirect-None-08114**
  Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, must be
valid if they are statically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was not created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDispatchIndirect-None-08115
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` **must** have been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDispatchIndirect-None-08116
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, **must** be valid if they are dynamically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

- VUID-vkCmdDispatchIndirect-None-08604
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, **must** be valid if they are dynamically used by any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDispatchIndirect-None-08117
  If a descriptor is dynamically used with a `VkPipeline` created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory **must** be resident

- VUID-vkCmdDispatchIndirect-None-08605
  If a descriptor is dynamically used with a `VkShaderEXT` created with a `VkDescriptorSetLayout` that was created with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory **must** be resident

- VUID-vkCmdDispatchIndirect-None-08606
  If the `shaderObject` feature is not enabled, a valid pipeline **must** be bound to the pipeline bind point used by this command

- VUID-vkCmdDispatchIndirect-None-08607
  If the `shaderObject` is enabled, either a valid pipeline **must** be bound to the pipeline bind point used by this command, or a valid combination of valid and `VK_NULL_HANDLE` shader objects **must** be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDispatchIndirect-None-08608
  If a pipeline is bound to the pipeline bind point used by this command, there **must** not have been any calls to dynamic state setting commands for any state not specified as dynamic in the `VkPipeline` object bound to the pipeline bind point used by this command, since that pipeline was bound

- VUID-vkCmdDispatchIndirect-None-08609
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any
VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used to sample from any VkImage with a VkImageView of the type VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY, VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage.

- VUID-vkCmdDispatchIndirect-None-08610
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage.

- VUID-vkCmdDispatchIndirect-None-08611
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage.

- VUID-vkCmdDispatchIndirect-uniformBuffers-06935
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- VUID-vkCmdDispatchIndirect-None-08612
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- VUID-vkCmdDispatchIndirect-storageBuffers-06936
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- VUID-vkCmdDispatchIndirect-None-08613
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- VUID-vkCmdDispatchIndirect-commandBuffer-02707
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported,
any resource accessed by **bound shaders** must not be a protected resource

- **VUID-vkCmdDispatchIndirect-None-06550**
  If a **bound shader** accesses a **VkSampler** or **VkImageView** object that enables **sampler YC_{aC_b} conversion**, that object **must** only be used with **OpImageSample* or OpImageSparseSample*** instructions

- **VUID-vkCmdDispatchIndirect-ConstOffset-06551**
  If a **bound shader** accesses a **VkSampler** or **VkImageView** object that enables **sampler YC_{aC_b} conversion**, that object **must** not use the **ConstOffset** and **Offset** operands

- **VUID-vkCmdDispatchIndirect-viewType-07752**
  If a **VkImageView** is accessed as a result of this command, then the image view's **viewType must** match the **Dim** operand of the **OpTypeImage** as described in Instruction/Sampler/Image View Validation

- **VUID-vkCmdDispatchIndirect-format-07753**
  If a **VkImageView** is accessed as a result of this command, then the **numeric type** of the image view’s **format** and the **Sampled Type** operand of the **OpTypeImage** **must** match

- **VUID-vkCmdDispatchIndirect-OpImageWrite-08795**
  If a **VkImageView** created with a format other than **VK_FORMAT_A8_UNORM_KHR** is accessed using **OpImageWrite** as a result of this command, then the **Type** of the **Texel** operand of that instruction **must** have at least as many components as the image view’s format

- **VUID-vkCmdDispatchIndirect-OpImageWrite-08796**
  If a **VkImageView** created with the format **VK_FORMAT_A8_UNORM_KHR** is accessed using **OpImageWrite** as a result of this command, then the **Type** of the **Texel** operand of that instruction **must** have four components

- **VUID-vkCmdDispatchIndirect-OpImageWrite-04469**
  If a **VkBufferView** is accessed using **OpImageWrite** as a result of this command, then the **Type** of the **Texel** operand of that instruction **must** have at least as many components as the buffer view’s format

- **VUID-vkCmdDispatchIndirect-SampledType-04470**
  If a **VkImageView** with a **VkFormat** that has a 64-bit component width is accessed as a result of this command, the **SampledType** of the **OpTypeImage** operand of that instruction **must** have a **Width** of 64

- **VUID-vkCmdDispatchIndirect-SampledType-04471**
  If a **VkImageView** with a **VkFormat** that has a component width less than 64-bit is accessed as a result of this command, the **SampledType** of the **OpTypeImage** operand of that instruction **must** have a **Width** of 32

- **VUID-vkCmdDispatchIndirect-SampledType-04472**
  If a **VkBufferView** with a **VkFormat** that has a 64-bit component width is accessed as a result of this command, the **SampledType** of the **OpTypeImage** operand of that instruction **must** have a **Width** of 64

- **VUID-vkCmdDispatchIndirect-SampledType-04473**
  If a **VkBufferView** with a **VkFormat** that has a component width less than 64-bit is accessed as a result of this command, the **SampledType** of the **OpTypeImage** operand of that instruction **must** have a **Width** of 32
If the `sparseImageInt64Atomics` feature is not enabled, `VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

If `OpImageWeightedSampleQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`.

If `OpImageWeightedSampleQCOM` uses a `VkImageView` as a sample weight image as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`.

If `OpImageBoxFilterQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM`.

If `OpImageBlockMatchWindowSSDQCOM` or `OpImageBlockMatchSSDQCOM` is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.

If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must not have been created with...
VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM

- VUID-vkCmdDispatchIndirect-OpImageBlockMatchWindow-09215
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

- VUID-vkCmdDispatchIndirect-OpImageBlockMatchWindow-09216
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format must be a single-component format.

- VUID-vkCmdDispatchIndirect-OpImageBlockMatchWindow-09217
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.

- VUID-vkCmdDispatchIndirect-None-07288
  Any shader invocation executed by this command must terminate.

- VUID-vkCmdDispatchIndirect-buffer-02708
  If `buffer` is non-sparse then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

- VUID-vkCmdDispatchIndirect-buffer-02709
  `buffer` must have been created with the `VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT` bit set.

- VUID-vkCmdDispatchIndirect-offset-02710
  `offset` must be a multiple of 4.

- VUID-vkCmdDispatchIndirect-commandBuffer-02711
  `commandBuffer` must not be a protected command buffer.

- VUID-vkCmdDispatchIndirect-offset-00407
  The sum of `offset` and the size of `VkDispatchIndirectCommand` must be less than or equal to the size of `buffer`.

Valid Usage (Implicit)

- VUID-vkCmdDispatchIndirect-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- VUID-vkCmdDispatchIndirect-buffer-parameter
  `buffer` must be a valid `VkBuffer` handle.

- VUID-vkCmdDispatchIndirect-commandBuffer-recording
  `commandBuffer` must be in the recording state.

- VUID-vkCmdDispatchIndirect-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support compute operations.

- VUID-vkCmdDispatchIndirect-renderpass
  This command must only be called outside of a render pass instance.
This command must only be called outside of a video coding scope.

Both of buffer and commandBuffer must have been created, allocated, or retrieved from the same VkDevice.

Host Synchronization

• Host access to commandBuffer must be externally synchronized
• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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The VkDispatchIndirectCommand structure is defined as:

```
// Provided by VK_VERSION_1_0
typedef struct VkDispatchIndirectCommand {
    uint32_t x;
    uint32_t y;
    uint32_t z;
} VkDispatchIndirectCommand;
```

• x is the number of local workgroups to dispatch in the X dimension.
• y is the number of local workgroups to dispatch in the Y dimension.
• z is the number of local workgroups to dispatch in the Z dimension.

The members of VkDispatchIndirectCommand have the same meaning as the corresponding parameters of vkCmdDispatch.

Valid Usage

• VUID-VkDispatchIndirectCommand-x-00417
  x must be less than or equal to VkPhysicalDeviceLimits::maxComputeWorkGroupCount[0]
• VUID-VkDispatchIndirectCommand-y-00418
  y must be less than or equal to VkPhysicalDeviceLimits::maxComputeWorkGroupCount[1]
To record a dispatch using non-zero base values for the components of `WorkgroupId`, call:

```c
// Provided by VK_VERSION_1_1
void vkCmdDispatchBase(
    VkCommandBuffer commandBuffer,
    uint32_t baseGroupX,
    uint32_t baseGroupY,
    uint32_t baseGroupZ,
    uint32_t groupCountX,
    uint32_t groupCountY,
    uint32_t groupCountZ);
```

or the equivalent command

```c
// Provided by VK_KHR_device_group
void vkCmdDispatchBaseKHR(
    VkCommandBuffer commandBuffer,
    uint32_t baseGroupX,
    uint32_t baseGroupY,
    uint32_t baseGroupZ,
    uint32_t groupCountX,
    uint32_t groupCountY,
    uint32_t groupCountZ);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `baseGroupX` is the start value for the X component of `WorkgroupId`.
- `baseGroupY` is the start value for the Y component of `WorkgroupId`.
- `baseGroupZ` is the start value for the Z component of `WorkgroupId`.
- `groupCountX` is the number of local workgroups to dispatch in the X dimension.
- `groupCountY` is the number of local workgroups to dispatch in the Y dimension.
- `groupCountZ` is the number of local workgroups to dispatch in the Z dimension.

When the command is executed, a global workgroup consisting of `groupCountX` × `groupCountY` × `groupCountZ` local workgroups is assembled, with `WorkgroupId` values ranging from `[baseGroup*, baseGroup* + groupCount*]` in each component. `vkCmdDispatch` is equivalent to `vkCmdDispatchBase(0, 0, 0, groupCountX, groupCountY, groupCountZ)`.

### Valid Usage

- **VUID-vkCmdDispatchBase-magFilter-04553**
  
  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and
compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- VUID-vkCmdDispatchBase-mipmapMode-04770
  If a VkSampler created with mipmapMode equal to VK_SAMPLER_MIPMAP_MODE_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- VUID-vkCmdDispatchBase-None-06479
  If a VkImageView is sampled with depth comparison, the image view’s format features must contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT

- VUID-vkCmdDispatchBase-None-02691
  If a VkImageView is accessed using atomic operations as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

- VUID-vkCmdDispatchBase-None-07888
  If a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer’s format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

- VUID-vkCmdDispatchBase-None-02692
  If a VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT

- VUID-vkCmdDispatchBase-filterCubic-02693
  If the VK_EXT_filter_cubic extension is not enabled and any VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, it must not have a VkImageViewType of VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

- VUID-vkCmdDispatchBase-filterCubicMinmax-02694
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2

- VUID-vkCmdDispatchBase-filterCubicMinmax-02695
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT with a reduction mode of either VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX as a result of this command must have a VkImageViewType and format that supports cubic filtering together with minmax filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax returned by vkGetPhysicalDeviceImageFormatProperties2

- VUID-vkCmdDispatchBase-cubicRangeClamp-09212
  If the cubicRangeClamp feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command
must not have a `VkSamplerReductionModeCreateInfo` `reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGE_CLAMP_QCOM`.

- VUID-vkCmdDispatchBase-reductionMode-09213
  Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo` `::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGE_CLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

- VUID-vkCmdDispatchBase-selectableCubicWeights-09214
  If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`.

- VUID-vkCmdDispatchBase-flags-02696
  Any `VkImage` created with a `VkImageCreateInfo` `::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

- VUID-vkCmdDispatchBase-OpTypeImage-07027
  For any `VkImageView` being written as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view's format features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

- VUID-vkCmdDispatchBase-OpTypeImage-07028
  For any `VkImageView` being read as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view's format features must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`.

- VUID-vkCmdDispatchBase-OpTypeImage-07029
  For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view's buffer features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

- VUID-vkCmdDispatchBase-OpTypeImage-07030
  Any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown` then the view's buffer features must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`.

- VUID-vkCmdDispatchBase-None-08600
  For each set `n` that is statically used by a bound shader, a descriptor set must have been bound to `n` at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set `n`, with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

- VUID-vkCmdDispatchBase-None-08601
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

- VUID-vkCmdDispatchBase-maintenance4-08602
If the maintenance feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility.

- **VUID-vkCmdDispatchBase-None-08114**
  Descriptors in each bound descriptor set, specified via vkCmdBindDescriptorSets, must be valid if they are statically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was not created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT.

- **VUID-vkCmdDispatchBase-None-08115**
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdBindDescriptorSets, the bound VkPipeline must have been created without VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT.

- **VUID-vkCmdDispatchBase-None-08116**
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT.

- **VUID-vkCmdDispatchBase-None-08604**
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command.

- **VUID-vkCmdDispatchBase-None-08117**
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdSetDescriptorBufferOffsetsEXT, the bound VkPipeline must have been created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT.

- **VUID-vkCmdDispatchBase-None-08119**
  If a descriptor is dynamically used with a VkPipeline created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident.

- **VUID-vkCmdDispatchBase-None-08605**
  If a descriptor is dynamically used with a VkShaderEXT created with a VkDescriptorSetLayout that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident.

- **VUID-vkCmdDispatchBase-None-08606**
  If the shaderObject feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command.

- **VUID-vkCmdDispatchBase-None-08607**
  If the shaderObject is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and VK_NULL_HANDLE shader objects must be bound to every supported shader stage corresponding to the
pipeline bind point used by this command

- **VUID-vkCmdDispatchBase-None-08608**
  If a pipeline is bound to the pipeline bind point used by this command, there **must** not have been any calls to dynamic state setting commands for any state not specified as dynamic in the *VkPipeline* object bound to the pipeline bind point used by this command, since that pipeline was bound

- **VUID-vkCmdDispatchBase-None-08609**
  If the *VkPipeline* object bound to the pipeline bind point used by this command or any *VkShaderEXT* bound to a stage corresponding to the pipeline bind point used by this command accesses a *VkSampler* object that uses unnormalized coordinates, that sampler **must** not be used to sample from any *VkImage* with a *VkImageView* of the type *VK_IMAGE_VIEW_TYPE_3D*, *VK_IMAGE_VIEW_TYPE_CUBE*, *VK_IMAGE_VIEW_TYPE_1D_ARRAY*, *VK_IMAGE_VIEW_TYPE_2D_ARRAY* or *VK_IMAGE_VIEW_TYPE_CUBE_ARRAY*, in any shader stage

- **VUID-vkCmdDispatchBase-None-08610**
  If the *VkPipeline* object bound to the pipeline bind point used by this command or any *VkShaderEXT* bound to a stage corresponding to the pipeline bind point used by this command accesses a *VkSampler* object that uses unnormalized coordinates, that sampler **must** not be used with any of the SPIR-V *OpImageSample* or *OpImageSparseSample* instructions with *ImplicitLod*, *Dref* or *Proj* in their name, in any shader stage

- **VUID-vkCmdDispatchBase-None-08611**
  If the *VkPipeline* object bound to the pipeline bind point used by this command or any *VkShaderEXT* bound to a stage corresponding to the pipeline bind point used by this command accesses a *VkSampler* object that uses unnormalized coordinates, that sampler **must** not be used with any of the SPIR-V *OpImageSample* or *OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage

- **VUID-vkCmdDispatchBase-uniformBuffers-06935**
  If any stage of the *VkPipeline* object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either *VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT* or *VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT* for *uniformBuffers*, and the *robustBufferAccess* feature is not enabled, that stage **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDispatchBase-None-08612**
  If the *robustBufferAccess* feature is not enabled, and any *VkShaderEXT* bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdDispatchBase-storageBuffers-06936**
  If any stage of the *VkPipeline* object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either *VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT* or *VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT* for *storageBuffers*, and the *robustBufferAccess* feature is not enabled, that stage **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same
pipeline bind point

- VUID-vkCmdDispatchBase-None-08613
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- VUID-vkCmdDispatchBase-commandBuffer-02707
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource.

- VUID-vkCmdDispatchBase-None-06550
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y'CbCr conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions.

- VUID-vkCmdDispatchBase-ConstOffset-06551
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y'CbCr conversion, that object must not use the ConstOffset and Offset operands.

- VUID-vkCmdDispatchBase-viewType-07752
  If a VkImageView is accessed as a result of this command, then the image view's viewType must match the Dim operand of the OpTypeImage as described in Instruction/Sampler/Image View Validation.

- VUID-vkCmdDispatchBase-format-07753
  If a VkImageView is accessed as a result of this command, then the numeric type of the image view's format and the Sampled Type operand of the OpTypeImage must match.

- VUID-vkCmdDispatchBase-OpImageWrite-08795
  If a VkImageView created with a format other than VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the image view's format.

- VUID-vkCmdDispatchBase-OpImageWrite-08796
  If a VkImageView created with the format VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have four components.

- VUID-vkCmdDispatchBase-OpImageWrite-04469
  If a VkBufferView is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the buffer view's format.

- VUID-vkCmdDispatchBase-SampledType-04470
  If a VkImageView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64.

- VUID-vkCmdDispatchBase-SampledType-04471
  If a VkImageView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32.
If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 64.

If a `VkBufferView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 32.

If the `sparseImageInt64Atomics` feature is not enabled, `VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` flag **must** not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag **must** not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

If `OpImageWeightedSampleQCOM` is used to sample a `VkImageView` as a result of this command, then the image view’s `format features` **must** contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`.

If `OpImageWeightedSampleQCOM` uses a `VkImageView` as a sample weight image as a result of this command, then the image view’s `format features` **must** contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`.

If `OpImageBoxFilterQCOM` is used to sample a `VkImageView` as a result of this command, then the image view’s `format features` **must** contain `VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM`.

If `OpImageBlockMatchWindowSSDQCOM` or `OpImageBlockMatchSSDQCOM` or `OpImageBlockMatchSADQCOM` or `OpImageBlockMatchGatherSSDQCOM` or `OpImageBlockMatchGatherSADQCOM` is used to read from a reference image as result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation.

uses a `VkSampler` as a result of this command, then the sampler must have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`

• VUID-vkCmdDispatchBase-OpImageWeightedSampleQCOM-06978
  If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must not have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`

• VUID-vkCmdDispatchBase-OpImageBlockMatchWindow-09215
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`

• VUID-vkCmdDispatchBase-OpImageBlockMatchWindow-09216
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format must be a single-component format.

• VUID-vkCmdDispatchBase-OpImageBlockMatchWindow-09217
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

• VUID-vkCmdDispatchBase-None-07288
  Any shader invocation executed by this command must terminate

• VUID-vkCmdDispatchBase-commandBuffer-02712
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, any resource written to by the `VkPipeline` object bound to the pipeline bind point used by this command must not be an unprotected resource

• VUID-vkCmdDispatchBase-commandBuffer-02713
  If `commandBuffer` is a protected command buffer and `protectedNoFault` is not supported, pipeline stages other than the framebuffer-space and compute stages in the `VkPipeline` object bound to the pipeline bind point used by this command must not write to any resource

• VUID-vkCmdDispatchBase-commandBuffer-04617
  If any of the shader stages of the `VkPipeline` bound to the pipeline bind point used by this command uses the `RayQueryKHR` capability, then `commandBuffer` must not be a protected command buffer

• VUID-vkCmdDispatchBase-baseGroupX-00421
  `baseGroupX` must be less than `VkPhysicalDeviceLimits::maxComputeWorkGroupCount[0]`

• VUID-vkCmdDispatchBase-baseGroupX-00422
  `baseGroupY` must be less than `VkPhysicalDeviceLimits::maxComputeWorkGroupCount[1]`

• VUID-vkCmdDispatchBase-baseGroupX-00423
  `baseGroupZ` must be less than `VkPhysicalDeviceLimits::maxComputeWorkGroupCount[2]`

• VUID-vkCmdDispatchBase-countGroupX-00424
  `2707`
groupCountX must be less than or equal to VkPhysicalDeviceLimits::maxComputeWorkGroupCount[0] minus baseGroupX

- VUID-vkCmdDispatchBase-groupCountY-00425
  groupCountY must be less than or equal to VkPhysicalDeviceLimits::maxComputeWorkGroupCount[1] minus baseGroupY

- VUID-vkCmdDispatchBase-groupCountZ-00426
  groupCountZ must be less than or equal to VkPhysicalDeviceLimits::maxComputeWorkGroupCount[2] minus baseGroupZ

- VUID-vkCmdDispatchBase-baseGroupX-00427
  If any of baseGroupX, baseGroupY, or baseGroupZ are not zero, then the bound compute pipeline must have been created with the VK_PIPELINE_CREATE_DISPATCH_BASE flag

Valid Usage (Implicit)

- VUID-vkCmdDispatchBase-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdDispatchBase-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdDispatchBase-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support compute operations

- VUID-vkCmdDispatchBase-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdDispatchBase-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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A subpass shading dispatches a compute pipeline work with the work dimension of render area of
the calling subpass and work groups are partitioned by specified work group size. Subpass operations like subpassLoad and subpassLoadMS are allowed to be used.

To record a subpass shading, call:

```c
// Provided by VK_HUAWEI_subpass_shading
void vkCmdSubpassShadingHUAWEI(  
    VkCommandBuffer commandBuffer);
```

- `commandBuffer` is the command buffer into which the command will be recorded.

When the command is executed, a global workgroup consisting of ceil (render area size / local workgroup size) local workgroups is assembled.

**Valid Usage**

- **VUID-vkCmdSubpassShadingHUAWEI-magFilter-04553**
  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- **VUID-vkCmdSubpassShadingHUAWEI-mipmapMode-04770**
  If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- **VUID-vkCmdSubpassShadingHUAWEI-None-06479**
  If a `VkImageView` is sampled with depth comparison, the image view's format features must contain `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT`

- **VUID-vkCmdSubpassShadingHUAWEI-None-02691**
  If a `VkImageView` is accessed using atomic operations as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT`

- **VUID-vkCmdSubpassShadingHUAWEI-None-07888**
  If a `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER` descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain `VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT`

- **VUID-vkCmdSubpassShadingHUAWEI-None-02692**
  If a `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`

- **VUID-vkCmdSubpassShadingHUAWEI-None-02693**
  If the `VK_EXT_filter_cubic` extension is not enabled and any `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, it must not have a `VkImageViewType` of `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`
Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkGetPhysicalDeviceImageFormatProperties2::filterCubic returned by VkGetPhysicalDeviceImageFormatProperties2.

Any VkImageView being sampled with VK_FILTER_CUBIC_EXT with a reduction mode of either VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX as a result of this command must have a VkImageViewType and format that supports cubic filtering together with minmax filtering, as specified by VkGetPhysicalDeviceImageFormatProperties2::filterCubicMinmax returned by VkGetPhysicalDeviceImageFormatProperties2.

If the cubicRangeClamp feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must not have a VkSamplerReductionModeCreateInfo

reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM

Any VkImageView being sampled with a VkSamplerReductionModeCreateInfo::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM as a result of this command must sample with VK_FILTER_CUBIC_EXT.

If the selectableCubicWeights feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights equal to VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM.

Any VkImage created with a VkImageCreateInfo::flags containing VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV sampled as a result of this command must only be sampled using a VkSamplerAddressMode of VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE.

For any VkImageView being written as a storage image where the image format field of the OpTypeImage is Unknown, the view's format features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT.

For any VkImageView being read as a storage image where the image format field of the OpTypeImage is Unknown, the view's format features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT.

For any VkBufferView being written as a storage texel buffer where the image format field of the OpTypeImage is Unknown, the view's buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT.
Any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown` then the view’s buffer features must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`.

- **VUID-vkCmdSubpassShadingHUAWEI-None-08600**
  For each set $n$ that is statically used by a `bound shader`, a descriptor set must have been bound to $n$ at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set $n$, with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

- **VUID-vkCmdSubpassShadingHUAWEI-None-08601**
  For each push constant that is statically used by a `bound shader`, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

- **VUID-vkCmdSubpassShadingHUAWEI-maintenance4-08602**
  If the `maintenance4` feature is not enabled, then for each push constant that is statically used by a `bound shader`, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

- **VUID-vkCmdSubpassShadingHUAWEI-None-08114**
  Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, must be valid if they are statically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was not created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- **VUID-vkCmdSubpassShadingHUAWEI-None-08115**
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` must have been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- **VUID-vkCmdSubpassShadingHUAWEI-None-08116**
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- **VUID-vkCmdSubpassShadingHUAWEI-None-08604**
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command.

- **VUID-vkCmdSubpassShadingHUAWEI-None-08117**
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdSetDescriptorBufferOffsetsEXT`, the bound `VkPipeline` must have been created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.
If a descriptor is dynamically used with a `VkPipeline` created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory **must** be resident.

If a descriptor is dynamically used with a `VkShaderEXT` created with a `VkDescriptorSetLayout` that was created with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory **must** be resident.

If the `shaderObject` feature is not enabled, a valid pipeline **must** be bound to the pipeline bind point used by this command.

If the `shaderObject` is enabled, either a valid pipeline **must** be bound to the pipeline bind point used by this command, or a valid combination of valid and `VK_NULL_HANDLE` shader objects **must** be bound to every supported shader stage corresponding to the pipeline bind point used by this command.

If a pipeline is bound to the pipeline bind point used by this command, there **must** not have been any calls to dynamic state setting commands for any state not specified as dynamic in the `VkPipeline` object bound to the pipeline bind point used by this command, since that pipeline was bound.

If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler **must** not be used to sample from any `VkImage` with a `VkImageView` of the type `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, `VK_IMAGE_VIEW_TYPE_1D_ARRAY`, `VK_IMAGE_VIEW_TYPE_2D_ARRAY` or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`, in any shader stage.

If any stage of the `VkPipeline` object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT` or `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT` for `uniformBuffers`,
and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdSubpassShadingHUAWEI-None-08612
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdSubpassShadingHUAWEI-storageBuffers-06936
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdSubpassShadingHUAWEI-None-08613
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdSubpassShadingHUAWEI-commandBuffer-02707
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource

- VUID-vkCmdSubpassShadingHUAWEI-None-06550
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y’C_bC_a conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions

- VUID-vkCmdSubpassShadingHUAWEI-ConstOffset-06551
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y’C_bC_a conversion, that object must not use the ConstOffset and Offset operands

- VUID-vkCmdSubpassShadingHUAWEI-viewType-07752
  If a VkImageView is accessed as a result of this command, then the image view’s viewType must match the Dim operand of the OpTypeImage as described in Instruction/Sampler/Image View Validation

- VUID-vkCmdSubpassShadingHUAWEI-format-07753
  If a VkImageView is accessed as a result of this command, then the numeric type of the image view’s format and the Sampled Type operand of the OpTypeImage must match

- VUID-vkCmdSubpassShadingHUAWEI-OpImageWrite-08795
  If a VkImageView created with a format other than VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the image view’s format

- VUID-vkCmdSubpassShadingHUAWEI-OpImageWrite-08796
  If a VkImageView created with the format VK_FORMAT_A8_UNORM_KHR is accessed using
OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have four components

- VUID-vkCmdSubpassShadingHUAWEI-OpImageWrite-04469
  If a VkBufferView is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the buffer view’s format

- VUID-vkCmdSubpassShadingHUAWEI-SampledType-04470
  If a VkImageView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64

- VUID-vkCmdSubpassShadingHUAWEI-SampledType-04471
  If a VkImageView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

- VUID-vkCmdSubpassShadingHUAWEI-SampledType-04472
  If a VkBufferView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64

- VUID-vkCmdSubpassShadingHUAWEI-SampledType-04473
  If a VkBufferView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

- VUID-vkCmdSubpassShadingHUAWEI-sparseImageInt64Atomics-04474
  If the sparseImageInt64Atomics feature is not enabled, VkImage objects created with the VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- VUID-vkCmdSubpassShadingHUAWEI-sparseImageInt64Atomics-04475
  If the sparseImageInt64Atomics feature is not enabled, VkBuffer objects created with the VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- VUID-vkCmdSubpassShadingHUAWEI-OpImageWeightedSampleQCOM-06971
  If OpImageWeightedSampleQCOM is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM

- VUID-vkCmdSubpassShadingHUAWEI-OpImageWeightedSampleQCOM-06972
  If OpImageWeightedSampleQCOM uses a VkImageView as a sample weight image as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM

- VUID-vkCmdSubpassShadingHUAWEI-OpImageBoxFilterQCOM-06973
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM

- VUID-vkCmdSubpassShadingHUAWEI-OpImageBoxFilterQCOM-06974
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM
If OpImageBlockMatchSSDQCOM is used to read from an VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdSubpassShadingHUAWEI-OpImageBlockMatchSADQCOM-06975
  If OpImageBlockMatchSADQCOM is used to read from an VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdSubpassShadingHUAWEI-OpImageBlockMatchSADQCOM-06976
  If OpImageBlockMatchSADQCOM or OpImageBlockMatchSSDQCOM is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- VUID-vkCmdSubpassShadingHUAWEI-OpImageWeightedSampleQCOM-06977
  If OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, or OpImageBlockMatchSSDQCOM uses a VkSampler as a result of this command, then the sampler must have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM

- VUID-vkCmdSubpassShadingHUAWEI-OpImageWeightedSampleQCOM-06978
  If any command other than OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, OpImageBlockMatchSSDQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this command, then the sampler must not have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM

- VUID-vkCmdSubpassShadingHUAWEI-OpImageBlockMatchWindow-09215
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdSubpassShadingHUAWEI-OpImageBlockMatchWindow-09216
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view’s format must be a single-component format.

- VUID-vkCmdSubpassShadingHUAWEI-OpImageBlockMatchWindow-09217
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- VUID-vkCmdSubpassShadingHUAWEI-None-07288
  Any shader invocation executed by this command must terminate

- VUID-vkCmdSubpassShadingHUAWEI-None-04931
  This command must be called in a subpass with bind point VK_PIPELINE_BIND_POINT_SUBPASS_SHADING_HUAWEI. No draw commands can be called in the same subpass. Only one vkCmdSubpassShadingHUAWEI command can be called in a subpass.
Valid Usage (Implicit)

- VUID-vkCmdSubpassShadingHUAWEI-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdSubpassShadingHUAWEI-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdSubpassShadingHUAWEI-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics operations

- VUID-vkCmdSubpassShadingHUAWEI-renderpass
  This command must only be called inside of a render pass instance

- VUID-vkCmdSubpassShadingHUAWEI-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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Chapter 32. Device-Generated Commands

This chapter discusses the generation of command buffer content on the device, for which these principle steps are to be taken:

- Define via `VkIndirectCommandsLayoutNV` the sequence of commands which should be generated.
- Optionally make use of device-bindable Shader Groups for graphics pipelines.
- Retrieve device addresses by `vkGetBufferDeviceAddressEXT` for setting buffers on the device.
- Retrieve device addresses of compute pipelines by `vkGetPipelineIndirectDeviceAddressNV` to be able to bind it in device generated rendering.
- Fill one or more `VkBuffer` with the appropriate content that gets interpreted by `VkIndirectCommandsLayoutNV`.
- Create a preprocess `VkBuffer` using the allocation information from `vkGetGeneratedCommandsMemoryRequirementsNV`.
- Optionally preprocess the input data using `vkCmdPreprocessGeneratedCommandsNV` in a separate action.
- Generate and execute the actual commands via `vkCmdExecuteGeneratedCommandsNV` passing all required data.

`vkCmdPreprocessGeneratedCommandsNV` executes in a separate logical pipeline from either graphics or compute. When preprocessing commands in a separate step they must be explicitly synchronized against the command execution. When not preprocessing, the preprocessing is automatically synchronized against the command execution.

32.1. Indirect Commands Layout

The device-side command generation happens through an iterative processing of an atomic sequence comprised of command tokens, which are represented by:

```c
// Provided by VK_NV_device_generated_commands
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkIndirectCommandsLayoutNV)
```

32.1.1. Creation and Deletion

Indirect command layouts are created by:

```c
// Provided by VK_NV_device_generated_commands
VkResult vkCreateIndirectCommandsLayoutNV(  
    VkDevice device,  
    const VkIndirectCommandsLayoutCreateInfoNV* pCreateInfo,  
    const VkAllocationCallbacks* pAllocator,  
    VkIndirectCommandsLayoutNV* pIndirectCommandsLayout);
```
• **device** is the logical device that creates the indirect command layout.

• **pCreateInfo** is a pointer to a `VkIndirectCommandsLayoutCreateInfoNV` structure containing parameters affecting creation of the indirect command layout.

• **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.

• **pIndirectCommandsLayout** is a pointer to a `VkIndirectCommandsLayoutNV` handle in which the resulting indirect command layout is returned.

### Valid Usage

- VUID-vkCreateIndirectCommandsLayoutNV-deviceGeneratedCommands-02929
  
  The `VkPhysicalDeviceDeviceGeneratedCommandsFeaturesNV::deviceGeneratedCommands` feature must be enabled

### Valid Usage (Implicit)

- VUID-vkCreateIndirectCommandsLayoutNV-device-parameter
  
  `device` must be a valid `VkDevice` handle

- VUID-vkCreateIndirectCommandsLayoutNV-pCreateInfo-parameter
  
  `pCreateInfo` must be a valid pointer to a valid `VkIndirectCommandsLayoutCreateInfoNV` structure

- VUID-vkCreateIndirectCommandsLayoutNV-pAllocator-parameter
  
  If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

- VUID-vkCreateIndirectCommandsLayoutNV-pIndirectCommandsLayout-parameter
  
  `pIndirectCommandsLayout` must be a valid pointer to a `VkIndirectCommandsLayoutNV` handle

### Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`

- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

The `VkIndirectCommandsLayoutCreateInfoNV` structure is defined as:

```c
// Provided by VK_NV_device_generated_commands
typedef struct VkIndirectCommandsLayoutCreateInfoNV {
    VkStructureType sType;
    const void* pNext;
} ...
```
VkIndirectCommandsLayoutCreateInfoNV
{
    sType
    pNext
    VkPipelineBindPoint
    uint32_t
    const VkIndirectCommandsLayoutTokenNV*
    uint32_t
    const uint32_t*
} VkIndirectCommandsLayoutCreateInfoNV;

• **sType** is a *VkStructureType* value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **pipelineBindPoint** is the *VkPipelineBindPoint* that this layout targets.

• **flags** is a bitmask of *VkIndirectCommandsLayoutUsageFlagBitsNV* specifying usage hints of this layout.

• **tokenCount** is the length of the individual command sequence.

• **pTokens** is an array describing each command token in detail. See *VkIndirectCommandsTokenTypeNV* and *VkIndirectCommandsLayoutTokenNV* below for details.

• **streamCount** is the number of streams used to provide the token inputs.

• **pStreamStrides** is an array defining the byte stride for each input stream.

The following code illustrates some of the flags:

```
void cmdProcessAllSequences(cmd, pipeline, indirectCommandsLayout, pIndirectCommandsTokens, sequencesCount, indexbuffer, indexbufferOffset)
{
    for (s = 0; s < sequencesCount; s++)
    {
        sUsed = s;

        if (indirectCommandsLayout.flags & VK间接命令布局使用的索引序列位)
            sUsed = indexbuffer.load_uint32( sUsed * sizeof(uint32_t) + indexbufferOffset);

        if (indirectCommandsLayout.flags & VK间接命令布局使用的无序序列位)
            sUsed = incoherent_implementation_dependent_permutation[ sUsed ];

        cmdProcessSequence(cmd, pipeline, indirectCommandsLayout, pIndirectCommandsTokens, sUsed);
    }
}
```

When tokens are consumed, an offset is computed based on token offset and stream stride. The resulting offset is required to be aligned. The alignment for a specific token is equal to the scalar
alignment of the data type as defined in Alignment Requirements, or VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV::minIndirectCommandsBufferOffsetAlignment, whichever is lower.

**Note**

A `minIndirectCommandsBufferOffsetAlignment` of 4 allows `VkDeviceAddress` to be packed as `uvec2` with scalar layout instead of `uint64_t` with 8 byte alignment. This enables direct compatibility with D3D12 command signature layouts.

### Valid Usage

- **VUID-VkIndirectCommandsLayoutCreateInfoNV-pipelineBindPoint-02930**
  The `pipelineBindPoint` must be `VK_PIPELINE_BIND_POINT_GRAPHICS` or `VK_PIPELINE_BIND_POINT_COMPUTE`.

- **VUID-VkIndirectCommandsLayoutCreateInfoNV-tokenCount-02931**
  `tokenCount` must be greater than 0 and less than or equal to `VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV::maxIndirectCommandsTokenCount`.

- **VUID-VkIndirectCommandsLayoutCreateInfoNV-pTokens-02932**
  If `pTokens` contains an entry of `VK_INDIRECT_COMMANDS_TOKEN_TYPE_SHADER_GROUP_NV` it must be the first element of the array and there must be only a single element of such token type.

- **VUID-VkIndirectCommandsLayoutCreateInfoNV-pTokens-02933**
  If `pTokens` contains an entry of `VK_INDIRECT_COMMANDS_TOKEN_TYPE_STATE_FLAGS_NV` there must be only a single element of such token type.

- **VUID-VkIndirectCommandsLayoutCreateInfoNV-pTokens-02934**
  All state tokens in `pTokens` must occur before any work provoking tokens (`VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_NV`, `VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_INDEXED_NV`, `VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_TASKS_NV`, `VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_MESH_TASKS_NV`, `VK_INDIRECT_COMMANDS_TOKEN_TYPE_DISPATCH_NV`).

- **VUID-VkIndirectCommandsLayoutCreateInfoNV-pTokens-02935**
  The content of `pTokens` must include one single work provoking token that is compatible with the `pipelineBindPoint`.

- **VUID-VkIndirectCommandsLayoutCreateInfoNV-streamCount-02936**
  `streamCount` must be greater than 0 and less or equal to ` VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV::maxIndirectCommandsStreamCount`.

- **VUID-VkIndirectCommandsLayoutCreateInfoNV-pStreamStrides-02937**
  Each element of `pStreamStrides` must be greater than 0 and less than or equal to `VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV::maxIndirectCommandsStreamStride`. Furthermore the alignment of each token input must be ensured.

- **VUID-VkIndirectCommandsLayoutCreateInfoNV-pipelineBindPoint-09088**
  If `pipelineBindPoint` is `VK_PIPELINE_BIND_POINT_COMPUTE` then the `VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV::deviceGeneratedCompute`...
**Valid Usage (Implicit)**

- VUID-VkIndirectCommandsLayoutCreateInfoNV-sType-sType
  
  *sType must be* `VK_STRUCTURE_TYPE_INDIRECT_COMMANDS_LAYOUT_CREATE_INFO_NV`

- VUID-VkIndirectCommandsLayoutCreateInfoNV-pNext-pNext
  
  *pNext must be* `NULL`

- VUID-VkIndirectCommandsLayoutCreateInfoNV-flags-parameter
  
  *flags must be a valid combination of* `VkIndirectCommandsLayoutUsageFlagBitsNV` values

- VUID-VkIndirectCommandsLayoutCreateInfoNV-pipelineBindPoint-parameter
  
  *pipelineBindPoint must be a valid* `VkPipelineBindPoint` value

- VUID-VkIndirectCommandsLayoutCreateInfoNV-pTokens-parameter
  
  *pTokens must be a valid pointer to an array of* `tokenCount` valid `VkIndirectCommandsLayoutTokenNV` structures

- VUID-VkIndirectCommandsLayoutCreateInfoNV-pStreamStrides-parameter
  
  *pStreamStrides must be a valid pointer to an array of* `streamCount uint32_t` values

- VUID-VkIndirectCommandsLayoutCreateInfoNV-tokenCount-arraylength
  
  *tokenCount must be greater than 0*

- VUID-VkIndirectCommandsLayoutCreateInfoNV-streamCount-arraylength
  
  *streamCount must be greater than 0*

Bits which can be set in `VkIndirectCommandsLayoutCreateInfoNV::flags`, specifying usage hints of an indirect command layout, are:

```c
// Provided by VK_NV_device_generated_commands
typedef enum VkIndirectCommandsLayoutUsageFlagBitsNV {
    VK_INDIRECT_COMMANDS_LAYOUT_USAGE_EXPLICIT_PREPROCESS_BIT_NV = 0x00000001,
    VK_INDIRECT_COMMANDS_LAYOUT_USAGE_INDEXED_SEQUENCES_BIT_NV = 0x00000002,
    VK_INDIRECT_COMMANDS_LAYOUT_USAGE_UNORDERED_SEQUENCES_BIT_NV = 0x00000004,
} VkIndirectCommandsLayoutUsageFlagBitsNV;
```
• **VK_INDIRECT_COMMANDS_LAYOUT_USAGE_EXPLICIT_PREPROCESS_BIT_NV** specifies that the layout is always used with the manual preprocessing step through calling `vkCmdPreprocessGeneratedCommandsNV` and executed by `vkCmdExecuteGeneratedCommandsNV` with `isPreprocessed` set to `VK_TRUE`.

• **VK_INDIRECT_COMMANDS_LAYOUT_USAGE_INDEXED_SEQUENCES_BIT_NV** specifies that the input data for the sequences is not implicitly indexed from 0..sequencesUsed but a user provided `VkBuffer` encoding the index is provided.

• **VK_INDIRECT_COMMANDS_LAYOUT_USAGE_UNORDERED_SEQUENCES_BIT_NV** specifies that the processing of sequences can happen at an implementation-dependent order, which is not guaranteed to be coherent using the same input data. This flag is ignored when the `pipelineBindPoint` is `VK_PIPELINE_BIND_POINT_COMPUTE` as it is implied that the dispatch sequence is always unordered.

// Provided by VK_NV_device_generated_commands

typedef VkFlags VkIndirectCommandsLayoutUsageFlagsNV;

**VkIndirectCommandsLayoutUsageFlagsNV** is a bitmask type for setting a mask of zero or more `VkIndirectCommandsLayoutUsageFlagBitsNV`.

Indirect command layouts are destroyed by:

// Provided by VK_NV_device_generated_commands

```c
void vkDestroyIndirectCommandsLayoutNV(
    VkDevice device,
    VkIndirectCommandsLayoutNV indirectCommandsLayout,
    const VkAllocationCallbacks* pAllocator);
```

• **device** is the logical device that destroys the layout.

• **indirectCommandsLayout** is the layout to destroy.

• **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.

**Valid Usage**

• VUID-vkDestroyIndirectCommandsLayoutNV-indirectCommandsLayout-02938
  All submitted commands that refer to `indirectCommandsLayout` must have completed execution

• VUID-vkDestroyIndirectCommandsLayoutNV-indirectCommandsLayout-02939
  If `VkAllocationCallbacks` were provided when `indirectCommandsLayout` was created, a compatible set of callbacks must be provided here

• VUID-vkDestroyIndirectCommandsLayoutNV-indirectCommandsLayout-02940
  If no `VkAllocationCallbacks` were provided when `indirectCommandsLayout` was created, `pAllocator` must be NULL

• VUID-vkDestroyIndirectCommandsLayoutNV-deviceGeneratedCommands-02941
  The `VkPhysicalDeviceDeviceGeneratedCommandsFeaturesNV::deviceGeneratedCommands` feature
must be enabled

Valid Usage (Implicit)

- VUID-vkDestroyIndirectCommandsLayoutNV-device-parameter
device must be a valid VkDevice handle

- VUID-vkDestroyIndirectCommandsLayoutNV-indirectCommandsLayout-parameter
If indirectCommandsLayout is not VK_NULL_HANDLE, indirectCommandsLayout must be a valid VkIndirectCommandsLayoutNV handle

- VUID-vkDestroyIndirectCommandsLayoutNV-pAllocator-parameter
If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkDestroyIndirectCommandsLayoutNV-indirectCommandsLayout-parent
If indirectCommandsLayout is a valid handle, it must have been created, allocated, or retrieved from device

Host Synchronization

- Host access to indirectCommandsLayout must be externally synchronized

32.1.2. Token Input Streams

The VkIndirectCommandsStreamNV structure specifies the input data for one or more tokens at processing time.

```c
// Provided by VK_NV_device_generated_commands
typedef struct VkIndirectCommandsStreamNV {
    VkBuffer buffer;
    VkDeviceSize offset;
} VkIndirectCommandsStreamNV;
```

- buffer specifies the VkBuffer storing the functional arguments for each sequence. These arguments can be written by the device.
- offset specifies an offset into buffer where the arguments start.

Valid Usage

- VUID-VkIndirectCommandsStreamNV-buffer-02942
The buffer’s usage flag must have the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT bit set

- VUID-VkIndirectCommandsStreamNV-offset-02943
The offset must be aligned to VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV::minIndirectCommandsBufferOffsetAlignment
If `buffer` is non-sparse then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object.

### Valid Usage (Implicit)

- **VUID-VkIndirectCommandsStreamNV-buffer-parameter**
  - `buffer` **must** be a valid `VkBuffer` handle

The input streams **can** contain raw `uint32_t` values, existing indirect commands such as:

- `VkDrawIndirectCommand`
- `VkDrawIndexedIndirectCommand`
- `VkDrawMeshTasksIndirectCommandNV`
- `VkDrawMeshTasksIndirectCommandEXT`
- `VkDispatchIndirectCommand`

or additional commands as listed below. How the data is used is described in the next section.

The `VkBindShaderGroupIndirectCommandNV` structure specifies the input data for the `VK_INDIRECT_COMMANDS_TOKEN_TYPE_SHADER_GROUP_NV` token.

```c
// Provided by VK_NV_device_generated_commands
typedef struct VkBindShaderGroupIndirectCommandNV {
    uint32_t groupIndex;
} VkBindShaderGroupIndirectCommandNV;
```

- `groupIndex` specifies which shader group of the current bound graphics pipeline is used.

### Valid Usage

- **VUID-VkBindShaderGroupIndirectCommandNV-None-02944**
  - The current bound graphics pipeline, as well as the pipelines it may reference, **must** have been created with `VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV`

- **VUID-VkBindShaderGroupIndirectCommandNV-index-02945**
  - The index **must** be within range of the accessible shader groups of the current bound graphics pipeline. See `vkCmdBindPipelineShaderGroupNV` for further details

The `VkBindIndexBufferIndirectCommandNV` structure specifies the input data for the `VK_INDIRECT_COMMANDS_TOKEN_TYPE_INDEX_BUFFER_NV` token.

```c
// Provided by VK_NV_device_generated_commands
typedef struct VkBindIndexBufferIndirectCommandNV {
    uint32_t index;
} VkBindIndexBufferIndirectCommandNV;
```
VkDeviceAddress bufferAddress;
uint32_t size;
VkIndexType indexType;
} VkBindIndexBufferIndirectCommandNV;

- **bufferAddress** specifies a physical address of the VkBuffer used as index buffer.
- **size** is the byte size range which is available for this operation from the provided address.
- **indexType** is a VkIndexType value specifying how indices are treated. Instead of the Vulkan enum values, a custom uint32_t value can be mapped to an VkIndexType by specifying the VkIndirectCommandsLayoutTokenNV::pIndexTypes and VkIndirectCommandsLayoutTokenNV::pIndexTypeValues arrays.

### Valid Usage

- **VUID-VkBindIndexBufferIndirectCommandNV-None-02946**
  The buffer’s usage flag from which the address was acquired must have the VK_BUFFER_USAGE_INDEX_BUFFER_BIT bit set

- **VUID-VkBindIndexBufferIndirectCommandNV-bufferAddress-02947**
  The bufferAddress must be aligned to the indexType used

- **VUID-VkBindIndexBufferIndirectCommandNV-None-02948**
  Each element of the buffer from which the address was acquired and that is non-sparse must be bound completely and contiguously to a single VkDeviceMemory object

### Valid Usage (Implicit)

- **VUID-VkBindIndexBufferIndirectCommandNV-indexType-parameter**
  indexType must be a valid VkIndexType value

The VkBindVertexBufferIndirectCommandNV structure specifies the input data for the VK_INDIRECT_COMMANDS_TOKEN_TYPE_VERTEX_BUFFER_NV token.

```c
// Provided by VK_NV_device_generated_commands
typedef struct VkBindVertexBufferIndirectCommandNV {
    VkDeviceAddress bufferAddress;
    uint32_t size;
    uint32_t stride;
} VkBindVertexBufferIndirectCommandNV;
```

- **bufferAddress** specifies a physical address of the VkBuffer used as vertex input binding.
- **size** is the byte size range which is available for this operation from the provided address.
- **stride** is the byte size stride for this vertex input binding as in VkVertexInputBindingDescription::stride. It is only used if VkIndirectCommandsLayoutTokenNV::vertexDynamicStride was set, otherwise the stride is inherited from the current bound graphics pipeline.
Valid Usage

- VUID-VkBindVertexBufferIndirectCommandNV-None-02949
  The buffer’s usage flag from which the address was acquired must have the VK_BUFFER_USAGE_VERTEX_BUFFER_BIT bit set

- VUID-VkBindVertexBufferIndirectCommandNV-None-02950
  Each element of the buffer from which the address was acquired and that is non-sparse must be bound completely and contiguously to a single VkDeviceMemory object

The VkSetStateFlagsIndirectCommandNV structure specifies the input data for the VK_INDIVIDUAL_INDIVIDUAL_TOKEN_TYPE_INDIVIDUAL_FLAGS_NV token. Which state is changed depends on the VkIndirectStateFlagBitsNV specified at VkIndirectCommandsLayoutNV creation time.

```c
// Provided by VK_NV_device_generated_commands
typedef struct VkSetStateFlagsIndirectCommandNV {
    uint32_t   data;
} VkSetStateFlagsIndirectCommandNV;
```

- data encodes packed state that this command alters.
  - Bit 0: If set represents VK_FRONT_FACE_CLOCKWISE, otherwise VK_FRONT_FACE_COUNTER_CLOCKWISE

A subset of the graphics pipeline state can be altered using indirect state flags:

```c
// Provided by VK_NV_device_generated_commands
typedef enum VkIndirectStateFlagBitsNV {
    VK_INDIVIDUAL_STATE_FLAG_FRONTFACE_BIT_NV = 0x00000001,
} VkIndirectStateFlagBitsNV;
```

- VK_INDIVIDUAL_STATE_FLAG_FRONTFACE_BIT_NV allows to toggle the VkFrontFace rasterization state for subsequent drawing commands.

```c
// Provided by VK_NV_device_generated_commands
typedef VkFlags VkIndirectStateFlagsNV;
```

VkIndirectStateFlagsNV is a bitmask type for setting a mask of zero or more VkIndirectStateFlagBitsNV.

The VkBindPipelineIndirectCommandNV structure specifies the input data for the VK_INDIVIDUAL_INDIVIDUAL_TOKEN_TYPE_INDIVIDUAL_PIPELINE_NV token.

```c
// Provided by VK_NV_device_generated_commands_compute
typedef struct VkBindPipelineIndirectCommandNV {
    VkDeviceAddress pipelineAddress;
} VkBindPipelineIndirectCommandNV;
```
- `pipelineAddress` specifies the pipeline address of the compute pipeline that will be used in device generated rendering.

### Valid Usage

- **VUID-VkBindPipelineIndirectCommandNV-deviceGeneratedComputePipelines-09091**
  
  The `VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV::deviceGeneratedComputePipelines` feature must be enabled

- **VUID-VkBindPipelineIndirectCommandNV-None-09092**
  
  The referenced pipeline must have been created with `VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV`

- **VUID-VkBindPipelineIndirectCommandNV-None-09093**
  
  The referenced pipeline must have been updated with `vkCmdUpdatePipelineIndirectBufferNV`

- **VUID-VkBindPipelineIndirectCommandNV-None-09094**
  
  The referenced pipeline’s address must have been queried with `vkGetPipelineIndirectDeviceAddressNV`

### 32.1.3. Tokenized Command Processing

The processing is in principle illustrated below:

```c
void cmdProcessSequence(cmd, pipeline, indirectCommandsLayout, pIndirectCommandsStreams, s)
{
    for (t = 0; t < indirectCommandsLayout.tokenCount; t++)
    {
        uint32_t stream = indirectCommandsLayout.pTokens[t].stream;
        uint32_t offset = indirectCommandsLayout.pTokens[t].offset;
        uint32_t stride = indirectCommandsLayout.pStreamStrides[stream];
        stream = pIndirectCommandsStreams[stream];
        const void* input = stream.buffer.pointer( stream.offset + stride * s + offset )

        // further details later
        indirectCommandsLayout.pTokens[t].command (cmd, pipeline, input, s);
    }
}

void cmdProcessAllSequences(cmd, pipeline, indirectCommandsLayout, pIndirectCommandsStreams, sequencesCount)
{
    for (s = 0; s < sequencesCount; s++)
    {
        cmdProcessSequence(cmd, pipeline, indirectCommandsLayout, pIndirectCommandsStreams, s);
    }
}
```
The processing of each sequence is considered stateless, therefore all state changes must occur prior work provoking commands within the sequence. A single sequence is strictly targeting the VkPipelineBindPoint it was created with.

The primary input data for each token is provided through VkBuffer content at preprocessing using vkCmdPreprocessGeneratedCommandsNV or execution time using vkCmdExecuteGeneratedCommandsNV, however some functional arguments, for example binding sets, are specified at layout creation time. The input size is different for each token.

Possible values of those elements of the VkIndirectCommandsLayoutCreateInfoNV::pTokens array specifying command tokens (other elements of the array specify command parameters) are:

```c
// Provided by VK_NV_device_generated_commands
typedef enum VkIndirectCommandsTokenTypeNV {
    VK_INDIRECT_COMMANDS_TOKEN_TYPE_SHADER_GROUP_NV = 0,
    VK_INDIRECT_COMMANDS_TOKEN_TYPE_STATE_FLAGS_NV = 1,
    VK_INDIRECT_COMMANDS_TOKEN_TYPE_INDEX_BUFFER_NV = 2,
    VK_INDIRECT_COMMANDS_TOKEN_TYPE_VERTEX_BUFFER_NV = 3,
    VK_INDIRECT_COMMANDS_TOKEN_TYPE_PUSH_CONSTANT_NV = 4,
    VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_INDEXED_NV = 5,
    VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_NV = 6,
    VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_TASKS_NV = 7,
// Provided by VK_EXT_mesh_shader with VK_NV_device_generated_commands
    VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_MESH_TASKS_NV = 1000328000,
// Provided by VK_NV_device_generated_commands_compute
    VK_INDIRECT_COMMANDS_TOKEN_TYPE_PIPELINE_NV = 1000428003,
// Provided by VK_NV_device_generated_commands_compute
    VK_INDIRECT_COMMANDS_TOKEN_TYPE_DISPATCH_NV = 1000428004,
} VkIndirectCommandsTokenTypeNV;
```

Table 46. Supported indirect command tokens

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<td>VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_INDEXED_NV</td>
<td>vkCmdDrawIndexedIndirect</td>
</tr>
</tbody>
</table>
The `VkIndirectCommandsLayoutTokenNV` structure specifies details to the function arguments that need to be known at layout creation time:

```c
// Provided by VK_NV_device_generated_commands
typedef struct VkIndirectCommandsLayoutTokenNV {
    VkStructureType sType;
    const void* pNext;
    VkIndirectCommandsTokenTypeNV tokenType;
    uint32_t stream;
    uint32_t offset;
    uint32_t vertexBindingUnit;
    VkBool32 vertexDynamicStride;
    VkPipelineLayout pushconstantPipelineLayout;
    VkShaderStageFlags pushconstantShaderStageFlags;
    uint32_t pushconstantOffset;
    uint32_t pushconstantSize;
    VkIndirectStateFlagsNV indirectStateFlags;
    uint32_t indexTypeCount;
    const VkIndexType* pIndexTypes;
    const uint32_t* pIndexTypeValues;
} VkIndirectCommandsLayoutTokenNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `tokenType` specifies the token command type.
- `stream` is the index of the input stream containing the token argument data.
- `offset` is a relative starting offset within the input stream memory for the token argument data.
- `vertexBindingUnit` is used for the vertex buffer binding command.
- `vertexDynamicStride` sets if the vertex buffer stride is provided by the binding command rather than the current bound graphics pipeline state.
- `pushconstantPipelineLayout` is the `VkPipelineLayout` used for the push constant command.
- `pushconstantShaderStageFlags` are the shader stage flags used for the push constant command.
- `pushconstantOffset` is the offset used for the push constant command.
- **pushconstantSize** is the size used for the push constant command.
- **indirectStateFlags** are the active states for the state flag command.
- **indexTypeCount** is the optional size of the pIndexTypes and pIndexTypeValues array pairings. If not zero, it allows to register a custom uint32_t value to be treated as specific VkIndexType.
- **pIndexTypes** is the used VkIndexType for the corresponding uint32_t value entry in pIndexTypeValues.

### Valid Usage

- **VUID-VkIndirectCommandsLayoutTokenNV-stream-02951**
  stream must be smaller than VkIndirectCommandsLayoutCreateInfoNV::streamCount

- **VUID-VkIndirectCommandsLayoutTokenNV-offset-02952**
  offset must be less than or equal to VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV::maxIndirectCommandsTokenOffset

- **VUID-VkIndirectCommandsLayoutTokenNV-tokenType-02976**
  If tokenType is VK_INDIRECT_COMMANDS_TOKEN_TYPE_VERTEX_BUFFER_NV, vertexBindingUnit must stay within device supported limits for the appropriate commands

- **VUID-VkIndirectCommandsLayoutTokenNV-tokenType-02977**
  If tokenType is VK_INDIRECT_COMMANDS_TOKEN_TYPE_PUSH_CONSTANT_NV, pushconstantPipelineLayout must be valid

- **VUID-VkIndirectCommandsLayoutTokenNV-tokenType-02978**
  If tokenType is VK_INDIRECT_COMMANDS_TOKEN_TYPE_PUSH_CONSTANT_NV, pushconstantOffset must be a multiple of 4

- **VUID-VkIndirectCommandsLayoutTokenNV-tokenType-02979**
  If tokenType is VK_INDIRECT_COMMANDS_TOKEN_TYPE_PUSH_CONSTANT_NV, pushconstantSize must be a multiple of 4

- **VUID-VkIndirectCommandsLayoutTokenNV-tokenType-02980**
  If tokenType is VK_INDIRECT_COMMANDS_TOKEN_TYPE_PUSH_CONSTANT_NV, pushconstantOffset must be less than VkPhysicalDeviceLimits::maxPushConstantsSize

- **VUID-VkIndirectCommandsLayoutTokenNV-tokenType-02981**
  If tokenType is VK_INDIRECT_COMMANDS_TOKEN_TYPE_PUSH_CONSTANT_NV, pushconstantSize must be less than or equal to VkPhysicalDeviceLimits::maxPushConstantsSize minus pushconstantOffset

- **VUID-VkIndirectCommandsLayoutTokenNV-tokenType-02982**
  If tokenType is VK_INDIRECT_COMMANDS_TOKEN_TYPE_PUSH_CONSTANT_NV, for each byte in the range specified by pushconstantOffset and pushconstantSize and for each shader stage in pushconstantShaderStageFlags, there must be a push constant range in pushconstantPipelineLayout that includes that byte and that stage

- **VUID-VkIndirectCommandsLayoutTokenNV-tokenType-02983**
If `tokenType` is `VK间接命令类型_PUSH_CONSTANT_NV`，对于指定的范围由`pushconstantOffset`和`pushconstantSize`，以及对于每个覆盖该字节的`push constant`范围，`pushconstantShaderStageFlags`必须包含该`push constant`范围的`VkPushConstantRange::stageFlags`。

- VUID-VkIndirectCommandsLayoutTokenNV-tokenType-02984

如果`tokenType`是`VK间接命令类型_STATE_FLAGS_NV`，`indirectStateFlags`不得为0。

### 操作有效使用（隐式）

- VUID-VkIndirectCommandsLayoutTokenNV-sType-sType
  sType必须是`VK_STRUCTURE_TYPE间接命令布局_TOKEN_NV`。

- VUID-VkIndirectCommandsLayoutTokenNV-pNext-pNext
  pNext必须是NULL。

- VUID-VkIndirectCommandsLayoutTokenNV-tokenType-parameter
  tokenType必须是有效的`VkIndirectCommandsTokenTypeNV`值。

- VUID-VkIndirectCommandsLayoutTokenNV-pushconstantPipelineLayout-parameter
  pushconstantPipelineLayout必须是有效的`VkPipelineLayout`句柄。

- VUID-VkIndirectCommandsLayoutTokenNV-pushconstantShaderStageFlags-parameter
  pushconstantShaderStageFlags必须是有效的`VkShaderStageFlagBits`。

- VUID-VkIndirectCommandsLayoutTokenNV-indirectStateFlags-parameter
  indirectStateFlags必须是有效的`VkIndirectStateFlagBitsNV`。

- VUID-VkIndirectCommandsLayoutTokenNV-pIndexTypes-parameter
  If `indexTypeCount` 不为0，pIndexTypes必须是有效的`VkIndexType`句柄。

- VUID-VkIndirectCommandsLayoutTokenNV-pIndexTypeValues-parameter
  If `indexTypeCount` 不为0，pIndexTypeValues必须是有效的`uint32_t`。

以下代码提供了详细的信息，说明如何处理单个序列。对于有效使用，所有限制都适用于常规命令。

```c
void cmdProcessSequence(cmd, pipeline, indirectCommandsLayout, pIndirectCommandsStreams, s)
{
    for (uint32_t t = 0; t < indirectCommandsLayout.tokenCount; t++){
        token = indirectCommandsLayout.pTokens[t];

        uint32_t stride = indirectCommandsLayout.pStreamStrides[token.stream];
        stream = pIndirectCommandsStreams[token.stream];
        uint32_t offset = stream.offset + stride * s + token.offset;
```
```
const void* input = stream.buffer.pointer( offset )

switch(input.type){
    case VK_INDIRECT_COMMANDS_TOKEN_TYPE_SHADER_GROUP_NV:
        VkBindShaderGroupIndirectCommandNV* bind = input;

        vkCmdBindPipelineShaderGroupNV(cmd, indirectCommandsLayout.pipelineBindPoint,
            pipeline, bind->groupIndex);
        break;

    case VK_INDIRECT_COMMANDS_TOKEN_TYPE_STATE_FLAGS_NV:
        VkSetStateFlagsIndirectCommandNV* state = input;

        if (token.indirectStateFlags & VK_INDIRECT_STATE_FLAG_FRONTFACE_BIT_NV){
            if (state.data & (1 << 0)){
                set VK_FRONT_FACE_CLOCKWISE;
            } else {
                set VK_FRONT_FACE_COUNTER_CLOCKWISE;
            }
        }
        break;

    case VK_INDIRECT_COMMANDS_TOKEN_TYPE_PUSH_CONSTANT_NV:
        uint32_t* data = input;

        vkCmdPushConstants(cmd,
            token.pushconstantPipelineLayout,
            token.pushconstantStageFlags,
            token.pushconstantOffset,
            token.pushconstantSize, data);
        break;

    case VK_INDIRECT_COMMANDS_TOKEN_TYPE_INDEX_BUFFER_NV:
        VkBindIndexBufferIndirectCommandNV* data = input;

        // the indexType may optionally be remapped
        // from a custom uint32_t value, via
        // VkIndirectCommandsLayoutTokenNV::pIndexTypeValues

        vkCmdBindIndexBuffer(cmd,
            deriveBuffer(data->bufferAddress),
            deriveOffset(data->bufferAddress),
            data->indexType);
        break;

    case VK_INDIRECT_COMMANDS_TOKEN_TYPE_VERTEX_BUFFER_NV:
        VkBindVertexBufferIndirectCommandNV* data = input;

        // if token.vertexDynamicStride is VK_TRUE
        // then the stride for this binding is set
        // using data->stride as well
```
vkCmdBindVertexBuffers(cmd, 
  token.vertexBindingUnit, 1, 
  &deriveBuffer(data->bufferAddress), 
  &deriveOffset(data->bufferAddress));
break;

case VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_INDEXED_NV: 
  vkCmdDrawIndexedIndirect(cmd, 
    stream.buffer, offset, 1, 0);
break;

case VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_NV: 
  vkCmdDrawIndirect(cmd, 
    stream.buffer, 
    offset, 1, 0);
break;

  // only available if VK_NV_mesh_shader is supported 
  case VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_TASKS_NV: 
    vkCmdDrawMeshTasksIndirectNV(cmd, 
      stream.buffer, offset, 1, 0);
break;

  // only available if VK_EXT_mesh_shader is supported 
  case VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_MESH_TASKS_NV: 
    vkCmdDrawMeshTasksIndirectEXT(cmd, 
      stream.buffer, offset, 1, 0);
break;

case VK_INDIRECT_COMMANDS_TOKEN_TYPE_PIPELINE_NV:
  VkBindPipelineIndirectCommandNV *data = input;
  VkPipeline computePipeline = deriveFromDeviceAddress(data->pipelineAddress);
  vkCmdBindPipeline(cmd, VK_PIPELINE_BIND_POINT_COMPUTE, computePipeline);
break;

case VK_INDIRECT_COMMANDS_TOKEN_TYPE_DISPATCH_NV:
  vkCmdDispatchIndirect(cmd, stream.buffer, offset);
break;
}

32.2. Indirect Commands Generation And Execution

The generation of commands on the device requires a preprocess buffer. To retrieve the memory size and alignment requirements of a particular execution state call:

// Provided by VK_NV_device_generated_commands
void vkGetGeneratedCommandsMemoryRequirementsNV(
    VkDevice device,
    const VkGeneratedCommandsMemoryRequirementsInfoNV* pInfo,
    VkMemoryRequirements2* pMemoryRequirements);

- **device** is the logical device that owns the buffer.
- **pInfo** is a pointer to a `VkGeneratedCommandsMemoryRequirementsInfoNV` structure containing parameters required for the memory requirements query.
- **pMemoryRequirements** is a pointer to a `VkMemoryRequirements2` structure in which the memory requirements of the buffer object are returned.

### Valid Usage

- **VUID-vkGetGeneratedCommandsMemoryRequirementsNV-deviceGeneratedCommands-02906**
  
  The `VkPhysicalDeviceDeviceGeneratedCommandsFeaturesNV::deviceGeneratedCommands` feature must be enabled.

- **VUID-vkGetGeneratedCommandsMemoryRequirementsNV-pInfo-09074**
  
  If `pInfo::pipelineBindPoint` is of type `VK_PIPELINE_BIND_POINT_COMPUTE`, then the `VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV::deviceGeneratedCompute` feature must be enabled.

### Valid Usage (Implicit)

- **VUID-vkGetGeneratedCommandsMemoryRequirementsNV-device-parameter**
  
  `device` must be a valid `VkDevice` handle.

- **VUID-vkGetGeneratedCommandsMemoryRequirementsNV-pInfo-parameter**
  
  `pInfo` must be a valid pointer to a valid `VkGeneratedCommandsMemoryRequirementsInfoNV` structure.

- **VUID-vkGetGeneratedCommandsMemoryRequirementsNV-pMemoryRequirements-parameter**
  
  `pMemoryRequirements` must be a valid pointer to a `VkMemoryRequirements2` structure.

```c
// Provided by VK_NV_device_generated_commands
typedef struct VkGeneratedCommandsMemoryRequirementsInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkPipelineBindPoint pipelineBindPoint;
    VkPipeline pipeline;
    VkIndirectCommandsLayoutNV indirectCommandsLayout;
    uint32_t maxSequencesCount;
} VkGeneratedCommandsMemoryRequirementsInfoNV;
```
• **sType** is a VkStructureType value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.
• **pipelineBindPoint** is the VkPipelineBindPoint of the pipeline that this buffer memory is intended to be used with during the execution.
• **pipeline** is the VkPipeline that this buffer memory is intended to be used with during the execution.
• **indirectCommandsLayout** is the VkIndirectCommandsLayoutNV that this buffer memory is intended to be used with.
• **maxSequencesCount** is the maximum number of sequences that this buffer memory in combination with the other state provided can be used with.

### Valid Usage

- **VUID-VkGeneratedCommandsMemoryRequirementsInfoNV-maxSequencesCount-02907**
  maxSequencesCount must be less or equal to VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV::maxIndirectSequenceCount

- **VUID-VkGeneratedCommandsMemoryRequirementsInfoNV-pipelineBindPoint-09075**
  If pipelineBindPoint is of type VK_PIPELINE_BIND_POINT_GRAPHICS, then pipeline must be a valid VkPipeline handle

- **VUID-VkGeneratedCommandsMemoryRequirementsInfoNV-pipelineBindPoint-09076**
  If pipelineBindPoint is of type VK_PIPELINE_BIND_POINT_COMPUTE, and the indirectCommandsLayout was not created with a VK_INDIRECT_COMMANDS_TOKEN_TYPE_PIPELINE_NV token, then the pipeline must be a valid VkPipeline handle

- **VUID-VkGeneratedCommandsMemoryRequirementsInfoNV-pipelineBindPoint-09077**
  If pipelineBindPoint is of type VK_PIPELINE_BIND_POINT_COMPUTE, and the indirectCommandsLayout contains a VK_INDIRECT_COMMANDS_TOKEN_TYPE_PIPELINE_NV token, then the pipeline must be NULL

### Valid Usage (Implicit)

- **VUID-VkGeneratedCommandsMemoryRequirementsInfoNV-sType-sType**
  sType must be VK_STRUCTURE_TYPE_GENERATED_COMMANDS_MEMORY_REQUIREMENTS_INFO_NV

- **VUID-VkGeneratedCommandsMemoryRequirementsInfoNV-pNext-pNext**
  pNext must be NULL

- **VUID-VkGeneratedCommandsMemoryRequirementsInfoNV-pipelineBindPoint-parameter pipelineBindPoint must** be a valid VkPipelineBindPoint value

- **VUID-VkGeneratedCommandsMemoryRequirementsInfoNV-pipeline-parameter pipeline** is not VK_NULL_HANDLE, pipeline must be a valid VkPipeline handle

- **VUID-VkGeneratedCommandsMemoryRequirementsInfoNV-indirectCommandsLayout-parameter indirectCommandsLayout must** be a valid VkIndirectCommandsLayoutNV handle
To bind a compute pipeline in Device-Generated Commands, an application must query the pipeline’s device address.

To query a compute pipeline’s 64-bit device address, call:

```c
// Provided by VK_NV_device_generated_commands_compute
VkDeviceAddress vkGetPipelineIndirectDeviceAddressNV(
    VkDevice device,
    const VkPipelineIndirectDeviceAddressInfoNV* pInfo);
```

- `device` is the logical device on which the pipeline was created.
- `pInfo` is a pointer to a `VkPipelineIndirectDeviceAddressInfoNV` structure specifying the pipeline to retrieve the address for.

**Valid Usage**

- VUID-vkGetPipelineIndirectDeviceAddressNV-deviceGeneratedComputePipelines-09078
  The `VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV::deviceGeneratedComputePipelines` feature must be enabled

**Valid Usage (Implicit)**

- VUID-vkGetPipelineIndirectDeviceAddressNV-device-parameter
  `device` must be a valid `VkDevice` handle
- VUID-vkGetPipelineIndirectDeviceAddressNV-pInfo-parameter
  `pInfo` must be a valid pointer to a valid `VkPipelineIndirectDeviceAddressInfoNV` structure

The `VkPipelineIndirectDeviceAddressInfoNV` structure is defined as:

```c
// Provided by VK_NV_device_generated_commands_compute
typedef struct VkPipelineIndirectDeviceAddressInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkPipelineBindPoint pipelineBindPoint;
    VkPipeline pipeline;
} VkPipelineIndirectDeviceAddressInfoNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
pipelineBindPoint is a VkPipelineBindPoint value specifying the type of pipeline whose device address is being queried.

pipeline specifies the pipeline whose device address is being queried.

Valid Usage

- VUID-VkPipelineIndirectDeviceAddressInfoNV-pipelineBindPoint-09079
  The provided pipelineBindPoint must be of type VK_PIPELINE_BIND_POINT_COMPUTE
- VUID-VkPipelineIndirectDeviceAddressInfoNV-pipeline-09080
  pipeline must have been created with flag VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV set
- VUID-VkPipelineIndirectDeviceAddressInfoNV-pipeline-09081
  pipeline must have been created with a VkComputePipelineIndirectBufferInfoNV structure specifying a valid address where its metadata will be saved

Valid Usage (Implicit)

- VUID-VkPipelineIndirectDeviceAddressInfoNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_PIPELINE_INDIRECT_DEVICE_ADDRESS_INFO_NV
- VUID-VkPipelineIndirectDeviceAddressInfoNV-pNext-pNext
  pNext must be NULL
- VUID-VkPipelineIndirectDeviceAddressInfoNV-pipelineBindPoint-parameter
  pipelineBindPoint must be a valid VkPipelineBindPoint value
- VUID-VkPipelineIndirectDeviceAddressInfoNV-pipeline-parameter
  pipeline must be a valid VkPipeline handle

To determine the memory requirements for a compute pipeline's metadata, call:

```c
// Provided by VK_NV_device_generated_commands_compute
define void vkGetPipelineIndirectMemoryRequirementsNV(
    VkDevice device,
    const VkComputePipelineCreateInfo* pCreateInfo,
    VkMemoryRequirements2* pMemoryRequirements);
```

- device is the logical device that owns the buffer.
- pCreateInfo is a VkComputePipelineCreateInfo structure specifying the creation parameters of the compute pipeline whose memory requirements are being queried.
- pMemoryRequirements is a pointer to a VkMemoryRequirements2 structure in which the requested pipeline’s memory requirements are returned.

If pCreateInfo::pNext chain includes a pointer to a VkComputePipelineIndirectBufferInfoNV structure, then the contents of that structure are ignored.
Valid Usage

- VUID-vkGetPipelineIndirectMemoryRequirementsNV-deviceGeneratedComputePipelines-09082
  The `VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV::deviceGeneratedComputePipelines` feature must be enabled.

- VUID-vkGetPipelineIndirectMemoryRequirementsNV-pCreateInfo-09083
  `pCreateInfo::flags` must include `VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV`.

Valid Usage (Implicit)

- VUID-vkGetPipelineIndirectMemoryRequirementsNV-device-parameter
  `device` must be a valid `VkDevice` handle.

- VUID-vkGetPipelineIndirectMemoryRequirementsNV-pCreateInfo-parameter
  `pCreateInfo` must be a valid pointer to a valid `VkComputePipelineCreateInfo` structure.

- VUID-vkGetPipelineIndirectMemoryRequirementsNV-pMemoryRequirements-parameter
  `pMemoryRequirements` must be a valid pointer to a `VkMemoryRequirements2` structure.

The actual generation of commands as well as their execution on the device is handled as single action with:

```c
// Provided by VK_NV_device_generated_commands
void vkCmdExecuteGeneratedCommandsNV(
    VkCommandBuffer commandBuffer,       // Provided by VK_NV_device_generated_commands
    VkBool32 isPreprocessed,              // Provided by VK_NV_device_generated_commands
    const VkGeneratedCommandsInfoNV* pGeneratedCommandsInfo); // Provided by VK_NV_device_generated_commands
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `isPreprocessed` represents whether the input data has already been preprocessed on the device. If it is `VK_FALSE` this command will implicitly trigger the preprocessing step, otherwise not.
- `pGeneratedCommandsInfo` is a pointer to a `VkGeneratedCommandsInfoNV` structure containing parameters affecting the generation of commands.

If the `VK_INDIRECT_COMMANDS_LAYOUT_USAGE_UNORDEREDSEQUENCES_BIT_NV` flag was used to create the `VkGeneratedCommandsInfoNV::indirectCommandsLayout` then the order of execution of individual draws through this command may execute in any order, and may not necessarily be in the same order as specified in `VkGeneratedCommandsInfoNV::pStreams`.

The order of execution of individual dispatches through this command may execute in any order and may not necessarily be in the same order as specified in `VkGeneratedCommandsInfoNV::pStreams`.  

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Valid Usage

- VUID-vkCmdExecuteGeneratedCommandsNV-magFilter-04553
  If a VkSampler created with magFilter or minFilter equal to VK_FILTER_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- VUID-vkCmdExecuteGeneratedCommandsNV-mipmapMode-04770
  If a VkSampler created with mipmapMode equal to VK_SAMPLER_MIPMAP_MODE_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- VUID-vkCmdExecuteGeneratedCommandsNV-None-06479
  If a VkImageView is sampled with depth comparison, the image view’s format features must contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT

- VUID-vkCmdExecuteGeneratedCommandsNV-None-02691
  If a VkImageView is accessed using atomic operations as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

- VUID-vkCmdExecuteGeneratedCommandsNV-None-02692
  If a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer’s format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

- VUID-vkCmdExecuteGeneratedCommandsNV-None-02693
  If the VK_EXT_filter_cubic extension is not enabled and any VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, it must not have a VkImageViewType of VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

- VUID-vkCmdExecuteGeneratedCommandsNV-filterCubic-02694
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2

- VUID-vkCmdExecuteGeneratedCommandsNV-filterCubicMinmax-02695
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT with a reduction mode of either VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX as a result of this command must have a VkImageViewType and format that supports cubic filtering together with minmax filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax returned by vkGetPhysicalDeviceImageFormatProperties2

- VUID-vkCmdExecuteGeneratedCommandsNV-cubicRangeClamp-09212
If the `cubicRangeClamp` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must not have a `VkSamplerReductionModeCreateInfo` `reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`.

- VUID-vkCmdExecuteGeneratedCommandsNV-reductionMode-09213
  Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo` `::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

- VUID-vkCmdExecuteGeneratedCommandsNV-selectableCubicWeights-09214
  Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo` `::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

- VUID-vkCmdExecuteGeneratedCommandsNV-flags-02696
  Any `VkImage` created with a `VkImageCreateInfo` `::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

- VUID-vkCmdExecuteGeneratedCommandsNV-OpTypeImage-07027
  For any `VkImageView` being written as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view’s format features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

- VUID-vkCmdExecuteGeneratedCommandsNV-OpTypeImage-07028
  For any `VkImageView` being read as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view’s format features must contain `VK_FORMAT_FEATURE_2_STORAGE_READWITHOUT_FORMAT_BIT`.

- VUID-vkCmdExecuteGeneratedCommandsNV-OpTypeImage-07029
  For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view’s buffer features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITEWITHOUT_FORMAT_BIT`.

- VUID-vkCmdExecuteGeneratedCommandsNV-OpTypeImage-07030
  Any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown` then the view’s buffer features must contain `VK_FORMAT_FEATURE_2_STORAGE_READWITHOUT_FORMAT_BIT`.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08600
  For each set `n` that is statically used by a bound shader, a descriptor set must have been bound to `n` at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set `n`, with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in `Pipeline Layout Compatibility`.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08601
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as
described in [Pipeline Layout Compatibility](#).

- **VUID-vkCmdExecuteGeneratedCommandsNV-maintenance4-08602**
  If the `maintenance4` feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in [Pipeline Layout Compatibility](#).

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08114**
  Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, must be valid if they are statically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was not created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08115**
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` must have been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08116**
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08604**
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, must be valid if they are dynamically used by any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08117**
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdSetDescriptorBufferOffsetsEXT`, the bound `VkPipeline` must have been created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08119**
  If a descriptor is dynamically used with a `VkPipeline` created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory must be resident.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08605**
  If a descriptor is dynamically used with a `VkShaderEXT` created with a `VkDescriptorSetLayout` that was created with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory must be resident.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08606**
  If the `shaderObject` feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08607**
  If the `shaderObject` is enabled, either a valid pipeline must be bound to the pipeline bind
point used by this command, or a valid combination of valid and `VK_NULL_HANDLE` shader objects **must** be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08608**
  If a pipeline is bound to the pipeline bind point used by this command, there **must** not have been any calls to dynamic state setting commands for any state not specified as dynamic in the `VkPipeline` object bound to the pipeline bind point used by this command, since that pipeline was bound.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08609**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler **must** not be used to sample from any `VkImage` with a `VkImageView` of the type `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, `VK_IMAGE_VIEW_TYPE_1D_ARRAY`, `VK_IMAGE_VIEW_TYPE_2D_ARRAY` or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`, in any shader stage.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08610**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler **must** not be used with any of the SPIR-V `OpImageSample*` or `OpImageSparseSample*` instructions with `ImplicitLod`, `Dref` or `Proj` in their name, in any shader stage.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08611**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler **must** not be used with any of the SPIR-V `OpImageSample*` or `OpImageSparseSample*` instructions that includes a LOD bias or any offset values, in any shader stage.

- **VUID-vkCmdExecuteGeneratedCommandsNV-uniformBuffers-06935**
  If any stage of the `VkPipeline` object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT` or `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT` for `uniformBuffers`, and the `robustBufferAccess` feature is not enabled, that stage **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08612**
  If the `robustBufferAccess` feature is not enabled, and any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdExecuteGeneratedCommandsNV-storageBuffers-06936**
  If any stage of the `VkPipeline` object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT` or `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT` for `storageBuffers`,
and the `robustBufferAccess` feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08613**
  If the `robustBufferAccess` feature is not enabled, and any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- **VUID-vkCmdExecuteGeneratedCommandsNV-commandBuffer-02707**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, any resource accessed by bound shaders must not be a protected resource

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-06550**
  If a bound shader accesses a `VkSampler` or `VkImageView` object that enables sampler Y'CbCr conversion, that object must only be used with `OpImageSample*` or `OpImageSparseSample*` instructions

- **VUID-vkCmdExecuteGeneratedCommandsNV-ConstOffset-06551**
  If a bound shader accesses a `VkSampler` or `VkImageView` object that enables sampler Y'CbCr conversion, that object must not use the `ConstOffset` and `Offset` operands

- **VUID-vkCmdExecuteGeneratedCommandsNV-viewType-07752**
  If a `VkImageView` is accessed as a result of this command, then the image view's `viewType` must match the `Dim` operand of the `OpTypeImage` as described in Instruction/Sampler/Image View Validation

- **VUID-vkCmdExecuteGeneratedCommandsNV-format-07753**
  If a `VkImageView` is accessed as a result of this command, then the numeric type of the image view's `format` and the Sampled Type operand of the `OpTypeImage` must match

- **VUID-vkCmdExecuteGeneratedCommandsNV-OpImageWrite-08795**
  If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have at least as many components as the image view's `format`

- **VUID-vkCmdExecuteGeneratedCommandsNV-OpImageWrite-08796**
  If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have four components

- **VUID-vkCmdExecuteGeneratedCommandsNV-OpImageWrite-04469**
  If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction must have at least as many components as the buffer view's `format`

- **VUID-vkCmdExecuteGeneratedCommandsNV-SampledType-04470**
  If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64

- **VUID-vkCmdExecuteGeneratedCommandsNV-SampledType-04471**
  If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is
accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

- VUID-vkCmdExecuteGeneratedCommandsNV-SampledType-04472
  If a VkBufferView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64

- VUID-vkCmdExecuteGeneratedCommandsNV-SampledType-04473
  If a VkBufferView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

- VUID-vkCmdExecuteGeneratedCommandsNV-sparseImageInt64Atomics-04474
  If the sparseImageInt64Atomics feature is not enabled, VkImage objects created with the VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- VUID-vkCmdExecuteGeneratedCommandsNV-sparseImageInt64Atomics-04475
  If the sparseImageInt64Atomics feature is not enabled, VkBuffer objects created with the VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- VUID-vkCmdExecuteGeneratedCommandsNV-OpImageWeightedSampleQCOM-06971
  If OpImageWeightedSampleQCOM is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM

- VUID-vkCmdExecuteGeneratedCommandsNV-OpImageWeightedSampleQCOM-06972
  If OpImageWeightedSampleQCOM uses a VkImageView as a sample weight image as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM

- VUID-vkCmdExecuteGeneratedCommandsNV-OpImageBoxFilterQCOM-06973
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM

- VUID-vkCmdExecuteGeneratedCommandsNV-OpImageBoxFilterQCOM-06974
  If OpImageBoxFilterQCOM is used to read from a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BOX_FILTER_MATCHED_BIT_QCOM

- VUID-vkCmdExecuteGeneratedCommandsNV-OpImageBlockMatchSSDQCOM-06975
  If OpImageBlockMatchSSDQCOM is used to read from a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdExecuteGeneratedCommandsNV-OpImageBlockMatchSADQCOM-06976
  If OpImageBlockMatchSADQCOM or OpImageBlockMatchSSDQCOM is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- VUID-vkCmdExecuteGeneratedCommandsNV-OpImageWeightedSampleQCOM-06977
If `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler **must** have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

- VUID-vkCmdExecuteGeneratedCommandsNV-OpImageWeightedSampleQCOM-06978
  If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler **must** not have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

- VUID-vkCmdExecuteGeneratedCommandsNV-OpImageBlockMatchWindow-09215
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

- VUID-vkCmdExecuteGeneratedCommandsNV-OpImageBlockMatchWindow-09216
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format **must** be a single-component format.

- VUID-vkCmdExecuteGeneratedCommandsNV-OpImageBlockMatchWindow-09217
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from a reference image as a result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07288
  Any shader invocation executed by this command **must** terminate.

- VUID-vkCmdExecuteGeneratedCommandsNV-renderPass-02684
  The current render pass **must** be compatible with the `renderPass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

- VUID-vkCmdExecuteGeneratedCommandsNV-subpass-02685
  The subpass index of the current render pass **must** be equal to the `subpass` member of the `VkGraphicsPipelineCreateInfo` structure specified when creating the `VkPipeline` bound to `VK_PIPELINE_BIND_POINT_GRAPHICS`.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07748
  If any shader statically accesses an input attachment, a valid descriptor **must** be bound to the pipeline via a descriptor set.

- VUID-vkCmdExecuteGeneratedCommandsNV-OpTypeImage-07468
  If any shader executed by this pipeline accesses an `OpTypeImage` variable with a `Dim` operand of `SubpassData`, it **must** be decorated with an `InputAttachmentIndex` that corresponds to a valid input attachment in the current subpass.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07469
  Input attachment views accessed in a subpass **must** be created with the same `VkFormat` as the corresponding subpass definition, and be created with a `VkImageView` that is
compatible with the attachment referenced by the subpass’ \texttt{pInputAttachments[InputAttachmentIndex]} in the currently bound \texttt{VkFramebuffer} as specified by \texttt{Fragment Input Attachment Compatibility}

- \texttt{VUID-vkCmdExecuteGeneratedCommandsNV-None-06537}
  Memory backing image subresources used as attachments in the current render pass \textbf{must} not be written in any way other than as an attachment by this command

- \texttt{VUID-vkCmdExecuteGeneratedCommandsNV-None-09000}
  If a color attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the \texttt{VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT} image layout, and either:
   - the \texttt{VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT} is set on the currently bound pipeline or
   - the last call to \texttt{vkCmdSetAttachmentFeedbackLoopEnableEXT} included \texttt{VK_IMAGE_ASPECT_COLOR_BIT} and
     - there is no currently bound graphics pipeline or
     - the currently bound graphics pipeline was created with \texttt{VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT} it \textbf{must} not be accessed in any way other than as an attachment by this command

- \texttt{VUID-vkCmdExecuteGeneratedCommandsNV-None-09001}
  If a depth attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the \texttt{VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT} image layout, and either:
   - the \texttt{VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT} is set on the currently bound pipeline or
   - the last call to \texttt{vkCmdSetAttachmentFeedbackLoopEnableEXT} included \texttt{VK_IMAGE_ASPECT_DEPTH_BIT} and
     - there is no currently bound graphics pipeline or
     - the currently bound graphics pipeline was created with \texttt{VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT} it \textbf{must} not be accessed in any way other than as an attachment by this command

- \texttt{VUID-vkCmdExecuteGeneratedCommandsNV-None-09002}
  If a stencil attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it is not in the \texttt{VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT} image layout, and either:
   - the \texttt{VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT} is set on the currently bound pipeline or
   - the last call to \texttt{vkCmdSetAttachmentFeedbackLoopEnableEXT} included \texttt{VK_IMAGE_ASPECT_STENCIL_BIT} and
     - there is no currently bound graphics pipeline or
     - the currently bound graphics pipeline was created with \texttt{VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT} it \textbf{must} not be accessed in
any way other than as an attachment by this command

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-09003**
  If an attachment is written by any prior command in this subpass or by the load, store, or resolve operations for this subpass, it **must** not be accessed in any way other than as an attachment, storage image, or sampled image by this command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-06539**
  If any previously recorded command in the current subpass accessed an image subresource used as an attachment in this subpass in any way other than as an attachment, this command **must** not write to that image subresource as an attachment.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-06886**
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the depth aspect, **depth writes must** be disabled.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-06887**
  If the current render pass instance uses a depth/stencil attachment with a read-only layout for the stencil aspect, both front and back writeMask are not zero, and stencil test is enabled, **all stencil ops must** be **VK_STENCIL_OP_KEEP**.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-07831**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_VIEWPORT** dynamic state enabled then **vkCmdSetViewport must** have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-07832**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SCISSOR** dynamic state enabled then **vkCmdSetScissor must** have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-07833**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_LINE_WIDTH** dynamic state enabled then **vkCmdSetLineWidth must** have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08617**
  If a shader object is bound to any graphics stage, and the most recent call to **vkCmdSetPolygonModeEXT** in the current command buffer set **polygonMode** to **VK_POLYGON_MODE_LINE**, **vkCmdSetLineWidth must** have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08618**
  If a shader object is bound to the **VK_SHADER_STAGE_VERTEX_BIT** stage, and the most recent call to **vkCmdSetPrimitiveTopology** in the current command buffer set **primitiveTopology** to any line topology, **vkCmdSetLineWidth must** have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08619**
  If a shader object that outputs line primitives is bound to the **VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT** or **VK_SHADER_STAGE_GEOMETRY_BIT** stage, **vkCmdSetLineWidth must** have been called in the current command buffer prior to this drawing command.
• VUID-vkCmdExecuteGeneratedCommandsNV-None-07834
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BIAS dynamic state enabled then vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08620
If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDepthBiasEnable in the current command buffer set depthBiasEnable to VK_TRUE, vkCmdSetDepthBias or vkCmdSetDepthBias2EXT must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-07835
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_BLEND_CONSTANTS dynamic state enabled then vkCmdSetBlendConstants must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08621
If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetColorBlendEnableEXT in the current command buffer set any element of pColorBlendEnables to VK_TRUE, and the most recent call to vkCmdSetColorBlendEquationEXT in the current command buffer set the same element of pColorBlendEquations to a VkColorBlendEquationEXT structure with any VkBlendFactor member with a value of VK_BLEND_FACTOR_CONSTANT_COLOR, VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_COLOR, VK_BLEND_FACTOR_CONSTANT_ALPHA, or VK_BLEND_FACTOR_ONE_MINUS_CONSTANT_ALPHA, vkCmdSetBlendConstants must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-07836
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BOUNDS dynamic state enabled then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08622
If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetDepthBoundsTestEnable in the current command buffer set depthBoundsTestEnable to VK_TRUE, then vkCmdSetDepthBounds must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-07837
If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_COMPARE_MASK dynamic state enabled then vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08623
If a shader object is bound to any graphics stage, and the most recent call to
vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilCompareMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07838
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_WRITE_MASK dynamic state enabled then vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08624
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilWriteMask must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07839
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_STENCIL_REFERENCE dynamic state enabled then vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08625
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetStencilTestEnable in the current command buffer set stencilTestEnable to VK_TRUE, vkCmdSetStencilReference must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-maxMultiviewInstanceIndex-02689
  If the draw is recorded in a render pass instance with multiview enabled, the maximum instance index must be less than or equal to VkPhysicalDeviceMultiviewProperties::maxMultiviewInstanceIndex

- VUID-vkCmdExecuteGeneratedCommandsNV-sampleLocationsEnable-02689
  If the bound graphics pipeline was created with VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable set to VK_TRUE and the current subpass has a depth/stencil attachment, then that attachment must have been created with the VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT bit set

- VUID-vkCmdExecuteGeneratedCommandsNV-None-06666
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT dynamic state enabled then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08626
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetSampleLocationsEnableEXT in the current command buffer set sampleLocationsEnable to VK_TRUE, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleLocationsEXT must have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_SAMPLE\_LOCATIONS\_EXT} state enabled, then the \texttt{sampleLocationsPerPixel} member of \texttt{pSampleLocationsInfo} in the last call to \texttt{vkCmdSetSampleLocationsEXT} must equal the \texttt{rasterizationSamples} member of the \texttt{VkPipelineMultisampleStateCreateInfo} structure the bound graphics pipeline has been created with.

If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_CULL\_MODE} dynamic state enabled then \texttt{vkCmdSetCullMode} must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, then \texttt{vkCmdSetCullMode} must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_FRONT\_FACE} dynamic state enabled then \texttt{vkCmdSetFrontFace} must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, then \texttt{vkCmdSetFrontFace} must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_DEPTH\_TEST\_ENABLE} dynamic state enabled then \texttt{vkCmdSetDepthTestEnable} must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, then \texttt{vkCmdSetDepthTestEnable} must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the \texttt{VK\_DYNAMIC\_STATE\_DEPTH\_WRITE\_ENABLE} dynamic state enabled then \texttt{vkCmdSetDepthWriteEnable} must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK\_FALSE}, then \texttt{vkCmdSetDepthWriteEnable} must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP` dynamic state enabled then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDepthTestEnable` in the current command buffer set `depthTestEnable` to `VK_TRUE`, then `vkCmdSetDepthCompareOp` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE` dynamic state enabled then `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the `depthBounds` feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `vkCmdSetDepthBoundsTestEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE` dynamic state enabled then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_OP` dynamic state enabled then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE` dynamic state enabled then `vkCmdSetStencilTestEnable` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetStencilTestEnable` in the current command buffer set `stencilTestEnable` to `VK_TRUE`, then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_STENCIL_OP` dynamic state enabled then `vkCmdSetStencilOp` must have been called in the current command buffer prior to this drawing command.
If the bound graphics pipeline state was created with the
\texttt{VK_DYNAMIC_STATE_VIEWPORT\_WITH\_COUNT} dynamic state enabled, but not the
\texttt{VK_DYNAMIC_STATE_\_SCISSOR\_WITH\_COUNT} dynamic state enabled, then
\texttt{vkCmdSetViewportWithCount} must have been called in the current command buffer
prior to this drawing command, and the \texttt{viewportCount} parameter of
\texttt{vkCmdSetViewportWithCount} must match the \texttt{VkPipelineViewportStateCreateInfo}::\texttt{viewportCount} of the pipeline

- \texttt{VUID-vkCmdExecuteGeneratedCommandsNV-scissorCount-03418}
  If the bound graphics pipeline state was created with the
  \texttt{VK_DYNAMIC_STATE_\_SCISSOR\_WITH\_COUNT} dynamic state enabled, but not the
  \texttt{VK_DYNAMIC_STATE_VIEWPORT\_WITH\_COUNT} dynamic state enabled, then
  \texttt{vkCmdSetScissorWithCount} must have been called in the current command buffer prior
to this drawing command, and the \texttt{scissorCount} parameter of \texttt{vkCmdSetScissorWithCount} must match the \texttt{VkPipelineViewportStateCreateInfo}::\texttt{scissorCount} of the pipeline

- \texttt{VUID-vkCmdExecuteGeneratedCommandsNV-viewportCount-03419}
  If the bound graphics pipeline state was created with both the
  \texttt{VK_DYNAMIC_STATE_\_SCISSOR\_WITH\_COUNT} and \texttt{VK_DYNAMIC_STATE_VIEWPORT\_WITH\_COUNT} dynamic states enabled then both \texttt{vkCmdSetViewportWithCount} and \texttt{vkCmdSetScissorWithCount} must have been called in the current command buffer prior to this drawing command, and the \texttt{viewportCount} parameter of \texttt{vkCmdSetViewportWithCount} must match the \texttt{scissorCount} parameter of \texttt{vkCmdSetScissorWithCount}

- \texttt{VUID-vkCmdExecuteGeneratedCommandsNV-None-08635}
  If a shader object is bound to any graphics stage, then both \texttt{vkCmdSetViewportWithCount}
  and \texttt{vkCmdSetScissorWithCount} must have been called in the current command buffer prior
to this drawing command, and the \texttt{viewportCount} parameter of \texttt{vkCmdSetViewportWithCount} must match the \texttt{scissorCount} parameter of \texttt{vkCmdSetScissorWithCount}

- \texttt{VUID-vkCmdExecuteGeneratedCommandsNV-viewportCount-04137}
  If the bound graphics pipeline state was created with the
  \texttt{VK_DYNAMIC_STATE_VIEWPORT\_WITH\_COUNT} dynamic state enabled, but not the
  \texttt{VK_DYNAMIC_STATE_VIEWPORT\_W\_SCALING\_NV} dynamic state enabled, then the bound graphics
  pipeline must have been created with \texttt{VkPipelineViewportWScalingStateCreateInfoNV}::\texttt{viewportCount} greater or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- \texttt{VUID-vkCmdExecuteGeneratedCommandsNV-viewportCount-04138}
  If the bound graphics pipeline state was created with the
  \texttt{VK_DYNAMIC_STATE_VIEWPORT\_WITH\_COUNT} and \texttt{VK_DYNAMIC_STATE_VIEWPORT\_W\_SCALING\_NV} dynamic states enabled then the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWScalingNV} must be greater than or equal to the \texttt{viewportCount} parameter in the last call to \texttt{vkCmdSetViewportWithCount}

- \texttt{VUID-vkCmdExecuteGeneratedCommandsNV-None-09232}
  If a shader object is bound to any graphics stage, and the \texttt{VK_NV_clip_space_w_scaling}
  extension is enabled on the device, then \texttt{vkCmdSetViewportWScalingNV} must have been
called in the current command buffer prior to this drawing command

- \texttt{VUID-vkCmdExecuteGeneratedCommandsNV-None-08636}
  If a shader object is bound to any graphics stage, and the \texttt{VK_NV_clip_space_w_scaling}
extension is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportWSCalingNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-viewportCount-04139**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportShadingRateImageStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-viewportCount-04140**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-shadingRateImage-09233**
  If the shadingRateImage feature is enabled, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set rasterizerDiscardEnable to `VK_FALSE`, then `vkCmdSetCoarseSampleOrderNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-shadingRateImage-09234**
  If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set rasterizerDiscardEnable to `VK_FALSE`, and the most recent call to `vkCmdSetShadingRateImageEnableNV` in the current command buffer set shadingRateImageEnable to `VK_TRUE`, then `vkCmdSetViewportShadingRatePaletteNV` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08637**
  If a shader object is bound to any graphics stage, and the shadingRateImage feature is enabled on the device, then the `viewportCount` parameter in the last call to `vkCmdSetViewportShadingRatePaletteNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-VkPipelineViewportCreateInfo-04141**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportSwizzleStateCreateInfoNV` structure chained from `VkPipelineViewportStateCreateInfo`, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-VkPipelineViewportCreateInfo-04142**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled and a `VkPipelineViewportExclusiveScissorStateCreateInfoNV` structure chained from
VkPipelineViewportStateCreateInfo, then the bound graphics pipeline must have been created with VkPipelineViewportExclusiveScissorStateCreateInfoNV::exclusiveScissorCount greater or equal to the viewportCount parameter in the last call to vkCmdSetViewportWithCount

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07878
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV dynamic state enabled then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07879
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV dynamic state enabled then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-exclusiveScissor-09235
  If a shader object is bound to any graphics stage, and the exclusiveScissor feature is enabled, then vkCmdSetExclusiveScissorEnableNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08638
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetExclusiveScissorEnableNV in the current command buffer set any element of pExclusiveScissorEnables to VK_TRUE, then vkCmdSetExclusiveScissorNV must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-04876
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE dynamic state enabled then vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08639
  If a shader object is bound to any graphics stage, then vkCmdSetRasterizerDiscardEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-04877
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE dynamic state enabled then vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08640
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetDepthBiasEnable must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-logicOp-04878
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_EXT dynamic state enabled then vkCmdSetLogicOpEXT must have been called in the current
command buffer prior to this drawing command and the logicOp must be a valid VkLogicOp value

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08641
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the logicOp feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEXT must have been called in the current command buffer prior to this drawing command and the logicOp must be a valid VkLogicOp value

- VUID-vkCmdExecuteGeneratedCommandsNV-primitiveFragmentShadingRateWithMultipleViewports-04552
  If the primitiveFragmentShadingRateWithMultipleViewports limit is not supported, the bound graphics pipeline was created with the VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT dynamic state enabled, and any of the shader stages of the bound graphics pipeline write to the PrimitiveShadingRateKHR built-in, then vkCmdSetViewportWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must be 1

- VUID-vkCmdExecuteGeneratedCommandsNV-primitiveFragmentShadingRateWithMultipleViewports-08642
  If the primitiveFragmentShadingRateWithMultipleViewports limit is not supported, and any shader object bound to a graphics stage writes to the PrimitiveShadingRateKHR built-in, then vkCmdSetViewportWithCount must have been called in the current command buffer prior to this drawing command, and the viewportCount parameter of vkCmdSetViewportWithCount must be 1

- VUID-vkCmdExecuteGeneratedCommandsNV-blendEnable-04727
  If rasterization is not disabled in the bound graphics pipeline, then for each color attachment in the subpass, if the corresponding image view's format features do not contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT, then the blendEnable member of the corresponding element of the pAttachments member of pColorBlendState must be VK_FALSE

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08643
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then for each color attachment in the render pass, if the corresponding image view's format features do not contain VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT, then the corresponding member of pColorBlendEnables in the most recent call to vkCmdSetColorBlendEnableEXT in the current command buffer that affected that attachment index must have been VK_FALSE

- VUID-vkCmdExecuteGeneratedCommandsNV-multisampledRenderToSingleSampled-07284
  If rasterization is not disabled in the bound graphics pipeline, and none of the VK_AMD_mixed_attachment_samples extension, the VK_NV_framebuffer_mixed_samples extension, or the multisampledRenderToSingleSampled feature is enabled, then rasterizationSamples for the currently bound graphics pipeline must be the same as the current subpass color and/or depth/stencil attachments
If a shader object is bound to any graphics stage, and the most recent call to
\texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set
\texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, and none of the \texttt{VK_AMD_mixed_attachment_samples}
extension, the \texttt{VK_NV_framebuffer_mixed_samples} extension, or the
\texttt{multisampledRenderToSingleSampled} feature is enabled, then the most recent call to
\texttt{vkCmdSetRasterizationSamplesEXT} in the current command buffer \textbf{must} have set
\texttt{rasterizationSamples} to be the same as the number of samples for the current render pass
color and/or depth/stencil attachments.

If a shader object is bound to any graphics stage, the current render pass instance \textbf{must}
have been begun with \texttt{vkCmdBeginRendering}.

If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{imageView}
member of \texttt{pDepthAttachment} is not \texttt{VK_NULL_HANDLE}, and the \texttt{layout} member of
\texttt{pDepthAttachment} is \texttt{VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL}, this command \textbf{must}
not write any values to the depth attachment.

If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{imageView}
member of \texttt{pStencilAttachment} is not \texttt{VK_NULL_HANDLE}, and the \texttt{layout} member of
\texttt{pStencilAttachment} is \texttt{VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL}, this command \textbf{must}
not write any values to the stencil attachment.

If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{imageView}
member of \texttt{pDepthAttachment} is not \texttt{VK_NULL_HANDLE}, and the \texttt{layout} member of
\texttt{pDepthAttachment} is \texttt{VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL}, this
command \textbf{must} not write any values to the depth attachment.

If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the \texttt{imageView}
member of \texttt{pStencilAttachment} is not \texttt{VK_NULL_HANDLE}, and the \texttt{layout} member of
\texttt{pStencilAttachment} is \texttt{VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL}, this command \textbf{must}
not write any values to the stencil attachment.

If the current render pass instance was begun with \texttt{vkCmdBeginRendering}, the currently
bound graphics pipeline \textbf{must} have been created with a \texttt{VkPipelineRenderingCreateInfo}.
::viewMask equal to VkRenderingInfo::viewMask

- **VUID-vkCmdExecuteGeneratedCommandsNV-colorAttachmentCount-06179**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound graphics pipeline **must** have been created with a `VkPipelineRenderingCreateInfo` `::colorAttachmentCount` equal to `VkRenderingInfo::colorAttachmentCount`

- **VUID-vkCmdExecuteGeneratedCommandsNV-dynamicRenderingUnusedAttachments-08910**
  If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` **must** have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline

- **VUID-vkCmdExecuteGeneratedCommandsNV-dynamicRenderingUnusedAttachments-08911**
  If the `dynamicRenderingUnusedAttachments` feature is enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` not equal to `VK_NULL_HANDLE` **must** have been created with a `VkFormat` equal to the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound graphics pipeline, or the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats`, if it exists, **must** be `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdExecuteGeneratedCommandsNV-dynamicRenderingUnusedAttachments-08912**
  If the `dynamicRenderingUnusedAttachments` feature is not enabled, and the current render pass instance was begun with `vkCmdBeginRendering` and `VkRenderingInfo::colorAttachmentCount` greater than 0, then each element of the `VkRenderingInfo::pColorAttachments` array with a `imageView` equal to `VK_NULL_HANDLE` **must** have the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the currently bound pipeline equal to `VK_FORMAT_UNDEFINED`

- **VUID-vkCmdExecuteGeneratedCommandsNV-attachmentCount-07750**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorWriteEnableEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdExecuteGeneratedCommandsNV-attachmentCount-07750**
  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteEnableEXT` **must** have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdExecuteGeneratedCommandsNV-attachmentCount-07750**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorWriteEnableEXT` **must** have been called in the current command buffer prior to this drawing command
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT` dynamic state enabled then the `attachmentCount` parameter of `vkCmdSetColorWriteEnableEXT` must be greater than or equal to the `VkPipelineColorBlendStateCreateInfo::attachmentCount` of the currently bound graphics pipeline

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08647**
  If the `colorWriteEnable` feature is enabled on the device, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then the `attachmentCount` parameter of most recent call to `vkCmdSetColorWriteEnableEXT` in the current command buffer must be greater than or equal to the number of color attachments in the current render pass instance

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-07751**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEXT` must have been called in the current command buffer prior to this drawing command for each discard rectangle in `VkPipelineDiscardRectangleStateCreateInfoEXT::discardRectangleCount`

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-07880**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT` dynamic state enabled then `vkCmdSetDiscardRectangleEnableEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdExecuteGeneratedCommandsNV-rasterizerDiscardEnable-09236**
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDiscardRectangleEXT` must have been called in the current command buffer prior to this drawing command

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08648**
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDiscardRectangleEnableEXT` in the current command buffer set

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-07881**
  If the `VK_EXT_discard_rectangles` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetDiscardRectangleModeEXT` in the current command buffer set
discardRectangleEnable to VK_TRUE, then vkCmdSetDiscardRectangleModeEXT must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-dynamicRenderingUnusedAttachments-08913**
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to VK_FORMAT_UNDEFINED.

- **VUID-vkCmdExecuteGeneratedCommandsNV-dynamicRenderingUnusedAttachments-08914**
  If current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline must be equal to the VkFormat used to create VkRenderingInfo::pDepthAttachment->imageView.

- **VUID-vkCmdExecuteGeneratedCommandsNV-dynamicRenderingUnusedAttachments-08915**
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo::pDepthAttachment->imageView was not VK_NULL_HANDLE, and the value of VkPipelineRenderingCreateInfo::depthAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pDepthAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED.

- **VUID-vkCmdExecuteGeneratedCommandsNV-dynamicRenderingUnusedAttachments-08916**
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pStencilAttachment->imageView was VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline must be equal to VK_FORMAT_UNDEFINED.

- **VUID-vkCmdExecuteGeneratedCommandsNV-dynamicRenderingUnusedAttachments-08917**
  If current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is not enabled, and VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, the value of VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline must be equal to the VkFormat used to create VkRenderingInfo::pStencilAttachment->imageView.

- **VUID-vkCmdExecuteGeneratedCommandsNV-dynamicRenderingUnusedAttachments-08918**
  If the current render pass instance was begun with vkCmdBeginRendering, the dynamicRenderingUnusedAttachments feature is enabled, VkRenderingInfo::pStencilAttachment->imageView was not VK_NULL_HANDLE, and the value of
VkPipelineRenderingCreateInfo::stencilAttachmentFormat used to create the currently bound graphics pipeline was not equal to the VkFormat used to create VkRenderingInfo::pStencilAttachment->imageView, the value of the format must be VK_FORMAT_UNDEFINED

- VUID-vkCmdExecuteGeneratedCommandsNV-imageView-06183
  If the current render pass instance was begun with vkCmdBeginRendering and VkRenderingFragmentShadingRateAttachmentInfoKHR::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

- VUID-vkCmdExecuteGeneratedCommandsNV-imageView-06184
  If the current render pass instance was begun with vkCmdBeginRendering and VkRenderingFragmentDensityMapAttachmentInfoEXT::imageView was not VK_NULL_HANDLE, the currently bound graphics pipeline must have been created with VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT

- VUID-vkCmdExecuteGeneratedCommandsNV-colorAttachmentCount-06185
  If the currently bound pipeline was created with a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the current render pass instance was begun with VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the VkRenderingInfo::pColorAttachments array with an imageView not equal to VK_NULL_HANDLE must have been created with a sample count equal to the corresponding element of the pColorAttachmentSamples member of VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV used to create the currently bound graphics pipeline

- VUID-vkCmdExecuteGeneratedCommandsNV-pDepthAttachment-06186
  If the currently bound pipeline was created without a VkAttachmentSampleCountInfoAMD or VkAttachmentSampleCountInfoNV structure, and the multisampledRenderToSingleSampled feature is not enabled, and the current render pass instance was begun with VkCmdBeginRendering with a VkRenderingInfo::colorAttachmentCount parameter greater than 0, then each element of the
VkRenderingInfo::pColorAttachments array with a `imageView` not equal to `VK_NULL_HANDLE` must have been created with a sample count equal to the value of `rasterizationSamples` for the currently bound graphics pipeline.

- **VUID-vkCmdExecuteGeneratedCommandsNV-multisampledRenderToSingleSampled-07286**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pDepthAttachment->imageView`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-multisampledRenderToSingleSampled-07287**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline was created without a `VkAttachmentSampleCountInfoAMD` or `VkAttachmentSampleCountInfoNV` structure, and the `multisampledRenderToSingleSampled` feature is not enabled, and `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to the sample count used to create `VkRenderingInfo::pStencilAttachment->imageView`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-pNext-07935**
  If this command has been called inside a render pass instance started with `vkCmdBeginRendering`, and the `pNext` chain of `VkRenderingInfo` includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the value of `rasterizationSamples` for the currently bound graphics pipeline must be equal to `VkMultisampledRenderToSingleSampledInfoEXT::rasterizationSamples`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-renderPass-06198**
  If the current render pass instance was begun with `vkCmdBeginRendering`, the currently bound pipeline must have been created with a `VkGraphicsPipelineCreateInfo::renderPass` equal to `VK_NULL_HANDLE`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-pColorAttachments-08963**
  If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound with a fragment shader that statically writes to a color attachment, the color write mask is not zero, color writes are enabled, and the corresponding element of the `VkRenderingInfo::pColorAttachments->imageView` was not `VK_NULL_HANDLE`, then the corresponding element of `VkPipelineRenderingCreateInfo::pColorAttachmentFormats` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-pDepthAttachment-08964**
  If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, depth test is enabled, depth write is enabled, and the `VkRenderingInfo::pDepthAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::depthAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`. 

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If the current render pass instance was begun with `vkCmdBeginRendering`, there is a graphics pipeline bound, stencil test is enabled and the `VkRenderingInfo::pStencilAttachment->imageView` was not `VK_NULL_HANDLE`, then the `VkPipelineRenderingCreateInfo::stencilAttachmentFormat` used to create the pipeline must not be `VK_FORMAT_UNDEFINED`.

If the `primitivesGeneratedQueryWithRasterizerDiscard` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, rasterization discard must not be enabled.

If the `primitivesGeneratedQueryWithNonZeroStreams` feature is not enabled and the `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query is active, the bound graphics pipeline must not have been created with a non-zero value in `VkPipelineRasterizationStateStreamCreateInfoEXT::rasterizationStream`.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT` dynamic state enabled then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to the `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT` stage, then `vkCmdSetTessellationDomainOriginEXT` must have been called in the current command buffer prior to this drawing command.

If the `depthClamp` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetDepthClampEnableEXT` must have been called in the current command buffer prior to this drawing command.

If a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetPolygonModeEXT` must have been called in the current command buffer prior to this drawing command.
called in the current command buffer prior to this drawing command

• VUID-vkCmdExecuteGeneratedCommandsNV-None-07622
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT dynamic state enabled then
  vkCmdSetRasterizationSamplesEXT must have been called in the current command
  buffer prior to this drawing command

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08652
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, then vkCmdSetRasterizationSamplesEXT must have
  been called in the current command buffer prior to this drawing command

• VUID-vkCmdExecuteGeneratedCommandsNV-None-07623
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_SAMPLE_MASK_EXT dynamic state enabled then vkCmdSetSampleMaskEXT
  must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08653
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, then vkCmdSetSampleMaskEXT must have
  been called in the current command buffer prior to this drawing command

• VUID-vkCmdExecuteGeneratedCommandsNV-None-07624
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled then
  vkCmdSetAlphaToCoverageEnableEXT must have been called in the current command
  buffer prior to this drawing command

• VUID-vkCmdExecuteGeneratedCommandsNV-alphaToCoverageEnable-08919
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT dynamic state enabled, and
  alphaToCoverageEnable was VK_TRUE in the last call to
  vkCmdSetAlphaToCoverageEnableEXT, then the Fragment Output Interface must contain
  a variable for the alpha Component word in Location 0 at Index 0

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08654
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToCoverageEnableEXT must
  have been called in the current command buffer prior to this drawing command

• VUID-vkCmdExecuteGeneratedCommandsNV-alphaToCoverageEnable-08920
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetAlphaToCoverageEnableEXT in the current command buffer set
  alphaToCoverageEnable to VK_TRUE, then the Fragment Output Interface must contain a
  variable for the alpha Component word in Location 0 at Index 0

• VUID-vkCmdExecuteGeneratedCommandsNV-None-07625
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT dynamic state enabled then
vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08655
  If the alphaToOne feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetAlphaToOneEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07626
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT dynamic state enabled then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08656
  If the logicOp feature is enabled, and a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetLogicOpEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07627
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT dynamic state enabled then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08657
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, then vkCmdSetColorBlendEnableEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07628
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT dynamic state enabled then vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08658
  If a shader object is bound to any graphics stage, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE, and the most recent call to vkCmdSetColorBlendEnableEXT for any attachment set that attachment's value in pColorBlendEnables to VK_TRUE, then vkCmdSetColorBlendEquationEXT must have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07629
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT dynamic state enabled then vkCmdSetColorWriteMaskEXT must have been called in the current command buffer prior to this drawing command
If a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT` dynamic state enabled then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

If the `geometryStreams` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_GEOMETRY_BIT` stage, then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

If the `geometryStreams` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_GEOMETRY_BIT` stage, then `vkCmdSetRasterizationStreamEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetConservativeRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

If the `VK_EXT_conservative_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetConservativeRasterizationModeEXT` in the current command buffer set `conservativeRasterizationMode` to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`, then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT` dynamic state enabled then `vkCmdSetExtraPrimitiveOverestimationSizeEXT` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT` dynamic state enabled then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.
If the `depthClipEnable` feature is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetDepthClipEnableEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07634
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT` dynamic state enabled then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08664
  If the `VK_EXT_sample_locations` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetSampleLocationsEnableEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07635
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then `vkCmdSetColorBlendAdvancedEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07636
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT` dynamic state enabled then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08665
  If the `VK_EXT_provoking_vertex` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetProvokingVertexModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07637
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT` dynamic state enabled then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08666
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetPolygonModeEXT` in the current command buffer set `polygonMode` to `VK_POLYGON_MODE_LINE`, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08667
  If the `VK_EXT_line_rasterization` extension is enabled, and a shader object is bound to the vertex stage, and the most recent call to `vkCmdSetPrimitiveTopology` in the current command buffer set `primitiveTopology` to any line topology, then `vkCmdSetLineRasterizationModeEXT` must have been called in the current command buffer prior to this drawing command.
If the **VK_EXT_line_rasterization** extension is enabled, and a shader object that outputs line primitives is bound to the tessellation evaluation or geometry stage, then *vkCmdSetLineRasterizationModeEXT* must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT** dynamic state enabled then *vkCmdSetLineStippleEnableEXT* must have been called in the current command buffer prior to this drawing command.

If the **VK_EXT_line_rasterization** extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to *vkCmdSetPolygonModeEXT* in the current command buffer set *polygonMode* to **VK_POLYGON_MODE_LINE**, then *vkCmdSetLineStippleEnableEXT* must have been called in the current command buffer prior to this drawing command.

If the **VK_EXT_line_rasterization** extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to *vkCmdSetPolygonModeEXT* in the current command buffer set *stippledLineEnable* to **VK_TRUE**, then *vkCmdSetLineStippleEXT* must have been called in the current command buffer prior to this drawing command.

If the **VK_EXT_line_rasterization** extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to *vkCmdSetDepthClipNegativeOneToOneEXT* in the current command buffer set *depthClipEnable* to **VK_TRUE**, then *vkCmdSetDepthClipNegativeOneToOneEXT* must have been called in the current command buffer prior to this drawing command.
• VUID-vkCmdExecuteGeneratedCommandsNV-None-07640
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV` dynamic state enabled then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08674
If the `VK_NV_clip_space_w_scaling` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportWScalingEnableNV` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-07641
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08675
If the `VK_NV_viewport_swizzle` extension is enabled, and a shader object is bound to any graphics stage, then `vkCmdSetViewportSwizzleNV` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-07642
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08676
If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageToColorEnableNV` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-07643
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV` dynamic state enabled then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08677
If the `VK_NV_fragment_coverage_to_color` extension is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetCoverageToColorEnableNV` in the current command buffer set `coverageToColorEnable` to `VK_TRUE`, then `vkCmdSetCoverageToColorLocationNV` must have been called in the current command buffer prior to this drawing command.

• VUID-vkCmdExecuteGeneratedCommandsNV-None-07644
If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV` dynamic state enabled then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

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If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetCoverageModulationModeNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationModeNV` in the current command buffer set `coverageModulationMode` to any value other than `VK_COVERAGE_MODULATION_MODE_NONE_NV`, then `vkCmdSetCoverageModulationTableEnableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV` dynamic state enabled then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command.

If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, and the most recent call to `vkCmdSetCoverageModulationTableEnableNV` in the current command buffer set `coverageModulationTableEnable` to `VK_TRUE`, then `vkCmdSetCoverageModulationTableNV` must have been called in the current command buffer prior to this drawing command.

If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV` dynamic state enabled then `vkCmdSetShadingRateImageEnableNV` must have been called in the current command buffer prior to this drawing command.

If the `pipelineFragmentShadingRate` feature is enabled, and a shader object is bound to the `VK_SHADER_STAGE_FRAGMENT_BIT` stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFragmentShadingRateKHR` must have been called in the current command buffer prior to this drawing command.

If the `shadingRateImage` feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to `vkCmdSetRasterizerDiscardEnable` in the current command buffer set `rasterizerDiscardEnable` to `VK_FALSE`, then `vkCmdSetFragmentShadingRateKHR` must have been called in the current command buffer prior to this drawing command.
command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetShadingRateImageEnableNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07648
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV} dynamic state enabled then \texttt{vkCmdSetRepresentativeFragmentTestEnableNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08682
  If the \texttt{representativeFragmentTest} feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetRepresentativeFragmentTestEnableNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07649
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV} dynamic state enabled then \texttt{vkCmdSetCoverageReductionModeNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-None-08683
  If the \texttt{coverageReductionMode} feature is enabled, and a shader object is bound to any graphics stage, and the most recent call to \texttt{vkCmdSetRasterizerDiscardEnable} in the current command buffer set \texttt{rasterizerDiscardEnable} to \texttt{VK_FALSE}, then \texttt{vkCmdSetCoverageReductionModeNV} \textbf{must} have been called in the current command buffer prior to this drawing command

- VUID-vkCmdExecuteGeneratedCommandsNV-pColorBlendEnables-07470
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT} state enabled and the last call to \texttt{vkCmdSetColorBlendEnableEXT} set \texttt{pColorBlendEnables} for any attachment to \texttt{VK_TRUE}, then for those attachments in the subpass the corresponding image view's \texttt{format features} \textbf{must} contain \texttt{VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT}

- VUID-vkCmdExecuteGeneratedCommandsNV-rasterizationSamples-07471
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT} state enabled, and the current subpass does not use any color and/or depth/stencil attachments, then the \texttt{rasterizationSamples} in the last call to \texttt{vkCmdSetRasterizationSamplesEXT} \textbf{must} follow the rules for a zero-attachment subpass

- VUID-vkCmdExecuteGeneratedCommandsNV-samples-07472
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_SAMPLE_MASK_EXT} state enabled and the \texttt{VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT} state disabled, then the \texttt{samples} parameter in the last call to \texttt{vkCmdSetSampleMaskEXT} \textbf{must} be greater or equal to the \texttt{VkPipelineMultisampleStateCreateInfo::rasterizationSamples} parameter used to create the bound graphics pipeline

- VUID-vkCmdExecuteGeneratedCommandsNV-samples-07473

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If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT` state and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, then the `samples` parameter in the last call to `vkCmdSetSampleMaskEXT` must be greater or equal to the `rasterizationSamples` parameter in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-rasterizationSamples-07474**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, and neither the `VK_AMD_mixed_attachment_samples` nor the `VK_NV_framebuffer_mixed_samples` extensions are enabled, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the current subpass color and/or depth/stencil attachments.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-09211**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` state enabled, or a shader object is bound to any graphics stage, and the current render pass instance includes a `VkMultisampledRenderToSingleSampledInfoEXT` structure with `multisampledRenderToSingleSampledEnable` equal to `VK_TRUE`, then the `rasterizationSamples` in the last call to `vkCmdSetRasterizationSamplesEXT` must be the same as the `rasterizationSamples` member of that structure.

- **VUID-vkCmdExecuteGeneratedCommandsNV-firstAttachment-07476**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT` dynamic state enabled then `vkCmdSetColorBlendEnableEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEnableEXT` calls must specify an enable for all active color attachments in the current subpass.

- **VUID-vkCmdExecuteGeneratedCommandsNV-firstAttachment-07477**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT` dynamic state enabled then `vkCmdSetColorBlendEquationEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorBlendEquationEXT` calls must specify the blend equations for all active color attachments in the current subpass where blending is enabled.

- **VUID-vkCmdExecuteGeneratedCommandsNV-firstAttachment-07478**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT` dynamic state enabled then `vkCmdSetColorWriteMaskEXT` must have been called in the current command buffer prior to this drawing command, and the attachments specified by the `firstAttachment` and `attachmentCount` parameters of `vkCmdSetColorWriteMaskEXT` calls must specify the color write mask for all active color attachments in the current subpass.

- **VUID-vkCmdExecuteGeneratedCommandsNV-firstAttachment-07479**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT` dynamic state enabled then
**vkCmdSetColorBlendAdvancedEXT** must have been called in the current command buffer prior to this drawing command, and the attachments specified by the **firstAttachment** and **attachmentCount** parameters of **vkCmdSetColorBlendAdvancedEXT** calls must specify the advanced blend equations for all active color attachments in the current subpass where blending is enabled.

- **VUID-vkCmdExecuteGeneratedCommandsNV-advancedBlendMaxColorAttachments-07480**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT** and **VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT** dynamic states enabled and the last calls to **vkCmdSetColorBlendEnableEXT** and **vkCmdSetColorBlendAdvancedEXT** have enabled advanced blending, then the number of active color attachments in the current subpass must not exceed **advancedBlendMaxColorAttachments**.

- **VUID-vkCmdExecuteGeneratedCommandsNV-primitivesGeneratedQueryWithNonZeroStreams-07481**
  If the **primitivesGeneratedQueryWithNonZeroStreams** feature is not enabled and the **VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT** query is active, and the bound graphics pipeline was created with **VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT** state enabled, the last call to **vkCmdSetRasterizationStreamEXT** must have set the **rasterizationStream** to zero.

- **VUID-vkCmdExecuteGeneratedCommandsNV-sampleLocationsPerPixel-07482**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT** state enabled and the **VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT** state disabled, then the **sampleLocationsPerPixel** member of **pSampleLocationsInfo** in the last call to **vkCmdSetSampleLocationsEXT** must equal the **rasterizationSamples** member of the **VkPipelineMultisampleStateCreateInfo** structure the bound graphics pipeline has been created with.

- **VUID-vkCmdExecuteGeneratedCommandsNV-sampleLocationsPerPixel-07483**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT** state enabled and the **VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT** state enabled, then the **sampleLocationsPerPixel** member of **pSampleLocationsInfo** in the last call to **vkCmdSetSampleLocationsEXT** must equal the **rasterizationSamples** parameter of the last call to **vkCmdSetRasterizationSamplesEXT**.

- **VUID-vkCmdExecuteGeneratedCommandsNV-sampleLocationsEnable-07484**
  If the bound graphics pipeline was created with the **VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT** state enabled, and **sampleLocationsEnable** was **VK_TRUE** in the last call to **vkCmdSetSampleLocationsEnableEXT**, and the current subpass has a depth/stencil attachment, then that attachment must have been created with the **VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT** bit set.

- **VUID-vkCmdExecuteGeneratedCommandsNV-sampleLocationsEnable-07485**
  If the bound graphics pipeline state was created with the **VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT** state enabled, and if **sampleLocationsEnable** was **VK_TRUE** in the last call to **vkCmdSetSampleLocationsEnableEXT**, then the
sampleLocationsInfo.sampleLocationGridSize.width in the last call to 
vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT ::sampleLocationGridSize.width as returned by 
vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples

• VUID-vkCmdExecuteGeneratedCommandsNV-sampleLocationsEnable-07486  
If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state enabled and the 
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, then the 
sampleLocationsInfo.sampleLocationGridSize.height in the last call to 
vkCmdSetSampleLocationsEXT must evenly divide VkMultisamplePropertiesEXT ::sampleLocationGridSize.height as returned by 
vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling rasterizationSamples

• VUID-vkCmdExecuteGeneratedCommandsNV-sampleLocationsEnable-07487  
If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, and if sampleLocationsEnable was VK_TRUE in the last call to vkCmdSetSampleLocationsEnableEXT, the fragment shader code must not statically use the extended instruction InterpolateAtSample

• VUID-vkCmdExecuteGeneratedCommandsNV-sampleLocationsEnable-07936  
If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the 
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.width must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.width as returned by 
vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

• VUID-vkCmdExecuteGeneratedCommandsNV-sampleLocationsEnable-07937  
If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the 
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.height must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by 
vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT

• VUID-vkCmdExecuteGeneratedCommandsNV-sampleLocationsEnable-07938  
If the bound graphics pipeline state was created with the 
VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT state disabled and the 
VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT state enabled, the sampleLocationsEnable member of a VkPipelineSampleLocationsStateCreateInfoEXT::sampleLocationsEnable in the bound graphics pipeline is VK_TRUE or VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT state enabled, then, sampleLocationsInfo.sampleLocationGridSize.height must evenly divide VkMultisamplePropertiesEXT::sampleLocationGridSize.height as returned by 
vkGetPhysicalDeviceMultisamplePropertiesEXT with a samples parameter equaling the value of rasterizationSamples in the last call to vkCmdSetRasterizationSamplesEXT
enabled, then, \( \text{sampleLocationsInfo.sampleLocationsPerPixel} \) must equal \( \text{rasterizationSamples} \) in the last call to `vkCmdSetRasterizationSamplesEXT`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-coverageModulationTableEnable-07488**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageModulationTableEnableNV` set `coverageModulationTableEnable` to `VK_TRUE`, then the `coverageModulationTableCount` parameter in the last call to `vkCmdSetCoverageModulationTableNV` must equal the current `rasterizationSamples` divided by the number of color samples in the current subpass.

- **VUID-vkCmdExecuteGeneratedCommandsNV-rasterizationSamples-07489**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if current subpass has a depth/stencil attachment and depth test, stencil test, or depth bounds test are enabled in the currently bound pipeline state, then the current `rasterizationSamples` must be the same as the sample count of the depth/stencil attachment.

- **VUID-vkCmdExecuteGeneratedCommandsNV-coverageToColorEnable-07490**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` state enabled and the last call to `vkCmdSetCoverageToColorEnableNV` set `coverageToColorEnable` to `VK_TRUE`, then the current subpass must have a color attachment at the location selected by the last call to `vkCmdSetCoverageToColorLocationNV` `coverageToColorLocation`, with a `VkFormat` of `VK_FORMAT_R8_UINT`, `VK_FORMAT_R8_SINT`, `VK_FORMAT_R16_UINT`, `VK_FORMAT_R16_SINT`, `VK_FORMAT_R32_UINT`, or `VK_FORMAT_R32_SINT`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-coverageReductionMode-07491**
  If this `VK_NV_coverage_reduction_mode` extension is enabled, the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV` and `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT` states enabled, the current coverage reduction mode `coverageReductionMode`, then the current `rasterizationSamples`, and the sample counts for the color and depth/stencil attachments (if the subpass has them) must be a valid combination returned by `vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-viewportCount-07492**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic state enabled, then the bound graphics pipeline must have been created with `VkPipelineViewportSwizzleStateCreateInfoNV::viewportCount` greater or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportWithCount`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-viewportCount-07493**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT` and `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV` dynamic states enabled then the `viewportCount` parameter in the last call to `vkCmdSetViewportSwizzleNV` must be greater than or equal to the `viewportCount` parameter in the last call to `vkCmdSetViewportSwizzleWithCount`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-rasterizationSamples-07494**
  If the `VK_NV_framebuffer_mixed_samples` extension is enabled, and if the current subpass...
has any color attachments and \texttt{rasterizationSamples} of the last call to \texttt{vkCmdSetRasterizationSamplesEXT} is greater than the number of color samples, then the pipeline \texttt{sampleShadingEnable} must be \texttt{VK_FALSE}.

- **VUID-vkCmdExecuteGeneratedCommandsNV-stippledLineEnable-07495**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT} or \texttt{VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT} dynamic states enabled, and if the current \texttt{stippledLineEnable} state is \texttt{VK_TRUE} and the current \texttt{lineRasterizationMode} state is \texttt{VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT}, then the \texttt{stippledRectangularLines} feature must be enabled.

- **VUID-vkCmdExecuteGeneratedCommandsNV-stippledLineEnable-07496**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT} or \texttt{VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT} dynamic states enabled, and if the current \texttt{stippledLineEnable} state is \texttt{VK_TRUE} and the current \texttt{lineRasterizationMode} state is \texttt{VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT}, then the \texttt{stippledBresenhamLines} feature must be enabled.

- **VUID-vkCmdExecuteGeneratedCommandsNV-stippledLineEnable-07497**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT} or \texttt{VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT} dynamic states enabled, and if the current \texttt{stippledLineEnable} state is \texttt{VK_TRUE} and the current \texttt{lineRasterizationMode} state is \texttt{VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT}, then the \texttt{stippledSmoothLines} feature must be enabled.

- **VUID-vkCmdExecuteGeneratedCommandsNV-stippledLineEnable-07498**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT} or \texttt{VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT} dynamic states enabled, and if the current \texttt{stippledLineEnable} state is \texttt{VK_TRUE} and the current \texttt{lineRasterizationMode} state is \texttt{VK_LINE_RASTERIZATION_MODE_DEFAULT_EXT}, then the \texttt{stippledRectangularLines} feature must be enabled and \texttt{VkPhysicalDeviceLimits::strictLines} must be \texttt{VK_TRUE}.

- **VUID-vkCmdExecuteGeneratedCommandsNV-conservativePointAndLineRasterization-07499**
  If the bound graphics pipeline state was created with the \texttt{VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT} dynamic state enabled, \texttt{conservativePointAndLineRasterization} is not supported, and the effective primitive topology output by the last pre-rasterization shader stage is a line or point, then the \texttt{conservativeRasterizationMode} set by the last call to \texttt{vkCmdSetConservativeRasterizationModeEXT} must be \texttt{VK_CONSERVATIVE_RASTERIZATION_MODE_DISABLED_EXT}.

- **VUID-vkCmdExecuteGeneratedCommandsNV-stage-07073**
  If the currently bound pipeline was created with the \texttt{VkPipelineShaderStageCreateInfo::stage} member of an element of \texttt{VkGraphicsPipelineCreateInfo::pStages} set to \texttt{VK_SHADER_STAGE_VERTEX_BIT}, \texttt{VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT}, \texttt{VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT} or \texttt{VK_SHADER_STAGE_GEOMETRY_BIT}, then \texttt{Mesh}
Shader Queries must not be active

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08877**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT` dynamic state, `vkCmdSetAttachmentFeedbackLoopEnableEXT` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-07850**
  If dynamic state was inherited from `VkCommandBufferInheritanceViewportScissorInfoNV`, it must be set in the current command buffer prior to this drawing command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08684**
  If there is no bound graphics pipeline, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_VERTEX_BIT`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08685**
  If there is no bound graphics pipeline, and the `tessellationShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08686**
  If there is no bound graphics pipeline, and the `tessellationShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08687**
  If there is no bound graphics pipeline, and the `geometryShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_GEOMETRY_BIT`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08688**
  If there is no bound graphics pipeline, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_FRAGMENT_BIT`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08689**
  If there is no bound graphics pipeline, and the `taskShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_TASK_BIT_EXT`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08690**
  If there is no bound graphics pipeline, and the `meshShader` feature is enabled, `vkCmdBindShadersEXT` must have been called in the current command buffer with `pStages` with an element of `VK_SHADER_STAGE_MESH_BIT_EXT`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08693**
  If there is no bound graphics pipeline, and at least one of the `taskShader` and `meshShader` features is enabled, one of the `VK_SHADER_STAGE_VERTEX_BIT` or `VK_SHADER_STAGE_MESH_BIT_EXT` stages must have a valid `VkShaderEXT` bound, and the other must have no `VkShaderEXT` bound.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08694**
  If there is no bound graphics pipeline, and both the `taskShader` and `meshShader` features...
are enabled, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_MESH_BIT_EXT stage, and that VkShaderEXT was created without the VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT flag, a valid VkShaderEXT must be bound to the VK_SHADER_STAGE_TASK_BIT_EXT stage

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08695
  If there is no bound graphics pipeline, and both the taskShader and meshShader features are enabled, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_MESH_BIT_EXT stage, and that VkShaderEXT was created with the VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT flag, there must be no VkShaderEXT bound to the VK_SHADER_STAGE_TASK_BIT_EXT stage

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08696
  If there is no bound graphics pipeline, and a valid VkShaderEXT is bound to the VK_SHADER_STAGE_VERTEX_BIT stage, there must be no VkShaderEXT bound to either the VK_SHADER_STAGE_TASK_BIT_EXT stage or the VK_SHADER_STAGE_MESH_BIT_EXT stage

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08698
  If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, then all shaders created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag in the same vkCreateShadersEXT call must also be bound

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08699
  If any graphics shader is bound which was created with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag, any stages in between stages whose shaders which did not create a shader with the VK_SHADER_CREATE_LINK_STAGE_BIT_EXT flag as part of the same vkCreateShadersEXT call must not have any VkShaderEXT bound

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08878
  All bound graphics shader objects must have been created with identical or identically defined push constant ranges

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08879
  All bound graphics shader objects must have been created with identical or identically defined arrays of descriptor set layouts

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08880
  If a shader object is bound to the VK_SHADER_STAGE_FRAGMENT_BIT stage and the attachmentFeedbackLoopDynamicState feature is enabled on the device, and the most recent call to vkCmdSetRasterizerDiscardEnable in the current command buffer set rasterizerDiscardEnable to VK_FALSE vkCmdSetAttachmentFeedbackLoopEnableEXT must have been called in the current command buffer prior to this drawing command

• VUID-vkCmdExecuteGeneratedCommandsNV-pDynamicStates-08715
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE set in VkPipelineDynamicStateCreateInfo::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpDepthAttachmentReadEXT, the depthWriteEnable parameter in the last call to vkCmdSetDepthWriteEnable must be VK_FALSE

• VUID-vkCmdExecuteGeneratedCommandsNV-pDynamicStates-08716
  If the bound graphics pipeline state includes a fragment shader stage, was created with VK_DYNAMIC_STATE_STENCIL_WRITE_MASK set in VkPipelineDynamicStateCreateInfo::pDynamicStates
::pDynamicStates, and the fragment shader declares the EarlyFragmentTests execution mode and uses OpStencilAttachmentReadEXT, the writeMask parameter in the last call to vkCmdSetStencilWriteMask must be 0.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-09116
  If a shader object is bound to any graphics stage or the currently bound graphics pipeline was created with VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT, and the format of any color attachment is VK_FORMAT_E5B9G9R9_UFLOAT_PACK32, the corresponding element of the pColorWriteMasks parameter of vkCmdSetColorWriteMaskEXT must either include all of VK_COLOR_COMPONENT_R_BIT, VK_COLOR_COMPONENT_G_BIT, and VK_COLOR_COMPONENT_B_BIT, or none of them.

- VUID-vkCmdExecuteGeneratedCommandsNV-maxFragmentDualSrcAttachments-09239
  If blending is enabled for any attachment where either the source or destination blend factors for that attachment use the secondary color input, the maximum value of Location for any output attachment statically used in the Fragment Execution Model executed by this command must be less than maxFragmentDualSrcAttachments.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-04007
  All vertex input bindings accessed via vertex input variables declared in the vertex shader entry point's interface must have either valid or VK_NULL_HANDLE buffers bound.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-04008
  If the nullDescriptor feature is not enabled, all vertex input bindings accessed via vertex input variables declared in the vertex shader entry point's interface must not be VK_NULL_HANDLE.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-02721
  For a given vertex buffer binding, any attribute data fetched must be entirely contained within the corresponding vertex buffer binding, as described in Vertex Input Description.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-07842
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled then vkCmdSetPrimitiveTopology must have been called in the current command buffer prior to this drawing command.

- VUID-vkCmdExecuteGeneratedCommandsNV-dynamicPrimitiveTopologyUnrestricted-07500
  If the bound graphics pipeline state was created with the VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY dynamic state enabled and the dynamicPrimitiveTopologyUnrestricted is VK_FALSE, then the primitiveTopology parameter of vkCmdSetPrimitiveTopology must be of the same topology class as the pipeline VkPipelineInputAssemblyStateCreateInfo::topology state.

- VUID-vkCmdExecuteGeneratedCommandsNV-None-04912
  If the bound graphics pipeline was created with both the VK_DYNAMIC_STATE_VERTEX_INPUT_EXT and VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT dynamic states enabled, then vkCmdSetVertexInputEXT must have been called in the current command buffer prior to this draw command.

- VUID-vkCmdExecuteGeneratedCommandsNV-pStrides-04913
If the bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT` dynamic state enabled, but not the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then `vkCmdBindVertexBuffers2EXT` must have been called in the current command buffer prior to this draw command, and the `pStrides` parameter of `vkCmdBindVertexBuffers2EXT` must not be `NULL`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08881**
  If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetPrimitiveTopology` must have been called in the current command buffer prior to this drawing command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-04914**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then `vkCmdSetVertexInputEXT` must have been called in the current command buffer prior to this draw command.

- **VUID-vkCmdExecuteGeneratedCommandsNV-Input-07939**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then all variables with the `Input` storage class decorated with `Location` in the `Vertex Execution Model OpEntryPoint` must contain a location in `VkVertexInputAttributeDescription2EXT::location`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-Input-08734**
  If the bound graphics pipeline state was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, then the numeric type associated with all `Input` variables of the corresponding `Location` in the `Vertex Execution Model OpEntryPoint` must be the same as `VkVertexInputAttributeDescription2EXT::format`.

- **VUID-vkCmdExecuteGeneratedCommandsNV-format-08936**
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and `VkVertexInputAttributeDescription2EXT::format` has a 64-bit component, then the scalar width associated with all `Input` variables of the corresponding `Location` in the `Vertex Execution Model OpEntryPoint` must be 64-bit.

- **VUID-vkCmdExecuteGeneratedCommandsNV-format-08937**
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and the scalar width associated with a `Location` decorated `Input` variable in the `Vertex Execution Model OpEntryPoint` is 64-bit, then the corresponding `VkVertexInputAttributeDescription2EXT::format` must have a 64-bit component.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-09203**
  If there is a shader object bound to a graphics stage or the currently bound graphics pipeline was created with the `VK_DYNAMIC_STATE_VERTEX_INPUT_EXT` dynamic state enabled, and `VkVertexInputAttributeDescription2EXT::format` has a 64-bit component, then all `Input` variables at the corresponding `Location` in the `Vertex Execution Model OpEntryPoint` must not use components that are not present in the format.

- **VUID-vkCmdExecuteGeneratedCommandsNV-None-08882**
  If a shader object is bound to the `VK_SHADER_STAGE_VERTEX_BIT` stage, then `vkCmdSetVertexInputEXT` must have been called in the current command buffer prior to
this drawing command

• VUID-vkCmdExecuteGeneratedCommandsNV-None-04875
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT dynamic state enabled then
  vkCmdSetPatchControlPointsEXT must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08883
  If a shader object is bound to the VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT stage, then
  vkCmdSetPatchControlPointsEXT must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdExecuteGeneratedCommandsNV-None-04879
  If the bound graphics pipeline state was created with the
  VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE dynamic state enabled then
  vkCmdSetPrimitiveRestartEnable must have been called in the current command buffer
  prior to this drawing command

• VUID-vkCmdExecuteGeneratedCommandsNV-rasterizerDiscardEnable-08884
  If a shader object is bound to any graphics stage, and the most recent call to
  vkCmdSetRasterizerDiscardEnable in the current command buffer set
  rasterizerDiscardEnable to VK_FALSE, vkCmdSetPrimitiveRestartEnable must have been
  called in the current command buffer prior to this drawing command

• VUID-vkCmdExecuteGeneratedCommandsNV-stage-06481
  The bound graphics pipeline must not have been created with the
  VkPipelineShaderStageCreateInfo::stage member of an element of
  VkGraphicsPipelineCreateInfo::pStages set to VK_SHADER_STAGE_TASK_BIT_EXT or
  VK_SHADER_STAGE_MESH_BIT_EXT

• VUID-vkCmdExecuteGeneratedCommandsNV-None-08885
  There must be no shader object bound to either of the VK_SHADER_STAGE_TASK_BIT_EXT or
  VK_SHADER_STAGE_MESH_BIT_EXT stages

• VUID-vkCmdExecuteGeneratedCommandsNV-commandBuffer-02970
  commandBuffer must not be a protected command buffer

• VUID-vkCmdExecuteGeneratedCommandsNV-isPreprocessed-02908
  If isPreprocessed is VK_TRUE then vkCmdPreprocessGeneratedCommandsNV must have
  already been executed on the device, using the same pGeneratedCommandsInfo content as
  well as the content of the input buffers it references (all except
  VkGeneratedCommandsInfoNV::preprocessBuffer). Furthermore pGeneratedCommandsInfo’s
  indirectCommandsLayout must have been created with the
  VK_INDIRECT_COMMANDS_LAYOUT_USAGE_EXPLICIT_PREPROCESS_BIT_NV bit set

• VUID-vkCmdExecuteGeneratedCommandsNV-pipeline-02909
  VkGeneratedCommandsInfoNV::pipeline must match the current bound pipeline at
  VkGeneratedCommandsInfoNV::pipelineBindPoint

• VUID-vkCmdExecuteGeneratedCommandsNV-None-02910
  Transform feedback must not be active

• VUID-vkCmdExecuteGeneratedCommandsNV-deviceGeneratedCommands-02911
The `VkPhysicalDeviceDeviceGeneratedCommandsFeaturesNV::deviceGeneratedCommands` feature must be enabled.

**Valid Usage (Implicit)**
- VUID-vkCmdExecuteGeneratedCommandsNV-commandBuffer-parameter `commandBuffer` must be a valid `VkCommandBuffer` handle.
- VUID-vkCmdExecuteGeneratedCommandsNV-pGeneratedCommandsInfo-parameter `pGeneratedCommandsInfo` must be a valid pointer to a valid `VkGeneratedCommandsInfoNV` structure.
- VUID-vkCmdExecuteGeneratedCommandsNV-commandBuffer-recording `commandBuffer` must be in the recording state.
- VUID-vkCmdExecuteGeneratedCommandsNV-commandBuffer-cmdpool The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, or compute operations.
- VUID-vkCmdExecuteGeneratedCommandsNV-renderpass This command must only be called inside of a render pass instance.
- VUID-vkCmdExecuteGeneratedCommandsNV-videocoding This command must only be called outside of a video coding scope.

**Host Synchronization**
- Host access to `commandBuffer` must be externally synchronized.
- Host access to the ` VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

**Command Properties**

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// Provided by VK_NV_device_generated_commands
typedef struct VkGeneratedCommandsInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkPipelineBindPoint pipelineBindPoint;
    VkPipeline pipeline;
    VkIndirectCommandsLayoutNV indirectCommandsLayout;
    uint32_t streamCount;
};
constVkIndirectCommandsStreamNV*pStreams;
uint32_t sequencesCount;
VkBuffer preprocessBuffer;
VkDeviceSize preprocessOffset;
VkDeviceSize preprocessSize;
VkBuffer sequencesCountBuffer;
VkDeviceSize sequencesCountOffset;
VkBuffer sequencesIndexBuffer;
VkDeviceSize sequencesIndexOffset;
}VkGeneratedCommandsInfoNV;

• **sType** is a VkStructureType value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **pipelineBindPoint** is the VkPipelineBindPoint used for the pipeline.

• **pipeline** is the VkPipeline used in the generation and execution process.

• **indirectCommandsLayout** is the VkIndirectCommandsLayoutNV that provides the command sequence to generate.

• **streamCount** defines the number of input streams

• **pStreams** is a pointer to an array of streamCount VkIndirectCommandsStreamNV structures providing the input data for the tokens used in indirectCommandsLayout.

• **sequencesCount** is the maximum number of sequences to reserve. If sequencesCountBuffer is VK_NULL_HANDLE, this is also the actual number of sequences generated.

• **preprocessBuffer** is the VkBuffer that is used for preprocessing the input data for execution. If this structure is used with vkCmdExecuteGeneratedCommandsNV with its isPreprocessed set to VK_TRUE, then the preprocessing step is skipped and data is only read from this buffer. The contents and the layout of this buffer is opaque to applications and must not be modified or copied to another buffer for reuse.

• **preprocessOffset** is the byte offset into preprocessBuffer where the preprocessed data is stored.

• **preprocessSize** is the maximum byte size within the preprocessBuffer after the preprocessOffset that is available for preprocessing.

• **sequencesCountBuffer** is a VkBuffer in which the actual number of sequences is provided as single uint32_t value.

• **sequencesCountOffset** is the byte offset into sequencesCountBuffer where the count value is stored.

• **sequencesIndexBuffer** is a VkBuffer that encodes the used sequence indices as uint32_t array.

• **sequencesIndexOffset** is the byte offset into sequencesIndexBuffer where the index values start.

**Valid Usage**

• VUID-VkGeneratedCommandsInfoNV-pipeline-02912
  The provided pipeline must match the pipeline bound at execution time

• VUID-VkGeneratedCommandsInfoNV-indirectCommandsLayout-02913
If the indirectCommandsLayout uses a token of VK_INDIRECT_COMMANDS_TOKEN_TYPE_SHADER_GROUP_NV, then the pipeline must have been created with multiple shader groups.

- VUID-VkGeneratedCommandsInfoNV-indirectCommandsLayout-02914
  If the indirectCommandsLayout uses a token of VK_INDIRECT_COMMANDS_TOKEN_TYPE_SHADER_GROUP_NV, then the pipeline must have been created with VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV set in VkGraphicsPipelineCreateInfo::flags.

- VUID-VkGeneratedCommandsInfoNV-indirectCommandsLayout-02915
  If the indirectCommandsLayout uses a token of VK_INDIRECT_COMMANDS_TOKEN_TYPE_SHADER_GROUP_NV, then the pipeline must have been created with multiple shader groups.

- VUID-VkGeneratedCommandsInfoNV-indirectCommandsLayout-02916
  streamCount must match the indirectCommandsLayout's streamCount.

- VUID-VkGeneratedCommandsInfoNV-pipelineBindPoint-09084
  If pipelineBindPoint is of type VK_PIPELINE_BIND_POINT_COMPUTE, then the pipeline must have been created with the flag VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV.

- VUID-VkGeneratedCommandsInfoNV-pipelineBindPoint-09085
  If pipelineBindPoint is of type VK_PIPELINE_BIND_POINT_COMPUTE, then the pipeline must have been created with a VkComputePipelineIndirectBufferInfoNV structure specifying a valid address where its metadata will be saved.

- VUID-VkGeneratedCommandsInfoNV-pipelineBindPoint-09086
  If pipelineBindPoint is of type VK_PIPELINE_BIND_POINT_COMPUTE, then vkCmdUpdatePipelineIndirectBufferNV must have been called on that pipeline to save its metadata to a device address.

- VUID-VkGeneratedCommandsInfoNV-pipelineBindPoint-09087
  If pipelineBindPoint is of type VK_PIPELINE_BIND_POINT_COMPUTE, and if VK_INDIRECT_COMMANDS_TOKEN_TYPE_PIPELINE_NV is used, then pipeline must be VK_NULL_HANDLE.

- VUID-VkGeneratedCommandsInfoNV-sequencesCount-02917
  sequencesCount must be less or equal to VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV::maxIndirectSequenceCount and VkGeneratedCommandsMemoryRequirementsInfoNV::maxSequencesCount that was used to determine the preprocessSize.

- VUID-VkGeneratedCommandsInfoNV-preprocessBuffer-02918
  preprocessBuffer must have the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT bit set in its usage flag.

- VUID-VkGeneratedCommandsInfoNV-preprocessOffset-02919
  preprocessOffset must be aligned to VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV::minIndirectCommandsBufferOffsetAlignment.

- VUID-VkGeneratedCommandsInfoNV-preprocessBuffer-02971
  If preprocessBuffer is non-sparse then it must be bound completely and contiguously to a
single VkDeviceMemory object

- **VUID-VkGeneratedCommandsInfoNV-preprocessSize-02920**
  preprocessSize must be at least equal to the memory requirement’s size returned by vkGetGeneratedCommandsMemoryRequirementsNV using the matching inputs (indirectCommandsLayout, ...) as within this structure

- **VUID-VkGeneratedCommandsInfoNV-sequencesCountBuffer-02921**
  sequencesCountBuffer can be set if the actual used count of sequences is sourced from the provided buffer. In that case the sequencesCount serves as upper bound

- **VUID-VkGeneratedCommandsInfoNV-sequencesCountBuffer-02922**
  If sequencesCountBuffer is not VK_NULL_HANDLE, its usage flag must have the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT bit set

- **VUID-VkGeneratedCommandsInfoNV-sequencesCountBuffer-02923**
  If sequencesCountBuffer is not VK_NULL_HANDLE, sequencesCountOffset must be aligned to VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV::minSequencesCountBufferOffsetAlignment

- **VUID-VkGeneratedCommandsInfoNV-sequencesCountBuffer-02924**
  If sequencesCountBuffer is not VK_NULL_HANDLE and is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- **VUID-VkGeneratedCommandsInfoNV-sequencesIndexBuffer-02924**
  If indirectCommandsLayout's VK_INDIRECT_COMMANDS_LAYOUT_USAGE_INDEXED_SEQUENCES_BIT_NV is set, sequencesIndexBuffer must be set otherwise it must be VK_NULL_HANDLE

- **VUID-VkGeneratedCommandsInfoNV-sequencesIndexBuffer-02925**
  If sequencesIndexBuffer is not VK_NULL_HANDLE, its usage flag must have the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT bit set

- **VUID-VkGeneratedCommandsInfoNV-sequencesIndexBuffer-02926**
  If sequencesIndexBuffer is not VK_NULL_HANDLE, sequencesIndexOffset must be aligned to VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV::minSequencesIndexBufferOffsetAlignment

- **VUID-VkGeneratedCommandsInfoNV-sequencesIndexBuffer-02927**
  If sequencesIndexBuffer is not VK_NULL_HANDLE and is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- **VUID-VkGeneratedCommandsInfoNV-indirectCommandsLayout-07078**
  If the indirectCommandsLayout uses a token of VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_TASKS_NV, then the pipeline must contain a shader stage using the MeshNV Execution Model

- **VUID-VkGeneratedCommandsInfoNV-indirectCommandsLayout-07079**
  If the indirectCommandsLayout uses a token of VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_MESH_TASKS_NV, then the pipeline must contain a shader stage using the MeshEXT Execution Model
Valid Usage (Implicit)

- VUID-VkGeneratedCommandsInfoNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_GENERATED_COMMANDS_INFO_NV

- VUID-VkGeneratedCommandsInfoNV-pNext-pNext
  pNext must be NULL

- VUID-VkGeneratedCommandsInfoNV-pipelineBindPoint-parameter
  pipelineBindPoint must be a valid VkPipelineBindPoint value

- VUID-VkGeneratedCommandsInfoNV-pipeline-parameter
  pipeline must be a valid VkPipeline handle

- VUID-VkGeneratedCommandsInfoNV-indirectCommandsLayout-parameter
  indirectCommandsLayout must be a valid VkIndirectCommandsLayoutNV handle

- VUID-VkGeneratedCommandsInfoNV-pStreams-parameter
  pStreams must be a valid pointer to an array of streamCount valid
  VkIndirectCommandsStreamNV structures

- VUID-VkGeneratedCommandsInfoNV-preprocessBuffer-parameter
  preprocessBuffer must be a valid VkBuffer handle

- VUID-VkGeneratedCommandsInfoNV-sequencesCountBuffer-parameter
  If sequencesCountBuffer is not VK_NULL_HANDLE, sequencesCountBuffer must be a valid
  VkBuffer handle

- VUID-VkGeneratedCommandsInfoNV-sequencesIndexBuffer-parameter
  If sequencesIndexBuffer is not VK_NULL_HANDLE, sequencesIndexBuffer must be a valid
  VkBuffer handle

- VUID-VkGeneratedCommandsInfoNV-streamCount-arraylength
  streamCount must be greater than 0

- VUID-VkGeneratedCommandsInfoNV-commonparent
  Each of indirectCommandsLayout, pipeline, preprocessBuffer, sequencesCountBuffer, and
  sequencesIndexBuffer that are valid handles of non-ignored parameters must have been
  created, allocated, or retrieved from the same VkDevice

Referencing the functions defined in Indirect Commands Layout, vkCmdExecuteGeneratedCommandsNV
behaves as:

```c
uint32_t sequencesCount = sequencesCountBuffer ?
    min(maxSequencesCount, sequencesCountBuffer.load_uint32(sequencesCountOffset)) :
    maxSequencesCount;

cmdProcessAllSequences(commandBuffer, pipeline,
    indirectCommandsLayout, pIndirectCommandsStreams,
    sequencesCount,
    sequencesIndexBuffer, sequencesIndexOffset);
```
The stateful commands within indirectCommandsLayout will not affect the state of subsequent commands in the target command buffer (cmd).

**Note**

It is important to note that the values of all state related to the pipelineBindPoint used are undefined after this command.

Commands can be preprocessed prior execution using the following command:

```c
// Provided by VK_NV_device_generated_commands
void vkCmdPreprocessGeneratedCommandsNV(
    VkCommandBuffer commandBuffer,
    const VkGeneratedCommandsInfoNV* pGeneratedCommandsInfo);
```

- `commandBuffer` is the command buffer which does the preprocessing.
- `pGeneratedCommandsInfo` is a pointer to a `VkGeneratedCommandsInfoNV` structure containing parameters affecting the preprocessing step.

**Valid Usage**

- VUID-vkCmdPreprocessGeneratedCommandsNV-commandBuffer-02974 `commandBuffer` must not be a protected command buffer
- VUID-vkCmdPreprocessGeneratedCommandsNV-pGeneratedCommandsInfo-02927 `pGeneratedCommandsInfo`'s indirectCommandsLayout must have been created with the `VK_INDIRECT_COMMANDS_LAYOUT_USAGE_EXPLICIT_PREPROCESS_BIT_NV` bit set
- VUID-vkCmdPreprocessGeneratedCommandsNV-deviceGeneratedCommands-02928 The `VkPhysicalDeviceDeviceGeneratedCommandsFeaturesNV::deviceGeneratedCommands` feature must be enabled

**Valid Usage (Implicit)**

- VUID-vkCmdPreprocessGeneratedCommandsNV-commandBuffer-parameter `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdPreprocessGeneratedCommandsNV-pGeneratedCommandsInfo-parameter `pGeneratedCommandsInfo` must be a valid pointer to a valid `VkGeneratedCommandsInfoNV` structure
- VUID-vkCmdPreprocessGeneratedCommandsNV-commandBuffer-recording `commandBuffer` must be in the recording state
- VUID-vkCmdPreprocessGeneratedCommandsNV-commandBuffer-cmdpool The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, or compute operations
Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Outside</td>
<td>Outside</td>
<td>Graphics, Compute</td>
<td>Action</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The bound descriptor sets and push constants that will be used with indirect command generation for the compute pipelines must already be specified at the time of preprocessing commands with vkCmdPreprocessGeneratedCommandsNV. They must not change until the execution of indirect commands is submitted with vkCmdExecuteGeneratedCommandsNV.

If push constants for the compute pipeline are also specified in the VkGeneratedCommandsInfoNV::indirectCommandsLayout with VK_INDIRECT_COMMANDS_TOKEN_TYPE_PUSH_CONSTANT_NV token, then those values override the push constants that were previously pushed for the compute pipeline.
Chapter 33. Sparse Resources

As documented in Resource Memory Association, VkBuffer and VkImage resources in Vulkan must be bound completely and contiguously to a single VkDeviceMemory object. This binding must be done before the resource is used, and the binding is immutable for the lifetime of the resource.

Sparse resources relax these restrictions and provide these additional features:

- Sparse resources can be bound non-contiguously to one or more VkDeviceMemory allocations.
- Sparse resources can be re-bound to different memory allocations over the lifetime of the resource.
- Sparse resources can have descriptors generated and used orthogonally with memory binding commands.

33.1. Sparse Resource Features

Sparse resources have several features that must be enabled explicitly at resource creation time. The features are enabled by including bits in the flags parameter of VkImageCreateInfo or VkBufferCreateInfo. Each feature also has one or more corresponding feature enables specified in VkPhysicalDeviceFeatures.

- The sparseBinding feature is the base, and provides the following capabilities:
  ◦ Resources can be bound at some defined (sparse block) granularity.
  ◦ The entire resource must be bound to memory before use regardless of regions actually accessed.
  ◦ No specific mapping of image region to memory offset is defined, i.e. the location that each texel corresponds to in memory is implementation-dependent.
  ◦ Sparse buffers have a well-defined mapping of buffer range to memory range, where an offset into a range of the buffer that is bound to a single contiguous range of memory corresponds to an identical offset within that range of memory.
  ◦ Requested via the VK_IMAGE_CREATE_SPARSE_BINDING_BIT and VK_BUFFER_CREATE_SPARSE_BINDING_BIT bits.
  ◦ A sparse image created using VK_IMAGE_CREATE_SPARSE_BINDING_BIT (but not VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT) supports all formats that non-sparse usage supports, and supports both VK_IMAGE_TILING_OPTIMAL and VK_IMAGE_TILING_LINEAR tiling.

- Sparse Residency builds on (and requires) the sparseBinding feature. It includes the following capabilities:
  ◦ Resources do not have to be completely bound to memory before use on the device.
  ◦ Images have a prescribed sparse image block layout, allowing specific rectangular regions of the image to be bound to specific offsets in memory allocations.
  ◦ Consistency of access to unbound regions of the resource is defined by the absence or presence of VkPhysicalDeviceSparseProperties::residencyNonResidentStrict. If this property is present, accesses to unbound regions of the resource are well defined and behave as if the
data bound is populated with all zeros; writes are discarded. When this property is absent, accesses are considered safe, but reads will return undefined values.

- Requested via the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` and `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` bits.
- Sparse residency support is advertised on a finer grain via the following features:
  
  - The `sparseResidencyBuffer` feature provides support for creating `VkBuffer` objects with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT`.
  - The `sparseResidencyImage2D` feature provides support for creating 2D single-sampled `VkImage` objects with `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`.
  - The `sparseResidencyImage3D` feature provides support for creating 3D `VkImage` objects with `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`.
  - The `sparseResidency2Samples` feature provides support for creating 2D `VkImage` objects with 2 samples and `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`.
  - The `sparseResidency4Samples` feature provides support for creating 2D `VkImage` objects with 4 samples and `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`.
  - The `sparseResidency8Samples` feature provides support for creating 2D `VkImage` objects with 8 samples and `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`.
  - The `sparseResidency16Samples` feature provides support for creating 2D `VkImage` objects with 16 samples and `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`.

Implementations supporting `sparseResidencyImage2D` are only required to support sparse 2D, single-sampled images. Support for sparse 3D and MSAA images is optional and can be enabled via `sparseResidencyImage3D`, `sparseResidency2Samples`, `sparseResidency4Samples`, `sparseResidency8Samples`, and `sparseResidency16Samples`.

- A sparse image created using `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` supports all non-compressed color formats with power-of-two element size that non-sparse usage supports. Additional formats may also be supported and can be queried via `vkGetPhysicalDeviceSparseImageFormatProperties`. `VK_IMAGE_TILING_LINEAR` tiling is not supported.

- The `sparseResidencyAliased` feature provides the following capability that can be enabled per resource:

  Allows physical memory ranges to be shared between multiple locations in the same sparse resource or between multiple sparse resources, with each binding of a memory location observing a consistent interpretation of the memory contents.

See Sparse Memory Aliasing for more information.

### 33.2. Sparse Buffers and Fully-Resident Images

Both `VkBuffer` and `VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_BINDING_BIT` or `VK_BUFFER_CREATE_SPARSE_BINDING_BIT` bits can be thought of as a linear region of address space. In the `VkImage` case if `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` is not used, this linear region is entirely...
opaque, meaning that there is no application-visible mapping between texel location and memory offset.

Unless `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` or `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` are also used, the entire resource must be bound to one or more `VkDeviceMemory` objects before use.

### 33.2.1. Sparse Buffer and Fully-Resident Image Block Size

The sparse block size in bytes for sparse buffers and fully-resident images is reported as `VkMemoryRequirements::alignment`. `alignment` represents both the memory alignment requirement and the binding granularity (in bytes) for sparse resources.

### 33.3. Sparse Partially-Resident Buffers

`VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` bit allow the buffer to be made only partially resident. Partially resident `VkBuffer` objects are allocated and bound identically to `VkBuffer` objects using only the `VK_BUFFER_CREATE_SPARSE_BINDING_BIT` feature. The only difference is the ability for some regions of the buffer to be unbound during device use.

### 33.4. Sparse Partially-Resident Images

`VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` bit allow specific rectangular regions of the image called sparse image blocks to be bound to specific ranges of memory. This allows the application to manage residency at either image subresource or sparse image block granularity. Each image subresource (outside of the mip tail) starts on a sparse block boundary and has dimensions that are integer multiples of the corresponding dimensions of the sparse image block.

**Note**

Applications can use these types of images to control LOD based on total memory consumption. If memory pressure becomes an issue the application can unbind and disable specific mipmap levels of images without having to recreate resources or modify texel data of unaffected levels.

The application can also use this functionality to access subregions of the image in a “megatexture” fashion. The application can create a large image and only populate the region of the image that is currently being used in the scene.

### 33.4.1. Accessing Unbound Regions

The following member of `VkPhysicalDeviceSparseProperties` affects how data in unbound regions of sparse resources are handled by the implementation:

- `residencyNonResidentStrict`

If this property is not present, reads of unbound regions of the image will return undefined values. Both reads and writes are still considered safe and will not affect other resources or populated regions of the image.
If this property is present, all reads of unbound regions of the image will behave as if the region was bound to memory populated with all zeros; writes will be discarded.

**Image operations** performed on unbound memory **may** still alter some component values in the natural way for those accesses, e.g. substituting a value of one for alpha in formats that do not have an alpha component.

Example: Reading the alpha component of an unbacked `VK_FORMAT_R8_UNORM` image will return a value of 1.0f.

See **Physical Device Enumeration** for instructions for retrieving physical device properties.

---

**Implementor’s Note**

For implementations that **cannot** natively handle access to unbound regions of a resource, the implementation **may** allocate and bind memory to the unbound regions. Reads and writes to unbound regions will access the implementation-managed memory instead.

Given that the values resulting from reads of unbound regions are undefined in this scenario, implementations **may** use the same physical memory for all unbound regions of multiple resources within the same process.

---

### 33.4.2. Mip Tail Regions

Sparse images created using `VK_IMAGE_CREATE_SPARSE_BINDING_BIT` (without also using `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`) have no specific mapping of image region or image subresource to memory offset defined, so the entire image can be thought of as a linear opaque address region. However, images created with `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` do have a prescribed sparse image block layout, and hence each image subresource must start on a sparse block boundary. Within each array layer, the set of mip levels that have a smaller size than the sparse block size in bytes are grouped together into a **mip tail region**.

If the `VK_SPARSE_IMAGE_FORMAT_ALIGNED_MIP_SIZE_BIT` flag is present in the `flags` member of `VkSparseImageFormatProperties`, for the image's `format`, then any mip level which has dimensions that are not integer multiples of the corresponding dimensions of the sparse image block, and all subsequent mip levels, are also included in the mip tail region.

The following member of `VkPhysicalDeviceSparseProperties` may affect how the implementation places mip levels in the mip tail region:

- `residencyAlignedMipSize`

Each mip tail region is bound to memory as an opaque region (i.e. **must** be bound using a `VkSparseImageOpaqueMemoryBindInfo` structure) and **may** be of a size greater than or equal to the sparse block size in bytes. This size is guaranteed to be an integer multiple of the sparse block size in bytes.
An implementation **may** choose to allow each array-layer's mip tail region to be bound to memory independently or require that all array-layer's mip tail regions be treated as one. This is dictated by `VK_SPARSE_IMAGE_FORMAT_SINGLE_MIPTAIL_BIT` in `VkSparseImageMemoryRequirements::flags`.

The following diagrams depict how `VK_SPARSE_IMAGE_FORMAT_ALIGNED_MIP_SIZE_BIT` and `VK_SPARSE_IMAGE_FORMAT_SINGLE_MIPTAIL_BIT` alter memory usage and requirements.

![Figure 22. Sparse Image](image)

In the absence of `VK_SPARSE_IMAGE_FORMAT_ALIGNED_MIP_SIZE_BIT` and `VK_SPARSE_IMAGE_FORMAT_SINGLE_MIPTAIL_BIT`, each array layer contains a mip tail region containing texel data for all mip levels smaller than the sparse image block in any dimension.

Mip levels that are as large or larger than a sparse image block in all dimensions **can** be bound individually. Right-edges and bottom-edges of each level are allowed to have partially used sparse blocks. Any bound partially-used-sparse-blocks **must** still have their full sparse block size in bytes allocated in memory.
Figure 23. Sparse Image with Single Mip Tail

When `VK_SPARSE_IMAGE_FORMAT_SINGLE_MIPTAIL_BIT` is present all array layers will share a single mip tail region.

Figure 24. Sparse Image with Aligned Mip Size

### Note
The mip tail regions are presented here in 2D arrays simply for figure size reasons. Each mip tail is logically a single array of sparse blocks with an implementation-dependent mapping of texels or compressed texel blocks to sparse blocks.

When `VK_SPARSE_IMAGE_FORMAT_ALIGNED_MIP_SIZE_BIT` is present the first mip level that would contain partially used sparse blocks begins the mip tail region. This level and all subsequent levels are placed in the mip tail. Only the first $N$ mip levels whose dimensions are an exact multiple of the sparse image block dimensions can be bound and unbound on a sparse block basis.

![Figure 25. Sparse Image with Aligned Mip Size and Single Mip Tail](image)

**Note**
The mip tail region is presented here in a 2D array simply for figure size reasons. It is logically a single array of sparse blocks with an implementation-dependent mapping of texels or compressed texel blocks to sparse blocks.

When both `VK_SPARSE_IMAGE_FORMAT_ALIGNED_MIP_SIZE_BIT` and `VK_SPARSE_IMAGE_FORMAT_SINGLE_MIPTAIL_BIT` are present the constraints from each of these flags are in effect.

### 33.4.3. Standard Sparse Image Block Shapes

Standard sparse image block shapes define a standard set of dimensions for sparse image blocks that depend on the format of the image. Layout of texels or compressed texel blocks within a sparse image block is implementation-dependent. All currently defined standard sparse image block shapes are 64 KB in size.

For block-compressed formats (e.g. `VK_FORMAT_BC5_UNORM_BLOCK`), the texel size is the size of the compressed texel block (e.g. 128-bit for BC5) thus the dimensions of the standard sparse image block...
shapes apply in terms of compressed texel blocks.

Note

For block-compressed formats, the dimensions of a sparse image block in terms of texels can be calculated by multiplying the sparse image block dimensions by the compressed texel block dimensions.
<table>
<thead>
<tr>
<th>TEXEL SIZE (bits)</th>
<th>Block Shape (2D)</th>
<th>Block Shape (3D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-Bit</td>
<td>256 × 256 × 1</td>
<td>64 × 32 × 32</td>
</tr>
<tr>
<td>16-Bit</td>
<td>256 × 128 × 1</td>
<td>32 × 32 × 32</td>
</tr>
<tr>
<td>32-Bit</td>
<td>128 × 128 × 1</td>
<td>32 × 32 × 16</td>
</tr>
<tr>
<td>64-Bit</td>
<td>128 × 64 × 1</td>
<td>32 × 16 × 16</td>
</tr>
<tr>
<td>128-Bit</td>
<td>64 × 64 × 1</td>
<td>16 × 16 × 16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TEXEL SIZE (bits)</th>
<th>Block Shape (2X)</th>
<th>Block Shape (4X)</th>
<th>Block Shape (8X)</th>
<th>Block Shape (16X)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-Bit</td>
<td>128 × 256 × 1</td>
<td>128 × 128 × 1</td>
<td>64 × 128 × 1</td>
<td>64 × 64 × 1</td>
</tr>
<tr>
<td>16-Bit</td>
<td>128 × 128 × 1</td>
<td>128 × 64 × 1</td>
<td>64 × 64 × 1</td>
<td>64 × 32 × 1</td>
</tr>
<tr>
<td>32-Bit</td>
<td>64 × 128 × 1</td>
<td>64 × 64 × 1</td>
<td>32 × 64 × 1</td>
<td>32 × 32 × 1</td>
</tr>
<tr>
<td>64-Bit</td>
<td>64 × 64 × 1</td>
<td>64 × 32 × 1</td>
<td>32 × 32 × 1</td>
<td>32 × 16 × 1</td>
</tr>
<tr>
<td>128-Bit</td>
<td>32 × 64 × 1</td>
<td>32 × 32 × 1</td>
<td>16 × 32 × 1</td>
<td>16 × 16 × 1</td>
</tr>
</tbody>
</table>

Implementations that support the standard sparse image block shape for all formats listed in the Standard Sparse Image Block Shapes (Single Sample) and Standard Sparse Image Block Shapes (MSAA) tables may advertise the following VkPhysicalDeviceSparseProperties:

- residencyStandard2DBlockShape
- residencyStandard2DMultisampleBlockShape
- residencyStandard3DBlockShape

Reporting each of these features does not imply that all possible image types are supported as sparse. Instead, this indicates that no supported sparse image of the corresponding type will use custom sparse image block dimensions for any formats that have a corresponding standard sparse image block shape.

### 33.4.4. Custom Sparse Image Block Shapes

An implementation that does not support a standard image block shape for a particular sparse partially-resident image may choose to support a custom sparse image block shape for it instead. The dimensions of such a custom sparse image block shape are reported in VkSparseImageFormatProperties::imageGranularity. As with standard sparse image block shapes, the size in bytes of the custom sparse image block shape will be reported in VkMemoryRequirements::alignment.

Custom sparse image block dimensions are reported through vkGetPhysicalDeviceSparseImageFormatProperties and vkGetImageSparseMemoryRequirements.

An implementation must not support both the standard sparse image block shape and a custom...
33.4.5. Multiple Aspects

Partially resident images are allowed to report separate sparse properties for different aspects of the image. One example is for depth/stencil images where the implementation separates the depth and stencil data into separate planes. Another reason for multiple aspects is to allow the application to manage memory allocation for implementation-private metadata associated with the image. See the figure below:

![Multiple Aspect Sparse Image](image)

*Figure 26. Multiple Aspect Sparse Image*

**Note**

The mip tail regions are presented here in 2D arrays simply for figure size reasons. Each mip tail is logically a single array of sparse blocks with an implementation-dependent mapping of texels or compressed texel blocks to sparse blocks.

In the figure above the depth, stencil, and metadata aspects all have unique sparse properties. The sparse image block shape for the same image. The standard sparse image block shape must be used if it is supported.
per-texel stencil data is \( \frac{1}{4} \) the size of the depth data, hence the stencil sparse blocks include \( 4 \times \) the number of texels. The sparse block size in bytes for all of the aspects is identical and defined by \( \text{VkMemoryRequirements::alignment} \).

**Metadata**

The metadata aspect of an image has the following constraints:

- All metadata is reported in the mip tail region of the metadata aspect.
- All metadata **must** be bound prior to device use of the sparse image.

### 33.5. Sparse Memory Aliasing

By default sparse resources have the same aliasing rules as non-sparse resources. See [Memory Aliasing](#) for more information.

\texttt{VkDevice} objects that have the \texttt{sparseResidencyAliased} feature enabled are able to use the \texttt{VK_BUFFER_CREATE_SPARSE_ALIASED_BIT} and \texttt{VK_IMAGE_CREATE_SPARSE_ALIASED_BIT} flags for resource creation. These flags allow resources to access physical memory bound into multiple locations within one or more sparse resources in a *data consistent* fashion. This means that reading physical memory from multiple aliased locations will return the same value.

Care **must** be taken when performing a write operation to aliased physical memory. Memory dependencies **must** be used to separate writes to one alias from reads or writes to another alias. Writes to aliased memory that are not properly guarded against accesses to different aliases will have undefined results for all accesses to the aliased memory.

Applications that wish to make use of data consistent sparse memory aliasing **must** abide by the following guidelines:

- All sparse resources that are bound to aliased physical memory **must** be created with the \texttt{VK_BUFFER_CREATE_SPARSE_ALIASED_BIT} / \texttt{VK_IMAGE_CREATE_SPARSE_ALIASED_BIT} flag.
- All resources that access aliased physical memory **must** interpret the memory in the same way. This implies the following:
  - Buffers and images **cannot** alias the same physical memory in a data consistent fashion. The physical memory ranges **must** be used exclusively by buffers or used exclusively by images for data consistency to be guaranteed.
  - Memory in sparse image mip tail regions **cannot** access aliased memory in a data consistent fashion.
  - Sparse images that alias the same physical memory **must** have compatible formats and be using the same sparse image block shape in order to access aliased memory in a data consistent fashion.

Failure to follow any of the above guidelines will require the application to abide by the normal, non-sparse resource aliasing rules. In this case memory **cannot** be accessed in a data consistent fashion.
Enabling sparse resource memory aliasing can be a way to lower physical memory use, but it may reduce performance on some implementations. An application developer can test on their target HW and balance the memory / performance trade-offs measured.

### 33.6. Sparse Resource Implementation Guidelines (Informative)

This section is Informative. It is included to aid in implementors’ understanding of sparse resources.

**Device Virtual Address**

The basic `sparseBinding` feature allows the resource to reserve its own device virtual address range at resource creation time rather than relying on a bind operation to set this. Without any other creation flags, no other constraints are relaxed compared to normal resources. All pages **must** be bound to physical memory before the device accesses the resource.

The `sparseResidency` features allow sparse resources to be used even when not all pages are bound to memory. Implementations that support access to unbound pages without causing a fault **may** support `residencyNonResidentStrict`.

Not faulting on access to unbound pages is not enough to support `residencyNonResidentStrict`. An implementation **must** also guarantee that reads after writes to unbound regions of the resource always return data for the read as if the memory contains zeros. Depending on any caching hierarchy of the implementation this **may** not always be possible.

Any implementation that does not fault, but does not guarantee correct read values **must** not support `residencyNonResidentStrict`.

Any implementation that **cannot** access unbound pages without causing a fault will require the implementation to bind the entire device virtual address range to physical memory. Any pages that the application does not bind to memory **may** be bound to one (or more) "placeholder" physical page(s) allocated by the implementation. Given the following properties:

- A process **must** not access memory from another process
- Reads return undefined values

It is sufficient for each host process to allocate these placeholder pages and use them for all resources in that process. Implementations **may** allocate more often (per instance, per device, or per resource).

**Binding Memory**

The byte size reported in `VkMemoryRequirements::size` **must** be greater than or equal to the amount of physical memory **required** to fully populate the resource. Some implementations
require “holes” in the device virtual address range that are never accessed. These holes may be included in the size reported for the resource.

Including or not including the device virtual address holes in the resource size will alter how the implementation provides support for VkSparseImageOpaqueMemoryBindInfo. This operation must be supported for all sparse images, even ones created with VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT.

- If the holes are included in the size, this bind function becomes very easy. In most cases the resourceOffset is simply a device virtual address offset and the implementation can easily determine what device virtual address to bind. The cost is that the application may allocate more physical memory for the resource than it needs.

- If the holes are not included in the size, the application can allocate less physical memory than otherwise for the resource. However, in this case the implementation must account for the holes when mapping resourceOffset to the actual device virtual address intended to be mapped.

**Note**

If the application always uses VkSparseImageMemoryBindInfo to bind memory for the non-tail mip levels, any holes that are present in the resource size may never be bound.

Since VkSparseImageMemoryBindInfo uses texel locations to determine which device virtual addresses to bind, it is impossible to bind device virtual address holes with this operation.

**Binding Metadata Memory**

All metadata for sparse images have their own sparse properties and are embedded in the mip tail region for said properties. See the Multiaspect section for details.

Given that metadata is in a mip tail region, and the mip tail region must be reported as contiguous (either globally or per-array-layer), some implementations will have to resort to complicated offset → device virtual address mapping for handling VkSparseImageOpaqueMemoryBindInfo.

To make this easier on the implementation, the VK_SPARSE_MEMORY_BIND_METADATA_BIT explicitly specifies when metadata is bound with VkSparseImageOpaqueMemoryBindInfo. When this flag is not present, the resourceOffset may be treated as a strict device virtual address offset.

When VK_SPARSE_MEMORY_BIND_METADATA_BIT is present, the resourceOffset must have been derived explicitly from the imageMipTailOffset in the sparse resource properties returned for the metadata aspect. By manipulating the value returned for imageMipTailOffset, the resourceOffset does not have to correlate directly to a device virtual address offset, and may instead be whatever value makes it easiest for the implementation to derive the correct device virtual address.
33.7. Sparse Resource API

The APIs related to sparse resources are grouped into the following categories:

- Physical Device Features
- Physical Device Sparse Properties
- Sparse Image Format Properties
- Sparse Resource Creation
- Sparse Resource Memory Requirements
- Binding Resource Memory

33.7.1. Physical Device Features

Some sparse-resource related features are reported and enabled in VkPhysicalDeviceFeatures. These features must be supported and enabled on the VkDevice object before applications can use them. See Physical Device Features for information on how to get and set enabled device features, and for more detailed explanations of these features.

Sparse Physical Device Features

- **sparseBinding**: Support for creating VkBuffer and VkImage objects with the VK_BUFFER_CREATE_SPARSE_BINDING_BIT and VK_IMAGE_CREATE_SPARSE_BINDING_BIT flags, respectively.
- **sparseResidencyBuffer**: Support for creating VkBuffer objects with the VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT flag.
- **sparseResidencyImage2D**: Support for creating 2D single-sampled VkImage objects with VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT.
- **sparseResidencyImage3D**: Support for creating 3D VkImage objects with VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT.
- **sparseResidency2Samples**: Support for creating 2D VkImage objects with 2 samples and VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT.
- **sparseResidency4Samples**: Support for creating 2D VkImage objects with 4 samples and VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT.
- **sparseResidency8Samples**: Support for creating 2D VkImage objects with 8 samples and VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT.
- **sparseResidency16Samples**: Support for creating 2D VkImage objects with 16 samples and VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT.
- **sparseResidencyAliased**: Support for creating VkBuffer and VkImage objects with the VK_BUFFER_CREATE_SPARSE_ALIASED_BIT and VK_IMAGE_CREATE_SPARSE_ALIASED_BIT flags, respectively.

33.7.2. Physical Device Sparse Properties

Some features of the implementation are not possible to disable, and are reported to allow applications to alter their sparse resource usage accordingly. These read-only capabilities are...
reported in the `VkPhysicalDeviceProperties::sparseProperties` member, which is a `VkPhysicalDeviceSparseProperties` structure.

The `VkPhysicalDeviceSparseProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPhysicalDeviceSparseProperties {
    VkBool32 residencyStandard2DBlockShape;
    VkBool32 residencyStandard2DMultisampleBlockShape;
    VkBool32 residencyStandard3DBlockShape;
    VkBool32 residencyAlignedMipSize;
    VkBool32 residencyNonResidentStrict;
} VkPhysicalDeviceSparseProperties;
```

- `residencyStandard2DBlockShape` is `VK_TRUE` if the physical device will access all single-sample 2D sparse resources using the standard sparse image block shapes (based on image format), as described in the Standard Sparse Image Block Shapes (Single Sample) table. If this property is not supported, the value returned in the `imageGranularity` member of the `VkSparseImageFormatProperties` structure for single-sample 2D images is not required to match the standard sparse image block dimensions listed in the table.

- `residencyStandard2DMultisampleBlockShape` is `VK_TRUE` if the physical device will access all multisample 2D sparse resources using the standard sparse image block shapes (based on image format), as described in the Standard Sparse Image Block Shapes (MSAA) table. If this property is not supported, the value returned in the `imageGranularity` member of the `VkSparseImageFormatProperties` structure for multisample 2D images is not required to match the standard sparse image block dimensions listed in the table.

- `residencyStandard3DBlockShape` is `VK_TRUE` if the physical device will access all 3D sparse resources using the standard sparse image block shapes (based on image format), as described in the Standard Sparse Image Block Shapes (Single Sample) table. If this property is not supported, the value returned in the `imageGranularity` member of the `VkSparseImageFormatProperties` structure for 3D images is not required to match the standard sparse image block dimensions listed in the table.

- `residencyAlignedMipSize` is `VK_TRUE` if images with mip level dimensions that are not integer multiples of the corresponding dimensions of the sparse image block may be placed in the mip tail. If this property is not reported, only mip levels with dimensions smaller than the `imageGranularity` member of the `VkSparseImageFormatProperties` structure will be placed in the mip tail. If this property is reported the implementation is allowed to return `VK_SPARSE_IMAGE_FORMAT_ALIGNED_MIP_SIZE_BIT` in the `flags` member of `VkSparseImageFormatProperties`, indicating that mip level dimensions that are not integer multiples of the corresponding dimensions of the sparse image block will be placed in the mip tail.

- `residencyNonResidentStrict` specifies whether the physical device can consistently access non-resident regions of a resource. If this property is `VK_TRUE`, access to non-resident regions of resources will be guaranteed to return values as if the resource was populated with 0; writes to non-resident regions will be discarded.
33.7.3. Sparse Image Format Properties

Given that certain aspects of sparse image support, including the sparse image block dimensions, may be implementation-dependent, `vkGetPhysicalDeviceSparseImageFormatProperties` can be used to query for sparse image format properties prior to resource creation. This command is used to check whether a given set of sparse image parameters is supported and what the sparse image block shape will be.

Sparse Image Format Properties API

The `VkSparseImageFormatProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkSparseImageFormatProperties {
    VkImageAspectFlags aspectMask;
    VkExtent3D imageGranularity;
    VkSparseImageFormatFlags flags;
} VkSparseImageFormatProperties;
```

- `aspectMask` is a bitmask `VkImageAspectFlagBits` specifying which aspects of the image the properties apply to.
- `imageGranularity` is the width, height, and depth of the sparse image block in texels or compressed texel blocks.
- `flags` is a bitmask of `VkSparseImageFormatFlagBits` specifying additional information about the sparse resource.

Bits which may be set in `VkSparseImageFormatProperties::flags`, specifying additional information about the sparse resource, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkSparseImageFormatFlagBits {
    VK_SPARSE_IMAGE_FORMAT_SINGLE_MIPTAIL_BIT = 0x00000001,
    VK_SPARSE_IMAGE_FORMAT_ALIGNED_MIP_SIZE_BIT = 0x00000002,
    VK_SPARSE_IMAGE_FORMAT_NONSTANDARD_BLOCK_SIZE_BIT = 0x00000004,
} VkSparseImageFormatFlagBits;
```

- `VK_SPARSE_IMAGE_FORMAT_SINGLE_MIPTAIL_BIT` specifies that the image uses a single mip tail region for all array layers.
- `VK_SPARSE_IMAGE_FORMAT_ALIGNED_MIP_SIZE_BIT` specifies that the first mip level whose dimensions are not integer multiples of the corresponding dimensions of the sparse image block begins the mip tail region.
- `VK_SPARSE_IMAGE_FORMAT_NONSTANDARD_BLOCK_SIZE_BIT` specifies that the image uses non-standard sparse image block dimensions, and the `imageGranularity` values do not match the standard sparse image block dimensions for the given format.
**VkSparseImageFormatFlags** is a bitmask type for setting a mask of zero or more

**VkSparseImageFormatFlagBits**.

**vkGetPhysicalDeviceSparseImageFormatProperties** returns an array of

**VkSparseImageFormatProperties**. Each element will describe properties for one set of image aspects that are bound simultaneously in the image. This is usually one element for each aspect in the image, but for interleaved depth/stencil images there is only one element describing the combined aspects.

```c
// Provided by VK_VERSION_1_0
void vkGetPhysicalDeviceSparseImageFormatProperties(
    VkPhysicalDevice physicalDevice,
    VkFormat format,
    VkImageType type,
    VkSampleCountFlagBits samples,
    VkImageUsageFlags usage,
    VkImageTiling tiling,
    uint32_t* pPropertyCount,
    VkSparseImageFormatProperties* pProperties);
```

- **physicalDevice** is the physical device from which to query the sparse image format properties.
- **format** is the image format.
- **type** is the dimensionality of image.
- **samples** is a **VkSampleCountFlagBits** value specifying the number of samples per texel.
- **usage** is a bitmask describing the intended usage of the image.
- **tiling** is the tiling arrangement of the texel blocks in memory.
- **pPropertyCount** is a pointer to an integer related to the number of sparse format properties available or queried, as described below.
- **pProperties** is either **NULL** or a pointer to an array of **VkSparseImageFormatProperties** structures.

If **pProperties** is **NULL**, then the number of sparse format properties available is returned in **pPropertyCount**. Otherwise, **pPropertyCount** must point to a variable set by the user to the number of elements in the **pProperties** array, and on return the variable is overwritten with the number of structures actually written to **pProperties**. If **pPropertyCount** is less than the number of sparse format properties available, at most **pPropertyCount** structures will be written.

If **VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT** is not supported for the given arguments, **pPropertyCount** will be set to zero upon return, and no data will be written to **pProperties**.

Multiple aspects are returned for depth/stencil images that are implemented as separate planes by the implementation. The depth and stencil data planes each have unique
VkSparseImageFormatProperties data.

Depth/stencil images with depth and stencil data interleaved into a single plane will return a single VkSparseImageFormatProperties structure with the aspectMask set to VK_IMAGE_ASPECT_DEPTH_BIT | VK_IMAGE_ASPECT_STENCIL_BIT.

**Valid Usage**

- VUID-vkGetPhysicalDeviceSparseImageFormatProperties-samples-01094 samples must be a bit value that is set in VkImageFormatProperties::sampleCounts returned by vkGetPhysicalDeviceImageFormatProperties with format, type, tiling, and usage equal to those in this command and flags equal to the value that is set in VkImageCreateInfo ::flags when the image is created

**Valid Usage (Implicit)**

- VUID-vkGetPhysicalDeviceSparseImageFormatProperties-physicalDevice-parameter physicalDevice must be a valid VkPhysicalDevice handle
- VUID-vkGetPhysicalDeviceSparseImageFormatProperties-format-parameter format must be a valid VkFormat value
- VUID-vkGetPhysicalDeviceSparseImageFormatProperties-type-parameter type must be a valid VkImageType value
- VUID-vkGetPhysicalDeviceSparseImageFormatProperties-samples-parameter samples must be a valid VkSampleCountFlagBits value
- VUID-vkGetPhysicalDeviceSparseImageFormatProperties-usage-parameter usage must be a valid combination of VkImageUsageFlagBits values
- VUID-vkGetPhysicalDeviceSparseImageFormatProperties-usage-requiredbitmask usage must not be 0
- VUID-vkGetPhysicalDeviceSparseImageFormatProperties-tiling-parameter tiling must be a valid VkImageTiling value
- VUID-vkGetPhysicalDeviceSparseImageFormatProperties-pPropertyCount-parameter pPropertyCount must be a valid pointer to a uint32_t value
- VUID-vkGetPhysicalDeviceSparseImageFormatProperties-pProperties-parameter If the value referenced by pPropertyCount is not 0, and pProperties is not NULL, pProperties must be a valid pointer to an array of pPropertyCount VkSparseImageFormatProperties structures

vkGetPhysicalDeviceSparseImageFormatProperties2 returns an array of VkSparseImageFormatProperties2. Each element will describe properties for one set of image aspects that are bound simultaneously in the image. This is usually one element for each aspect in the image, but for interleaved depth/stencil images there is only one element describing the combined aspects.
or the equivalent command

```c
void vkGetPhysicalDeviceSparseImageFormatProperties2KHR(
    VkPhysicalDevice physicalDevice,
    const VkPhysicalDeviceSparseImageFormatInfo2* pFormatInfo,
    uint32_t* pPropertyCount,
    VkSparseImageFormatProperties2* pProperties);
```

- `physicalDevice` is the physical device from which to query the sparse image format properties.
- `pFormatInfo` is a pointer to a `VkPhysicalDeviceSparseImageFormatInfo2` structure containing input parameters to the command.
- `pPropertyCount` is a pointer to an integer related to the number of sparse format properties available or queried, as described below.
- `pProperties` is either `NULL` or a pointer to an array of `VkSparseImageFormatProperties2` structures.

`vkGetPhysicalDeviceSparseImageFormatProperties2` behaves identically to `vkGetPhysicalDeviceSparseImageFormatProperties`, with the ability to return extended information by adding extending structures to the `pNext` chain of its `pProperties` parameter.

### Valid Usage (Implicit)

- **VUID-vkGetPhysicalDeviceSparseImageFormatProperties2-physicalDevice-parameter** physicalDevice must be a valid `VkPhysicalDevice` handle
- **VUID-vkGetPhysicalDeviceSparseImageFormatProperties2-pFormatInfo-parameter** `pFormatInfo` must be a valid pointer to a valid `VkPhysicalDeviceSparseImageFormatInfo2` structure
- **VUID-vkGetPhysicalDeviceSparseImageFormatProperties2-pPropertyCount-parameter** `pPropertyCount` must be a valid pointer to a `uint32_t` value
- **VUID-vkGetPhysicalDeviceSparseImageFormatProperties2-pProperties-parameter** If the value referenced by `pPropertyCount` is not 0, and `pProperties` is not `NULL`, `pProperties` must be a valid pointer to an array of `pPropertyCount` `VkSparseImageFormatProperties2` structures

The `VkPhysicalDeviceSparseImageFormatInfo2` structure is defined as:
// Provided by VK_VERSION_1_1

typedef struct VkPhysicalDeviceSparseImageFormatInfo2 {
    VkStructureType sType;
    const void* pNext;
    VkFormat format;
    VkImageType type;
    VkSampleCountFlagBits samples;
    VkImageUsageFlags usage;
    VkImageTiling tiling;
} VkPhysicalDeviceSparseImageFormatInfo2;

or the equivalent

// Provided by VK_KHR_get_physical_device_properties2

typedef VkPhysicalDeviceSparseImageFormatInfo2 VkPhysicalDeviceSparseImageFormatInfo2KHR;

• **sType** is a *VkStructureType* value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **format** is the image format.

• **type** is the dimensionality of image.

• **samples** is a *VkSampleCountFlagBits* value specifying the number of samples per texel.

• **usage** is a bitmask describing the intended usage of the image.

• **tiling** is the tiling arrangement of the texel blocks in memory.

**Valid Usage**

• VUID-VkPhysicalDeviceSparseImageFormatInfo2-samples-01095 samples must be a bit value that is set in *VkImageFormatProperties::sampleCounts* returned by *vkGetPhysicalDeviceImageFormatProperties* with format, type, tiling, and usage equal to those in this command and flags equal to the value that is set in *VkImageCreateInfo::flags* when the image is created.

**Valid Usage (Implicit)**

• VUID-VkPhysicalDeviceSparseImageFormatInfo2-sType-sType sType must be *VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SPARSE_IMAGE_FORMAT_INFO_2*

• VUID-VkPhysicalDeviceSparseImageFormatInfo2-pNext-pNext pNext must be NULL

• VUID-VkPhysicalDeviceSparseImageFormatInfo2-format-parameter format must be a valid *VkFormat* value

• VUID-VkPhysicalDeviceSparseImageFormatInfo2-type-parameter
**type** must be a valid *VkImageType* value

- **VUID-VkPhysicalDeviceSparseImageFormatInfo2-samples-parameter**
  **samples** must be a valid *VkSampleCountFlagBits* value

- **VUID-VkPhysicalDeviceSparseImageFormatInfo2-usage-parameter**
  **usage** must be a valid combination of *VkImageUsageFlagBits* values

- **VUID-VkPhysicalDeviceSparseImageFormatInfo2-usage-requiredbitmask**
  **usage** must not be 0

- **VUID-VkPhysicalDeviceSparseImageFormatInfo2-tiling-parameter**
  **tiling** must be a valid *VkImageTiling* value

The **VkSparseImageFormatProperties2** structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkSparseImageFormatProperties2 {
  VkStructureType sType;
  void* pNext;
  VkSparseImageFormatProperties properties;
} VkSparseImageFormatProperties2;
```

or the equivalent

```c
// Provided by VK_KHR_get_physical_device_properties2
typedef VkSparseImageFormatProperties2 VkSparseImageFormatProperties2KHR;
```

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **properties** is a **VkSparseImageFormatProperties** structure which is populated with the same values as in **vkGetPhysicalDeviceSparseImageFormatProperties**.

### Valid Usage (Implicit)

- **VUID-VkSparseImageFormatProperties2-sType-sType**
  **sType** must be **VK_STRUCTURE_TYPE_SPARSE_IMAGE_FORMAT_PROPERTIES_2**

- **VUID-VkSparseImageFormatProperties2-pNext-pNext**
  **pNext** must be **NULL**

### 33.7.4. Sparse Resource Creation

Sparse resources require that one or more sparse feature flags be specified (as part of the **VkPhysicalDeviceFeatures** structure described previously in the **Physical Device Features** section) when calling **vkCreateDevice**. When the appropriate device features are enabled, the **VK_BUFFER_CREATE_SPARSE_** and **VK_IMAGE_CREATE_SPARSE_** flags can be used. See **vkCreateBuffer** and
vkCreateImage for details of the resource creation APIs.

Note
Specifying VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT or VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT requires specifying VK_BUFFER_CREATE_SPARSE_BINDING_BIT or VK_IMAGE_CREATE_SPARSE_BINDING_BIT, respectively, as well. This means that resources must be created with the appropriate *_SPARSE_BINDING_BIT to be used with the sparse binding command (vkQueueBindSparse).

33.7.5. Sparse Resource Memory Requirements

Sparse resources have specific memory requirements related to binding sparse memory. These memory requirements are reported differently for VkBuffer objects and VkImage objects.

Buffer and Fully-Resident Images

Buffers (both fully and partially resident) and fully-resident images can be bound to memory using only the data from VkMemoryRequirements. For all sparse resources the VkMemoryRequirements::alignment member specifies both the bindable sparse block size in bytes and required alignment of VkDeviceMemory.

Partially Resident Images

Partially resident images have a different method for binding memory. As with buffers and fully resident images, the VkMemoryRequirements::alignment field specifies the bindable sparse block size in bytes for the image.

Requesting sparse memory requirements for VkImage objects using vkGetImageSparseMemoryRequirements will return an array of one or more VkSparseImageMemoryRequirements structures. Each structure describes the sparse memory requirements for a group of aspects of the image.

The sparse image must have been created using the VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT flag to retrieve valid sparse image memory requirements.

Sparse Image Memory Requirements

The VkSparseImageMemoryRequirements structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkSparseImageMemoryRequirements {
    VkSparseImageFormatProperties formatProperties;
    uint32_t imageMipTailFirstLod;
    VkDeviceSize imageMipTailSize;
    VkDeviceSize imageMipTailOffset;
    VkDeviceSize imageMipTailStride;
} VkSparseImageMemoryRequirements;
```
- `formatProperties` is a `VkSparseImageFormatProperties` structure specifying properties of the image format.

- `imageMipTailFirstLod` is the first mip level at which image subresources are included in the mip tail region.

- `imageMipTailSize` is the memory size (in bytes) of the mip tail region. If `formatProperties.flags` contains `VK_SPARSE_IMAGE_FORMAT_SINGLE_MIPTAIL_BIT`, this is the size of the whole mip tail, otherwise this is the size of the mip tail of a single array layer. This value is guaranteed to be a multiple of the sparse block size in bytes.

- `imageMipTailOffset` is the opaque memory offset used with `VkSparseImageOpaqueMemoryBindInfo` to bind the mip tail region(s).

- `imageMipTailStride` is the offset stride between each array-layer’s mip tail, if `formatProperties.flags` does not contain `VK_SPARSE_IMAGE_FORMAT_SINGLE_MIPTAIL_BIT` (otherwise the value is undefined).

To query sparse memory requirements for an image, call:

```c
// Provided by VK_VERSION_1_0
void vkGetImageSparseMemoryRequirements(
    VkDevice device,
    VkImage image,
    uint32_t* pSparseMemoryRequirementCount,  // pSparseMemoryRequirementCount is a pointer to an integer related to the number of sparse memory requirements available or queried, as described below.
    VkSparseImageMemoryRequirements* pSparseMemoryRequirements,  // pSparseMemoryRequirements is either NULL or a pointer to an array of VkSparseImageMemoryRequirements structures.
);
```

- `device` is the logical device that owns the image.

- `image` is the `VkImage` object to get the memory requirements for.

- `pSparseMemoryRequirementCount` is a pointer to an integer related to the number of sparse memory requirements available or queried, as described below.

- `pSparseMemoryRequirements` is either `NULL` or a pointer to an array of `VkSparseImageMemoryRequirements` structures.

If `pSparseMemoryRequirements` is `NULL`, then the number of sparse memory requirements available is returned in `pSparseMemoryRequirementCount`. Otherwise, `pSparseMemoryRequirementCount` must point to a variable set by the user to the number of elements in the `pSparseMemoryRequirements` array, and on return the variable is overwritten with the number of structures actually written to `pSparseMemoryRequirements`. If `pSparseMemoryRequirementCount` is less than the number of sparse memory requirements available, at most `pSparseMemoryRequirementCount` structures will be written.

If the image was not created with `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` then `pSparseMemoryRequirementCount` will be set to zero and `pSparseMemoryRequirements` will not be written to.

**Note**

It is legal for an implementation to report a larger value in `VkMemoryRequirements::size` than would be obtained by adding together memory sizes for all `VkSparseImageMemoryRequirements` returned by `vkGetImageSparseMemoryRequirements`. 

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This may occur when the implementation requires unused padding in the address range describing the resource.

Valid Usage (Implicit)

- VUID-vkGetImageSparseMemoryRequirements-device-parameter
  device must be a valid VkDevice handle

- VUID-vkGetImageSparseMemoryRequirements-image-parameter
  image must be a valid VkImage handle

- VUID-vkGetImageSparseMemoryRequirements-pSparseMemoryRequirementCount-parameter
  pSparseMemoryRequirementCount must be a valid pointer to a uint32_t value

- VUID-vkGetImageSparseMemoryRequirements-pSparseMemoryRequirements-parameter
  If the value referenced by pSparseMemoryRequirementCount is not 0, and pSparseMemoryRequirements is not NULL, pSparseMemoryRequirements must be a valid pointer to an array of pSparseMemoryRequirementCount VkSparseImageMemoryRequirements structures

- VUID-vkGetImageSparseMemoryRequirements-image-parent
  image must have been created, allocated, or retrieved from device

To query sparse memory requirements for an image, call:

```c
// Provided by VK_VERSION_1_1
void vkGetImageSparseMemoryRequirements2(
  VkDevice device,
  const VkImageSparseMemoryRequirementsInfo2* pInfo,
  uint32_t* pSparseMemoryRequirementCount,
  VkSparseImageMemoryRequirements2* pSparseMemoryRequirements);
```

or the equivalent command

```c
// Provided by VK_KHR_get_memory_requirements2
void vkGetImageSparseMemoryRequirements2KHR(
  VkDevice device,
  const VkImageSparseMemoryRequirementsInfo2* pInfo,
  uint32_t* pSparseMemoryRequirementCount,
  VkSparseImageMemoryRequirements2* pSparseMemoryRequirements);
```

- device is the logical device that owns the image.
- pInfo is a pointer to a VkImageSparseMemoryRequirementsInfo2 structure containing parameters required for the memory requirements query.
- pSparseMemoryRequirementCount is a pointer to an integer related to the number of sparse memory requirements available or queried, as described below.
• `pSparseMemoryRequirements` is either NULL or a pointer to an array of `VkSparseImageMemoryRequirements2` structures.

## Valid Usage (Implicit)

- VUID-vkGetImageSparseMemoryRequirements2-device-parameter
  `device` must be a valid `VkDevice` handle

- VUID-vkGetImageSparseMemoryRequirements2-pInfo-parameter
  `pInfo` must be a valid pointer to a valid `VkImageSparseMemoryRequirementsInfo2` structure

- VUID-vkGetImageSparseMemoryRequirements2-pSparseMemoryRequirementCount-parameter
  `pSparseMemoryRequirementCount` must be a valid pointer to a `uint32_t` value

- VUID-vkGetImageSparseMemoryRequirements2-pSparseMemoryRequirements-parameter
  If the value referenced by `pSparseMemoryRequirementCount` is not 0, and `pSparseMemoryRequirements` is not NULL, `pSparseMemoryRequirements` must be a valid pointer to an array of `pSparseMemoryRequirementCount` `VkSparseImageMemoryRequirements2` structures

To determine the sparse memory requirements for an image resource without creating an object, call:

```c
// Provided by VK_VERSION_1_3
void vkGetDeviceImageSparseMemoryRequirements(
    VkDevice device,
    const VkDeviceImageMemoryRequirements* pInfo,
    uint32_t* pSparseMemoryRequirementCount,
    VkSparseImageMemoryRequirements2* pSparseMemoryRequirements);
```

or the equivalent command

```c
// Provided by VK_KHR_maintenance4
void vkGetDeviceImageSparseMemoryRequirementsKHR(
    VkDevice device,
    const VkDeviceImageMemoryRequirements* pInfo,
    uint32_t* pSparseMemoryRequirementCount,
    VkSparseImageMemoryRequirements2* pSparseMemoryRequirements);
```

- `device` is the logical device intended to own the image.
- `pInfo` is a pointer to a `VkDeviceImageMemoryRequirements` structure containing parameters required for the memory requirements query.
- `pSparseMemoryRequirementCount` is a pointer to an integer related to the number of sparse memory requirements available or queried, as described below.
pSparseMemoryRequirements is either NULL or a pointer to an array of VkSparseImageMemoryRequirements2 structures.

Valid Usage (Implicit)

- VUID-vkGetDeviceImageSparseMemoryRequirements-device-parameter device must be a valid VkDevice handle
- VUID-vkGetDeviceImageSparseMemoryRequirements-pInfo-parameter pInfo must be a valid pointer to a valid VkDeviceImageMemoryRequirements structure
- VUID-vkGetDeviceImageSparseMemoryRequirements-pSparseMemoryRequirementCount-parameter pSparseMemoryRequirementCount must be a valid pointer to a uint32_t value
- VUID-vkGetDeviceImageSparseMemoryRequirements-pSparseMemoryRequirements- parameter If the value referenced by pSparseMemoryRequirementCount is not 0, and pSparseMemoryRequirements is not NULL, pSparseMemoryRequirements must be a valid pointer to an array of pSparseMemoryRequirementCount VkSparseImageMemoryRequirements2 structures

The VkImageSparseMemoryRequirementsInfo2 structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkImageSparseMemoryRequirementsInfo2 {
    VkStructureType sType;
    const void* pNext;
    VkImage image;
} VkImageSparseMemoryRequirementsInfo2;
```

or the equivalent

```c
// Provided by VK_KHR_get_memory_requirements2
typedef VkImageSparseMemoryRequirementsInfo2 VkImageSparseMemoryRequirementsInfo2KHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- image is the image to query.

Valid Usage (Implicit)

- VUID-VkImageSparseMemoryRequirementsInfo2-sType-sType sType must be VK_STRUCTURE_TYPE_IMAGE_SPARSE_MEMORY_REQUIREMENTS_INFO_2
- VUID-VkImageSparseMemoryRequirementsInfo2-pNext-pNext pNext must be NULL
The `VkSparseImageMemoryRequirements2` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkSparseImageMemoryRequirements2 {
    VkStructureType sType;
    void* pNext;
    VkSparseImageMemoryRequirements memoryRequirements;
} VkSparseImageMemoryRequirements2;
```

or the equivalent

```c
// Provided by VK_KHR_get_memory_requirements2
typedef VkSparseImageMemoryRequirements2 VkSparseImageMemoryRequirements2KHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `memoryRequirements` is a `VkSparseImageMemoryRequirements` structure describing the memory requirements of the sparse image.

### Valid Usage (Implicit)

- `VUID-VkSparseImageMemoryRequirements2-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_SPARSE_IMAGE_MEMORY_REQUIREMENTS_2`
- `VUID-VkSparseImageMemoryRequirements2-pNext-pNext`  
  `pNext` must be `NULL`

### 33.7.6. Binding Resource Memory

Non-sparse resources are backed by a single physical allocation prior to device use (via `vkBindImageMemory` or `vkBindBufferMemory`), and their backing must not be changed. On the other hand, sparse resources can be bound to memory non-contiguously and these bindings can be altered during the lifetime of the resource.

> **Note**
> It is important to note that freeing a `VkDeviceMemory` object with `vkFreeMemory` will not cause resources (or resource regions) bound to the memory object to become unbound. Applications must not access resources bound to memory that has been freed.

Sparse memory bindings execute on a queue that includes the `VK_QUEUE_SPARSE_BINDING_BIT` bit.
Applications **must** use synchronization primitives to guarantee that other queues do not access ranges of memory concurrently with a binding change. Applications **can** access other ranges of the same resource while a bind operation is executing.

**Note**

Implementations **must** provide a guarantee that simultaneously binding sparse blocks while another queue accesses those same sparse blocks via a sparse resource **must** not access memory owned by another process or otherwise corrupt the system.

While some implementations **may** include `VK_QUEUE_SPARSE_BINDING_BIT` support in queue families that also include graphics and compute support, other implementations **may** only expose a `VK_QUEUE_SPARSE_BINDING_BIT`-only queue family. In either case, applications **must** use synchronization primitives to explicitly request any ordering dependencies between sparse memory binding operations and other graphics/compute/transfer operations, as sparse binding operations are not automatically ordered against command buffer execution, even within a single queue.

When binding memory explicitly for the `VK_IMAGE_ASPECT_METADATA_BIT` the application **must** use the `VK_SPARSE_MEMORY_BIND_METADATA_BIT` in the `VkSparseMemoryBind::flags` field when binding memory. Binding memory for metadata is done the same way as binding memory for the mip tail, with the addition of the `VK_SPARSE_MEMORY_BIND_METADATA_BIT` flag.

Binding the mip tail for any aspect **must** only be performed using `VkSparseImageOpaqueMemoryBindInfo`. If `formatProperties.flags` contains `VK_SPARSE_IMAGE_FORMAT_SINGLE_MIPTAIL_BIT`, then it **can** be bound with a single `VkSparseMemoryBind` structure, with `resourceOffset = imageMipTailOffset` and `size = imageMipTailSize`.

If `formatProperties.flags` does not contain `VK_SPARSE_IMAGE_FORMAT_SINGLE_MIPTAIL_BIT` then the offset for the mip tail in each array layer is given as:

\[
\text{arrayMipTailOffset} = \text{imageMipTailOffset} + \text{arrayLayer} \times \text{imageMipTailStride};
\]

and the mip tail **can** be bound with `layerCount` `VkSparseMemoryBind` structures, each using `size = imageMipTailSize` and `resourceOffset = arrayMipTailOffset` as defined above.

Sparse memory binding is handled by the following APIs and related data structures.

**Sparse Memory Binding Functions**

The `VkSparseMemoryBind` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkSparseMemoryBind {
    VkDeviceSize resourceOffset;
    VkDeviceSize size;
    VkDeviceMemory memory;
} VkSparseMemoryBind;
```
VkDeviceSize memoryOffset;
VkSparseMemoryBindFlags flags;
} VkSparseMemoryBind;

- **resourceOffset** is the offset into the resource.
- **size** is the size of the memory region to be bound.
- **memory** is the `VkDeviceMemory` object that the range of the resource is bound to. If `memory` is `VK_NULL_HANDLE`, the range is unbound.
- **memoryOffset** is the offset into the `VkDeviceMemory` object to bind the resource range to. If `memory` is `VK_NULL_HANDLE`, this value is ignored.
- **flags** is a bitmask of `VkSparseMemoryBindFlagBits` specifying usage of the binding operation.

The **binding range** \([\text{resourceOffset}, \text{resourceOffset} + \text{size})\) has different constraints based on **flags**. If **flags** contains `VK_SPARSE_MEMORY_BIND_METADATA_BIT`, the binding range **must** be within the mip tail region of the metadata aspect. This metadata region is defined by:

\[
\text{metadataRegion} = [\text{base}, \text{base} + \text{imageMipTailSize})
\]

\[
\text{base} = \text{imageMipTailOffset} + \text{imageMipTailStride} \times n
\]

and **imageMipTailOffset**, **imageMipTailSize**, and **imageMipTailStride** values are from the `VkSparseImageMemoryRequirements` corresponding to the metadata aspect of the image, and **n** is a valid array layer index for the image,

**imageMipTailStride** is considered to be zero for aspects where `VkSparseImageMemoryRequirements::formatProperties.flags` contains `VK_SPARSE_IMAGE_FORMAT_SINGLE_MIPTAIL_BIT`.

If **flags** does not contain `VK_SPARSE_MEMORY_BIND_METADATA_BIT`, the binding range **must** be within the range \([0, \text{VkMemoryRequirements::size})\).

### Valid Usage

- **VUID-VkSparseMemoryBind-memory-01096**
  - If `memory` is not `VK_NULL_HANDLE`, `memory` and `memoryOffset` **must** match the memory requirements of the resource, as described in section **Resource Memory Association**
- **VUID-VkSparseMemoryBind-memory-01097**
  - If `memory` is not `VK_NULL_HANDLE`, `memory` **must** not have been created with a memory type that reports `VK_MEMORY_PROPERTY_LAZILY_ALLOCATED_BIT` bit set
- **VUID-VkSparseMemoryBind-size-01098**
  - **size** **must** be greater than 0
- **VUID-VkSparseMemoryBind-resourceOffset-01099**
  - **resourceOffset** **must** be less than the size of the resource
- **VUID-VkSparseMemoryBind-size-01100**
size must be less than or equal to the size of the resource minus resourceOffset

- VUID-VkSparseMemoryBind-memoryOffset-01101
  memoryOffset must be less than the size of memory

- VUID-VkSparseMemoryBind-size-01102
  size must be less than or equal to the size of memory minus memoryOffset

- VUID-VkSparseMemoryBind-memory-02730
  If memory was created with VkExportMemoryAllocateInfo::handleTypes not equal to 0, at least one handle type it contained must also have been set in VkExternalMemoryBufferCreateInfo::handleTypes or VkExternalMemoryImageCreateInfo::handleTypes when the resource was created

- VUID-VkSparseMemoryBind-memory-02731
  If memory was created by a memory import operation, the external handle type of the imported memory must also have been set in VkExternalMemoryBufferCreateInfo::handleTypes or VkExternalMemoryImageCreateInfo::handleTypes when the resource was created

Valid Usage (Implicit)

- VUID-VkSparseMemoryBind-memory-parameter
  If memory is not VK_NULL_HANDLE, memory must be a valid VkDeviceMemory handle

- VUID-VkSparseMemoryBind-flags-parameter
  flags must be a valid combination of VkSparseMemoryBindFlagBits values

Bits which can be set in VkSparseMemoryBind::flags, specifying usage of a sparse memory binding operation, are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkSparseMemoryBindFlagBits {
    VK_SPARSE_MEMORY_BIND_METADATA_BIT = 0x00000001,
} VkSparseMemoryBindFlagBits;
```

- VK_SPARSE_MEMORY_BIND_METADATA_BIT specifies that the memory being bound is only for the metadata aspect.

```c
// Provided by VK_VERSION_1_0
typedef VkFlags VkSparseMemoryBindFlags;
```

VkSparseMemoryBindFlags is a bitmask type for setting a mask of zero or more VkSparseMemoryBindFlagBits.

Memory is bound to VkBuffer objects created with the VK_BUFFER_CREATE_SPARSE_BINDING_BIT flag using the following structure:
typedef struct VkSparseBufferMemoryBindInfo {
    VkBuffer buffer;
    uint32_t bindCount;
    const VkSparseMemoryBind* pBinds;
} VkSparseBufferMemoryBindInfo;

- **buffer** is the VkBuffer object to be bound.
- **bindCount** is the number of VkSparseMemoryBind structures in the pBinds array.
- **pBinds** is a pointer to an array of VkSparseMemoryBind structures.

Valid Usage (Implicit)

- VUID-VkSparseBufferMemoryBindInfo-buffer-parameter buffer must be a valid VkBuffer handle
- VUID-VkSparseBufferMemoryBindInfo-pBinds-parameter pBinds must be a valid pointer to an array of bindCount valid VkSparseMemoryBind structures
- VUID-VkSparseBufferMemoryBindInfo-bindCount-arraylength bindCount must be greater than 0

Memory is bound to opaque regions of VkImage objects created with the VK_IMAGE_CREATE_SPARSE_BINDING_BIT flag using the following structure:

typedef struct VkSparseImageOpaqueMemoryBindInfo {
    VkImage image;
    uint32_t bindCount;
    const VkSparseMemoryBind* pBinds;
} VkSparseImageOpaqueMemoryBindInfo;

- **image** is the VkImage object to be bound.
- **bindCount** is the number of VkSparseMemoryBind structures in the pBinds array.
- **pBinds** is a pointer to an array of VkSparseMemoryBind structures.

Valid Usage

- VUID-VkSparseImageOpaqueMemoryBindInfo-pBinds-01103 If the flags member of any element of pBinds contains VK_SPARSE_MEMORY_BIND_METADATA_BIT, the binding range defined must be within the mip tail region of the metadata aspect of image
Valid Usage (Implicit)

- VUID-VkSparseImageOpaqueMemoryBindInfo-image-parameter
  image must be a valid VkImage handle

- VUID-VkSparseImageOpaqueMemoryBindInfo-pBinds-parameter
  pBinds must be a valid pointer to an array of bindCount valid VkSparseMemoryBind structures

- VUID-VkSparseImageOpaqueMemoryBindInfo-bindCount-arraylength
  bindCount must be greater than 0

Note

This operation is normally used to bind memory to fully-resident sparse images or for mip tail regions of partially resident images. However, it can also be used to bind memory for the entire binding range of partially resident images.

In case flags does not contain VK_SPARSE_MEMORY_BIND_METADATA_BIT, the resourceOffset is in the range [0, VkMemoryRequirements::size), This range includes data from all aspects of the image, including metadata. For most implementations this will probably mean that the resourceOffset is a simple device address offset within the resource. It is possible for an application to bind a range of memory that includes both resource data and metadata. However, the application would not know what part of the image the memory is used for, or if any range is being used for metadata.

When flags contains VK_SPARSE_MEMORY_BIND_METADATA_BIT, the binding range specified must be within the mip tail region of the metadata aspect. In this case the resourceOffset is not required to be a simple device address offset within the resource. However, it is defined to be within [imageMipTailOffset, imageMipTailOffset + imageMipTailSize) for the metadata aspect. See VkSparseMemoryBind for the full constraints on binding region with this flag present.

Memory can be bound to sparse image blocks of VkImage objects created with the VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT flag using the following structure:

```c
// Provided by VK_VERSION_1_0
typedef struct VkSparseImageMemoryBindInfo {
    VkImage image;
    uint32_t bindCount;
    const VkSparseImageMemoryBind* pBinds;
} VkSparseImageMemoryBindInfo;
```

- image is the VkImage object to be bound
- bindCount is the number of VkSparseImageMemoryBind structures in pBinds array
• \textit{pBinds} is a pointer to an array of \texttt{VkSparseImageMemoryBind} structures

### Valid Usage

- VUID-VkSparseImageMemoryBindInfo-subresource-01722
  The \texttt{subresource.mipLevel} member of each element of \textit{pBinds} \textbf{must} be less than the \texttt{mipLevels} specified in \texttt{VkImageCreateInfo} when \textit{image} was created.

- VUID-VkSparseImageMemoryBindInfo-subresource-01723
  The \texttt{subresource.arrayLayer} member of each element of \textit{pBinds} \textbf{must} be less than the \texttt{arrayLayers} specified in \texttt{VkImageCreateInfo} when \textit{image} was created.

- VUID-VkSparseImageMemoryBindInfo-image-02901
  \textit{image} \textbf{must} have been created with \texttt{VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT} set.

### Valid Usage (Implicit)

- VUID-VkSparseImageMemoryBindInfo-image-parameter
  \textit{image} \textbf{must} be a valid \texttt{VkImage} handle.

- VUID-VkSparseImageMemoryBindInfo-pBinds-parameter
  \textit{pBinds} \textbf{must} be a valid pointer to an array of \texttt{bindCount} valid \texttt{VkSparseImageMemoryBind} structures.

- VUID-VkSparseImageMemoryBindInfo-bindCount-arraylength
  \texttt{bindCount} \textbf{must} be greater than 0.

The \texttt{VkSparseImageMemoryBind} structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkSparseImageMemoryBind {
    VkImageSubresource subresource;
    VkOffset3D offset;
    VkExtent3D extent;
    VkDeviceMemory memory;
    VkDeviceSize memoryOffset;
    VkSparseMemoryBindFlags flags;
} VkSparseImageMemoryBind;
```

- \texttt{subresource} is the image \textit{aspect} and region of interest in the image.

- \texttt{offset} are the coordinates of the first texel within the image subresource to bind.

- \texttt{extent} is the size in texels of the region within the image subresource to bind. The extent \textbf{must} be a multiple of the sparse image block dimensions, except when binding sparse image blocks along the edge of an image subresource it \textbf{can} instead be such that any coordinate of \texttt{offset + extent} equals the corresponding dimensions of the image subresource.

- \texttt{memory} is the \texttt{VkDeviceMemory} object that the sparse image blocks of the image are bound to. If \texttt{memory} is \texttt{VK_NULL_HANDLE}, the sparse image blocks are unbound.
- `memoryOffset` is an offset into `VkDeviceMemory` object. If `memory` is `VK_NULL_HANDLE`, this value is ignored.

- `flags` are sparse memory binding flags.

## Valid Usage

- **VUID-VkSparseImageMemoryBind-memory-01104**
  If the `sparseResidencyAliased` feature is not enabled, and if any other resources are bound to ranges of `memory`, the range of `memory` being bound **must** not overlap with those bound ranges.

- **VUID-VkSparseImageMemoryBind-memory-01105**
  `memory` and `memoryOffset` **must** match the memory requirements of the calling command’s `image`, as described in section Resource Memory Association.

- **VUID-VkSparseImageMemoryBind-subresource-01106**
  `subresource` **must** be a valid image subresource for `image` (see Image Views).

- **VUID-VkSparseImageMemoryBind-offset-01107**
  `offset.x` **must** be a multiple of the sparse image block width (`VkSparseImageFormatProperties::imageGranularity.width`) of the image.

- **VUID-VkSparseImageMemoryBind-offset-01110**
  `extent.width` **must** either be a multiple of the sparse image block width of the image, or else `(extent.width + offset.x)` **must** equal the width of the image subresource.

- **VUID-VkSparseImageMemoryBind-offset-01109**
  `offset.y` **must** be a multiple of the sparse image block height (`VkSparseImageFormatProperties::imageGranularity.height`) of the image.

- **VUID-VkSparseImageMemoryBind-extent-01110**
  `extent.height` **must** either be a multiple of the sparse image block height of the image, or else `(extent.height + offset.y)` **must** equal the height of the image subresource.

- **VUID-VkSparseImageMemoryBind-offset-01111**
  `offset.z` **must** be a multiple of the sparse image block depth (`VkSparseImageFormatProperties::imageGranularity.depth`) of the image.

- **VUID-VkSparseImageMemoryBind-extent-01112**
  `extent.depth` **must** either be a multiple of the sparse image block depth of the image, or else `(extent.depth + offset.z)` **must** equal the depth of the image subresource.

- **VUID-VkSparseImageMemoryBind-memory-02732**
  If `memory` was created with `VkExportMemoryAllocateInfo::handleTypes` not equal to 0, at least one handle type it contained **must** also have been set in `VkExternalMemoryImageCreateInfo::handleTypes` when the image was created.

- **VUID-VkSparseImageMemoryBind-memory-02733**
  If `memory` was created by a memory import operation, the external handle type of the imported memory **must** also have been set in `VkExternalMemoryImageCreateInfo::handleTypes` when `image` was created.
Valid Usage (Implicit)

- VUID-VkSparseImageMemoryBind-subresource-parameter
  subresource **must** be a valid VkImageSubresource structure

- VUID-VkSparseImageMemoryBind-memory-parameter
  If **memory** is not VK_NULL_HANDLE, **memory** **must** be a valid VkDeviceMemory handle

- VUID-VkSparseImageMemoryBind-flags-parameter
  flags **must** be a valid combination of VkSparseMemoryBindFlagBits values

To submit sparse binding operations to a queue, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkQueueBindSparse(
    VkQueue queue,                          // Provided by VK_VERSION_1_0
    uint32_t bindInfoCount,                 // Provided by VK_VERSION_1_0
    const VkBindSparseInfo* pBindInfo,      // Provided by VK_VERSION_1_0
    VkFence fence);                         // Provided by VK_VERSION_1_0
```

- **queue** is the queue that the sparse binding operations will be submitted to.
- **bindInfoCount** is the number of elements in the **pBindInfo** array.
- **pBindInfo** is a pointer to an array of VkBindSparseInfo structures, each specifying a sparse binding submission batch.
- **fence** is an **optional** handle to a fence to be signaled. If **fence** is not VK_NULL_HANDLE, it defines a fence signal operation.

*vkQueueBindSparse* is a **queue submission command**, with each batch defined by an element of **pBindInfo** as a VkBindSparseInfo structure. Batches begin execution in the order they appear in **pBindInfo**, but may complete out of order.

Within a batch, a given range of a resource **must** not be bound more than once. Across batches, if a range is to be bound to one allocation and offset and then to another allocation and offset, then the application **must** guarantee (usually using semaphores) that the binding operations are executed in the correct order, as well as to order binding operations against the execution of command buffer submissions.

As no operation to *vkQueueBindSparse* causes any pipeline stage to access memory, synchronization primitives used in this command effectively only define execution dependencies.

Additional information about fence and semaphore operation is described in the synchronization chapter.

Valid Usage

- VUID-vkQueueBindSparse-fence-01113
  If **fence** is not VK_NULL_HANDLE, **fence** **must** be unsignaled
• **VUID-vkQueueBindSparse-fence-01114**
  If fence is not VK_NULL_HANDLE, fence **must** not be associated with any other queue command that has not yet completed execution on that queue.

• **VUID-vkQueueBindSparse-pSignalSemaphores-01115**
  Each element of the pSignalSemaphores member of each element of pBindInfo **must** be unsignaled when the semaphore signal operation it defines is executed on the device.

• **VUID-vkQueueBindSparse-pWaitSemaphores-01116**
  When a semaphore wait operation referring to a binary semaphore defined by any element of the pWaitSemaphores member of any element of pBindInfo executes on queue, there **must** be no other queues waiting on the same semaphore.

• **VUID-vkQueueBindSparse-pWaitSemaphores-03245**
  All elements of the pWaitSemaphores member of all elements of pBindInfo created with a VkSemaphoreType of VK_SEMAPHORE_TYPE_BINARY **must** reference a semaphore signal operation that has been submitted for execution and any semaphore signal operations on which it depends (if any) **must** have also been submitted for execution.

---

**Valid Usage (Implicit)**

• **VUID-vkQueueBindSparse-queue-parameter**
  queue **must** be a valid VkQueue handle.

• **VUID-vkQueueBindSparse-pBindInfo-parameter**
  If bindInfoCount is not 0, pBindInfo **must** be a valid pointer to an array of bindInfoCount valid VkBindSparseInfo structures.

• **VUID-vkQueueBindSparse-fence-parameter**
  If fence is not VK_NULL_HANDLE, fence **must** be a valid VkFence handle.

• **VUID-vkQueueBindSparse-queuetype**
  The queue **must** support sparse binding operations.

• **VUID-vkQueueBindSparse-commonparent**
  Both of fence, and queue that are valid handles of non-ignored parameters **must** have been created, allocated, or retrieved from the same VkDevice.

---

**Host Synchronization**

• Host access to queue **must** be externally synchronized.

• Host access to fence **must** be externally synchronized.
Command Properties

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Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_DEVICE_LOST

The `VkBindSparseInfo` structure is defined as:

```c
typedef struct VkBindSparseInfo {
    VkStructureType sType;
    const void* pNext;
    uint32_t waitSemaphoreCount;
    const VkSemaphore* pWaitSemaphores;
    uint32_t bufferBindCount;
    const VkSparseBufferMemoryBindInfo* pBufferBinds;
    uint32_t imageOpaqueBindCount;
    const VkSparseImageOpaqueMemoryBindInfo* pImageOpaqueBinds;
    uint32_t signalSemaphoreCount;
    const VkSemaphore* pSignalSemaphores;
} VkBindSparseInfo;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **waitSemaphoreCount** is the number of semaphores upon which to wait before executing the sparse binding operations for the batch.
- **pWaitSemaphores** is a pointer to an array of semaphores upon which to wait on before the sparse binding operations for this batch begin execution. If semaphores to wait on are provided, they define a semaphore wait operation.
- **bufferBindCount** is the number of sparse buffer bindings to perform in the batch.
- `pBufferBinds` is a pointer to an array of `VkSparseBufferMemoryBindInfo` structures.
- `imageOpaqueBindCount` is the number of opaque sparse image bindings to perform.
- `pImageOpaqueBinds` is a pointer to an array of `VkSparseImageOpaqueMemoryBindInfo` structures, indicating opaque sparse image bindings to perform.
- `imageBindCount` is the number of sparse image bindings to perform.
- `pImageBinds` is a pointer to an array of `VkSparseImageMemoryBindInfo` structures, indicating sparse image bindings to perform.
- `signalSemaphoreCount` is the number of semaphores to be signaled once the sparse binding operations specified by the structure have completed execution.
- `pSignalSemaphores` is a pointer to an array of semaphores which will be signaled when the sparse binding operations for this batch have completed execution. If semaphores to be signaled are provided, they define a semaphore signal operation.

### Valid Usage

- VUID-VkBindSparseInfo-pWaitSemaphores-03246
  If any element of `pWaitSemaphores` or `pSignalSemaphores` was created with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_TIMELINE` then the `pNext` chain must include a `VkTimelineSemaphoreSubmitInfo` structure.

- VUID-VkBindSparseInfo-pNext-03247
  If the `pNext` chain of this structure includes a `VkTimelineSemaphoreSubmitInfo` structure and any element of `pWaitSemaphores` was created with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_TIMELINE` then its `waitSemaphoreValueCount` member must equal `waitSemaphoreCount`.

- VUID-VkBindSparseInfo-pNext-03248
  If the `pNext` chain of this structure includes a `VkTimelineSemaphoreSubmitInfo` structure and any element of `pSignalSemaphores` was created with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_TIMELINE` then its `signalSemaphoreValueCount` member must equal `signalSemaphoreCount`.

- VUID-VkBindSparseInfo-pSignalSemaphores-03249
  For each element of `pSignalSemaphores` created with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_TIMELINE` the corresponding element of `VkTimelineSemaphoreSubmitInfo::pSignalSemaphoreValues` must have a value greater than the current value of the semaphore when the semaphore signal operation is executed.

- VUID-VkBindSparseInfo-pWaitSemaphores-03250
  For each element of `pWaitSemaphores` created with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_TIMELINE` the corresponding element of `VkTimelineSemaphoreSubmitInfo::pWaitSemaphoreValues` must have a value which does not differ from the current value of the semaphore or from the value of any outstanding semaphore wait or signal operation on that semaphore by more than `maxTimelineSemaphoreValueDifference`.

- VUID-VkBindSparseInfo-pSignalSemaphores-03251
For each element of `pSignalSemaphores` created with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_TIMELINE` the corresponding element of `VkTimelineSemaphoreSubmitInfo::pSignalSemaphoreValues` must have a value which does not differ from the current value of the semaphore or from the value of any outstanding semaphore wait or signal operation on that semaphore by more than `maxTimelineSemaphoreValueDifference`.

Valid Usage (Implicit)

- VUID-VkBindSparseInfo-sType-sType
  
  The `sType` value of each struct in the `pNext` chain must be unique.

- VUID-VkBindSparseInfo-pNext-pNext
  
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkDeviceGroupBindSparseInfo`, `VkFrameBoundaryEXT`, or `VkTimelineSemaphoreSubmitInfo`.

- VUID-VkBindSparseInfo-sType-unique
  
  The `sType` value of each struct in the `pNext` chain must be unique.

- VUID-VkBindSparseInfo-pWaitSemaphores-parameter
  
  If `waitSemaphoreCount` is not 0, `pWaitSemaphores` must be a valid pointer to an array of `VkSemaphore` handles.

- VUID-VkBindSparseInfo-pBufferBinds-parameter
  
  If `bufferBindCount` is not 0, `pBufferBinds` must be a valid pointer to an array of `VkSparseBufferMemoryBindInfo` structures.

- VUID-VkBindSparseInfo-pImageOpaqueBinds-parameter
  
  If `imageOpaqueBindCount` is not 0, `pImageOpaqueBinds` must be a valid pointer to an array of `VkSparseImageOpaqueMemoryBindInfo` structures.

- VUID-VkBindSparseInfo-pImageBinds-parameter
  
  If `imageBindCount` is not 0, `pImageBinds` must be a valid pointer to an array of `VkSparseImageMemoryBindInfo` structures.

To specify the values to use when waiting for and signaling semaphores created with a `VkSemaphoreType` of `VK_SEMAPHORE_TYPE_TIMELINE`, add a `VkTimelineSemaphoreSubmitInfo` structure to the `pNext` chain of the `VkBindSparseInfo` structure.

If the `pNext` chain of `VkBindSparseInfo` includes a `VkDeviceGroupBindSparseInfo` structure, then that structure includes device indices specifying which instance of the resources and memory are
The `VkDeviceGroupBindSparseInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkDeviceGroupBindSparseInfo {
    VkStructureType sType;
    const void* pNext;
    uint32_t resourceDeviceIndex;
    uint32_t memoryDeviceIndex;
} VkDeviceGroupBindSparseInfo;
```

or the equivalent

```c
// Provided by VK_KHR_device_group
typedef VkDeviceGroupBindSparseInfo VkDeviceGroupBindSparseInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `resourceDeviceIndex` is a device index indicating which instance of the resource is bound.
- `memoryDeviceIndex` is a device index indicating which instance of the memory the resource instance is bound to.

These device indices apply to all buffer and image memory binds included in the batch pointing to this structure. The semaphore waits and signals for the batch are executed only by the physical device specified by the `resourceDeviceIndex`.

If this structure is not present, `resourceDeviceIndex` and `memoryDeviceIndex` are assumed to be zero.

### Valid Usage

- VUID-VkDeviceGroupBindSparseInfo-resourceDeviceIndex-01118  
  `resourceDeviceIndex` and `memoryDeviceIndex` must both be valid device indices

- VUID-VkDeviceGroupBindSparseInfo-memoryDeviceIndex-01119  
  Each memory allocation bound in this batch must have allocated an instance for `memoryDeviceIndex`

### Valid Usage (Implicit)

- VUID-VkDeviceGroupBindSparseInfo-sType-sType  
  `sType` must be `VK_STRUCTURE_TYPE_DEVICE_GROUP_BIND_SPARSE_INFO`
Chapter 34. Window System Integration (WSI)

This chapter discusses the window system integration (WSI) between the Vulkan API and the various forms of displaying the results of rendering to a user. Since the Vulkan API can be used without displaying results, WSI is provided through the use of optional Vulkan extensions. This chapter provides an overview of WSI. See the appendix for additional details of each WSI extension, including which extensions must be enabled in order to use each of the functions described in this chapter.

34.1. WSI Platform

A platform is an abstraction for a window system, OS, etc. Some examples include MS Windows, Android, and Wayland. The Vulkan API may be integrated in a unique manner for each platform.

The Vulkan API does not define any type of platform object. Platform-specific WSI extensions are defined, each containing platform-specific functions for using WSI. Use of these extensions is guarded by preprocessor symbols as defined in the Window System-Specific Header Control appendix.

In order for an application to be compiled to use WSI with a given platform, it must either:

• define the appropriate preprocessor symbol prior to including the vulkan.h header file, or
• include vulkan_core.h and any native platform headers, followed by the appropriate platform-specific header.

The preprocessor symbols and platform-specific headers are defined in the Window System Extensions and Headers table.

Each platform-specific extension is an instance extension. The application must enable instance extensions with vkCreateInstance before using them.

34.2. WSI Surface

Native platform surface or window objects are abstracted by surface objects, which are represented by VkSurfaceKHR handles:

```
// Provided by VK_KHR_surface
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkSurfaceKHR)
```

The VK_KHR_surface extension declares the VkSurfaceKHR object, and provides a function for destroying VkSurfaceKHR objects. Separate platform-specific extensions each provide a function for creating a VkSurfaceKHR object for the respective platform. From the application's perspective this is an opaque handle, just like the handles of other Vulkan objects.

Note
34.2.1. Android Platform

To create a VkSurfaceKHR object for an Android native window, call:

```c
// Provided by VK_KHR_android_surface
VkResult vkCreateAndroidSurfaceKHR(
    VkInstance instance,
    const VkAndroidSurfaceCreateInfoKHR* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkSurfaceKHR* pSurface);
```

- `instance` is the instance to associate the surface with.
- `pCreateInfo` is a pointer to a VkAndroidSurfaceCreateInfoKHR structure containing parameters affecting the creation of the surface object.
- `pAllocator` is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).
- `pSurface` is a pointer to a VkSurfaceKHR handle in which the created surface object is returned.

During the lifetime of a surface created using a particular ANativeWindow handle any attempts to create another surface for the same ANativeWindow and any attempts to connect to the same ANativeWindow through other platform mechanisms will fail.

**Note**

In particular, only one VkSurfaceKHR can exist at a time for a given window. Similarly, a native window cannot be used by both a VkSurfaceKHR and EGLSurface simultaneously.

If successful, vkCreateAndroidSurfaceKHR increments the ANativeWindow's reference count, and vkDestroySurfaceKHR will decrement it.

On Android, when a swapchain's imageExtent does not match the surface's currentExtent, the presentable images will be scaled to the surface's dimensions during presentation. minImageExtent is (1,1), and maxImageExtent is the maximum image size supported by the consumer. For the system compositor, currentExtent is the window size (i.e. the consumer's preferred size).

**Valid Usage (Implicit)**

- VUID-vkCreateAndroidSurfaceKHR-instance-parameter
  instance must be a valid VkInstance handle
• VUID-vkCreateAndroidSurfaceKHR-pCreateInfo-parameter
  pCreateInfo must be a valid pointer to a valid VkAndroidSurfaceCreateInfoKHR structure

• VUID-vkCreateAndroidSurfaceKHR-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

• VUID-vkCreateAndroidSurfaceKHR-pSurface-parameter
  pSurface must be a valid pointer to a VkSurfaceKHR handle

Return Codes

Success
  • VK_SUCCESS

Failure
  • VK_ERROR_OUT_OF_HOST_MEMORY
  • VK_ERROR_OUT_OF_DEVICE_MEMORY
  • VK_ERROR_NATIVE_WINDOW_IN_USE_KHR

The VkAndroidSurfaceCreateInfoKHR structure is defined as:

```c
// Provided by VK_KHR_android_surface
typedef struct VkAndroidSurfaceCreateInfoKHR {
  VkStructureType sType;
  const void* pNext;
  VkAndroidSurfaceCreateFlagsKHR flags;
  struct ANativeWindow* window;
} VkAndroidSurfaceCreateInfoKHR;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• flags is reserved for future use.
• window is a pointer to the ANativeWindow to associate the surface with.

Valid Usage

• VUID-VkAndroidSurfaceCreateInfoKHR-window-01248
  window must point to a valid Android ANativeWindow

Valid Usage (Implicit)

• VUID-VkAndroidSurfaceCreateInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_ANDROID_SURFACE_CREATE_INFO_KHR
To remove an unnecessary compile time dependency, an incomplete type definition of `ANativeWindow` is provided in the Vulkan headers:

```c
// Provided by VK_KHR_android_surface
struct ANativeWindow;
```

The actual `ANativeWindow` type is defined in Android NDK headers.

```c
// Provided by VK_KHR_android_surface
typedef VkFlags VkAndroidSurfaceCreateFlagsKHR;
```

`VkAndroidSurfaceCreateFlagsKHR` is a bitmask type for setting a mask, but is currently reserved for future use.

### 34.2.2. Wayland Platform

To create a `VkSurfaceKHR` object for a Wayland surface, call:

```c
// Provided by VK_KHR_wayland_surface
VkResult vkCreateWaylandSurfaceKHR(
    VkInstance instance,
    const VkWaylandSurfaceCreateInfoKHR* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkSurfaceKHR* pSurface);
```

- `instance` is the instance to associate the surface with.
- `pCreateInfo` is a pointer to a `VkWaylandSurfaceCreateInfoKHR` structure containing parameters affecting the creation of the surface object.
- `pAllocator` is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).
- `pSurface` is a pointer to a `VkSurfaceKHR` handle in which the created surface object is returned.

#### Valid Usage (Implicit)

- VUID-vkCreateWaylandSurfaceKHR-instance-parameter
  `instance` must be a valid `VkInstance` handle
- VUID-vkCreateWaylandSurfaceKHR-pCreateInfo-parameter
  `pCreateInfo` must be a valid pointer to a valid `VkWaylandSurfaceCreateInfoKHR` structure
If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure.

`pSurface` must be a valid pointer to a `VkSurfaceKHR` handle.

Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

The `VkWaylandSurfaceCreateInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_wayland_surface
typedef struct VkWaylandSurfaceCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkWaylandSurfaceCreateFlagsKHR flags;
    struct wl_display* display;
    struct wl_surface* surface;
} VkWaylandSurfaceCreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is reserved for future use.
- `display` and `surface` are pointers to the Wayland `wl_display` and `wl_surface` to associate the surface with.

Valid Usage

- VUID-VkWaylandSurfaceCreateInfoKHR-display-01304 display must point to a valid Wayland `wl_display`
- VUID-VkWaylandSurfaceCreateInfoKHR-surface-01305 surface must point to a valid Wayland `wl_surface`

Valid Usage (Implicit)

- VUID-VkWaylandSurfaceCreateInfoKHR-sType-sType
sType must be VK_STRUCTURE_TYPE_WAYLAND_SURFACE_CREATE_INFO_KHR

- VUID-VkWaylandSurfaceCreateInfoKHR-pNext-pNext
  pNext must be NULL

- VUID-VkWaylandSurfaceCreateInfoKHR-flags-zero bitmask
  flags must be 0

On Wayland, currentExtent is the special value (0xFFFFFFFF, 0xFFFFFFFF), indicating that the surface size will be determined by the extent of a swapchain targeting the surface. Whatever the application sets a swapchain's imageExtent to will be the size of the window, after the first image is presented. minImageExtent is (1,1), and maxImageExtent is the maximum supported surface size. Any calls to vkGetPhysicalDeviceSurfacePresentModesKHR on a surface created with vkCreateWaylandSurfaceKHR are required to return VK_PRESENT_MODE_MAILBOX_KHR as one of the valid present modes.

Some Vulkan functions may send protocol over the specified wl_display connection when using a swapchain or presentable images created from a VkSurfaceKHR referring to a wl_surface. Applications must therefore ensure that both the wl_display and the wl_surface remain valid for the lifetime of any VkSwapchainKHR objects created from a particular wl_display and wl_surface. Also, calling vkQueuePresentKHR will result in Vulkan sending wl_surface.commit requests to the underlying wl_surface of each. The wl_surface.attach, wl_surface.damage, and wl_surface.commit requests must be issued by the implementation during the call to vkQueuePresentKHR and must not be issued by the implementation outside of vkQueuePresentKHR. This ensures that any Wayland requests sent by the client after the call to vkQueuePresentKHR returns will be received by the compositor after the wl_surface.commit. Regardless of the mode of swapchain creation, a new wl_event_queue must be created for each successful vkCreateWaylandSurfaceKHR call, and every Wayland object created by the implementation must be assigned to this event queue. If the platform provides Wayland 1.11 or greater, this must be implemented by the use of Wayland proxy object wrappers, to avoid race conditions.

If the application wishes to synchronize any window changes with a particular frame, such requests must be sent to the Wayland display server prior to calling vkQueuePresentKHR.

```c
// Provided by VK_KHR_wayland_surface
typedef VkFlags VkWaylandSurfaceCreateFlagsKHR;
```

VkWaylandSurfaceCreateFlagsKHR is a bitmask type for setting a mask, but is currently reserved for future use.

### 34.2.3. Win32 Platform

To create a VkSurfaceKHR object for a Win32 window, call:

```c
// Provided by VK_KHR_win32_surface
VkResult vkCreateWin32SurfaceKHR(
    VkInstance instance,
    const VkWin32SurfaceCreateInfoKHR* pCreateInfo,
);```
const VkAllocationCallbacks* pAllocator,
VkSurfaceKHR* pSurface);

• **instance** is the instance to associate the surface with.

• **pCreateInfo** is a pointer to a VkWin32SurfaceCreateInfoKHR structure containing parameters affecting the creation of the surface object.

• **pAllocator** is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).

• **pSurface** is a pointer to a VkSurfaceKHR handle in which the created surface object is returned.

### Valid Usage (Implicit)

- VUID-vkCreateWin32SurfaceKHR-instance-parameter
  instance must be a valid VkInstance handle

- VUID-vkCreateWin32SurfaceKHR-pCreateInfo-parameter
  pCreateInfo must be a valid pointer to a valid VkWin32SurfaceCreateInfoKHR structure

- VUID-vkCreateWin32SurfaceKHR-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkCreateWin32SurfaceKHR-pSurface-parameter
  pSurface must be a valid pointer to a VkSurfaceKHR handle

### Return Codes

**Success**

- VK_SUCCESS

**Failure**

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkWin32SurfaceCreateInfoKHR structure is defined as:

```c
// Provided by VK_KHR_win32_surface
typedef struct VkWin32SurfaceCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkWin32SurfaceCreateFlagsKHR flags;
    HINSTANCE hinstance;
    HWND hwnd;
} VkWin32SurfaceCreateInfoKHR;
```
• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **flags** is reserved for future use.

• **hinstance** is the Win32 `HINSTANCE` for the window to associate the surface with.

• **hwnd** is the Win32 `HWND` for the window to associate the surface with.

### Valid Usage

- VUID-VkWin32SurfaceCreateInfoKHR-hinstance-01307
  
  **hinstance** **must** be a valid Win32 `HINSTANCE`

- VUID-VkWin32SurfaceCreateInfoKHR-hwnd-01308
  
  **hwnd** **must** be a valid Win32 `HWND`

### Valid Usage (Implicit)

- VUID-VkWin32SurfaceCreateInfoKHR-sType-sType
  
  **sType** **must** be `VK_STRUCTURE_TYPE_WIN32_SURFACE_CREATE_INFO_KHR`

- VUID-VkWin32SurfaceCreateInfoKHR-pNext-pNext
  
  **pNext** **must** be `NULL`

- VUID-VkWin32SurfaceCreateInfoKHR-flags-zerobitmask
  
  **flags** **must** be `0`

With Win32, **minImageExtent**, **maxImageExtent**, and **currentExtent** **must** always equal the window size.

The **currentExtent** of a Win32 surface **must** have both **width** and **height** greater than 0, or both of them 0.

### Note

Due to above restrictions, unless `VkSwapchainPresentScalingCreateInfoEXT` is used to specify handling of disparities between surface and swapchain dimensions, it is only possible to create a new swapchain on this platform with **imageExtent** being equal to the current size of the window, as reported in `VkSurfaceCapabilitiesKHR::currentExtent`.

The window size **may** become (0, 0) on this platform (e.g. when the window is minimized), and so a swapchain **cannot** be created until the size changes.

```c
// Provided by VK_KHR_win32_surface
typedef VkFlags VkWin32SurfaceCreateFlagsKHR;
```

`VkWin32SurfaceCreateFlagsKHR` is a bitmask type for setting a mask, but is currently reserved for future use.
34.2.4. XCB Platform

To create a VkSurfaceKHR object for an X11 window, using the XCB client-side library, call:

```c
// Provided by VK_KHR_xcb_surface
VkResult vkCreateXcbSurfaceKHR(
    VkInstance instance,
    const VkXcbSurfaceCreateInfoKHR* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkSurfaceKHR* pSurface);
```

- `instance` is the instance to associate the surface with.
- `pCreateInfo` is a pointer to a VkXcbSurfaceCreateInfoKHR structure containing parameters affecting the creation of the surface object.
- `pAllocator` is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).
- `pSurface` is a pointer to a VkSurfaceKHR handle in which the created surface object is returned.

### Valid Usage (Implicit)

- VUID-vkCreateXcbSurfaceKHR-instance-parameter  
  `instance` must be a valid VkInstance handle
- VUID-vkCreateXcbSurfaceKHR-pCreateInfo-parameter  
  `pCreateInfo` must be a valid pointer to a valid VkXcbSurfaceCreateInfoKHR structure

- VUID-vkCreateXcbSurfaceKHR-pAllocator-parameter  
  If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid VkAllocationCallbacks structure
- VUID-vkCreateXcbSurfaceKHR-pSurface-parameter  
  `pSurface` must be a valid pointer to a VkSurfaceKHR handle

### Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkXcbSurfaceCreateInfoKHR structure is defined as:

```c
// Provided by VK_KHR_xcb_surface
typedef struct VkXcbSurfaceCreateInfoKHR {
```
VkStructureType         sType;
const void*              pNext;
VkXcbSurfaceCreateFlagsKHR flags;
xcb_connection_t*        connection;
xcb_window_t             window;
} VkXcbSurfaceCreateInfoKHR;

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **connection** is a pointer to an **xcb_connection_t** to the X server.
- **window** is the **xcb_window_t** for the X11 window to associate the surface with.

**Valid Usage**

- VUID-VkXcbSurfaceCreateInfoKHR-connection-01310
  connection must point to a valid X11 **xcb_connection_t**
- VUID-VkXcbSurfaceCreateInfoKHR-window-01311
  window must be a valid X11 **xcb_window_t**

**Valid Usage (Implicit)**

- VUID-VkXcbSurfaceCreateInfoKHR-sType-sType
  sType must be **VK_STRUCTURE_TYPE_XCB_SURFACE_CREATE_INFO_KHR**
- VUID-VkXcbSurfaceCreateInfoKHR-pNext-pNext
  pNext must be NULL
- VUID-VkXcbSurfaceCreateInfoKHR-flags-zerobitmask
  flags must be 0

With Xcb, **minImageExtent**, **maxImageExtent**, and **currentExtent** must always equal the window size.

The **currentExtent** of an Xcb surface must have both **width** and **height** greater than 0, or both of them 0.

**Note**

Due to above restrictions, unless **VkSwapchainPresentScalingCreateInfoEXT** is used to specify handling of disparities between surface and swapchain dimensions, it is only possible to create a new swapchain on this platform with **imageExtent** being equal to the current size of the window, as reported in **VkSurfaceCapabilitiesKHR::currentExtent**.

The window size may become (0, 0) on this platform (e.g. when the window is minimized), and so a swapchain cannot be created until the size changes.
Some Vulkan functions **may** send protocol over the specified xcb connection when using a swapchain or presentable images created from a VkSurfaceKHR referring to an xcb window. Applications **must** therefore ensure the xcb connection is available to Vulkan for the duration of any functions that manipulate such swapchains or their presentable images, and any functions that build or queue command buffers that operate on such presentable images. Specifically, applications using Vulkan with xcb-based swapchains **must**

- Avoid holding a server grab on an xcb connection while waiting for Vulkan operations to complete using a swapchain derived from a different xcb connection referring to the same X server instance. Failing to do so **may** result in deadlock.

```c
// Provided by VK_KHR_xcb_surface
typedef VkFlags VkXcbSurfaceCreateFlagsKHR;
```

VkXcbSurfaceCreateFlagsKHR is a bitmask type for setting a mask, but is currently reserved for future use.

### 34.2.5. Xlib Platform

To create a VkSurfaceKHR object for an X11 window, using the Xlib client-side library, call:

```c
// Provided by VK_KHR_xlib_surface
VkResult vkCreateXlibSurfaceKHR(
    VkInstance instance,
    const VkXlibSurfaceCreateInfoKHR* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkSurfaceKHR* pSurface);
```

- **instance** is the instance to associate the surface with.
- **pCreateInfo** is a pointer to a VkXlibSurfaceCreateInfoKHR structure containing the parameters affecting the creation of the surface object.
- **pAllocator** is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).
- **pSurface** is a pointer to a VkSurfaceKHR handle in which the created surface object is returned.

**Valid Usage (Implicit)**

- VUID-vkCreateXlibSurfaceKHR-instance-parameter
  instance **must** be a valid VkInstance handle
- VUID-vkCreateXlibSurfaceKHR-pCreateInfo-parameter
  pCreateInfo **must** be a valid pointer to a valid VkXlibSurfaceCreateInfoKHR structure
- VUID-vkCreateXlibSurfaceKHR-pAllocator-parameter
  If pAllocator is not NULL, pAllocator **must** be a valid pointer to a valid VkAllocationCallbacks structure
• VUID-vkCreateXlibSurfaceKHR-pSurface-parameter
  pSurface must be a valid pointer to a VkSurfaceKHR handle

Return Codes

Success
  • VK_SUCCESS

Failure
  • VK_ERROR_OUT_OF_HOST_MEMORY
  • VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkXlibSurfaceCreateInfoKHR structure is defined as:

```c
// Provided by VK_KHR_xlib_surface
typedef struct VkXlibSurfaceCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkXlibSurfaceCreateFlagsKHR flags;
    Display* dpy;
    Window window;
} VkXlibSurfaceCreateInfoKHR;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• flags is reserved for future use.
• dpy is a pointer to an Xlib Display connection to the X server.
• window is an Xlib Window to associate the surface with.

Valid Usage

• VUID-VkXlibSurfaceCreateInfoKHR-dpy-01313
dpy must point to a valid Xlib Display

• VUID-VkXlibSurfaceCreateInfoKHR-window-01314
  window must be a valid Xlib Window

Valid Usage (Implicit)

• VUID-VkXlibSurfaceCreateInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_XLIB_SURFACE_CREATE_INFO_KHR

• VUID-VkXlibSurfaceCreateInfoKHR-pNext-pNext
  pNext must be NULL
With Xlib, `minImageExtent`, `maxImageExtent`, and `currentExtent` **must** always equal the window size.

The `currentExtent` of an Xlib surface **must** have both `width` and `height` greater than 0, or both of them 0.

**Note**

Due to above restrictions, unless `VkSwapchainPresentScalingCreateInfoEXT` is used to specify handling of disparities between surface and swapchain dimensions, it is only possible to create a new swapchain on this platform with `imageExtent` being equal to the current size of the window, as reported in `VkSurfaceCapabilitiesKHR::currentExtent`.

The window size **may** become (0, 0) on this platform (e.g. when the window is minimized), and so a swapchain **cannot** be created until the size changes.

Some Vulkan functions **may** send protocol over the specified Xlib `Display` connection when using a swapchain or presentable images created from a `VkSurfaceKHR` referring to an Xlib window. Applications **must** therefore ensure the display connection is available to Vulkan for the duration of any functions that manipulate such swapchains or their presentable images, and any functions that build or queue command buffers that operate on such presentable images. Specifically, applications using Vulkan with Xlib-based swapchains **must**

- Avoid holding a server grab on a display connection while waiting for Vulkan operations to complete using a swapchain derived from a different display connection referring to the same X server instance. Failing to do so may result in deadlock.

Some implementations may require threads to implement some presentation modes so applications **must** call `XInitThreads()` before calling any other Xlib functions.

```c
// Provided by VK_KHR_xlib_surface
typedef VkFlags VkXlibSurfaceCreateFlagsKHR;
```

`VkXlibSurfaceCreateFlagsKHR` is a bitmask type for setting a mask, but is currently reserved for future use.

### 34.2.6. DirectFB Platform

To create a `VkSurfaceKHR` object for a DirectFB surface, call:

```c
// Provided by VK_EXT_directfb_surface
VkResult vkCreateDirectFBSurfaceEXT(  
    VkInstance instance,  
    const VkDirectFBSurfaceCreateInfoEXT* pCreateInfo,  
    const VkAllocationCallbacks* pAllocator,  
    VkSurfaceKHR* pSurface)
```

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• **instance** is the instance to associate the surface with.

• **pCreateInfo** is a pointer to a `VkDirectFBSurfaceCreateInfoEXT` structure containing parameters affecting the creation of the surface object.

• **pAllocator** is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).

• **pSurface** is a pointer to a `VkSurfaceKHR` handle in which the created surface object is returned.

### Valid Usage (Implicit)

- VUID-vkCreateDirectFBSurfaceEXT-instance-parameter
  
  `instance` must be a valid `VkInstance` handle

- VUID-vkCreateDirectFBSurfaceEXT-pCreateInfo-parameter
  
  `pCreateInfo` must be a valid pointer to a valid `VkDirectFBSurfaceCreateInfoEXT` structure

- VUID-vkCreateDirectFBSurfaceEXT-pAllocator-parameter
  
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

- VUID-vkCreateDirectFBSurfaceEXT-pSurface-parameter
  
  `pSurface` must be a valid pointer to a `VkSurfaceKHR` handle

### Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

The `VkDirectFBSurfaceCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_directfb_surface
typedef struct VkDirectFBSurfaceCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkDirectFBSurfaceCreateFlagsEXT flags;
    IDirectFB* dfb;
    IDirectFBSurface* surface;
} VkDirectFBSurfaceCreateInfoEXT;
```

• **sType** is a `VkStructureType` value identifying this structure.
• **pNext** is **NULL** or a pointer to a structure extending this structure.
• **flags** is reserved for future use.
• **dfb** is a pointer to the **IDirectFB** main interface of DirectFB.
• **surface** is a pointer to a **IDirectFBSurface** surface interface.

### Valid Usage

- **VUID-VkDirectFBSurfaceCreateInfoEXT-dfb-04117**
  
  **dfb** must point to a valid DirectFB **IDirectFB**

- **VUID-VkDirectFBSurfaceCreateInfoEXT-surface-04118**
  
  **surface** must point to a valid DirectFB **IDirectFBSurface**

### Valid Usage (Implicit)

- **VUID-VkDirectFBSurfaceCreateInfoEXT-sType-sType**
  
  **sType** must be **VK_STRUCTURE_TYPE_DIRECTFB_SURFACE_CREATE_INFO_EXT**

- **VUID-VkDirectFBSurfaceCreateInfoEXT-pNext-pNext**
  
  **pNext** must be **NULL**

- **VUID-VkDirectFBSurfaceCreateInfoEXT-flags-zerobitmask**
  
  **flags** must be **0**

With DirectFB, **minImageExtent**, **maxImageExtent**, and **currentExtent** must always equal the surface size.

```c
// Provided by VK_EXT_directfb_surface
typedef VkFlags VkDirectFBSurfaceCreateFlagsEXT;
```

**VkDirectFBSurfaceCreateFlagsEXT** is a bitmask type for setting a mask, but is currently reserved for future use.

### 34.2.7. Fuchsia Platform

To create a **VkSurfaceKHR** object for a Fuchsia ImagePipe, call:

```c
// Provided by VK_FUCHSIA_imagepipe_surface
VkResult vkCreateImagePipeSurfaceFUCHSIA(
   VkInstance instance,
    const VkImagePipeSurfaceCreateInfoFUCHSIA* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkSurfaceKHR* pSurface);
```

• **instance** is the instance to associate with the surface.
• **pCreateInfo** is a pointer to a `VkImagePipeSurfaceCreateInfoFUCHSIA` structure containing parameters affecting the creation of the surface object.

• **pAllocator** is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).

• **pSurface** is a pointer to a `VkSurfaceKHR` handle in which the created surface object is returned.

---

### Valid Usage (Implicit)

- VUID-vkCreateImagePipeSurfaceFUCHSIA-instance-parameter
  - `instance` must be a valid `VkInstance` handle

- VUID-vkCreateImagePipeSurfaceFUCHSIA-pCreateInfo-parameter
  - `pCreateInfo` must be a valid pointer to a valid `VkImagePipeSurfaceCreateInfoFUCHSIA` structure

- VUID-vkCreateImagePipeSurfaceFUCHSIA-pAllocator-parameter
  - If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

- VUID-vkCreateImagePipeSurfaceFUCHSIA-pSurface-parameter
  - `pSurface` must be a valid pointer to a `VkSurfaceKHR` handle

---

### Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

---

The `VkImagePipeSurfaceCreateInfoFUCHSIA` structure is defined as:

```c
// Provided by VK_FUCHSIA_imagepipe_surface
typedef struct VkImagePipeSurfaceCreateInfoFUCHSIA {
    VkStructureType          sType;
    const void*              pNext;
    VkImagePipeSurfaceCreateFlagsFUCHSIA flags;
    zx_handle_t              imagePipeHandle;
} VkImagePipeSurfaceCreateInfoFUCHSIA;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **imagePipeHandle** is a `zx_handle_t` referring to the ImagePipe to associate with the surface.
Valid Usage

- VUID-VkImagePipeSurfaceCreateInfoFUCHSIA-imagePipeHandle-04863
  \textit{imagePipeHandle} must be a valid \texttt{zx}_handle_t

Valid Usage (Implicit)

- VUID-VkImagePipeSurfaceCreateInfoFUCHSIA-sType-sType
  \textit{sType} must be \texttt{VK}_\texttt{STRUCTURE}_\texttt{TYPE}_\texttt{IMAGEPIPE}_\texttt{SURFACE}_\texttt{CREATE}_\texttt{INFO}_\texttt{FUCHSIA}

- VUID-VkImagePipeSurfaceCreateInfoFUCHSIA-pNext-pNext
  \textit{pNext} must be NULL

- VUID-VkImagePipeSurfaceCreateInfoFUCHSIA-flags-zerobitmask
  \textit{flags} must be 0

On Fuchsia, the surface \texttt{currentExtent} is the special value (0xFFFFFFFF, 0xFFFFFFFF), indicating that the surface size will be determined by the extent of a swapchain targeting the surface.

```c
// Provided by VK_FUCHSIA_imagepipe_surface
typedef VkFlags VkImagePipeSurfaceCreateFlagsFUCHSIA;
```

\texttt{VkImagePipeSurfaceCreateFlagsFUCHSIA} is a bitmask type for setting a mask, but is currently reserved for future use.

34.2.8. Google Games Platform

To create a \texttt{VkSurfaceKHR} object for a Google Games Platform stream descriptor, call:

```c
// Provided by VK_GGP_stream_descriptor_surface
VkResult vkCreateStreamDescriptorSurfaceGGP(
    VkInstance instance,
    const VkStreamDescriptorSurfaceCreateInfoGGP* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkSurfaceKHR* pSurface);
```

- \texttt{instance} is the instance to associate with the surface.
- \texttt{pCreateInfo} is a pointer to a \texttt{VkStreamDescriptorSurfaceCreateInfoGGP} structure containing parameters that affect the creation of the surface object.
- \texttt{pAllocator} is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).
- \texttt{pSurface} is a pointer to a \texttt{VkSurfaceKHR} handle in which the created surface object is returned.
Valid Usage (Implicit)

- VUID-vkCreateStreamDescriptorSurfaceGGP-instance-parameter
  instance must be a valid VkInstance handle

- VUID-vkCreateStreamDescriptorSurfaceGGP-pCreateInfo-parameter
  pCreateInfo must be a valid pointer to a valid VkStreamDescriptorSurfaceCreateInfoGGP structure

- VUID-vkCreateStreamDescriptorSurfaceGGP-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkCreateStreamDescriptorSurfaceGGP-pSurface-parameter
  pSurface must be a valid pointer to a VkSurfaceKHR handle

Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_NATIVE_WINDOW_IN_USE_KHR

The VkStreamDescriptorSurfaceCreateInfoGGP structure is defined as:

```c
// Provided by VK_GGP_stream_descriptor_surface
typedef struct VkStreamDescriptorSurfaceCreateInfoGGP {
    VkStructureType sType;
    const void* pNext;
    VkStreamDescriptorSurfaceCreateFlagsGGP flags;
    GgpStreamDescriptor streamDescriptor;
} VkStreamDescriptorSurfaceCreateInfoGGP;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **streamDescriptor** is a GgpStreamDescriptor referring to the GGP stream descriptor to associate with the surface.

Valid Usage

- VUID-VkStreamDescriptorSurfaceCreateInfoGGP-streamDescriptor-02681
streamDescriptor must be a valid GgpStreamDescriptor

Valid Usage (Implicit)

- VUID-VkStreamDescriptorSurfaceCreateInfoGGP-sType-sType
  sType must be VK_STRUCTURE_TYPE_STREAM_DESCRIPTOR_SURFACE_CREATE_INFO_GGP
- VUID-VkStreamDescriptorSurfaceCreateInfoGGP-pNext-pNext
  pNext must be NULL
- VUID-VkStreamDescriptorSurfaceCreateInfoGGP-flags-zerobitmask
  flags must be 0

On Google Games Platform, the surface extents are dynamic. The minImageExtent will never be greater than 1080p and the maxImageExtent will never be less than 1080p. The currentExtent will reflect the current optimal resolution.

Applications are expected to choose an appropriate size for the swapchain’s imageExtent, within the bounds of the surface. Using the surface’s currentExtent will offer the best performance and quality. When a swapchain’s imageExtent does not match the surface’s currentExtent, the presentable images are scaled to the surface’s dimensions during presentation if possible and VK_SUBOPTIMAL_KHR is returned, otherwise presentation fails with VK_ERROR_OUT_OF_DATE_KHR.

// Provided by VK_GGP_stream_descriptor_surface
typedef VkFlags VkStreamDescriptorSurfaceCreateFlagsGGP;

VkStreamDescriptorSurfaceCreateFlagsGGP is a bitmask type for setting a mask, but is currently reserved for future use.

34.2.9. iOS Platform

To create a VkSurfaceKHR object for an iOS UIView or CAMetalLayer, call:

// Provided by VK_MVK_ios_surface
VkResult vkCreateIOSSurfaceMVK(
    VkInstance instance,
    const VkIOSSurfaceCreateInfoMVK* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkSurfaceKHR* pSurface);

Note

The vkCreateIOSSurfaceMVK function is considered deprecated and has been superseded by vkCreateMetalSurfaceEXT from the VK_EXT_metal_surface extension.

- instance is the instance with which to associate the surface.
• `pCreateInfo` is a pointer to a `VkIOSSurfaceCreateInfoMVK` structure containing parameters affecting the creation of the surface object.

• `pAllocator` is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).

• `pSurface` is a pointer to a `VkSurfaceKHR` handle in which the created surface object is returned.

### Valid Usage (Implicit)

- VUID-vkCreateIOSSurfaceMVK-instance-parameter
  instance must be a valid `VkInstance` handle

- VUID-vkCreateIOSSurfaceMVK-pCreateInfo-parameter
  `pCreateInfo` must be a valid pointer to a valid `VkIOSSurfaceCreateInfoMVK` structure

- VUID-vkCreateIOSSurfaceMVK-pAllocator-parameter
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

- VUID-vkCreateIOSSurfaceMVK-pSurface-parameter
  `pSurface` must be a valid pointer to a `VkSurfaceKHR` handle

### Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_NATIVE_WINDOW_IN_USE_KHR`

The `VkIOSSurfaceCreateInfoMVK` structure is defined as:

```c
// Provided by VK_MVK_ios_surface
typedef struct VkIOSSurfaceCreateInfoMVK {
    VkStructureType sType;
    const void* pNext;
    VkIOSSurfaceCreateFlagsMVK flags;
    const void* pView;
} VkIOSSurfaceCreateInfoMVK;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is reserved for future use.
- `pView` is a reference to either a `CAMetalLayer` object or a `UIView` object.
Valid Usage

- VUID-VkIOSSurfaceCreateInfoMVK-pView-04143
  If `pView` is a `CAMetalLayer` object, it **must** be a valid `CAMetalLayer`

- VUID-VkIOSSurfaceCreateInfoMVK-pView-01316
  If `pView` is a `UIView` object, it **must** be a valid `UIView`, **must** be backed by a `CALayer` object of type `CAMetalLayer`, and `vkCreateIOSSurfaceMVK` **must** be called on the main thread

Valid Usage (Implicit)

- VUID-VkIOSSurfaceCreateInfoMVK-sType-sType
  `sType` **must** be `VK_STRUCTURE_TYPE_IOS_SURFACE_CREATE_INFO_MVK`

- VUID-VkIOSSurfaceCreateInfoMVK-pNext-pNext
  `pNext` **must** be `NULL`

- VUID-VkIOSSurfaceCreateInfoMVK-flags-zerobitmask
  `flags` **must** be `0`

// Provided by VK_MVK_ios_surface
typedef VkFlags VkIOSurfaceCreateFlagsMVK;

`VkIOSurfaceCreateFlagsMVK` is a bitmask type for setting a mask, but is currently reserved for future use.

34.2.10. macOS Platform

To create a `VkSurfaceKHR` object for a macOS `NSView` or `CAMetalLayer`, call:

// Provided by VK_MVK_macos_surface
VkResult vkCreateMacOSSurfaceMVK(
    VkInstance instance,
    const VkMacOSSurfaceCreateInfoMVK* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkSurfaceKHR* pSurface);

**Note**

The `vkCreateMacOSSurfaceMVK` function is considered deprecated and has been superseded by `vkCreateMetalSurfaceEXT` from the `VK_EXT_metal_surface` extension.

- `instance` is the instance with which to associate the surface.
- `pCreateInfo` is a pointer to a `VkMacOSSurfaceCreateInfoMVK` structure containing parameters affecting the creation of the surface object.
- `pAllocator` is the allocator used for host memory allocated for the surface object when there is
no more specific allocator available (see Memory Allocation).

• pSurface is a pointer to a VkSurfaceKHR handle in which the created surface object is returned.

Valid Usage (Implicit)

- VUID-vkCreateMacOSSurfaceMVK-instance-parameter
  instance must be a valid VkInstance handle
- VUID-vkCreateMacOSSurfaceMVK-pCreateInfo-parameter
  pCreateInfo must be a valid pointer to a valid VkMacOSSurfaceCreateInfoMVK structure
- VUID-vkCreateMacOSSurfaceMVK-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure
- VUID-vkCreateMacOSSurfaceMVK-pSurface-parameter
  pSurface must be a valid pointer to a VkSurfaceKHR handle

Return Codes

Success
  • VK_SUCCESS

Failure
  • VK_ERROR_OUT_OF_HOST_MEMORY
  • VK_ERROR_OUT_OF_DEVICE_MEMORY
  • VK_ERROR_NATIVE_WINDOW_IN_USE_KHR

The VkMacOSSurfaceCreateInfoMVK structure is defined as:

```c
// Provided by VK_MVK_macos_surface
typedef struct VkMacOSSurfaceCreateInfoMVK {
    VkStructureType sType;
    const void* pNext;
    VkMacOSSurfaceCreateFlagsMVK flags;
    const void* pView;
} VkMacOSSurfaceCreateInfoMVK;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• flags is reserved for future use.
• pView is a reference to either a CAMetalLayer object or an NSView object.
Valid Usage

- VUID-VkMacOSSurfaceCreateInfoMVK-pView-04144
  If `pView` is a `CAMetalLayer` object, it **must** be a valid `CAMetalLayer`.

- VUID-VkMacOSSurfaceCreateInfoMVK-pView-01317
  If `pView` is an `NSView` object, it **must** be a valid `NSView`, **must** be backed by a `CALayer` object of type `CAMetalLayer`, and `vkCreateMacOSSurfaceMVK` **must** be called on the main thread.

Valid Usage (Implicit)

- VUID-VkMacOSSurfaceCreateInfoMVK-sType-sType
  `sType` **must** be `VK_STRUCTURE_TYPE_MACOS_SURFACE_CREATE_INFO_MVK`.

- VUID-VkMacOSSurfaceCreateInfoMVK-pNext-pNext
  `pNext` **must** be `NULL`.

- VUID-VkMacOSSurfaceCreateInfoMVK-flags-zero bitmask
  `flags` **must** be `0`.

----

```c
// Provided by VK_MVK_macos_surface
typedef VkFlags VkMacOSSurfaceCreateFlagsMVK;
```

**VkMacOSSurfaceCreateFlagsMVK** is a bitmask type for setting a mask, but is currently reserved for future use.

### 34.2.11. VI Platform

To create a `VkSurfaceKHR` object for an `nn::vi::Layer`, query the layer's native handle using `nn::vi::GetNativeWindow`, and then call:

```c
// Provided by VK_NN_vi_surface
VkResult vkCreateViSurfaceNN(
    VkInstance instance,
    const VkViSurfaceCreateInfoNN* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkSurfaceKHR* pSurface);
```

- `instance` is the instance with which to associate the surface.
- `pCreateInfo` is a pointer to a `VkViSurfaceCreateInfoNN` structure containing parameters affecting the creation of the surface object.
- `pAllocator` is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).
- `pSurface` is a pointer to a `VkSurfaceKHR` handle in which the created surface object is returned.
During the lifetime of a surface created using a particular `nn::vi::NativeWindowHandle`, applications must not attempt to create another surface for the same `nn::vi::Layer` or attempt to connect to the same `nn::vi::Layer` through other platform mechanisms.

If the native window is created with a specified size, `currentExtent` will reflect that size. In this case, applications should use the same size for the swapchain's `imageExtent`. Otherwise, the `currentExtent` will have the special value (0xFFFFFFFF, 0xFFFFFFFF), indicating that applications are expected to choose an appropriate size for the swapchain's `imageExtent` (e.g., by matching the result of a call to `nn::vi::GetDisplayResolution`).

Valid Usage (Implicit)

- VUID-vkCreateViSurfaceNN-instance-parameter
  instance must be a valid `VkInstance` handle
- VUID-vkCreateViSurfaceNN-pCreateInfo-parameter
  `pCreateInfo` must be a valid pointer to a valid `VkViSurfaceCreateInfoNN` structure
- VUID-vkCreateViSurfaceNN-pAllocator-parameter
  If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure
- VUID-vkCreateViSurfaceNN-pSurface-parameter
  `pSurface` must be a valid pointer to a `VkSurfaceKHR` handle

Return Codes

Success

- VK_SUCCESS

Failure

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_NATIVE_WINDOW_IN_USE_KHR

The `VkViSurfaceCreateInfoNN` structure is defined as:

```c
// Provided by VK_NN_vi_surface
typedef struct VkViSurfaceCreateInfoNN {
    VkStructureType sType;
    const void* pNext;
    VkViSurfaceCreateFlagsNN flags;
    void* window;
} VkViSurfaceCreateInfoNN;
```

- `sType` is a `VkStructureType` value identifying this structure.
• `pNext` is NULL or a pointer to a structure extending this structure.
• `flags` is reserved for future use.
• `window` is the `nn::vi::NativeWindowHandle` for the `nn::vi::Layer` with which to associate the surface.

**Valid Usage**

- VUID-VkViSurfaceCreateInfoNN-window-01318  
  `window` must be a valid `nn::vi::NativeWindowHandle`

**Valid Usage (Implicit)**

- VUID-VkViSurfaceCreateInfoNN-sType-sType  
  `sType` must be `VK_STRUCTURE_TYPE_VI_SURFACE_CREATE_INFO_NN`
- VUID-VkViSurfaceCreateInfoNN-pNext-pNext  
  `pNext` must be NULL
- VUID-VkViSurfaceCreateInfoNN-flags-zerobitmask  
  `flags` must be 0

// Provided by VK_NN_vi_surface  
typedef VkFlags VkViSurfaceCreateFlagsNN;

`VkViSurfaceCreateFlagsNN` is a bitmask type for setting a mask, but is currently reserved for future use.

### 34.2.12. Metal Platform

To create a `VkSurfaceKHR` object for a `CAMetalLayer`, call:

// Provided by VK_EXT_metal_surface  
VkResult vkCreateMetalSurfaceEXT(  
   VkInstance instance,  
   const VkMetalSurfaceCreateInfoEXT* pCreateInfo,  
   const VkAllocationCallbacks* pAllocator,  
   VkSurfaceKHR* pSurface);

- `instance` is the instance with which to associate the surface.
- `pCreateInfo` is a pointer to a `VkMetalSurfaceCreateInfoEXT` structure specifying parameters affecting the creation of the surface object.
- `pAllocator` is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).
- `pSurface` is a pointer to a `VkSurfaceKHR` handle in which the created surface object is returned.
Valid Usage (Implicit)

- VUID-vkCreateMetalSurfaceEXT-instance-parameter
  instance must be a valid VkInstance handle

- VUID-vkCreateMetalSurfaceEXT-pCreateInfo-parameter
  pCreateInfo must be a valid pointer to a valid VkMetalSurfaceCreateInfoEXT structure

- VUID-vkCreateMetalSurfaceEXT-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkCreateMetalSurfaceEXT-pSurface-parameter
  pSurface must be a valid pointer to a VkSurfaceKHR handle

Return Codes

Success
  - VK_SUCCESS

Failure
  - VK_ERROR_OUT_OF_HOST_MEMORY
  - VK_ERROR_OUT_OF_DEVICE_MEMORY
  - VK_ERROR_NATIVE_WINDOW_IN_USE_KHR

The VkMetalSurfaceCreateInfoEXT structure is defined as:

```c
// Provided by VK_EXT_metal_surface
typedef struct VkMetalSurfaceCreateInfoEXT {
  VkStructureType sType;
  const void* pNext;
  VkMetalSurfaceCreateFlagsEXT flags;
  const CAMetalLayer* pLayer;
} VkMetalSurfaceCreateInfoEXT;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **pLayer** is a reference to a CAMetalLayer object representing a renderable surface.

Valid Usage (Implicit)

- VUID-VkMetalSurfaceCreateInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_METAL_SURFACE_CREATE_INFO_EXT
To remove an unnecessary compile time dependency, an incomplete type definition of `CAMetalLayer` is provided in the Vulkan headers:

```c
// Provided by VK_EXT_metal_surface
#ifdef __OBJC__
@class CAMetalLayer;
#else
typedef void CAMetalLayer;
#endif
```

The actual `CAMetalLayer` type is defined in the QuartzCore framework.

```c
// Provided by VK_EXT_metal_surface
typedef VkFlags VkMetalSurfaceCreateFlagsEXT;
```

`VkMetalSurfaceCreateFlagsEXT` is a bitmask type for setting a mask, but is currently reserved for future use.

### 34.2.13. QNX Screen Platform

To create a `VkSurfaceKHR` object for a QNX Screen surface, call:

```c
// Provided by VK_QNX_screen_surface
VkResult vkCreateScreenSurfaceQNX(
    VkInstance instance, const VkScreenSurfaceCreateInfoQNX* pCreateInfo, const VkAllocationCallbacks* pAllocator, VkSurfaceKHR* pSurface);
```

- **instance** is the instance to associate the surface with.
- **pCreateInfo** is a pointer to a `VkScreenSurfaceCreateInfoQNX` structure containing parameters affecting the creation of the surface object.
- **pAllocator** is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).
- **pSurface** is a pointer to a `VkSurfaceKHR` handle in which the created surface object is returned.

### Valid Usage (Implicit)

- VUID-vkCreateScreenSurfaceQNX-instance-parameter

---

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instance must be a valid VkInstance handle

- VUID-vkCreateScreenSurfaceQNX-pCreateInfo-parameter
  pCreateInfo must be a valid pointer to a valid VkScreenSurfaceCreateInfoQNX structure

- VUID-vkCreateScreenSurfaceQNX-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkCreateScreenSurfaceQNX-pSurface-parameter
  pSurface must be a valid pointer to a VkSurfaceKHR handle

**Return Codes**

**Success**

- VK_SUCCESS

**Failure**

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkScreenSurfaceCreateInfoQNX structure is defined as:

```c
typedef struct VkScreenSurfaceCreateInfoQNX {
    VkStructureType sType;
    const void* pNext;
    VkScreenSurfaceCreateFlagsQNX flags;
    struct _screen_context* context;
    struct _screen_window* window;
} VkScreenSurfaceCreateInfoQNX;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- flags is reserved for future use.
- context and window are QNX Screen context and window to associate the surface with.

**Valid Usage**

- VUID-VkScreenSurfaceCreateInfoQNX-context-04741
  context must point to a valid QNX Screen struct _screen_context

- VUID-VkScreenSurfaceCreateInfoQNX-window-04742
  window must point to a valid QNX Screen struct _screen_window
Valid Usage (Implicit)

- VUID-VkScreenSurfaceCreateInfoQNX-sType-sType
  sType must be VK_STRUCTURE_TYPE_SCREEN_SURFACE_CREATE_INFO_QNX
- VUID-VkScreenSurfaceCreateInfoQNX-pNext-pNext
  pNext must be NULL
- VUID-VkScreenSurfaceCreateInfoQNX-flags-zerobitmask
  flags must be 0

```c
// Provided by VK_QNX_screen_surface
typedef VkFlags VkScreenSurfaceCreateFlagsQNX;
```

VkScreenSurfaceCreateFlagsQNX is a bitmask type for setting a mask, but is currently reserved for future use.

### 34.2.14. Platform-Independent Information

Once created, VkSurfaceKHR objects can be used in this and other extensions, in particular the VK_KHR_swapchain extension.

Several WSI functions return VK_ERROR_SURFACE_LOST_KHR if the surface becomes no longer available. After such an error, the surface (and any child swapchain, if one exists) should be destroyed, as there is no way to restore them to a not-lost state. Applications may attempt to create a new VkSurfaceKHR using the same native platform window object, but whether such re-creation will succeed is platform-dependent and may depend on the reason the surface became unavailable. A lost surface does not otherwise cause devices to be lost.

To destroy a VkSurfaceKHR object, call:

```c
// Provided by VK_KHR_surface
void vkDestroySurfaceKHR(  
    VkInstance instance,  
    VkSurfaceKHR surface,  
    const VkAllocationCallbacks* pAllocator);
```

- instance is the instance used to create the surface.
- surface is the surface to destroy.
- pAllocator is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).

Destroying a VkSurfaceKHR merely severs the connection between Vulkan and the native surface, and does not imply destroying the native surface, closing a window, or similar behavior.
Valid Usage

- VUID-vkDestroySurfaceKHR-surface-01266
  All VkSwapchainKHR objects created for surface must have been destroyed prior to destroying surface

- VUID-vkDestroySurfaceKHR-surface-01267
  If VkAllocationCallbacks were provided when surface was created, a compatible set of callbacks must be provided here

- VUID-vkDestroySurfaceKHR-surface-01268
  If no VkAllocationCallbacks were provided when surface was created, pAllocator must be NULL

Valid Usage (Implicit)

- VUID-vkDestroySurfaceKHR-instance-parameter
  instance must be a valid VkInstance handle

- VUID-vkDestroySurfaceKHR-surface-parameter
  If surface is not VK_NULL_HANDLE, surface must be a valid VkSurfaceKHR handle

- VUID-vkDestroySurfaceKHR-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkDestroySurfaceKHR-surface-parent
  If surface is a valid handle, it must have been created, allocated, or retrieved from instance

Host Synchronization

- Host access to surface must be externally synchronized

34.3. Presenting Directly to Display Devices

In some environments applications can also present Vulkan rendering directly to display devices without using an intermediate windowing system. This can be useful for embedded applications, or implementing the rendering/presentation backend of a windowing system using Vulkan. The VK_KHR_display extension provides the functionality necessary to enumerate display devices and create VkSurfaceKHR objects that target displays.

34.3.1. Display Enumeration

Displays are represented by VkDisplayKHR handles:

```// Provided by VK_KHR_display```
Various functions are provided for enumerating the available display devices present on a Vulkan physical device. To query information about the available displays, call:

```c
// Provided by VK_KHR_display
VkResult vkGetPhysicalDeviceDisplayPropertiesKHR(
    VkPhysicalDevice physicalDevice,
    uint32_t* pPropertyCount,
    VkDisplayPropertiesKHR* pProperties);
```

- `physicalDevice` is a physical device.
- `pPropertyCount` is a pointer to an integer related to the number of display devices available or queried, as described below.
- `pProperties` is either `NULL` or a pointer to an array of `VkDisplayPropertiesKHR` structures.

If `pProperties` is `NULL`, then the number of display devices available for `physicalDevice` is returned in `pPropertyCount`. Otherwise, `pPropertyCount` must point to a variable set by the user to the number of elements in the `pProperties` array, and on return the variable is overwritten with the number of structures actually written to `pProperties`. If the value of `pPropertyCount` is less than the number of display devices for `physicalDevice`, at most `pPropertyCount` structures will be written, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available properties were returned.

### Valid Usage (Implicit)
- `VUID-vkGetPhysicalDeviceDisplayPropertiesKHR-physicalDevice-parameter` `physicalDevice` must be a valid `VkPhysicalDevice` handle
- `VUID-vkGetPhysicalDeviceDisplayPropertiesKHR-pPropertyCount-parameter` `pPropertyCount` must be a valid pointer to a `uint32_t` value
- `VUID-vkGetPhysicalDeviceDisplayPropertiesKHR-pProperties-parameter` If the value referenced by `pPropertyCount` is not `0`, and `pProperties` is not `NULL`, `pProperties` must be a valid pointer to an array of `pPropertyCount` `VkDisplayPropertiesKHR` structures

### Return Codes

**Success**
- `VK_SUCCESS`
- `VK_INCOMPLETE`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
The `VkDisplayPropertiesKHR` structure is defined as:

```c
// Provided by VK_KHR_display
typedef struct VkDisplayPropertiesKHR {
    VkDisplayKHR display;
    const char* displayName;
    VkExtent2D physicalDimensions;
    VkExtent2D physicalResolution;
    VkSurfaceTransformFlagsKHR supportedTransforms;
    VkBool32 planeReorderPossible;
    VkBool32 persistentContent;
} VkDisplayPropertiesKHR;
```

- **display** is a handle that is used to refer to the display described here. This handle will be valid for the lifetime of the Vulkan instance.

- **displayName** is NULL or a pointer to a null-terminated UTF-8 string containing the name of the display. Generally, this will be the name provided by the display’s EDID. If NULL, no suitable name is available. If not NULL, the string pointed to must remain accessible and unmodified as long as display is valid.

- **physicalDimensions** describes the physical width and height of the visible portion of the display, in millimeters.

- **physicalResolution** describes the physical, native, or preferred resolution of the display.

  **Note**
  For devices which have no natural value to return here, implementations should return the maximum resolution supported.

- **supportedTransforms** is a bitmask of `VkSurfaceTransformFlagBitsKHR` describing which transforms are supported by this display.

- **planeReorderPossible** tells whether the planes on this display can have their z order changed. If this is VK_TRUE, the application can re-arrange the planes on this display in any order relative to each other.

- **persistentContent** tells whether the display supports self-refresh/internal buffering. If this is true, the application can submit persistent present operations on swapchains created against this display.

  **Note**
  Persistent presents may have higher latency, and may use less power when the screen content is updated infrequently, or when only a portion of the screen needs to be updated in most frames.

To query information about the available displays, call:

```c
// Provided by VK_KHR_get_display_properties2
VkResult vkGetPhysicalDeviceDisplayProperties2KHR(
```

```c```
VkPhysicalDevice
uint32_t*
pPropertyCount,
VkDisplayProperties2KHR*
pProperties);

- `physicalDevice` is a physical device.
- `pPropertyCount` is a pointer to an integer related to the number of display devices available or queried, as described below.
- `pProperties` is either NULL or a pointer to an array of `VkDisplayProperties2KHR` structures.

`vkGetPhysicalDeviceDisplayProperties2KHR` behaves similarly to `vkGetPhysicalDeviceDisplayPropertiesKHR`, with the ability to return extended information via chained output structures.

### Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceDisplayProperties2KHR-physicalDevice-parameter `physicalDevice` must be a valid `VkPhysicalDevice` handle
- VUID-vkGetPhysicalDeviceDisplayProperties2KHR-pPropertyCount-parameter `pPropertyCount` must be a valid pointer to a `uint32_t` value
- VUID-vkGetPhysicalDeviceDisplayProperties2KHR-pProperties-parameter If the value referenced by `pPropertyCount` is not 0, and `pProperties` is not NULL, `pProperties` must be a valid pointer to an array of `VkDisplayProperties2KHR` structures

### Return Codes

**Success**
- VK_SUCCESS
- VK_INCOMPLETE

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The `VkDisplayProperties2KHR` structure is defined as:

```c
// Provided by VK_KHR_get_display_properties2
typedef struct VkDisplayProperties2KHR {
    VkStructureType sType;
    void* pNext;
    VkDisplayPropertiesKHR displayProperties;
} VkDisplayProperties2KHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.

• displayProperties is a VkDisplayPropertiesKHR structure.

Valid Usage (Implicit)

• VUID-VkDisplayProperties2KHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_DISPLAY_PROPERTIES_2_KHR

• VUID-VkDisplayProperties2KHR-pNext-pNext
  pNext must be NULL

Acquiring and Releasing Displays

On some platforms, access to displays is limited to a single process or native driver instance. On such platforms, some or all of the displays may not be available to Vulkan if they are already in use by a native windowing system or other application.

To acquire permission to directly access a display in Vulkan from an X11 server, call:

```c
// Provided by VK_EXT_acquire_xlib_display
VkResult vkAcquireXlibDisplayEXT(
  VkPhysicalDevice physicalDevice,  // The physical device the display is on.
  Display* dpy,                     // A connection to the X11 server that currently owns display.
  VkDisplayKHR display);            // The display the caller wishes to control in Vulkan.
```

All permissions necessary to control the display are granted to the Vulkan instance associated with `physicalDevice` until the display is released or the X11 connection specified by `dpy` is terminated. Permission to access the display may be temporarily revoked during periods when the X11 server from which control was acquired itself loses access to `display`. During such periods, operations which require access to the display must fail with an appropriate error code. If the X11 server associated with `dpy` does not own `display`, or if permission to access it has already been acquired by another entity, the call must return the error code `VK_ERROR_INITIALIZATION_FAILED`.

**Note**

One example of when an X11 server loses access to a display is when it loses ownership of its virtual terminal.

Valid Usage (Implicit)

• VUID-vkAcquireXlibDisplayEXT-physicalDevice-parameter
  `physicalDevice` must be a valid VkPhysicalDevice handle
Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_INITIALIZATION_FAILED

When acquiring displays from an X11 server, an application may also wish to enumerate and identify them using a native handle rather than a VkDisplayKHR handle. To determine the VkDisplayKHR handle corresponding to an X11 RandR Output, call:

```c
// Provided by VK_EXT_acquire_xlib_display
VkResult vkGetRandROutputDisplayEXT(
    VkPhysicalDevice physicalDevice,
    Display* dpy,
    RROutput rrOutput,
    VkDisplayKHR* pDisplay);
```

- `physicalDevice` The physical device to query the display handle on.
- `dpy` A connection to the X11 server from which `rrOutput` was queried.
- `rrOutput` An X11 RandR output ID.
- `pDisplay` The corresponding VkDisplayKHR handle will be returned here.

If there is no VkDisplayKHR corresponding to `rrOutput` on `physicalDevice`, `VK_NULL_HANDLE` must be returned in `pDisplay`.

Valid Usage (Implicit)

- VUID-vkGetRandROutputDisplayEXT-physicalDevice-parameter `physicalDevice` must be a valid VkPhysicalDevice handle
- VUID-vkGetRandROutputDisplayEXT-dpy-parameter `dpy` must be a valid pointer to a Display value
- VUID-vkGetRandROutputDisplayEXT-pDisplay-parameter `pDisplay` must be a valid pointer to a VkDisplayKHR handle
Return Codes

Success
• VK_SUCCESS

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY

To acquire permission to directly access a display in Vulkan on Windows 10, call:

```c
// Provided by VK_NV_acquire_winrt_display
VkResult vkAcquireWinrtDisplayNV(
    VkPhysicalDevice physicalDevice,
    VkDisplayKHR display);
```

• physicalDevice The physical device the display is on.
• display The display the caller wishes to control in Vulkan.

All permissions necessary to control the display are granted to the Vulkan instance associated with `physicalDevice` until the display is released or the application is terminated. Permission to access the display may be revoked by events that cause Windows 10 itself to lose access to `display`. If this has happened, operations which require access to the display must fail with an appropriate error code. If permission to access `display` has already been acquired by another entity, the call must return the error code `VK_ERROR_INITIALIZATION_FAILED`.

**Note**
The Vulkan instance acquires control of a “winrt::Windows::Devices::Display::Core::DisplayTarget” by performing an operation equivalent to “winrt::Windows::Devices::Display::Core::DisplayManager.TryAcquireTarget()” on the “DisplayTarget”.

**Note**
One example of when Windows 10 loses access to a display is when the display is hot-unplugged.

**Note**
One example of when a display has already been acquired by another entity is when the Windows desktop compositor (DWM) is in control of the display. Beginning with Windows 10 version 2004 it is possible to cause DWM to release a display by using the “Advanced display settings” sub-page of the “Display settings” control panel. `vkAcquireWinrtDisplayNV` does not itself cause DWM to release a display; this action must be performed outside of Vulkan.
Valid Usage (Implicit)

• VUID-vkAcquireWinrtDisplayNV-physicalDevice-parameter
  physicalDevice must be a valid VkPhysicalDevice handle

• VUID-vkAcquireWinrtDisplayNV-display-parameter
  display must be a valid VkDisplayKHR handle

• VUID-vkAcquireWinrtDisplayNV-display-parent
  display must have been created, allocated, or retrieved from physicalDevice

Return Codes

Success
  • VK_SUCCESS

Failure
  • VK_ERROR_OUT_OF_HOST_MEMORY
  • VK_ERROR_DEVICE_LOST
  • VK_ERROR_INITIALIZATION_FAILED

When acquiring displays on Windows 10, an application may also wish to enumerate and identify them using a native handle rather than a VkDisplayKHR handle.

To determine the VkDisplayKHR handle corresponding to a “winrt::Windows::Devices::Display::Core::DisplayTarget”, call:

```c
// Provided by VK_NV_acquire_winrt_display
VkResult vkGetWinrtDisplayNV(
    VkPhysicalDevice physicalDevice,
    uint32_t deviceRelativeId,
    VkDisplayKHR* pDisplay);
```

• physicalDevice The physical device on which to query the display handle.

• deviceRelativeId The value of the “AdapterRelativeId” property of a “DisplayTarget” that is enumerated by a “DisplayAdapter” with an “Id” property matching the deviceId property of a VkPhysicalDeviceIDProperties for physicalDevice.

• pDisplay The corresponding VkDisplayKHR handle will be returned here.

If there is no VkDisplayKHR corresponding to deviceRelativeId on physicalDevice, VK_NULL_HANDLE must be returned in pDisplay.

Valid Usage (Implicit)

• VUID-vkGetWinrtDisplayNV-physicalDevice-parameter
physicalDevice must be a valid VkPhysicalDevice handle

- VUID-vkGetWinrtDisplayNV-pDisplay-parameter
  pDisplay must be a valid pointer to a VkDisplayKHR handle

## Return Codes

### Success
- VK_SUCCESS

### Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_DEVICE_LOST
- VK_ERROR_INITIALIZATION_FAILED

To acquire permission to directly a display in Vulkan from the Direct Rendering Manager (DRM) interface, call:

```c
// Provided by VK_EXT_acquire_drm_display
VkResult vkAcquireDrmDisplayEXT(VkPhysicalDevice physicalDevice,
                                 int32_t drmFd,
                                 VkDisplayKHR display);
```

- **physicalDevice** The physical device the display is on.
- **drmFd** DRM primary file descriptor.
- **display** The display the caller wishes Vulkan to control.

All permissions necessary to control the display are granted to the Vulkan instance associated with the provided **physicalDevice** until the display is either released or the connector is unplugged. The provided **drmFd** must correspond to the one owned by the **physicalDevice**. If not, the error code **VK_ERROR_UNKNOWN** must be returned. The DRM FD must have DRM master permissions. If any error is encountered during the acquisition of the display, the call must return the error code **VK_ERROR_INITIALIZATION_FAILED**.

The provided DRM fd should not be closed before the display is released, attempting to do it may result in undefined behaviour.

## Valid Usage (Implicit)

- VUID-vkAcquireDrmDisplayEXT-physicalDevice-parameter
  physicalDevice must be a valid VkPhysicalDevice handle

- VUID-vkAcquireDrmDisplayEXT-display-parameter
  display must be a valid VkDisplayKHR handle
Before acquiring a display from the DRM interface, the caller may want to select a specific VkDisplayKHR handle by identifying it using a connectorId. To do so, call:

```c
// Provided by VK_EXT_acquire_drm_display
VkResult vkGetDrmDisplayEXT(
    VkPhysicalDevice physicalDevice,  
    int32_t drmFd,  
    uint32_t connectorId,  
    VkDisplayKHR* display);
```

- **physicalDevice** The physical device to query the display from.
- **drmFd** DRM primary file descriptor.
- **connectorId** Identifier of the specified DRM connector.
- **display** The corresponding VkDisplayKHR handle will be returned here.

If there is no VkDisplayKHR corresponding to the connectorId on the physicalDevice, the returning display must be set to VK_NULL_HANDLE. The provided drmFd must correspond to the one owned by the physicalDevice. If not, the error code VK_ERROR_UNKNOWN must be returned. Master permissions are not required, because the file descriptor is just used for information gathering purposes. The given connectorId must be a resource owned by the provided drmFd. If not, the error code VK_ERROR_UNKNOWN must be returned. If any error is encountered during the identification of the display, the call must return the error code VK_ERROR_INITIALIZATION_FAILED.

### Valid Usage (Implicit)

- VUID-vkAcquireDrmDisplayEXT-display-parent
  display **must** have been created, allocated, or retrieved from physicalDevice

### Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_INITIALIZATION_FAILED

Valid Usage (Implicit)

- VUID-vkGetDrmDisplayEXT-physicalDevice-parameter
  physicalDevice **must** be a valid VkPhysicalDevice handle

- VUID-vkGetDrmDisplayEXT-display-parameter
  display **must** be a valid pointer to a VkDisplayKHR handle
Return Codes

Success
  • VK_SUCCESS

Failure
  • VK_ERROR_INITIALIZATION_FAILED
  • VK_ERROR_OUT_OF_HOST_MEMORY

To release a previously acquired display, call:

```cpp
// Provided by VK_EXT_direct_mode_display
VkResult vkReleaseDisplayEXT(
    VkPhysicalDevice physicalDevice,
    VkDisplayKHR display);
```

- `physicalDevice` The physical device the display is on.
- `display` The display to release control of.

Valid Usage (Implicit)

- VUID-vkReleaseDisplayEXT-physicalDevice-parameter
  `physicalDevice` must be a valid `VkPhysicalDevice` handle

- VUID-vkReleaseDisplayEXT-display-parameter
  `display` must be a valid `VkDisplayKHR` handle

- VUID-vkReleaseDisplayEXT-display-parent
  `display` must have been created, allocated, or retrieved from `physicalDevice`

Return Codes

Success
  • VK_SUCCESS

Display Planes

Images are presented to individual planes on a display. Devices **must** support at least one plane on each display. Planes **can** be stacked and blended to composite multiple images on one display. Devices **may** support only a fixed stacking order and fixed mapping between planes and displays, or they **may** allow arbitrary application specified stacking orders and mappings between planes and displays. To query the properties of device display planes, call:

```cpp
// Provided by VK_KHR_display
```
VkResult vkGetPhysicalDeviceDisplayPlanePropertiesKHR(
    VkPhysicalDevice physicalDevice,
    uint32_t* pPropertyCount,
    VkDisplayPlanePropertiesKHR* pProperties);

- `physicalDevice` is a physical device.
- `pPropertyCount` is a pointer to an integer related to the number of display planes available or queried, as described below.
- `pProperties` is either `NULL` or a pointer to an array of `VkDisplayPlanePropertiesKHR` structures.

If `pProperties` is `NULL`, then the number of display planes available for `physicalDevice` is returned in `pPropertyCount`. Otherwise, `pPropertyCount` must point to a variable set by the user to the number of elements in the `pProperties` array, and on return the variable is overwritten with the number of structures actually written to `pProperties`. If the value of `pPropertyCount` is less than the number of display planes for `physicalDevice`, at most `pPropertyCount` structures will be written.

**Valid Usage (Implicit)**

- VUID-vkGetPhysicalDeviceDisplayPlanePropertiesKHR-physicalDevice-parameter `physicalDevice` must be a valid `VkPhysicalDevice` handle
- VUID-vkGetPhysicalDeviceDisplayPlanePropertiesKHR-pPropertyCount-parameter `pPropertyCount` must be a valid pointer to a `uint32_t` value
- VUID-vkGetPhysicalDeviceDisplayPlanePropertiesKHR-pProperties-parameter If the value referenced by `pPropertyCount` is not 0, and `pProperties` is not `NULL`, `pProperties` must be a valid pointer to an array of `pPropertyCount` `VkDisplayPlanePropertiesKHR` structures

**Return Codes**

**Success**
- VK_SUCCESS
- VK_INCOMPLETE

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The `VkDisplayPlanePropertiesKHR` structure is defined as:

```c
// Provided by VK_KHR_display
typedef struct VkDisplayPlanePropertiesKHR {
    VkDisplayKHR currentDisplay;
    uint32_t currentStackIndex;
} VkDisplayPlanePropertiesKHR;
```
VkDisplayPlanePropertiesKHR;

- `currentDisplay` is the handle of the display the plane is currently associated with. If the plane is not currently attached to any displays, this will be `VK_NULL_HANDLE`.
- `currentStackIndex` is the current z-order of the plane. This will be between 0 and the value returned by `vkGetPhysicalDeviceDisplayPlanePropertiesKHR` in `pPropertyCount`.

To query the properties of a device's display planes, call:

```c
// Provided by VK_KHR_get_display_properties2
VkResult vkGetPhysicalDeviceDisplayPlaneProperties2KHR(
    VkPhysicalDevice physicalDevice,  
    uint32_t* pPropertyCount,         
    VkDisplayPlaneProperties2KHR* pProperties);
```

- `physicalDevice` is a physical device.
- `pPropertyCount` is a pointer to an integer related to the number of display planes available or queried, as described below.
- `pProperties` is either `NULL` or a pointer to an array of `VkDisplayPlaneProperties2KHR` structures.

`vkGetPhysicalDeviceDisplayPlaneProperties2KHR` behaves similarly to `vkGetPhysicalDeviceDisplayPlanePropertiesKHR`, with the ability to return extended information via chained output structures.

**Valid Usage (Implicit)**

- `VUID-vkGetPhysicalDeviceDisplayPlaneProperties2KHR-physicalDevice-parameter` physicalDevice must be a valid `VkPhysicalDevice` handle
- `VUID-vkGetPhysicalDeviceDisplayPlaneProperties2KHR-pPropertyCount-parameter` pPropertyCount must be a valid pointer to a `uint32_t` value
- `VUID-vkGetPhysicalDeviceDisplayPlaneProperties2KHR-pProperties-parameter` If the value referenced by `pPropertyCount` is not 0, and `pProperties` is not `NULL`, `pProperties` must be a valid pointer to an array of `pPropertyCount` `VkDisplayPlaneProperties2KHR` structures

**Return Codes**

**Success**
- `VK_SUCCESS`
- `VK_INCOMPLETE`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
The `VkDisplayPlaneProperties2KHR` structure is defined as:

```c
typedef struct VkDisplayPlaneProperties2KHR {
    VkStructureType sType;
    void* pNext;
    VkDisplayPlanePropertiesKHR displayPlaneProperties;
} VkDisplayPlaneProperties2KHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `displayPlaneProperties` is a `VkDisplayPlanePropertiesKHR` structure.

### Valid Usage (Implicit)

- `VUID-VkDisplayPlaneProperties2KHR-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_DISPLAY_PLANE_PROPERTIES_2_KHR`

- `VUID-VkDisplayPlaneProperties2KHR-pNext-pNext`  
  `pNext` must be `NULL`

To determine which displays a plane is usable with, call

```c
// Provided by VK_KHR_display
VkResult vkGetDisplayPlaneSupportedDisplaysKHR(
    VkPhysicalDevice           physicalDevice,
    uint32_t                   planeIndex,
    uint32_t*                  pDisplayCount,
    VkDisplayKHR*              pDisplays);
```

- `physicalDevice` is a physical device.
- `planeIndex` is the plane which the application wishes to use, and **must** be in the range [0, physical device plane count - 1].
- `pDisplayCount` is a pointer to an integer related to the number of displays available or queried, as described below.
- `pDisplays` is either `NULL` or a pointer to an array of `VkDisplayKHR` handles.

If `pDisplays` is `NULL`, then the number of displays usable with the specified `planeIndex` for `physicalDevice` is returned in `pDisplayCount`. Otherwise, `pDisplayCount` **must** point to a variable set by the user to the number of elements in the `pDisplays` array, and on return the variable is overwritten with the number of handles actually written to `pDisplays`. If the value of `pDisplayCount` is less than the number of usable display-plane pairs for `physicalDevice`, at most `pDisplayCount`
handles will be written, and **VK_INCOMPLETE** will be returned instead of **VK_SUCCESS**, to indicate that not all the available pairs were returned.

### Valid Usage

- **VUID-vkGetDisplayPlaneSupportedDisplaysKHR-planeIndex-01249**
  
  `planeIndex` **must** be less than the number of display planes supported by the device as determined by calling `vkGetPhysicalDeviceDisplayPlanePropertiesKHR`.

### Valid Usage (Implicit)

- **VUID-vkGetDisplayPlaneSupportedDisplaysKHR-physicalDevice-parameter**
  
  `physicalDevice` **must** be a valid `VkPhysicalDevice` handle.

- **VUID-vkGetDisplayPlaneSupportedDisplaysKHR-pDisplayCount-parameter**
  
  `pDisplayCount` **must** be a valid pointer to a `uint32_t` value.

- **VUID-vkGetDisplayPlaneSupportedDisplaysKHR-pDisplays-parameter**
  
  If the value referenced by `pDisplayCount` is not `0`, and `pDisplays` is not `NULL`, `pDisplays` **must** be a valid pointer to an array of `pDisplayCount` `VkDisplayKHR` handles.

### Return Codes

#### Success

- **VK_SUCCESS**
- **VK_INCOMPLETE**

#### Failure

- **VK_ERROR_OUT_OF_HOST_MEMORY**
- **VK_ERROR_OUT_OF_DEVICE_MEMORY**

Additional properties of displays are queried using specialized query functions.

### Display Modes

Display modes are represented by `VkDisplayModeKHR` handles:

```c
// Provided by VK_KHR_display
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkDisplayModeKHR)
```

Each display has one or more supported modes associated with it by default. These built-in modes are queried by calling:

```c
// Provided by VK_KHR_display
VkResult vkGetDisplayModePropertiesKHR(
```
VkPhysicalDevice
VkDisplayKHR
uint32_t*
VkDisplayModePropertiesKHR*

• **physicalDevice** is the physical device associated with **display**.
• **display** is the display to query.
• **pPropertyCount** is a pointer to an integer related to the number of display modes available or queried, as described below.
• **pProperties** is either **NULL** or a pointer to an array of **VkDisplayModePropertiesKHR** structures.

If **pProperties** is **NULL**, then the number of display modes available on the specified **display** for **physicalDevice** is returned in **pPropertyCount**. Otherwise, **pPropertyCount** must point to a variable set by the user to the number of elements in the **pProperties** array, and on return the variable is overwritten with the number of structures actually written to **pProperties**. If the value of **pPropertyCount** is less than the number of display modes for **physicalDevice**, at most **pPropertyCount** structures will be written, and **VK_INCOMPLETE** will be returned instead of **VK_SUCCESS**, to indicate that not all the available display modes were returned.

**Valid Usage (Implicit)**

- VUID-vkGetDisplayModePropertiesKHR-physicalDevice-parameter **physicalDevice** must be a valid **VkPhysicalDevice** handle
- VUID-vkGetDisplayModePropertiesKHR-display-parameter **display** must be a valid **VkDisplayKHR** handle
- VUID-vkGetDisplayModePropertiesKHR-pPropertyCount-parameter **pPropertyCount** must be a valid pointer to a **uint32_t** value
- VUID-vkGetDisplayModePropertiesKHR-pProperties-parameter If the value referenced by **pPropertyCount** is not 0, and **pProperties** is not **NULL**, **pProperties** must be a valid pointer to an array of **pPropertyCount** **VkDisplayModePropertiesKHR** structures
- VUID-vkGetDisplayModePropertiesKHR-display-parent **display** must have been created, allocated, or retrieved from **physicalDevice**

**Return Codes**

**Success**
- **VK_SUCCESS**
- **VK_INCOMPLETE**

**Failure**
- **VK_ERROR_OUT_OF_HOST_MEMORY**
- **VK_ERROR_OUT_OF_DEVICE_MEMORY**
The `VkDisplayModePropertiesKHR` structure is defined as:

```c
// Provided by VK_KHR_display
typedef struct VkDisplayModePropertiesKHR {
    VkDisplayModeKHR displayMode;
    VkDisplayModeParametersKHR parameters;
} VkDisplayModePropertiesKHR;
```

- `displayMode` is a handle to the display mode described in this structure. This handle will be valid for the lifetime of the Vulkan instance.
- `parameters` is a `VkDisplayModeParametersKHR` structure describing the display parameters associated with `displayMode`.

`VkDisplayModeCreateFlagsKHR` is a bitmask type for setting a mask, but is currently reserved for future use.

To query the properties of a device’s built-in display modes, call:

```c
// Provided by VK_KHR_get_display_properties2
VkResult vkGetDisplayModeProperties2KHR(
    VkPhysicalDevice physicalDevice,
    VkDisplayKHR display,
    uint32_t* pPropertyCount,  // pPropertyCount is a pointer to an integer related to the number of display modes available or queried, as described below.
    VkDisplayModeProperties2KHR* pProperties);  // pProperties is either NULL or a pointer to an array of VkDisplayModeProperties2KHR structures.
```

- `physicalDevice` is the physical device associated with `display`.
- `display` is the display to query.
- `pPropertyCount` is a pointer to an integer related to the number of display modes available or queried, as described below.
- `pProperties` is either NULL or a pointer to an array of `VkDisplayModeProperties2KHR` structures.

`vkGetDisplayModeProperties2KHR` behaves similarly to `vkGetDisplayModePropertiesKHR`, with the ability to return extended information via chained output structures.

### Valid Usage (Implicit)

- VUID-vkGetDisplayModeProperties2KHR-physicalDevice-parameter
  `physicalDevice` must be a valid `VkPhysicalDevice` handle
- VUID-vkGetDisplayModeProperties2KHR-display-parameter
  `display` must be a valid `VkDisplayKHR` handle
- VUID-vkGetDisplayModeProperties2KHR-pPropertyCount-parameter
  `pPropertyCount` must be a valid integer value
pPropertyCount must be a valid pointer to a uint32_t value

• VUID-vkGetDisplayModeProperties2KHR-pProperties-parameter
  If the value referenced by pPropertyCount is not 0, and pProperties is not NULL, pProperties must be a valid pointer to an array of pPropertyCount VkDisplayModeProperties2KHR structures

• VUID-vkGetDisplayModeProperties2KHR-display-parent
display must have been created, allocated, or retrieved from physicalDevice

Return Codes

Success
• VK_SUCCESS
• VK_INCOMPLETE

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkDisplayModeProperties2KHR structure is defined as:

```c
// Provided by VK_KHR_get_display_properties2
typedef struct VkDisplayModeProperties2KHR {
    VkStructureType sType;
    void* pNext;
    VkDisplayModePropertiesKHR displayModeProperties;
} VkDisplayModeProperties2KHR;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• displayModeProperties is a VkDisplayModePropertiesKHR structure.

Valid Usage (Implicit)

• VUID-VkDisplayModeProperties2KHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_DISPLAY_MODE_PROPERTIES_2_KHR

• VUID-VkDisplayModeProperties2KHR-pNext-pNext
  pNext must be NULL

The VkDisplayModeParametersKHR structure is defined as:

```c
// Provided by VK_KHR_display
typedef struct VkDisplayModeParametersKHR {
```
• `visibleRegion` is the 2D extents of the visible region.
• `refreshRate` is a `uint32_t` that is the number of times the display is refreshed each second multiplied by 1000.

**Note**
For example, a 60Hz display mode would report a `refreshRate` of 60,000.

### Valid Usage

- VUID-VkDisplayModeParametersKHR-width-01990
  The `width` member of `visibleRegion` must be greater than 0
- VUID-VkDisplayModeParametersKHR-height-01991
  The `height` member of `visibleRegion` must be greater than 0
- VUID-VkDisplayModeParametersKHR-refreshRate-01992
  `refreshRate` must be greater than 0

Additional modes may also be created by calling:

```c
// Provided by VK_KHR_display
VkResult vkCreateDisplayModeKHR(
    VkPhysicalDevice physicalDevice, 
    VkDisplayKHR display, 
    const VkDisplayModeCreateInfoKHR* pCreateInfo, 
    const VkAllocationCallbacks* pAllocator, 
    VkDisplayModeKHR* pMode);
```

- `physicalDevice` is the physical device associated with `display`.
- `display` is the display to create an additional mode for.
- `pCreateInfo` is a pointer to a `VkDisplayModeCreateInfoKHR` structure describing the new mode to create.
- `pAllocator` is the allocator used for host memory allocated for the display mode object when there is no more specific allocator available (see Memory Allocation).
- `pMode` is a pointer to a `VkDisplayModeKHR` handle in which the mode created is returned.

### Valid Usage (Implicit)

- VUID-vkCreateDisplayModeKHR-physicalDevice-parameter
  `physicalDevice` must be a valid `VkPhysicalDevice` handle
• VUID-vkCreateDisplayModeKHR-display-parameter
display must be a valid VkDisplayKHR handle

• VUID-vkCreateDisplayModeKHR-pCreateInfo-parameter
pCreateInfo must be a valid pointer to a valid VkDisplayModeCreateInfoKHR structure

• VUID-vkCreateDisplayModeKHR-pAllocator-parameter
If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

• VUID-vkCreateDisplayModeKHR-pMode-parameter
pMode must be a valid pointer to a VkDisplayModeKHR handle

• VUID-vkCreateDisplayModeKHR-display-parent
display must have been created, allocated, or retrieved from physicalDevice

**Host Synchronization**

• Host access to display must be externally synchronized

**Return Codes**

**Success**

• VK_SUCCESS

**Failure**

• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY
• VK_ERROR_INITIALIZATION_FAILED

The VkDisplayModeCreateInfoKHR structure is defined as:

```c
// Provided by VK_KHR_display
typedef struct VkDisplayModeCreateInfoKHR {
    VkStructureType sType;
    const void*pNext;
    VkDisplayModeCreateFlagsKHR flags;
    VkDisplayModeParametersKHR parameters;
} VkDisplayModeCreateInfoKHR;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• flags is reserved for future use, and must be zero.
• parameters is a VkDisplayModeParametersKHR structure describing the display parameters to use in creating the new mode. If the parameters are not compatible with the specified display,
the implementation must return VK_ERROR_INITIALIZATION_FAILED.

Valid Usage (Implicit)

- VUID-VkDisplayModeCreateInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_DISPLAY_MODE_CREATE_INFO_KHR

- VUID-VkDisplayModeCreateInfoKHR-pNext-pNext
  pNext must be NULL

- VUID-VkDisplayModeCreateInfoKHR-flags-zerobitmask
  flags must be 0

- VUID-VkDisplayModeCreateInfoKHR-parameters-parameter
  parameters must be a valid VkDisplayModeParametersKHR structure

Applications that wish to present directly to a display must select which layer, or “plane” of the display they wish to target, and a mode to use with the display. Each display supports at least one plane. The capabilities of a given mode and plane combination are determined by calling:

```c
// Provided by VK_KHR_display
VkResult vkGetDisplayPlaneCapabilitiesKHR(
    VkPhysicalDevice physicalDevice,
    VkDisplayModeKHR mode,
    uint32_t planeIndex,
    VkDisplayPlaneCapabilitiesKHR* pCapabilities);
```

- physicalDevice is the physical device associated with the display specified by mode
- mode is the display mode the application intends to program when using the specified plane. Note this parameter also implicitly specifies a display.
- planeIndex is the plane which the application intends to use with the display, and is less than the number of display planes supported by the device.
- pCapabilities is a pointer to a VkDisplayPlaneCapabilitiesKHR structure in which the capabilities are returned.

Valid Usage (Implicit)

- VUID-vkGetDisplayPlaneCapabilitiesKHR-physicalDevice-parameter
  physicalDevice must be a valid VkPhysicalDevice handle

- VUID-vkGetDisplayPlaneCapabilitiesKHR-mode-parameter
  mode must be a valid VkDisplayModeKHR handle

- VUID-vkGetDisplayPlaneCapabilitiesKHR-pCapabilities-parameter
  pCapabilities must be a valid pointer to a VkDisplayPlaneCapabilitiesKHR structure

- VUID-vkGetDisplayPlaneCapabilitiesKHR-mode-parent
  mode must have been created, allocated, or retrieved from physicalDevice
Host Synchronization

- Host access to mode must be externally synchronized

Return Codes

Success

- VK_SUCCESS

Failure

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkDisplayPlaneCapabilitiesKHR structure is defined as:

```c
// Provided by VK_KHR_display
typedef struct VkDisplayPlaneCapabilitiesKHR {
    VkDisplayPlaneAlphaFlagsKHR supportedAlpha;
    VkOffset2D minSrcPosition;
    VkOffset2D maxSrcPosition;
    VkOffset2D minSrcExtent;
    VkOffset2D maxSrcExtent;
    VkOffset2D minDstPosition;
    VkOffset2D maxDstPosition;
    VkExtent2D minSrcExtent;
    VkExtent2D maxSrcExtent;
    VkExtent2D minDstExtent;
    VkExtent2D maxDstExtent;
} VkDisplayPlaneCapabilitiesKHR;
```

- supportedAlpha is a bitmask of VkDisplayPlaneAlphaFlagBitsKHR describing the supported alpha blending modes.

- minSrcPosition is the minimum source rectangle offset supported by this plane using the specified mode.

- maxSrcPosition is the maximum source rectangle offset supported by this plane using the specified mode. The x and y components of maxSrcPosition must each be greater than or equal to the x and y components of minSrcPosition, respectively.

- minSrcExtent is the minimum source rectangle size supported by this plane using the specified mode.

- maxSrcExtent is the maximum source rectangle size supported by this plane using the specified mode.

- minDstPosition, maxDstPosition, minDstExtent, maxDstExtent all have similar semantics to their corresponding *Src* equivalents, but apply to the output region within the mode rather than the input region within the source image. Unlike the *Src* offsets, minDstPosition and maxDstPosition may contain negative values.
The minimum and maximum position and extent fields describe the implementation limits, if any, as they apply to the specified display mode and plane. Vendors may support displaying a subset of a swapchain's presentable images on the specified display plane. This is expressed by returning \texttt{minSrcPosition}, \texttt{maxSrcPosition}, \texttt{minSrcExtent}, and \texttt{maxSrcExtent} values that indicate a range of possible positions and sizes which may be used to specify the region within the presentable images that source pixels will be read from when creating a swapchain on the specified display mode and plane.

Vendors may also support mapping the presentable images' content to a subset or superset of the visible region in the specified display mode. This is expressed by returning \texttt{minDstPosition}, \texttt{maxDstPosition}, \texttt{minDstExtent} and \texttt{maxDstExtent} values that indicate a range of possible positions and sizes which may be used to describe the region within the display mode that the source pixels will be mapped to.

Other vendors may support only a 1-1 mapping between pixels in the presentable images and the display mode. This may be indicated by returning (0,0) for \texttt{minSrcPosition}, \texttt{maxSrcPosition}, \texttt{minDstPosition}, and \texttt{maxDstPosition}, and (display mode width, display mode height) for \texttt{minSrcExtent}, \texttt{maxSrcExtent}, \texttt{minDstExtent}, and \texttt{maxDstExtent}.

The value \texttt{supportedAlpha} must contain at least one valid \texttt{VkDisplayPlaneAlphaFlagBitsKHR} bit.

These values indicate the limits of the implementation's individual fields. Not all combinations of values within the offset and extent ranges returned in \texttt{VkDisplayPlaneCapabilitiesKHR} are guaranteed to be supported. Presentation requests specifying unsupported combinations may fail.

To query the capabilities of a given mode and plane combination, call:

```c
// Provided by VK_KHR_get_display_properties2
VkResult vkGetDisplayPlaneCapabilities2KHR(
    VkPhysicalDevice physicalDevice,
    const VkDisplayPlaneInfo2KHR* pDisplayPlaneInfo,
    VkDisplayPlaneCapabilities2KHR* pCapabilities);
```

- \texttt{physicalDevice} is the physical device associated with \texttt{pDisplayPlaneInfo}.
- \texttt{pDisplayPlaneInfo} is a pointer to a \texttt{VkDisplayPlaneInfo2KHR} structure describing the plane and mode.
- \texttt{pCapabilities} is a pointer to a \texttt{VkDisplayPlaneCapabilities2KHR} structure in which the capabilities are returned.

\texttt{vkGetDisplayPlaneCapabilities2KHR} behaves similarly to \texttt{vkGetDisplayPlaneCapabilitiesKHR}, with the ability to specify extended inputs via chained input structures, and to return extended information via chained output structures.

**Valid Usage (Implicit)**

- VUID-vkGetDisplayPlaneCapabilities2KHR-physicalDevice-parameter \texttt{physicalDevice} must be a valid \texttt{VkPhysicalDevice} handle
Return Codes

Success
• VK_SUCCESS

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkDisplayPlaneInfo2KHR structure is defined as:

```c
// Provided by VK_KHR_get_display_properties2
typedef struct VkDisplayPlaneInfo2KHR {
    VkStructureType sType;
    const void* pNext;
    VkDisplayModeKHR mode;
    uint32_t planeIndex;
} VkDisplayPlaneInfo2KHR;
```

• `sType` is a `VkStructureType` value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.
• `mode` is the display mode the application intends to program when using the specified plane.

**Note**
This parameter also implicitly specifies a display.

• `planeIndex` is the plane which the application intends to use with the display.

The members of `VkDisplayPlaneInfo2KHR` correspond to the arguments to `vkGetDisplayPlaneCapabilitiesKHR`, with `sType` and `pNext` added for extensibility.

Valid Usage (Implicit)

• VUID-VkDisplayPlaneInfo2KHR-sType-sType
  `sType must` be `VK_STRUCTURE_TYPE_DISPLAY_PLANE_INFO_2_KHR`

• VUID-VkDisplayPlaneInfo2KHR-pNext-pNext
  `pNext must` be `NULL`

• VUID-VkDisplayPlaneInfo2KHR-mode-parameter
mode must be a valid VkDisplayModeKHR handle

Host Synchronization

• Host access to mode must be externally synchronized.

The VkDisplayPlaneCapabilities2KHR structure is defined as:

```c
// Provided by VK_KHR_get_display_properties2
typedef struct VkDisplayPlaneCapabilities2KHR {
    VkStructureType sType;
    void* pNext;
    VkDisplayPlaneCapabilitiesKHR capabilities;
} VkDisplayPlaneCapabilities2KHR;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• capabilities is a VkDisplayPlaneCapabilitiesKHR structure.

Valid Usage (Implicit)

• VUID-VkDisplayPlaneCapabilities2KHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_DISPLAY_PLANE_CAPABILITIES_2_KHR
• VUID-VkDisplayPlaneCapabilities2KHR-pNext-pNext
  pNext must be NULL

34.3.2. Display Control

To set the power state of a display, call:

```c
// Provided by VK_EXT_display_control
VkResult vkDisplayPowerControlEXT(
    VkDevice device,
    VkDisplayKHR display,
    const VkDisplayPowerInfoEXT* pDisplayPowerInfo);
```

• device is a logical device associated with display.
• display is the display whose power state is modified.
• pDisplayPowerInfo is a pointer to a VkDisplayPowerInfoEXT structure specifying the new power state of display.
Valid Usage (Implicit)

- VUID-vkDisplayPowerControlEXT-device-parameter
device must be a valid VkDevice handle

- VUID-vkDisplayPowerControlEXT-display-parameter
display must be a valid VkDisplayKHR handle

- VUID-vkDisplayPowerControlEXT-pDisplayPowerInfo-parameter
pDisplayPowerInfo must be a valid pointer to a valid VkDisplayPowerInfoEXT structure

- VUID-vkDisplayPowerControlEXT-commonparent
Both of device, and display must have been created, allocated, or retrieved from the same VkPhysicalDevice

Valid Usage (Implicit)

- VUID-VkDisplayPowerInfoEXT-sType-sType
sType must be VK_STRUCTURE_TYPE_DISPLAY_POWER_INFO_EXT

- VUID-VkDisplayPowerInfoEXT-pNext-pNext
pNext must be NULL

- VUID-VkDisplayPowerInfoEXT-powerState-parameter
powerState must be a valid VkDisplayPowerStateEXT value

Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY

The VkDisplayPowerInfoEXT structure is defined as:

```c
typedef struct VkDisplayPowerInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkDisplayPowerStateEXT powerState;
} VkDisplayPowerInfoEXT;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- powerState is a VkDisplayPowerStateEXT value specifying the new power state of the display.
Possible values of `VkDisplayPowerInfoEXT::powerState`, specifying the new power state of a display, are:

```c
// Provided by VK_EXT_display_control
typedef enum VkDisplayPowerStateEXT {
    VK_DISPLAY_POWER_STATE_OFF_EXT = 0,
    VK_DISPLAY_POWER_STATE_SUSPEND_EXT = 1,
    VK_DISPLAY_POWER_STATE_ON_EXT = 2,
} VkDisplayPowerStateEXT;
```

- **VK_DISPLAY_POWER_STATE_OFF_EXT** specifies that the display is powered down.
- **VK_DISPLAY_POWER_STATE_SUSPEND_EXT** specifies that the display is put into a low power mode, from which it may be able to transition back to **VK_DISPLAY_POWER_STATE_ON_EXT** more quickly than if it were in **VK_DISPLAY_POWER_STATE_OFF_EXT**. This state may be the same as **VK_DISPLAY_POWER_STATE_OFF_EXT**.
- **VK_DISPLAY_POWER_STATE_ON_EXT** specifies that the display is powered on.

### 34.3.3. Display Surfaces

A complete display configuration includes a mode, one or more display planes and any parameters describing their behavior, and parameters describing some aspects of the images associated with those planes. Display surfaces describe the configuration of a single plane within a complete display configuration. To create a `VkSurfaceKHR` object for a display plane, call:

```c
// Provided by VK_KHR_display
VkResult vkCreateDisplayPlaneSurfaceKHR(
    VkInstance instance, const VkDisplaySurfaceCreateInfoKHR* pCreateInfo, const VkAllocationCallbacks* pAllocator, VkSurfaceKHR* pSurface);
```

- **instance** is the instance corresponding to the physical device the targeted display is on.
- **pCreateInfo** is a pointer to a `VkDisplaySurfaceCreateInfoKHR` structure specifying which mode, plane, and other parameters to use, as described below.
- **pAllocator** is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).
- **pSurface** is a pointer to a `VkSurfaceKHR` handle in which the created surface is returned.

### Valid Usage (Implicit)

- **VUID-vkCreateDisplayPlaneSurfaceKHR-instance-parameter**
  - **instance** must be a valid `VkInstance` handle
- **VUID-vkCreateDisplayPlaneSurfaceKHR-pCreateInfo-parameter**
  - **pCreateInfo** must be a valid pointer to a valid `VkDisplaySurfaceCreateInfoKHR` structure
• VUID-vkCreateDisplayPlaneSurfaceKHR-pAllocator-parameter
  If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure.

• VUID-vkCreateDisplayPlaneSurfaceKHR-pSurface-parameter
  `pSurface` must be a valid pointer to a `VkSurfaceKHR` handle.

## Return Codes

**Success**
- *VK_SUCCESS*

**Failure**
- *VK_ERROR_OUT_OF_HOST_MEMORY*
- *VK_ERROR_OUT_OF_DEVICE_MEMORY*

The `VkDisplaySurfaceCreateInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_display
typedef struct VkDisplaySurfaceCreateInfoKHR {
    VkStructureType             sType;
    const void*                 pNext;
    VkDisplaySurfaceCreateFlagsKHR flags;
    VkDisplayModeKHR            displayMode;
    uint32_t                     planeIndex;
    uint32_t                     planeStackIndex;
    VkSurfaceTransformFlagBitsKHR transform;
    float                        globalAlpha;
    VkDisplayPlaneAlphaFlagBitsKHR alphaMode;
    VkExtent2D                   imageExtent;
} VkDisplaySurfaceCreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `flags` is reserved for future use, and must be zero.
- `displayMode` is a `VkDisplayModeKHR` handle specifying the mode to use when displaying this surface.
- `planeIndex` is the plane on which this surface appears.
- `planeStackIndex` is the z-order of the plane.
- `transform` is a `VkSurfaceTransformFlagBitsKHR` value specifying the transformation to apply to images as part of the scanout operation.
- `globalAlpha` is the global alpha value. This value is ignored if `alphaMode` is not `VK_DISPLAY_PLANE_ALPHA_GLOBAL_BIT_KHR`.
• **alphaMode** is a `VkDisplayPlaneAlphaFlagBitsKHR` value specifying the type of alpha blending to use.

• **imageExtent** is the size of the presentable images to use with the surface.

---

**Note**

Creating a display surface **must** not modify the state of the displays, planes, or other resources it names. For example, it **must** not apply the specified mode to be set on the associated display. Application of display configuration occurs as a side effect of presenting to a display surface.

---

### Valid Usage

- **VUID-VkDisplaySurfaceCreateInfoKHR-planeIndex-01252**
  - `planeIndex` **must** be less than the number of display planes supported by the device as determined by calling `vkGetPhysicalDeviceDisplayPlanePropertiesKHR`.

- **VUID-VkDisplaySurfaceCreateInfoKHR-planeReorderPossible-01253**
  - If the `planeReorderPossible` member of the `VkDisplayPropertiesKHR` structure returned by `vkGetPhysicalDeviceDisplayPropertiesKHR` for the display corresponding to `displayMode` is `VK_TRUE` then `planeStackIndex` **must** be less than the number of display planes supported by the device as determined by calling `vkGetPhysicalDeviceDisplayPlanePropertiesKHR`; otherwise `planeStackIndex` **must** equal the `currentStackIndex` member of `VkDisplayPlanePropertiesKHR` returned by `vkGetPhysicalDeviceDisplayPlanePropertiesKHR` for the display plane corresponding to `displayMode`.

- **VUID-VkDisplaySurfaceCreateInfoKHR-alphaMode-01254**
  - If `alphaMode` is `VK_DISPLAY_PLANE_ALPHA_GLOBAL_BIT_KHR` then `globalAlpha` **must** be between 0 and 1, inclusive.

- **VUID-VkDisplaySurfaceCreateInfoKHR-alphaMode-01255**
  - `alphaMode` **must** be one of the bits present in the `supportedAlpha` member of `VkDisplayPlaneCapabilitiesKHR` for the display plane corresponding to `displayMode`.

- **VUID-VkDisplaySurfaceCreateInfoKHR-transform-06740**
  - `transform` **must** be one of the bits present in the `supportedTransforms` member of `VkDisplayPropertiesKHR` for the display corresponding to `displayMode`.

- **VUID-VkDisplaySurfaceCreateInfoKHR-width-01256**
  - The `width` and `height` members of `imageExtent` **must** be less than or equal to `VkPhysicalDeviceLimits::maxImageDimension2D`.

---

### Valid Usage (Implicit)

- **VUID-VkDisplaySurfaceCreateInfoKHR-sType-sType**
  - `sType` **must** be `VK_STRUCTURE_TYPE_DISPLAY_SURFACE_CREATE_INFO_KHR`.

- **VUID-VkDisplaySurfaceCreateInfoKHR-pNext-pNext**
  - `pNext` **must** be `NULL`.

- **VUID-VkDisplaySurfaceCreateInfoKHR-flags-zerobitmask**
  - `flags` **must** be a zero bit mask.
flags must be 0

- VUID-VkDisplaySurfaceCreateInfoKHR-displayMode-parameter
displayMode must be a valid VkDisplayModeKHR handle

- VUID-VkDisplaySurfaceCreateInfoKHR-transform-parameter
transform must be a valid VkSurfaceTransformFlagBitsKHR value

- VUID-VkDisplaySurfaceCreateInfoKHR-alphaMode-parameter
alphaMode must be a valid VkDisplayPlaneAlphaFlagBitsKHR value

// Provided by VK_KHR_display

typedef VkFlags VkDisplaySurfaceCreateFlagsKHR;

VkDisplaySurfaceCreateFlagsKHR is a bitmask type for setting a mask, but is currently reserved for future use.

Bits which can be set in VkDisplaySurfaceCreateInfoKHR::alphaMode, specifying the type of alpha blending to use on a display, are:

// Provided by VK_KHR_display

typedef enum VkDisplayPlaneAlphaFlagBitsKHR {
    VK_DISPLAY_PLANE_ALPHA_OPAQUE_BIT_KHR = 0x00000001,
    VK_DISPLAY_PLANE_ALPHA_GLOBAL_BIT_KHR = 0x00000002,
    VK_DISPLAY_PLANE_ALPHA_PER_PIXEL_BIT_KHR = 0x00000004,
    VK_DISPLAY_PLANE_ALPHA_PER_PIXEL_PREMULTIPLIED_BIT_KHR = 0x00000008,
} VkDisplayPlaneAlphaFlagBitsKHR;

- VK_DISPLAY_PLANE_ALPHA_OPAQUE_BIT_KHR specifies that the source image will be treated as opaque.
- VK_DISPLAY_PLANE_ALPHA_GLOBAL_BIT_KHR specifies that a global alpha value must be specified that will be applied to all pixels in the source image.
- VK_DISPLAY_PLANE_ALPHA_PER_PIXEL_BIT_KHR specifies that the alpha value will be determined by the alpha component of the source image's pixels. If the source format contains no alpha values, no blending will be applied. The source alpha values are not premultiplied into the source image's other color components.
- VK_DISPLAY_PLANE_ALPHA_PER_PIXEL_PREMULTIPLIED_BIT_KHR is equivalent to VK_DISPLAY_PLANE_ALPHA_PER_PIXEL_BIT_KHR, except the source alpha values are assumed to be premultiplied into the source image's other color components.

// Provided by VK_KHR_display

typedef VkFlags VkDisplayPlaneAlphaFlagsKHR;

VkDisplayPlaneAlphaFlagsKHR is a bitmask type for setting a mask of zero or more VkDisplayPlaneAlphaFlagBitsKHR.
34.3.4. Presenting to headless surfaces

Vulkan rendering can be presented to a headless surface, where the presentation operation is a no-op producing no externally-visible result.

**Note**

Because there is no real presentation target, the headless presentation engine may be extended to impose an arbitrary or customisable set of restrictions and features. This makes it a useful portable test target for applications targeting a wide range of presentation engines where the actual target presentation engines might be scarce, unavailable or otherwise undesirable or inconvenient to use for general Vulkan application development.

The usual surface query mechanisms must be used to determine the actual restrictions and features of the implementation.

To create a headless `VkSurfaceKHR` object, call:

```c
// Provided by VK_EXT_headless_surface
VkResult vkCreateHeadlessSurfaceEXT(
    VkInstance instance,           // Provided by VK_EXT_headless_surface
    const VkHeadlessSurfaceCreateInfoEXT* pCreateInfo,   // Provided by VK_EXT_headless_surface
    const VkAllocationCallbacks* pAllocator,              // Provided by VK_EXT_headless_surface
    VkSurfaceKHR* pSurface);                               // Provided by VK_EXT_headless_surface
```

- **instance** is the instance to associate the surface with.
- **pCreateInfo** is a pointer to a `VkHeadlessSurfaceCreateInfoEXT` structure containing parameters affecting the creation of the surface object.
- **pAllocator** is the allocator used for host memory allocated for the surface object when there is no more specific allocator available (see Memory Allocation).
- **pSurface** is a pointer to a `VkSurfaceKHR` handle in which the created surface object is returned.

**Valid Usage (Implicit)**

- **VUID-vkCreateHeadlessSurfaceEXT-instance-parameter**
  instance must be a valid `VkInstance` handle
- **VUID-vkCreateHeadlessSurfaceEXT-pCreateInfo-parameter**
  pCreateInfo must be a valid pointer to a valid ` VkHeadlessSurfaceCreateInfoEXT` structure
- **VUID-vkCreateHeadlessSurfaceEXT-pAllocator-parameter**
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid `VkAllocationCallbacks` structure
- **VUID-vkCreateHeadlessSurfaceEXT-pSurface-parameter**
  pSurface must be a valid pointer to a `VkSurfaceKHR` handle
Return Codes

Success
  • VK_SUCCESS

Failure
  • VK_ERROR_OUT_OF_HOST_MEMORY
  • VK_ERROR_OUT_OF_DEVICE_MEMORY

The `VkHeadlessSurfaceCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_headless_surface
typedef struct VkHeadlessSurfaceCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkHeadlessSurfaceCreateFlagsEXT flags;
} VkHeadlessSurfaceCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is reserved for future use.

Valid Usage (Implicit)

- `VUID-VkHeadlessSurfaceCreateInfoEXT-sType-sType` `sType` must be `VK_STRUCTURE_TYPE_HEADLESS_SURFACE_CREATE_INFO_EXT`
- `VUID-VkHeadlessSurfaceCreateInfoEXT-pNext-pNext` `pNext` must be `NULL`
- `VUID-VkHeadlessSurfaceCreateInfoEXT-flags-zerobitmask` `flags` must be `0`

For headless surfaces, `currentExtent` is the reserved value (0xFFFFFFFF, 0xFFFFFFFF). Whatever the application sets a swapchain's `imageExtent` to will be the size of the surface, after the first image is presented.

```c
// Provided by VK_EXT_headless_surface
typedef VkFlags VkHeadlessSurfaceCreateFlagsEXT;
```

`VkHeadlessSurfaceCreateFlagsEXT` is a bitmask type for setting a mask, but is currently reserved for future use.
34.4. Querying for WSI Support

Not all physical devices will include WSI support. Within a physical device, not all queue families will support presentation. WSI support and compatibility can be determined in a platform-neutral manner (which determines support for presentation to a particular surface object) and additionally may be determined in platform-specific manners (which determine support for presentation on the specified physical device but do not guarantee support for presentation to a particular surface object).

To determine whether a queue family of a physical device supports presentation to a given surface, call:

```cpp
// Provided by VK_KHR_surface
VkResult vkGetPhysicalDeviceSurfaceSupportKHR(
    VkPhysicalDevice physicalDevice,
    uint32_t queueFamilyIndex,
    VkSurfaceKHR surface,
    VkBool32* pSupported);
```

- **physicalDevice** is the physical device.
- **queueFamilyIndex** is the queue family.
- **surface** is the surface.
- **pSupported** is a pointer to a `VkBool32`, which is set to `VK_TRUE` to indicate support, and `VK_FALSE` otherwise.

### Valid Usage

- **VUID-vkGetPhysicalDeviceSurfaceSupportKHR-queueFamilyIndex-01269**
  `queueFamilyIndex` must be less than `pQueueFamilyPropertyCount` returned by `vkGetPhysicalDeviceQueueFamilyProperties` for the given `physicalDevice`

### Valid Usage (Implicit)

- **VUID-vkGetPhysicalDeviceSurfaceSupportKHR-physicalDevice-parameter**
  `physicalDevice` must be a valid `VkPhysicalDevice` handle

- **VUID-vkGetPhysicalDeviceSurfaceSupportKHR-surface-parameter**
  `surface` must be a valid `VkSurfaceKHR` handle

- **VUID-vkGetPhysicalDeviceSurfaceSupportKHR-pSupported-parameter**
  `pSupported` must be a valid pointer to a `VkBool32` value

- **VUID-vkGetPhysicalDeviceSurfaceSupportKHR-commonparent**
  Both of `physicalDevice`, and `surface` must have been created, allocated, or retrieved from the same `VkInstance`
Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_SURFACE_LOST_KHR

34.4.1. Android Platform

On Android, all physical devices and queue families must be capable of presentation with any native window. As a result there is no Android-specific query for these capabilities.

34.4.2. Wayland Platform

To determine whether a queue family of a physical device supports presentation to a Wayland compositor, call:

```c
// Provided by VK_KHR_wayland_surface
VkBool32 vkGetPhysicalDeviceWaylandPresentationSupportKHR(
    VkPhysicalDevice physicalDevice,
    uint32_t queueFamilyIndex,
    struct wl_display* display);
```

- `physicalDevice` is the physical device.
- `queueFamilyIndex` is the queue family index.
- `display` is a pointer to the `wl_display` associated with a Wayland compositor.

This platform-specific function can be called prior to creating a surface.

Valid Usage

- VUID-vkGetPhysicalDeviceWaylandPresentationSupportKHR-queueFamilyIndex-01306
  - `queueFamilyIndex` must be less than `pQueueFamilyPropertyCount` returned by `vkGetPhysicalDeviceQueueFamilyProperties` for the given `physicalDevice`.

Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceWaylandPresentationSupportKHR-physicalDevice-parameter
  - `physicalDevice` must be a valid `VkPhysicalDevice` handle
- VUID-vkGetPhysicalDeviceWaylandPresentationSupportKHR-display-parameter
display must be a valid pointer to a \texttt{wl\_display} value

### 34.4.3. Win32 Platform

To determine whether a queue family of a physical device supports presentation to the Microsoft Windows desktop, call:

```c
// Provided by VK_KHR_win32_surface
VkBool32 vkGetPhysicalDeviceWin32PresentationSupportKHR(
    VkPhysicalDevice physicalDevice,
    uint32_t queueFamilyIndex);
```

- \texttt{physicalDevice} is the physical device.
- \texttt{queueFamilyIndex} is the queue family index.

This platform-specific function can be called prior to creating a surface.

### Valid Usage

- VUID-vkGetPhysicalDeviceWin32PresentationSupportKHR-queueFamilyIndex-01309 queueFamilyIndex must be less than \texttt{pQueueFamilyPropertyCount} returned by \texttt{vkGetPhysicalDeviceQueueFamilyProperties} for the given \texttt{physicalDevice}

### Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceWin32PresentationSupportKHR-physicalDevice-parameter physicalDevice must be a valid \texttt{VkPhysicalDevice} handle

### 34.4.4. XCB Platform

To determine whether a queue family of a physical device supports presentation to an X11 server, using the XCB client-side library, call:

```c
// Provided by VK_KHR_xcb_surface
VkBool32 vkGetPhysicalDeviceXcbPresentationSupportKHR(
    VkPhysicalDevice physicalDevice,
    uint32_t queueFamilyIndex,
    xcb_connection_t* connection,
    xcb_visualid_t visual_id);
```

- \texttt{physicalDevice} is the physical device.
- \texttt{queueFamilyIndex} is the queue family index.
- \texttt{connection} is a pointer to an \texttt{xcb\_connection\_t} to the X server.
• `visual_id` is an X11 visual (`xcb_visualid_t`).

This platform-specific function **can** be called prior to creating a surface.

### Valid Usage

- VUID-vkGetPhysicalDeviceXcbPresentationSupportKHR-queueFamilyIndex-01312
  
  `queueFamilyIndex` **must** be less than `pQueueFamilyPropertyCount` returned by `vkGetPhysicalDeviceQueueFamilyProperties` for the given `physicalDevice`.

### Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceXcbPresentationSupportKHR-physicalDevice-parameter
  
  `physicalDevice` **must** be a valid `VkPhysicalDevice` handle.

- VUID-vkGetPhysicalDeviceXcbPresentationSupportKHR-connection-parameter
  
  `connection` **must** be a valid pointer to an `xcb_connection_t` value.

### 34.4.5. Xlib Platform

To determine whether a queue family of a physical device supports presentation to an X11 server, using the Xlib client-side library, call:

```c
// Provided by VK_KHR_xlib_surface
VkBool32 vkGetPhysicalDeviceXcbPresentationSupportKHR(
    VkPhysicalDevice physicalDevice,
    uint32_t queueFamilyIndex,
    Display* dpy,
    VisualID visualID);
```

- `physicalDevice` is the physical device.
- `queueFamilyIndex` is the queue family index.
- `dpy` is a pointer to an Xlib `Display` connection to the server.
- `visualID` is an X11 visual (`VisualID`).

This platform-specific function **can** be called prior to creating a surface.

### Valid Usage

- VUID-vkGetPhysicalDeviceXcbPresentationSupportKHR-queueFamilyIndex-01315
  
  `queueFamilyIndex` **must** be less than `pQueueFamilyPropertyCount` returned by `vkGetPhysicalDeviceQueueFamilyProperties` for the given `physicalDevice`.
34.4.6. DirectFB Platform

To determine whether a queue family of a physical device supports presentation with DirectFB library, call:

```c
// Provided by VK_EXT_directfb_surface
VkBool32 vkGetPhysicalDeviceDirectFBPresentationSupportEXT(
    VkPhysicalDevice physicalDevice,
    uint32_t queueFamilyIndex,
    IDirectFB* dfb);
```

- `physicalDevice` is the physical device.
- `queueFamilyIndex` is the queue family index.
- `dfb` is a pointer to the IDirectFB main interface of DirectFB.

This platform-specific function can be called prior to creating a surface.

34.4.7. Fuchsia Platform

On Fuchsia, all physical devices and queue families **must** be capable of presentation with any ImagePipe. As a result there is no Fuchsia-specific query for these capabilities.
34.4.8. Google Games Platform

On Google Games Platform, all physical devices and queue families with the `VK_QUEUE_GRAPHICS_BIT` or `VK_QUEUE_COMPUTE_BIT` capabilities must be capable of presentation with any Google Games Platform stream descriptor. As a result, there is no query specific to Google Games Platform for these capabilities.

34.4.9. iOS Platform

On iOS, all physical devices and queue families must be capable of presentation with any layer. As a result there is no iOS-specific query for these capabilities.

34.4.10. macOS Platform

On macOS, all physical devices and queue families must be capable of presentation with any layer. As a result there is no macOS-specific query for these capabilities.

34.4.11. VI Platform

On VI, all physical devices and queue families must be capable of presentation with any layer. As a result there is no VI-specific query for these capabilities.

34.4.12. QNX Screen Platform

To determine whether a queue family of a physical device supports presentation to a QNX Screen compositor, call:

```c
// Provided by VK_QNX_screen_surface
VkBool32 vkGetPhysicalDeviceScreenPresentationSupportQNX(
    VkPhysicalDevice physicalDevice,
    uint32_t queueFamilyIndex,
    struct _screen_window* window);
```

- `physicalDevice` is the physical device.
- `queueFamilyIndex` is the queue family index.
- `window` is the QNX Screen `window` object.

This platform-specific function can be called prior to creating a surface.

**Valid Usage**

- VUID-vkGetPhysicalDeviceScreenPresentationSupportQNX-queueFamilyIndex-04743: queueFamilyIndex must be less than `pQueueFamilyPropertyCount` returned by `vkGetPhysicalDeviceQueueFamilyProperties` for the given `physicalDevice`. 
34.5. Surface Queries

The capabilities of a swapchain targeting a surface are the intersection of the capabilities of the WSI platform, the native window or display, and the physical device. The resulting capabilities can be obtained with the queries listed below in this section.

**Note**

In addition to the surface capabilities as obtained by surface queries below, swapchain images are also subject to ordinary image creation limits as reported by `vkGetPhysicalDeviceImageFormatProperties`. As an application is instructed by the appropriate Valid Usage sections, both the surface capabilities and the image creation limits have to be satisfied whenever swapchain images are created.

34.5.1. Surface Capabilities

To query the basic capabilities of a surface, needed in order to create a swapchain, call:

```c
// Provided by VK_KHR_surface
VkResult vkGetPhysicalDeviceSurfaceCapabilitiesKHR(
    VkPhysicalDevice physicalDevice,
    VkSurfaceKHR surface,
    VkSurfaceCapabilitiesKHR* pSurfaceCapabilities);
```

- `physicalDevice` is the physical device that will be associated with the swapchain to be created, as described for `vkCreateSwapchainKHR`.
- `surface` is the surface that will be associated with the swapchain.
- `pSurfaceCapabilities` is a pointer to a `VkSurfaceCapabilitiesKHR` structure in which the capabilities are returned.

**Valid Usage**

- VUID-vkGetPhysicalDeviceSurfaceCapabilitiesKHR-surface-06523
  `surface` must be a valid `VkSurfaceKHR` handle

- VUID-vkGetPhysicalDeviceSurfaceCapabilitiesKHR-surface-06211
  `surface` must be supported by `physicalDevice`, as reported by `vkGetPhysicalDeviceSurfaceSupportKHR` or an equivalent platform-specific mechanism
Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceSurfaceCapabilitiesKHR-physicalDevice-parameter
  physicalDevice must be a valid VkPhysicalDevice handle

- VUID-vkGetPhysicalDeviceSurfaceCapabilitiesKHR-surface-parameter
  surface must be a valid VkSurfaceKHR handle

- VUID-vkGetPhysicalDeviceSurfaceCapabilitiesKHR-pSurfaceCapabilities-parameter
  pSurfaceCapabilities must be a valid pointer to a VkSurfaceCapabilitiesKHR structure

- VUID-vkGetPhysicalDeviceSurfaceCapabilitiesKHR-commonparent
  Both of physicalDevice, and surface must have been created, allocated, or retrieved from
  the same VkInstance

Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_SURFACE_LOST_KHR

The VkSurfaceCapabilitiesKHR structure is defined as:

```c
// Provided by VK_KHR_surface
typedef struct VkSurfaceCapabilitiesKHR {
    uint32_t minImageCount;
    uint32_t maxImageCount;
    VkExtent2D currentExtent;
    VkExtent2D minImageExtent;
    VkExtent2D maxImageExtent;
    uint32_t maxImageArrayLayers;
    VkSurfaceTransformFlagsKHR supportedTransforms;
    VkSurfaceTransformFlagBitsKHR currentTransform;
    VkCompositeAlphaFlagsKHR supportedCompositeAlpha;
    VkImageUsageFlags supportedUsageFlags;
} VkSurfaceCapabilitiesKHR;
```

- **minImageCount** is the minimum number of images the specified device supports for a swapchain
  created for the surface, and will be at least one.

- **maxImageCount** is the maximum number of images the specified device supports for a swapchain
  created for the surface, and will be either 0, or greater than or equal to **minImageCount**. A value of
  0 means that there is no limit on the number of images, though there **may** be limits related to
the total amount of memory used by presentable images.

- **currentExtent** is the current width and height of the surface, or the special value (0xFFFFFFFF, 0xFFFFFFFF) indicating that the surface size will be determined by the extent of a swapchain targeting the surface.

- **minImageExtent** contains the smallest valid swapchain extent for the surface on the specified device. The *width* and *height* of the extent will each be less than or equal to the corresponding *width* and *height* of *currentExtent*, unless *currentExtent* has the special value described above.

- **maxImageExtent** contains the largest valid swapchain extent for the surface on the specified device. The *width* and *height* of the extent will each be greater than or equal to the corresponding *width* and *height* of *minImageExtent*. The *width* and *height* of the extent will each be greater than or equal to the corresponding *width* and *height* of *currentExtent*, unless *currentExtent* has the special value described above.

- **maxImageArrayLayers** is the maximum number of layers presentable images can have for a swapchain created for this device and surface, and will be at least one.

- **supportedTransforms** is a bitmask of `VkSurfaceTransformFlagBitsKHR` indicating the presentation transforms supported for the surface on the specified device. At least one bit will be set.

- **currentTransform** is `VkSurfaceTransformFlagBitsKHR` value indicating the surface’s current transform relative to the presentation engine’s natural orientation.

- **supportedCompositeAlpha** is a bitmask of `VkCompositeAlphaFlagBitsKHR`, representing the alpha compositing modes supported by the presentation engine for the surface on the specified device, and at least one bit will be set. Opaque composition can be achieved in any alpha compositing mode by either using an image format that has no alpha component, or by ensuring that all pixels in the presentable images have an alpha value of 1.0.

- **supportedUsageFlags** is a bitmask of `VkImageUsageFlagBits` representing the ways the application can use the presentable images of a swapchain created with `VkPresentModeKHR` set to `VK_PRESENT_MODE_IMMEDIATE_KHR`, `VK_PRESENT_MODE_MAILBOX_KHR`, `VK_PRESENT_MODE_FIFO_KHR` or `VK_PRESENT_MODE_FIFO_RELAXED_KHR` for the surface on the specified device. `VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT` must be included in the set. Implementations may support additional usages.

```plaintext
Note
Supported usage flags of a presentable image when using `VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR` or `VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR` presentation mode are provided by `VkSharedPresentSurfaceCapabilitiesKHR::sharedPresentSupportedUsageFlags`.

Note
Formulas such as min(N, maxImageCount) are not correct, since maxImageCount may be zero.
```

To query the basic capabilities of a surface defined by the core or extensions, call:
VkResult vkGetPhysicalDeviceSurfaceCapabilities2KHR(
    VkPhysicalDevice physicalDevice,
    const VkPhysicalDeviceSurfaceInfo2KHR* pSurfaceInfo,
    VkSurfaceCapabilities2KHR* pSurfaceCapabilities);

- **physicalDevice** is the physical device that will be associated with the swapchain to be created, as described for `vkCreateSwapchainKHR`.

- **pSurfaceInfo** is a pointer to a `VkPhysicalDeviceSurfaceInfo2KHR` structure describing the surface and other fixed parameters that would be consumed by `vkCreateSwapchainKHR`.

- **pSurfaceCapabilities** is a pointer to a `VkSurfaceCapabilities2KHR` structure in which the capabilities are returned.

`vkGetPhysicalDeviceSurfaceCapabilities2KHR` behaves similarly to `vkGetPhysicalDeviceSurfaceCapabilitiesKHR`, with the ability to specify extended inputs via chained input structures, and to return extended information via chained output structures.

### Valid Usage

- **VUID-vkGetPhysicalDeviceSurfaceCapabilities2KHR-pSurfaceInfo-06521**
  If the `VK_GOOGLE_surfaceless_query` extension is not enabled, `pSurfaceInfo->surface` must be a valid `VkSurfaceKHR` handle.

- **VUID-vkGetPhysicalDeviceSurfaceCapabilities2KHR-pSurfaceInfo-06522**
  If `pSurfaceInfo->surface` is not `VK_NULL_HANDLE`, it must be supported by `physicalDevice`, as reported by `vkGetPhysicalDeviceSurfaceSupportKHR` or an equivalent platform-specific mechanism.

- **VUID-vkGetPhysicalDeviceSurfaceCapabilities2KHR-pNext-02671**
  If a `VkSurfaceCapabilitiesFullScreenExclusiveEXT` structure is included in the `pNext` chain of `pSurfaceCapabilities`, a `VkSurfaceFullScreenExclusiveWin32InfoEXT` structure must be included in the `pNext` chain of `pSurfaceInfo`.

- **VUID-vkGetPhysicalDeviceSurfaceCapabilities2KHR-pNext-07776**
  If a `VkSurfacePresentModeCompatibilityEXT` structure is included in the `pNext` chain of `pSurfaceCapabilities`, a `VkSurfacePresentModeEXT` structure must be included in the `pNext` chain of `pSurfaceInfo`.

- **VUID-vkGetPhysicalDeviceSurfaceCapabilities2KHR-pNext-07777**
  If a `VkSurfacePresentScalingCapabilitiesEXT` structure is included in the `pNext` chain of `pSurfaceCapabilities`, a `VkSurfacePresentModeEXT` structure must be included in the `pNext` chain of `pSurfaceInfo`.

- **VUID-vkGetPhysicalDeviceSurfaceCapabilities2KHR-pNext-07778**
  If a `VkSurfacePresentModeCompatibilityEXT` structure is included in the `pNext` chain of `pSurfaceCapabilities`, `pSurfaceInfo->surface` must be a valid `VkSurfaceKHR` handle.

- **VUID-vkGetPhysicalDeviceSurfaceCapabilities2KHR-pNext-07779**
  If a `VkSurfacePresentScalingCapabilitiesEXT` structure is included in the `pNext` chain of
pSurfaceCapabilities, pSurfaceInfo->surface must be a valid VkSurfaceKHR handle

Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceSurfaceCapabilities2KHR-physicalDevice-parameter
  
it must be a valid VkPhysicalDevice handle

- VUID-vkGetPhysicalDeviceSurfaceCapabilities2KHR-pSurfaceInfo-parameter
  
pSurfaceInfo must be a valid pointer to a valid VkPhysicalDeviceSurfaceInfo2KHR structure

- VUID-vkGetPhysicalDeviceSurfaceCapabilities2KHR-pSurfaceCapabilities-parameter
  
pSurfaceCapabilities must be a valid pointer to a VkSurfaceCapabilities2KHR structure

Return Codes

Success

• VK_SUCCESS

Failure

• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY
• VK_ERROR_SURFACE_LOST_KHR

The VkPhysicalDeviceSurfaceInfo2KHR structure is defined as:

```c
typedef struct VkPhysicalDeviceSurfaceInfo2KHR {
    VkStructureType sType;
    const void* pNext;
    VkSurfaceKHR surface;
} VkPhysicalDeviceSurfaceInfo2KHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- surface is the surface that will be associated with the swapchain.

The members of VkPhysicalDeviceSurfaceInfo2KHR correspond to the arguments to
vkGetPhysicalDeviceSurfaceCapabilitiesKHR, with sType and pNext added for extensibility.

Additional capabilities of a surface may be available to swapchains created with different full-screen exclusive settings - particularly if exclusive full-screen access is application controlled. These additional capabilities can be queried by adding a VkSurfaceFullScreenExclusiveInfoEXT structure to the pNext chain of this structure when used to query surface properties. Additionally, for Win32 surfaces with application controlled exclusive full-screen access, chaining a
The `VkSurfaceFullScreenExclusiveWin32InfoEXT` structure may also report additional surface capabilities. These additional capabilities only apply to swapchains created with the same parameters included in the `pNext` chain of `VkSwapchainCreateInfoKHR`.

### Valid Usage

- **VUID-VkPhysicalDeviceSurfaceInfo2KHR-pNext-02672**
  If the `pNext` chain includes a `VkSurfaceFullScreenExclusiveInfoEXT` structure with its `fullScreenExclusive` member set to `VK_FULL_SCREEN_EXCLUSIVE_APPLICATION_CONTROLLED_EXT`, and the surface was created using `vkCreateWin32SurfaceKHR`, a `VkSurfaceFullScreenExclusiveWin32InfoEXT` structure must be included in the `pNext` chain.

- **VUID-VkPhysicalDeviceSurfaceInfo2KHR-surface-07919**
  If the `VK_GOOGLE_surfaceless_query` extension is not enabled, the `surface` must be a valid `VkSurfaceKHR` handle.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceSurfaceInfo2KHR-sType-sType**
  The `sType` value of each struct in the `pNext` chain must be unique.

- **VUID-VkPhysicalDeviceSurfaceInfo2KHR-surface-parameter**
  If `surface` is not `VK_NULL_HANDLE`, the `surface` must be a valid `VkSurfaceKHR` handle.

If the `pNext` chain of `VkSwapchainCreateInfoKHR` includes a `VkSurfaceFullScreenExclusiveInfoEXT` structure, then that structure specifies the application’s preferred full-screen transition behavior.

The `VkSurfaceFullScreenExclusiveInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_full_screen_exclusive
typedef struct VkSurfaceFullScreenExclusiveInfoEXT {
    VkStructureType sType;
    void* pNext;
    VkFullScreenExclusiveEXT fullScreenExclusive;
} VkSurfaceFullScreenExclusiveInfoEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
• **fullScreenExclusive** is a VkFullScreenExclusiveEXT value specifying the preferred full-screen transition behavior.

If this structure is not present, **fullScreenExclusive** is considered to be **VK_FULL_SCREEN_EXCLUSIVE_DEFAULT_EXT**.

### Valid Usage (Implicit)

- VUID-VkSurfaceFullScreenExclusiveInfoEXT-sType-sType
  
  *sType* **must** be **VK_STRUCTURE_TYPE_SURFACE_FULLSCREEN_EXCLUSIVE_INFO_EXT**

- VUID-VkSurfaceFullScreenExclusiveInfoEXT-fullScreenExclusive-parameter
  
  **fullScreenExclusive** **must** be a valid VkFullScreenExclusiveEXT value

Possible values of VkSurfaceFullScreenExclusiveInfoEXT::fullScreenExclusive are:

```c
// Provided by VK_EXT_full_screen_exclusive
typedef enum VkFullScreenExclusiveEXT {
    VK_FULL_SCREEN_EXCLUSIVE_DEFAULT_EXT = 0,
    VK_FULL_SCREEN_EXCLUSIVE_ALLOWED_EXT = 1,
    VK_FULL_SCREEN_EXCLUSIVE_DISALLOWED_EXT = 2,
    VK_FULL_SCREEN_EXCLUSIVE_APPLICATION_CONTROLLED_EXT = 3,
} VkFullScreenExclusiveEXT;
```

- **VK_FULL_SCREEN_EXCLUSIVE_DEFAULT_EXT** indicates the implementation **should** determine the appropriate full-screen method by whatever means it deems appropriate.

- **VK_FULL_SCREEN_EXCLUSIVE_ALLOWED_EXT** indicates the implementation **may** use full-screen exclusive mechanisms when available. Such mechanisms **may** result in better performance and/or the availability of different presentation capabilities, but **may** require a more disruptive transition during swapchain initialization, first presentation and/or destruction.

- **VK_FULL_SCREEN_EXCLUSIVE_DISALLOWED_EXT** indicates the implementation **should** avoid using full-screen mechanisms which rely on disruptive transitions.

- **VK_FULL_SCREEN_EXCLUSIVE_APPLICATION_CONTROLLED_EXT** indicates the application will manage full-screen exclusive mode by using the vkAcquireFullScreenExclusiveModeEXT and vkReleaseFullScreenExclusiveModeEXT commands.

The VkSurfaceFullScreenExclusiveWin32InfoEXT structure is defined as:

```c
// Provided by VK_KHR_win32_surface with VK_EXT_full_screen_exclusive
typedef struct VkSurfaceFullScreenExclusiveWin32InfoEXT {
    VkStructureType sType;
    const void* pNext;
    HMONITOR hmonitor;
} VkSurfaceFullScreenExclusiveWin32InfoEXT;
```

- **sType** is a VkStructureType value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.
• `hmonitor` is the Win32 `HMONITOR` handle identifying the display to create the surface with.

**Note**
If `hmonitor` is invalidated (e.g. the monitor is unplugged) during the lifetime of a swapchain created with this structure, operations on that swapchain will return `VK_ERROR_OUT_OF_DATE_KHR`.

**Note**
It is the responsibility of the application to change the display settings of the targeted Win32 display using the appropriate platform APIs. Such changes may alter the surface capabilities reported for the created surface.

---

### Valid Usage

- VUID-VkSurfaceFullScreenExclusiveWin32InfoEXT-hmonitor-02673
  
  `hmonitor` must be a valid `HMONITOR`

---

### Valid Usage (Implicit)

- VUID-VkSurfaceFullScreenExclusiveWin32InfoEXT-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_SURFACE_FULLSCREEN_EXCLUSIVE_WIN32_INFO_EXT`

---

The `VkSurfaceCapabilities2KHR` structure is defined as:

```c
// Provided by VK_KHR_get_surface_capabilities2
typedef struct VkSurfaceCapabilities2KHR {
    VkStructureType sType;
    void* pNext;
    VkSurfaceCapabilitiesKHR surfaceCapabilities;
} VkSurfaceCapabilities2KHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `surfaceCapabilities` is a `VkSurfaceCapabilitiesKHR` structure describing the capabilities of the specified surface.

If the `VK_GOOGLE_surfaceless_query` extension is enabled and `VkPhysicalDeviceSurfaceInfo2KHR::surface` in the `vkGetPhysicalDeviceSurfaceCapabilities2KHR` call is `VK_NULL_HANDLE`, the values returned in `minImageCount`, `maxImageCount`, `currentExtent`, and `currentTransform` will not reflect that of any surface and will instead be as such:

- `minImageCount` and `maxImageCount` will be `0xFFFFFFFF`
• `currentExtent` will be (0xFFFFFFFF, 0xFFFFFFFF)
• `currentTransform` will be `VK_SURFACE_TRANSFORM_INHERIT_BIT_KHR`

## Valid Usage (Implicit)

- **VUID-VkSurfaceCapabilities2KHR-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_SURFACE_CAPABILITIES_2_KHR`
- **VUID-VkSurfaceCapabilities2KHR-pNext-pNext**
  - Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkDisplayNativeHdrSurfaceCapabilitiesAMD`, `VkSharedPresentSurfaceCapabilitiesKHR`, `VkSurfaceCapabilitiesFullScreenExclusiveEXT`, `VkSurfaceCapabilitiesPresentBarrierNV`, `VkSurfacePresentModeCompatibilityEXT`, `VkSurfacePresentScalingCapabilitiesEXT`, or `VkSurfaceProtectedCapabilitiesKHR`
- **VUID-VkSurfaceCapabilities2KHR-sType-unique**
  - The `sType` value of each struct in the `pNext` chain must be unique

An application queries if a protected `VkSurfaceKHR` is displayable on a specific windowing system using `VkSurfaceProtectedCapabilitiesKHR`, which can be passed in `pNext` parameter of `VkSurfaceCapabilities2KHR`.

The `VkSurfaceProtectedCapabilitiesKHR` structure is defined as:

```c
// Provided by VK_KHR_surface_protected_capabilities
typedef struct VkSurfaceProtectedCapabilitiesKHR {
  VkStructureType sType;
  const void* pNext;
  VkBool32 supportsProtected;
} VkSurfaceProtectedCapabilitiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `supportsProtected` specifies whether a protected swapchain created from `VkPhysicalDeviceSurfaceInfo2KHR::surface` for a particular windowing system can be displayed on screen or not. If `supportsProtected` is `VK_TRUE`, then creation of swapchains with the `VK_SWAPCHAIN_CREATE_PROTECTED_BIT_KHR` flag set must be supported for `surface`.

If the `VK_GOOGLE_surfaceless_query` extension is enabled, the value returned in `supportsProtected` will be identical for every valid surface created on this physical device, and so in the `vkGetPhysicalDeviceSurfaceCapabilities2KHR::surface` for a particular windowing system can be `VK_NULL_HANDLE`. In that case, the contents of `VkSurfaceCapabilities2KHR::surfaceCapabilities` as well as any other struct chained to it will be undefined.
Valid Usage (Implicit)

- **VUID-VkSurfaceProtectedCapabilitiesKHR-sType-sType**
  
  `sType` **must** be `VK_STRUCTURE_TYPE_SURFACE_PROTECTED_CAPABILITIES_KHR`.

The `VkSurfacePresentScalingCapabilitiesEXT` structure is defined as:

```c
// Provided by VK_EXT_surface_maintenance1
typedef struct VkSurfacePresentScalingCapabilitiesEXT {
    VkStructureType sType;
    void* pNext;
    VkPresentScalingFlagsEXT supportedPresentScaling;
    VkPresentGravityFlagsEXT supportedPresentGravityX;
    VkPresentGravityFlagsEXT supportedPresentGravityY;
    VkExtent2D minScaledImageExtent;
    VkExtent2D maxScaledImageExtent;
} VkSurfacePresentScalingCapabilitiesEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `supportedPresentScaling` is a bitmask of `VkPresentScalingFlagBitsEXT` representing the scaling methods supported by the surface, or `0` if application-defined scaling is not supported.
- `supportedPresentGravityX` is a bitmask of `VkPresentGravityFlagBitsEXT` representing the X-axis pixel gravity supported by the surface, or `0` if Vulkan-defined pixel gravity is not supported for the X axis.
- `supportedPresentGravityY` is a bitmask of `VkPresentGravityFlagBitsEXT` representing the Y-axis pixel gravity supported by the surface, or `0` if Vulkan-defined pixel gravity is not supported for the Y axis.
- `minScaledImageExtent` contains the smallest valid swapchain extent for the surface on the specified device when one of the scaling methods specified in `supportedPresentScaling` is used, or the special value (0xFFFFFFFF, 0xFFFFFFFF) indicating that the surface size will be determined by the extent of a swapchain targeting the surface. The width and height of the extent will each be smaller than or equal to the corresponding width and height of `VkSurfaceCapabilitiesKHR::minImageExtent`.
- `maxScaledImageExtent` contains the largest valid swapchain extent for the surface on the specified device when one of the scaling methods specified in `supportedPresentScaling` is used, or the special value described above for `minScaledImageExtent`. The width and height of the extent will each be greater than or equal to the corresponding width and height of `VkSurfaceCapabilitiesKHR::maxImageExtent`.

Before creating a swapchain whose scaling mode **can** be specified through the use of `VkSwapchainPresentScalingCreateInfoEXT`, obtain the set of supported scaling modes by including a `VkSurfacePresentModeEXT` structure in the `pNext` chain of `VkPhysicalDeviceSurfaceInfo2KHR` when calling `vkGetPhysicalDeviceSurfaceCapabilities2KHR`. The implementation **must** return the
same values in `VkSurfacePresentScalingCapabilitiesEXT` for any of the compatible present modes as obtained through `VkSurfacePresentModeCompatibilityEXT`.

### Valid Usage (Implicit)

- VUID-VkSurfacePresentScalingCapabilitiesEXT-sType-sType
  sType **must** be `VK_STRUCTURE_TYPE_SURFACE_PRESENT_SCALING_CAPABILITIES_EXT`

- VUID-VkSurfacePresentScalingCapabilitiesEXT-supportedPresentScaling-parameter
  supportedPresentScaling **must** be a valid combination of `VkPresentScalingFlagBitsEXT` values

- VUID-VkSurfacePresentScalingCapabilitiesEXT-supportedPresentGravityX-parameter
  supportedPresentGravityX **must** be a valid combination of `VkPresentGravityFlagBitsEXT` values

- VUID-VkSurfacePresentScalingCapabilitiesEXT-supportedPresentGravityY-parameter
  supportedPresentGravityY **must** be a valid combination of `VkPresentGravityFlagBitsEXT` values

Bits which **may** be set in `VkSurfacePresentScalingCapabilitiesEXT::supportedPresentScaling`, specifying scaling modes supported by the surface, are:

```c
// Provided by VK_EXT_surface_maintenance1
typedef enum VkPresentScalingFlagBitsEXT {
    VK_PRESENT_SCALING_ONE_TO_ONE_BIT_EXT = 0x00000001,
    VK_PRESENT_SCALING_ASPECT_RATIO_STRETCH_BIT_EXT = 0x00000002,
    VK_PRESENT_SCALING_STRETCH_BIT_EXT = 0x00000004,
} VkPresentScalingFlagBitsEXT;
```

- `VK_PRESENT_SCALING_ONE_TO_ONE_BIT_EXT` specifies that no scaling occurs, and pixels in the swapchain image are mapped to one and only one pixel in the surface. The mapping between pixels is defined by the chosen presentation gravity.

- `VK_PRESENT_SCALING_ASPECT_RATIO_STRETCH_BIT_EXT` specifies that the swapchain image will be minified or magnified such that at least one of the resulting width or height is equal to the corresponding surface dimension, and the other resulting dimension is less than or equal to the corresponding surface dimension, with the aspect ratio of the resulting image being identical to that of the original swapchain image.

- `VK_PRESENT_SCALING_STRETCH_BIT_EXT` specifies that the swapchain image will be minified or magnified such that the resulting image dimensions are equal to those of the surface.

```c
// Provided by VK_EXT_surface_maintenance1
typedef VkFlags VkPresentScalingFlagsEXT;
```

`VkPresentScalingFlagsEXT` is a bitmask type for setting a mask of zero or more `VkPresentScalingFlagBitsEXT`. 
Bits which **may** be set in the `VkSurfacePresentScalingCapabilitiesEXT::supportedPresentGravityX` or `supportedPresentGravityY` fields, specifying the gravity of presented pixels supported by the surface, are:

```cpp
// Provided by VK_EXT_surface_maintenance1
typedef enum VkPresentGravityFlagBitsEXT {
    VK_PRESENT_GRAVITY_MIN_BIT_EXT = 0x00000001,
    VK_PRESENT_GRAVITY_MAX_BIT_EXT = 0x00000002,
    VK_PRESENT_GRAVITY_CENTERED_BIT_EXT = 0x00000004,
} VkPresentGravityFlagBitsEXT;
```

- **VK_PRESENT_GRAVITY_MIN_BIT_EXT** means that the pixels will gravitate towards the top or left side of the surface.
- **VK_PRESENT_GRAVITY_MAX_BIT_EXT** means that the pixels will gravitate towards the bottom or right side of the surface.
- **VK_PRESENT_GRAVITY_CENTERED_BIT_EXT** means that the pixels will be centered in the surface.

If the value in `VkSurfaceCapabilitiesKHR::currentTransform` is not `VK_SURFACE_TRANSFORM_IDENTITY_BIT_KHR`, it is implementation-defined whether the gravity configuration applies to the presented image before or after transformation.

```cpp
// Provided by VK_EXT_surface_maintenance1
typedef VkFlags VkPresentGravityFlagsEXT;
```

`VkPresentGravityFlagsEXT` is a bitmask type for setting a mask of zero or more `VkPresentGravityFlagBitsEXT`.

The `VkSurfacePresentModeEXT` structure is defined as:

```cpp
// Provided by VK_EXT_surface_maintenance1
typedef struct VkSurfacePresentModeEXT {
    VkStructureType sType;
    void* pNext;
    VkPresentModeKHR presentMode;
} VkSurfacePresentModeEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **presentMode** is the presentation mode the swapchain will use.

If the `VkSurfacePresentModeEXT` structure is included in the `pNext` chain of `VkPhysicalDeviceSurfaceInfo2KHR`, the values returned in `VkSurfaceCapabilitiesKHR::minImageCount`, `VkSurfaceCapabilitiesKHR::maxImageCount`, `VkSurfacePresentScalingCapabilitiesEXT::minScaledImageExtent`, and `VkSurfacePresentScalingCapabilitiesEXT::maxScaledImageExtent` are valid only for the specified
If `presentMode` is `VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR` or `VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR`, the per-present mode image counts must both be one. The per-present mode image counts may be less-than or greater-than the image counts returned when `VkSurfacePresentModeEXT` is not provided.

**Note**

If `VkSwapchainPresentModesCreateInfoEXT` is provided to swapchain creation, the requirements for forward progress may be less strict. For example, a FIFO swapchain might only require 2 images to guarantee forward progress, but a MAILBOX one might require 4. Without the per-present image counts, such an implementation would have to return 4 in `VkSurfaceCapabilitiesKHR::minImageCount`, which pessimizes FIFO. Conversely, an implementation may return a low number for `minImageCount`, but internally bump the image count when application queries `vkGetSwapchainImagesKHR`, which can surprise applications, and is not discoverable until swapchain creation. Using `VkSurfacePresentModeEXT` and `VkSwapchainPresentModesCreateInfoEXT` together effectively removes this problem.

`VkSwapchainPresentModesCreateInfoEXT` is required for the specification to be backwards compatible with applications that do not know about, or make use of this feature.

**Valid Usage**

- VUID-VkSurfacePresentModeEXT-presentMode-07780

`presentMode` must be a value reported by `vkGetPhysicalDeviceSurfacePresentModesKHR` for the specified surface.

**Valid Usage (Implicit)**

- VUID-VkSurfacePresentModeEXT-sType-sType

`sType` must be `VK_STRUCTURE_TYPE_SURFACE_PRESENT_MODE_EXT`

- VUID-VkSurfacePresentModeEXT-presentMode-parameter

`presentMode` must be a valid `VkPresentModeKHR` value

The `VkSurfacePresentModeCompatibilityEXT` structure is defined as:

```c
// Provided by VK_EXT_surface_maintenance1
typedef struct VkSurfacePresentModeCompatibilityEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t presentModeCount;
    VkPresentModeKHR* pPresentModes;
} VkSurfacePresentModeCompatibilityEXT;
```
sType is a VkStructureType value identifying this structure.

pNext is NULL or a pointer to a structure extending this structure.

presentModeCount is an integer related to the number of present modes available or queried, as described below.

pPresentModes is a pointer to an array of VkPresentModeKHR in which present modes compatible with a given present mode are returned.

If pPresentModes is NULL, then the number of present modes that are compatible with the one specified in VkSurfacePresentModeEXT is returned in presentModeCount. Otherwise, presentModeCount must be set by the user to the number of elements in the pPresentModes array, and on return the variable is overwritten with the number of values actually written to pPresentModes. If the value of presentModeCount is less than the number of compatible present modes that are supported, at most presentModeCount values will be written to pPresentModes. The implementation must include the present mode passed to VkSurfacePresentModeEXT in pPresentModes, unless presentModeCount is zero.

Before creating a swapchain whose present modes can be modified through the use of VkSwapchainPresentModesCreateInfoEXT, obtain the set of present modes compatible with a given initial present mode by including a VkSurfacePresentModeEXT structure in the pNext chain of VkPhysicalDeviceSurfaceInfo2KHR when calling vkGetPhysicalDeviceSurfaceCapabilities2KHR.

Valid Usage (Implicit)

- VUID-VkSurfacePresentModeCompatibilityEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_SURFACE_PRESENT_MODE_COMPATIBILITY_EXT

- VUID-VkSurfacePresentModeCompatibilityEXT-pPresentModes-parameter
  If presentModeCount is not 0, and pPresentModes is not NULL, pPresentModes must be a valid pointer to an array of presentModeCount VkPresentModeKHR values

The VkSharedPresentSurfaceCapabilitiesKHR structure is defined as:

```c
// Provided by VK_KHR_shared_presentable_image
typedef struct VkSharedPresentSurfaceCapabilitiesKHR {
    VkStructureType sType;
    void* pNext;
    VkImageUsageFlags sharedPresentSupportedUsageFlags;
} VkSharedPresentSurfaceCapabilitiesKHR;
```

- sType is a VkStructureType value identifying this structure.

- pNext is NULL or a pointer to a structure extending this structure.

- sharedPresentSupportedUsageFlags is a bitmask of VkImageUsageFlagBits representing the ways the application can use the shared presentable image from a swapchain created with VkPresentModeKHR set to VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR or VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR for the surface on the specified device.
VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT must be included in the set but implementations may support additional usages.

Valid Usage (Implicit)

- VUID-VkSharedPresentSurfaceCapabilitiesKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_SHARED_PRESENT_SURFACE_CAPABILITIES_KHR

The VkDisplayNativeHdrSurfaceCapabilitiesAMD structure is defined as:

```c
// Provided by VK_AMD_display_native_hdr
typedef struct VkDisplayNativeHdrSurfaceCapabilitiesAMD {
    VkStructureType sType;
    void* pNext;
    VkBool32 localDimmingSupport;
} VkDisplayNativeHdrSurfaceCapabilitiesAMD;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **localDimmingSupport** specifies whether the surface supports local dimming. If this is VK_TRUE, VkSwapchainDisplayNativeHdrCreateInfoAMD can be used to explicitly enable or disable local dimming for the surface. Local dimming may also be overridden by vkSetLocalDimmingAMD during the lifetime of the swapchain.

Valid Usage (Implicit)

- VUID-VkDisplayNativeHdrSurfaceCapabilitiesAMD-sType-sType
  sType must be VK_STRUCTURE_TYPE_DISPLAY_NATIVE_HDR_SURFACE_CAPABILITIES_AMD

The VkSurfaceCapabilitiesFullScreenExclusiveEXT structure is defined as:

```c
// Provided by VK_EXT_full_screen_exclusive
typedef struct VkSurfaceCapabilitiesFullScreenExclusiveEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 fullScreenExclusiveSupported;
} VkSurfaceCapabilitiesFullScreenExclusiveEXT;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **fullScreenExclusiveControlSupported** is a boolean describing whether the surface is able to make use of exclusive full-screen access.

This structure can be included in the **pNext** chain of VkSurfaceCapabilities2KHR to determine
support for exclusive full-screen access. If `fullScreenExclusiveSupported` is `VK_FALSE`, it indicates that exclusive full-screen access is not obtainable for this surface.

Applications **must** not attempt to create swapchains with `VK_FULL_SCREEN_EXCLUSIVE_APPLICATION_CONTROLLED_EXT` set if `fullScreenExclusiveSupported` is `VK_FALSE`.

### Valid Usage (Implicit)

- VUID-VkSurfaceCapabilitiesFullScreenExclusiveEXT-sType-sType
  
  `sType` **must** be `VK_STRUCTURE_TYPE_SURFACE_CAPABILITIES_FULL_SCREEN_EXCLUSIVE_EXT`

The `VkSurfaceCapabilitiesPresentBarrierNV` structure is defined as:

```c
typedef struct VkSurfaceCapabilitiesPresentBarrierNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 presentBarrierSupported;
} VkSurfaceCapabilitiesPresentBarrierNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `presentBarrierSupported` is a boolean describing whether the surface is able to make use of the present barrier feature.

This structure **can** be included in the `pNext` chain of `VkSurfaceCapabilities2KHR` to determine support for present barrier access. If `presentBarrierSupported` is `VK_FALSE`, it indicates that the present barrier feature is not obtainable for this surface.

### Valid Usage (Implicit)

- VUID-VkSurfaceCapabilitiesPresentBarrierNV-sType-sType
  
  `sType` **must** be `VK_STRUCTURE_TYPE_SURFACE_CAPABILITIES_PRESENT_BARRIER_NV`

To query the basic capabilities of a surface, needed in order to create a swapchain, call:

```c
// Provided by VK_EXT_display_surface_counter
VkResult vkGetPhysicalDeviceSurfaceCapabilities2EXT(
    VkPhysicalDevice physicalDevice,  // physical device
    VkSurfaceKHR surface,              // surface
    VkSurfaceCapabilities2EXT* pSurfaceCapabilities);  // pSurfaceCapabilities
```

- `physicalDevice` is the physical device that will be associated with the swapchain to be created, as
described for \texttt{vkCreateSwapchainKHR}.

- \texttt{surface} is the surface that will be associated with the swapchain.
- \texttt{pSurfaceCapabilities} is a pointer to a \texttt{VkSurfaceCapabilities2EXT} structure in which the capabilities are returned.

\texttt{vkGetPhysicalDeviceSurfaceCapabilities2EXT} behaves similarly to \texttt{vkGetPhysicalDeviceSurfaceCapabilitiesKHR}, with the ability to return extended information by adding extending structures to the \texttt{pNext} chain of its \texttt{pSurfaceCapabilities} parameter.

### Valid Usage

- VUID-vkGetPhysicalDeviceSurfaceCapabilities2EXT-surface-06523 \texttt{surface} \textbf{must} be a valid \texttt{VkSurfaceKHR} handle
- VUID-vkGetPhysicalDeviceSurfaceCapabilities2EXT-surface-06211 \texttt{surface} \textbf{must} be supported by \texttt{physicalDevice}, as reported by \texttt{vkGetPhysicalDeviceSurfaceSupportKHR} or an equivalent platform-specific mechanism

### Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceSurfaceCapabilities2EXT-physicalDevice-parameter \texttt{physicalDevice} \textbf{must} be a valid \texttt{VkPhysicalDevice} handle
- VUID-vkGetPhysicalDeviceSurfaceCapabilities2EXT-surface-parameter \texttt{surface} \textbf{must} be a valid \texttt{VkSurfaceKHR} handle
- VUID-vkGetPhysicalDeviceSurfaceCapabilities2EXT-pSurfaceCapabilities-parameter \texttt{pSurfaceCapabilities} \textbf{must} be a valid pointer to a \texttt{VkSurfaceCapabilities2EXT} structure
- VUID-vkGetPhysicalDeviceSurfaceCapabilities2EXT-commonparent Both of \texttt{physicalDevice}, and \texttt{surface} \textbf{must} have been created, allocated, or retrieved from the same \texttt{VkInstance}

### Return Codes

**Success**
- \texttt{VK_SUCCESS}

**Failure**
- \texttt{VK_ERROR_OUT_OF_HOST_MEMORY}
- \texttt{VK_ERROR_OUT_OF_DEVICE_MEMORY}
- \texttt{VK_ERROR_SURFACE_LOST_KHR}

The \texttt{VkSurfaceCapabilities2EXT} structure is defined as:

```c
// Provided by VK_EXT_display_surface_counter
```
typedef struct VkSurfaceCapabilities2EXT {
    VkStructureType sType;
    void* pNext;
    uint32_t minImageCount;
    uint32_t maxImageCount;
    VkExtent2D currentExtent;
    VkExtent2D minImageExtent;
    VkExtent2D maxImageExtent;
    uint32_t maxImageArrayLayers;
    VkSurfaceTransformFlagsKHR supportedTransforms;
    VkSurfaceTransformFlagBitsKHR currentTransform;
    VkCompositeAlphaFlagsKHR supportedCompositeAlpha;
    VkImageUsageFlags supportedUsageFlags;
    VkSurfaceCounterFlagsEXT supportedSurfaceCounters;
} VkSurfaceCapabilities2EXT;

• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **minImageCount** is the minimum number of images the specified device supports for a swapchain created for the surface, and will be at least one.

• **maxImageCount** is the maximum number of images the specified device supports for a swapchain created for the surface, and will be either 0, or greater than or equal to `minImageCount`. A value of 0 means that there is no limit on the number of images, though there may be limits related to the total amount of memory used by presentable images.

• **currentExtent** is the current width and height of the surface, or the special value (0xFFFFFFFF, 0xFFFFFFFF) indicating that the surface size will be determined by the extent of a swapchain targeting the surface.

• **minImageExtent** contains the smallest valid swapchain extent for the surface on the specified device. The width and height of the extent will each be less than or equal to the corresponding width and height of `currentExtent`, unless `currentExtent` has the special value described above.

• **maxImageExtent** contains the largest valid swapchain extent for the surface on the specified device. The width and height of the extent will each be greater than or equal to the corresponding width and height of `minImageExtent`. The width and height of the extent will each be greater than or equal to the corresponding width and height of `currentExtent`, unless `currentExtent` has the special value described above.

• **maxImageArrayLayers** is the maximum number of layers presentable images can have for a swapchain created for this device and surface, and will be at least one.

• **supportedTransforms** is a bitmask of `VkSurfaceTransformFlagBitsKHR` indicating the presentation transforms supported for the surface on the specified device. At least one bit will be set.

• **currentTransform** is `VkSurfaceTransformFlagBitsKHR` value indicating the surface's current transform relative to the presentation engine's natural orientation.

• **supportedCompositeAlpha** is a bitmask of `VkCompositeAlphaFlagBitsKHR`, representing the alpha compositing modes supported by the presentation engine for the surface on the specified
device, and at least one bit will be set. Opaque composition can be achieved in any alpha compositing mode by either using an image format that has no alpha component, or by ensuring that all pixels in the presentable images have an alpha value of 1.0.

- supportedUsageFlags is a bitmask of VkImageUsageFlagBits representing the ways the application can use the presentable images of a swapchain created with VkPresentModeKHR set to VK_PRESENT_MODE_IMMEDIATE_KHR, VK_PRESENT_MODE_MAILBOX_KHR, VK_PRESENT_MODE_FIFO_KHR or VK_PRESENT_MODE_FIFO_RELAXED_KHR for the surface on the specified device. VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT must be included in the set. Implementations may support additional usages.

- supportedSurfaceCounters is a bitmask of VkSurfaceCounterFlagBitsEXT indicating the supported surface counter types.

Valid Usage

- VUID-VkSurfaceCapabilities2EXT-supportedSurfaceCounters-01246
  supportedSurfaceCounters must not include VK_SURFACE_COUNTER_VBLANK_BIT_EXT unless the surface queried is a display surface

Valid Usage (Implicit)

- VUID-VkSurfaceCapabilities2EXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_SURFACE_CAPABILITIES_2_EXT

- VUID-VkSurfaceCapabilities2EXT-pNext-pNext
  pNext must be NULL

Bits which can be set in VkSurfaceCapabilities2EXT::supportedSurfaceCounters, indicating supported surface counter types, are:

```c
// Provided by VK_EXT_display_surface_counter
typedef enum VkSurfaceCounterFlagBitsEXT {
    VK_SURFACE_COUNTER_VBLANK_BIT_EXT = 0x00000001,
    VK_SURFACE_COUNTER_VBLANK_EXT = VK_SURFACE_COUNTER_VBLANK_BIT_EXT,
} VkSurfaceCounterFlagBitsEXT;
```

- VK_SURFACE_COUNTER_VBLANK_BIT_EXT specifies a counter incrementing once every time a vertical blanking period occurs on the display associated with the surface.

```c
// Provided by VK_EXT_display_surface_counter
typedef VkFlags VkSurfaceCounterFlagsEXT;
```

VkSurfaceCounterFlagsEXT is a bitmask type for setting a mask of zero or more VkSurfaceCounterFlagBitsEXT.
Bits which may be set in `VkSurfaceCapabilitiesKHR::supportedTransforms` indicating the presentation transforms supported for the surface on the specified device, and possible values of `VkSurfaceCapabilitiesKHR::currentTransform` indicating the surface’s current transform relative to the presentation engine’s natural orientation, are:

```c
// Provided by VK_KHR_surface
typedef enum VkSurfaceTransformFlagBitsKHR {
    VK_SURFACE_TRANSFORM_IDENTITY_BIT_KHR = 0x00000001,
    VK_SURFACE_TRANSFORM_ROTATE_90_BIT_KHR = 0x00000002,
    VK_SURFACE_TRANSFORM_ROTATE_180_BIT_KHR = 0x00000004,
    VK_SURFACE_TRANSFORM_ROTATE_270_BIT_KHR = 0x00000008,
    VK_SURFACE_TRANSFORM_HORIZONTAL_MIRROR_BIT_KHR = 0x00000010,
    VK_SURFACE_TRANSFORM_HORIZONTAL_MIRROR_ROTATE_90_BIT_KHR = 0x00000020,
    VK_SURFACE_TRANSFORM_HORIZONTAL_MIRROR_ROTATE_180_BIT_KHR = 0x00000040,
    VK_SURFACE_TRANSFORM_HORIZONTAL_MIRROR_ROTATE_270_BIT_KHR = 0x00000080,
    VK_SURFACE_TRANSFORM_INHERIT_BIT_KHR = 0x00000100,
} VkSurfaceTransformFlagBitsKHR;
```

- **VK_SURFACE_TRANSFORM_IDENTITY_BIT_KHR** specifies that image content is presented without being transformed.
- **VK_SURFACE_TRANSFORM_ROTATE_90_BIT_KHR** specifies that image content is rotated 90 degrees clockwise.
- **VK_SURFACE_TRANSFORM_ROTATE_180_BIT_KHR** specifies that image content is rotated 180 degrees clockwise.
- **VK_SURFACE_TRANSFORM_ROTATE_270_BIT_KHR** specifies that image content is rotated 270 degrees clockwise.
- **VK_SURFACE_TRANSFORM_HORIZONTAL_MIRROR_BIT_KHR** specifies that image content is mirrored horizontally.
- **VK_SURFACE_TRANSFORM_HORIZONTAL_MIRROR_ROTATE_90_BIT_KHR** specifies that image content is mirrored horizontally, then rotated 90 degrees clockwise.
- **VK_SURFACE_TRANSFORM_HORIZONTAL_MIRROR_ROTATE_180_BIT_KHR** specifies that image content is mirrored horizontally, then rotated 180 degrees clockwise.
- **VK_SURFACE_TRANSFORM_HORIZONTAL_MIRROR_ROTATE_270_BIT_KHR** specifies that image content is mirrored horizontally, then rotated 270 degrees clockwise.
- **VK_SURFACE_TRANSFORM_INHERIT_BIT_KHR** specifies that the presentation transform is not specified, and is instead determined by platform-specific considerations and mechanisms outside Vulkan.

```c
// Provided by VK_KHR_display
typedef VkFlags VkSurfaceTransformFlagsKHR;
```

`VkSurfaceTransformFlagsKHR` is a bitmask type for setting a mask of zero or more `VkSurfaceTransformFlagBitsKHR`.

The `supportedCompositeAlpha` member is of type `VkCompositeAlphaFlagBitsKHR`, containing the
following values:

```c
// Provided by VK_KHR_surface
typedef enum VkCompositeAlphaFlagBitsKHR {
    VK_COMPOSITE_ALPHA_OPAQUE_BIT_KHR = 0x00000001,
    VK_COMPOSITE_ALPHA_PRE_MULTIPLIED_BIT_KHR = 0x00000002,
    VK_COMPOSITE_ALPHA_POST_MULTIPLIED_BIT_KHR = 0x00000004,
    VK_COMPOSITE_ALPHA_INHERIT_BIT_KHR = 0x00000008,
} VkCompositeAlphaFlagBitsKHR;
```

These values are described as follows:

- **VK_COMPOSITE_ALPHA_OPAQUE_BIT_KHR**: The alpha component, if it exists, of the images is ignored in the compositing process. Instead, the image is treated as if it has a constant alpha of 1.0.

- **VK_COMPOSITE_ALPHA_PRE_MULTIPLIED_BIT_KHR**: The alpha component, if it exists, of the images is respected in the compositing process. The non-alpha components of the image are expected to already be multiplied by the alpha component by the application.

- **VK_COMPOSITE_ALPHA_POST_MULTIPLIED_BIT_KHR**: The alpha component, if it exists, of the images is respected in the compositing process. The non-alpha components of the image are not expected to already be multiplied by the alpha component by the application; instead, the compositor will multiply the non-alpha components of the image by the alpha component during compositing.

- **VK_COMPOSITE_ALPHA_INHERIT_BIT_KHR**: The way in which the presentation engine treats the alpha component in the images is unknown to the Vulkan API. Instead, the application is responsible for setting the composite alpha blending mode using native window system commands. If the application does not set the blending mode using native window system commands, then a platform-specific default will be used.

```c
// Provided by VK_KHR_surface
typedef VkFlags VkCompositeAlphaFlagsKHR;
```

**VkCompositeAlphaFlagsKHR** is a bitmask type for setting a mask of zero or more **VkCompositeAlphaFlagBitsKHR**.

### 34.5.2. Surface Format Support

To query the supported swapchain format-color space pairs for a surface, call:

```c
// Provided by VK_KHR_surface
VkResult vkGetPhysicalDeviceSurfaceFormatsKHR(
    VkPhysicalDevice physicalDevice,      // Physical device
    VkSurfaceKHR surface,                 // Surface
    uint32_t* pSurfaceFormatCount,        // Count of surface formats
    VkSurfaceFormatKHR* pSurfaceFormats   // Surface formats
);
```

- **physicalDevice** is the physical device that will be associated with the swapchain to be created, as
described for `vkCreateSwapchainKHR`.

- `surface` is the surface that will be associated with the swapchain.
- `pSurfaceFormatCount` is a pointer to an integer related to the number of format pairs available or queried, as described below.
- `pSurfaceFormats` is either `NULL` or a pointer to an array of `VkSurfaceFormatKHR` structures.

If `pSurfaceFormats` is `NULL`, then the number of format pairs supported for the given `surface` is returned in `pSurfaceFormatCount`. Otherwise, `pSurfaceFormatCount` must point to a variable set by the user to the number of elements in the `pSurfaceFormats` array, and on return the variable is overwritten with the number of structures actually written to `pSurfaceFormats`. If the value of `pSurfaceFormatCount` is less than the number of format pairs supported, at most `pSurfaceFormatCount` structures will be written, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available format pairs were returned.

The number of format pairs supported must be greater than or equal to 1. `pSurfaceFormats` must not contain an entry whose value for `format` is `VK_FORMAT_UNDEFINED`.

If `pSurfaceFormats` includes an entry whose value for `colorSpace` is `VK_COLOR_SPACE_SRGB_NONLINEAR_KHR` and whose value for `format` is a UNORM (or SRGB) format and the corresponding SRGB (or UNORM) format is a color renderable format for `VK_IMAGE_TILING_OPTIMAL`, then `pSurfaceFormats` must also contain an entry with the same value for `colorSpace` and `format` equal to the corresponding SRGB (or UNORM) format.

If the `VK_GOOGLE_surfaceless_query` extension is enabled, the values returned in `pSurfaceFormats` will be identical for every valid surface created on this physical device, and so `surface` can be `VK_NULL_HANDLE`.

---

**Valid Usage**

- **VUID-vkGetPhysicalDeviceSurfaceFormatsKHR-surface-06524**
  If the `VK_GOOGLE_surfaceless_query` extension is not enabled, `surface` must be a valid `VkSurfaceKHR` handle

- **VUID-vkGetPhysicalDeviceSurfaceFormatsKHR-surface-06525**
  If `surface` is not `VK_NULL_HANDLE`, it must be supported by `physicalDevice`, as reported by `vkGetPhysicalDeviceSurfaceSupportKHR` or an equivalent platform-specific mechanism

---

**Valid Usage (Implicit)**

- **VUID-vkGetPhysicalDeviceSurfaceFormatsKHR-physicalDevice-parameter**
  `physicalDevice` must be a valid `VkPhysicalDevice` handle

- **VUID-vkGetPhysicalDeviceSurfaceFormatsKHR-surface-parameter**
  If `surface` is not `VK_NULL_HANDLE`, `surface` must be a valid `VkSurfaceKHR` handle

- **VUID-vkGetPhysicalDeviceSurfaceFormatsKHR-pSurfaceFormatCount-parameter**
  `pSurfaceFormatCount` must be a valid pointer to a `uint32_t` value
If the value referenced by `pSurfaceFormatCount` is not 0, and `pSurfaceFormats` is not NULL, `pSurfaceFormats` must be a valid pointer to an array of `pSurfaceFormatCount` `VkSurfaceFormatKHR` structures.

Both of `physicalDevice`, and `surface` that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same `VkInstance`.

**Return Codes**

**Success**
- `VK_SUCCESS`
- `VK_INCOMPLETE`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_SURFACE_LOST_KHR`

The `VkSurfaceFormatKHR` structure is defined as:

```c
typedef struct VkSurfaceFormatKHR {
    VkFormat format;
    VkColorSpaceKHR colorSpace;
} VkSurfaceFormatKHR;
```

- `format` is a `VkFormat` that is compatible with the specified surface.
- `colorSpace` is a presentation `VkColorSpaceKHR` that is compatible with the surface.

To query the supported swapchain format tuples for a surface, call:

```c
VKResult vkGetPhysicalDeviceSurfaceFormats2KHR(
    VkPhysicalDevice physicalDevice,    
    const VkPhysicalDeviceSurfaceInfo2KHR* pSurfaceInfo,    
    uint32_t* pSurfaceFormatCount,    
    VkSurfaceFormat2KHR* pSurfaceFormats);
```

- `physicalDevice` is the physical device that will be associated with the swapchain to be created, as described for `vkCreateSwapchainKHR`.
- `pSurfaceInfo` is a pointer to a `VkPhysicalDeviceSurfaceInfo2KHR` structure describing the surface and other fixed parameters that would be consumed by `vkCreateSwapchainKHR`. 
- \texttt{pSurfaceFormatCount} is a pointer to an integer related to the number of format tuples available or queried, as described below.
- \texttt{pSurfaceFormats} is either \texttt{NULL} or a pointer to an array of \texttt{VkSurfaceFormat2KHR} structures.

\texttt{vkGetPhysicalDeviceSurfaceFormats2KHR} behaves similarly to \texttt{vkGetPhysicalDeviceSurfaceFormatsKHR}, with the ability to be extended via \texttt{pNext} chains.

If \texttt{pSurfaceFormats} is \texttt{NULL}, then the number of format tuples supported for the given \texttt{surface} is returned in \texttt{pSurfaceFormatCount}. Otherwise, \texttt{pSurfaceFormatCount} must point to a variable set by the user to the number of elements in the \texttt{pSurfaceFormats} array, and on return the variable is overwritten with the number of structures actually written to \texttt{pSurfaceFormats}. If the value of \texttt{pSurfaceFormatCount} is less than the number of format tuples supported, at most \texttt{pSurfaceFormatCount} structures will be written, and \texttt{VK_INCOMPLETE} will be returned instead of \texttt{VK_SUCCESS}, to indicate that not all the available values were returned.

### Valid Usage

- VUID-vkGetPhysicalDeviceSurfaceFormats2KHR-pSurfaceInfo-06521
  If the \texttt{VK_GOOGLE_surfaceless_query} extension is not enabled, \texttt{pSurfaceInfo->surface} must be a valid \texttt{VkSurfaceKHR} handle

- VUID-vkGetPhysicalDeviceSurfaceFormats2KHR-pSurfaceInfo-06522
  If \texttt{pSurfaceInfo->surface} is not \texttt{VK_NULL_HANDLE}, it must be supported by \texttt{physicalDevice}, as reported by \texttt{vkGetPhysicalDeviceSurfaceSupportKHR} or an equivalent platform-specific mechanism

### Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceSurfaceFormats2KHR-physicalDevice-parameter
  \texttt{physicalDevice} must be a valid \texttt{VkPhysicalDevice} handle

- VUID-vkGetPhysicalDeviceSurfaceFormats2KHR-pSurfaceInfo-parameter
  \texttt{pSurfaceInfo} must be a valid pointer to a valid \texttt{VkPhysicalDeviceSurfaceInfo2KHR} structure

- VUID-vkGetPhysicalDeviceSurfaceFormats2KHR-pSurfaceFormatCount-parameter
  \texttt{pSurfaceFormatCount} must be a valid pointer to a \texttt{uint32_t} value

- VUID-vkGetPhysicalDeviceSurfaceFormats2KHR-pSurfaceFormats-parameter
  If the value referenced by \texttt{pSurfaceFormatCount} is not \texttt{0}, and \texttt{pSurfaceFormats} is not \texttt{NULL}, \texttt{pSurfaceFormats} must be a valid pointer to an array of \texttt{pSurfaceFormatCount} \texttt{VkSurfaceFormat2KHR} structures

### Return Codes

**Success**
- \texttt{VK_SUCCESS}
The `VkSurfaceFormat2KHR` structure is defined as:

```c
// Provided by VK_KHR_get_surface_capabilities2
typedef struct VkSurfaceFormat2KHR {
    VkStructureType sType;
    void* pNext;
    VkSurfaceFormatKHR surfaceFormat;
} VkSurfaceFormat2KHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `surfaceFormat` is a `VkSurfaceFormatKHR` structure describing a format-color space pair that is compatible with the specified surface.

If the `imageCompressionControlSwapchain` feature is supported and a `VkImageCompressionPropertiesEXT` structure is included in the `pNext` chain of this structure, then it will be filled with the compression properties that are supported for the `surfaceFormat`.

### Valid Usage

- VUID-VkSurfaceFormat2KHR-pNext-06750
  If the `imageCompressionControlSwapchain` feature is not enabled, the `pNext` chain must not include an `VkImageCompressionPropertiesEXT` structure

### Valid Usage (Implicit)

- VUID-VkSurfaceFormat2KHR-sType-sType
  The `sType` value of each struct in the `pNext` chain must be unique

While the `format` of a presentable image refers to the encoding of each pixel, the `colorSpace` determines how the presentation engine interprets the pixel values. A color space in this document refers to a specific color space (defined by the chromaticities of its primaries and a white point in...
CIE Lab), and a transfer function that is applied before storing or transmitting color data in the
given color space.

Possible values of `VkSurfaceFormatKHR::colorSpace`, specifying supported color spaces of a
presentation engine, are:

```c
// Provided by VK_KHR_surface
typedef enum VkColorSpaceKHR {
  VK_COLOR_SPACE_SRGB_NONLINEAR_KHR = 0,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_DISPLAY_P3_NONLINEAR_EXT = 1000104001,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_EXTENDED_SRGB_LINEAR_EXT = 1000104002,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_DISPLAY_P3_LINEAR_EXT = 1000104003,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_DCI_P3_LINEAR_EXT = 1000104004,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_BT709_LINEAR_EXT = 1000104005,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_BT709_NONLINEAR_EXT = 1000104006,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_BT2020_LINEAR_EXT = 1000104007,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_HDR10_ST2084_EXT = 1000104008,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_DOLBYVISION_EXT = 1000104009,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_HDR10_HLG_EXT = 1000104010,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_ADOBERGB_LINEAR_EXT = 1000104011,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_ADOBERGB_NONLINEAR_EXT = 1000104012,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_PASS_THROUGH_EXT = 1000104013,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_EXTENDED_SRGB_NONLINEAR_EXT = 1000104014,
  // Provided by VK_AMD_display_native_hdr
  VK_COLOR_SPACE_DISPLAY_NATIVE_AMD = 1000213000,
  VK_COLORSPACE_SRGB_NONLINEAR_KHR = VK_COLOR_SPACE_SRGB_NONLINEAR_KHR,
  // Provided by VK_EXT_swapchain_colorspace
  VK_COLOR_SPACE_DCI_P3_LINEAR_EXT = VK_COLOR_SPACE_DISPLAY_P3_LINEAR_EXT,
} VkColorSpaceKHR;
```

- `VK_COLOR_SPACE_SRGB_NONLINEAR_KHR` specifies support for the sRGB color space.
- `VK_COLOR_SPACE_DISPLAY_P3_NONLINEAR_EXT` specifies support for the Display-P3 color space to be
displayed using an sRGB-like EOTF (defined below).
- `VK_COLOR_SPACE_EXTENDED_SRGB_LINEAR_EXT` specifies support for the extended sRGB color space to be
displayed using a linear EOTF.
• **VK_COLOR_SPACE_EXTENDED_SRGB_NONLINEAR_EXT** specifies support for the extended sRGB color space to be displayed using an sRGB EOTF.

• **VK_COLOR_SPACE_DISPLAY_P3_LINEAR_EXT** specifies support for the Display-P3 color space to be displayed using a linear EOTF.

• **VK_COLOR_SPACE_DCI_P3_NONLINEAR_EXT** specifies support for the DCI-P3 color space to be displayed using the DCI-P3 EOTF. Note that values in such an image are interpreted as XYZ encoded color data by the presentation engine.

• **VK_COLOR_SPACE_BT709_LINEAR_EXT** specifies support for the BT709 color space to be displayed using a linear EOTF.

• **VK_COLOR_SPACE_BT709_NONLINEAR_EXT** specifies support for the BT709 color space to be displayed using the SMPTE 170M EOTF.

• **VK_COLOR_SPACE_BT2020_LINEAR_EXT** specifies support for the BT2020 color space to be displayed using a linear EOTF.

• **VK_COLOR_SPACE_HDR10_ST2084_EXT** specifies support for the HDR10 (BT2020 color) space to be displayed using the SMPTE ST2084 Perceptual Quantizer (PQ) EOTF.

• **VK_COLOR_SPACE_DOLBYVISION_EXT** specifies support for the Dolby Vision (BT2020 color space), proprietary encoding, to be displayed using the SMPTE ST2084 EOTF.

• **VK_COLOR_SPACE_HDR10_HLG_EXT** specifies support for the HDR10 (BT2020 color space) to be displayed using the Hybrid Log Gamma (HLG) EOTF.

• **VK_COLOR_SPACE_ADOBERGB_LINEAR_EXT** specifies support for the AdobeRGB color space to be displayed using a linear EOTF.

• **VK_COLOR_SPACE_ADOBERGB_NONLINEAR_EXT** specifies support for the AdobeRGB color space to be displayed using the Gamma 2.2 EOTF.

• **VK_COLOR_SPACE_PASS_THROUGH_EXT** specifies that color components are used “as is”. This is intended to allow applications to supply data for color spaces not described here.

• **VK_COLOR_SPACE_DISPLAY_NATIVE_AMD** specifies support for the display’s native color space. This matches the color space expectations of AMD’s FreeSync2 standard, for displays supporting it.

---

**Note**

In the initial release of the [VK_KHR_surface](https://www.khronos.org/registry/vulkan/specs/1.2-extensions/man/html/vk_KHR_surface.html) and [VK_KHR_swapchain](https://www.khronos.org/registry/vulkan/specs/1.2-extensions/man/html/vk_KHR_swapchain.html) extensions, the token **VK_COLORSPACE_SRGB_NONLINEAR_KHR** was used. Starting in the 2016-05-13 updates to the extension branches, matching release 1.0.13 of the core API specification, **VK_COLOR_SPACE_SRGB_NONLINEAR_KHR** is used instead for consistency with Vulkan naming rules. The older enum is still available for backwards compatibility.

---

**Note**

In older versions of this extension [VK_COLOR_SPACE_DISPLAY_P3_LINEAR_EXT](https://www.khronos.org/registry/vulkan/specs/1.2-extensions/man/html/vk_KHR_swapchain.html) was misnamed **VK_COLOR_SPACE_DCI_P3_LINEAR_EXT**. This has been updated to indicate that it uses RGB color encoding, not XYZ. The old name is deprecated but is maintained for backwards compatibility.
Note
For a traditional “Linear” or non-gamma transfer function color space use
\texttt{VK\_COLOR\_SPACE\_PASS\_THROUGH\_EXT}.

The color components of non-linear color space swapchain images \textbf{must} have had the appropriate transfer function applied. The color space selected for the swapchain image will not affect the processing of data written into the image by the implementation. Vulkan requires that all implementations support the sRGB transfer function by use of an SRGB pixel format. Other transfer functions, such as SMPTE 170M or SMPTE2084, can be performed by the application shader. This extension defines enums for \texttt{VkColorSpaceKHR} that correspond to the following color spaces:

\textbf{Table 49. Color Spaces and Attributes}

<table>
<thead>
<tr>
<th>Name</th>
<th>Red Primary</th>
<th>Green Primary</th>
<th>Blue Primary</th>
<th>White-point</th>
<th>Transfer function</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCI-P3</td>
<td>1.000, 0.000</td>
<td>0.000, 1.000</td>
<td>0.000, 0.000</td>
<td>0.3333, 0.3333</td>
<td>DCI P3</td>
</tr>
<tr>
<td>Display-P3</td>
<td>0.680, 0.320</td>
<td>0.265, 0.690</td>
<td>0.150, 0.060</td>
<td>0.3127, 0.3290 (D65)</td>
<td>Display-P3</td>
</tr>
<tr>
<td>BT709</td>
<td>0.640, 0.330</td>
<td>0.300, 0.600</td>
<td>0.150, 0.060</td>
<td>0.3127, 0.3290 (D65)</td>
<td>ITU (SMPTE 170M)</td>
</tr>
<tr>
<td>sRGB</td>
<td>0.640, 0.330</td>
<td>0.300, 0.600</td>
<td>0.150, 0.060</td>
<td>0.3127, 0.3290 (D65)</td>
<td>sRGB</td>
</tr>
<tr>
<td>extended sRGB</td>
<td>0.640, 0.330</td>
<td>0.300, 0.600</td>
<td>0.150, 0.060</td>
<td>0.3127, 0.3290 (D65)</td>
<td>extended sRGB</td>
</tr>
<tr>
<td>HDR10_ST2084</td>
<td>0.708, 0.292</td>
<td>0.170, 0.797</td>
<td>0.131, 0.046</td>
<td>0.3127, 0.3290 (D65)</td>
<td>ST2084 PQ</td>
</tr>
<tr>
<td>DOLBYVISION</td>
<td>0.708, 0.292</td>
<td>0.170, 0.797</td>
<td>0.131, 0.046</td>
<td>0.3127, 0.3290 (D65)</td>
<td>ST2084 PQ</td>
</tr>
<tr>
<td>HDR10_HLG</td>
<td>0.708, 0.292</td>
<td>0.170, 0.797</td>
<td>0.131, 0.046</td>
<td>0.3127, 0.3290 (D65)</td>
<td>HLG</td>
</tr>
<tr>
<td>AdobeRGB</td>
<td>0.640, 0.330</td>
<td>0.210, 0.710</td>
<td>0.150, 0.060</td>
<td>0.3127, 0.3290 (D65)</td>
<td>AdobeRGB</td>
</tr>
</tbody>
</table>

The transfer functions are described in the “Transfer Functions” chapter of the Khronos Data Format Specification.

Except Display-P3 OETF, which is:

\[
E = \begin{cases} 
1.055 \times L^{0.4} - 0.055 & \text{for } 0.0030186 \leq L \leq 1 \\
12.92 \times L & \text{for } 0 \leq L < 0.0030186 
\end{cases}
\]

where L is the linear value of a color component and E is the encoded value (as stored in the image in memory).
Note
For most uses, the sRGB OETF is equivalent.

34.5.3. Surface Presentation Mode Support

To query the supported presentation modes for a surface, call:

```c
// Provided by VK_KHR_surface
VkResult vkGetPhysicalDeviceSurfacePresentModesKHR(
    VkPhysicalDevice physicalDevice,
    VkSurfaceKHR surface,
    uint32_t* pPresentModeCount,
    VkPresentModeKHR* pPresentModes);
```

- `physicalDevice` is the physical device that will be associated with the swapchain to be created, as described for `vkCreateSwapchainKHR`.
- `surface` is the surface that will be associated with the swapchain.
- `pPresentModeCount` is a pointer to an integer related to the number of presentation modes available or queried, as described below.
- `pPresentModes` is either `NULL` or a pointer to an array of `VkPresentModeKHR` values, indicating the supported presentation modes.

If `pPresentModes` is `NULL`, then the number of presentation modes supported for the given `surface` is returned in `pPresentModeCount`. Otherwise, `pPresentModeCount` must point to a variable set by the user to the number of elements in the `pPresentModes` array, and on return the variable is overwritten with the number of values actually written to `pPresent Modes`. If the value of `pPresentModeCount` is less than the number of presentation modes supported, at most `pPresentModeCount` values will be written, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available modes were returned.

If the `VK_GOOGLE_surfaceless_query` extension is enabled and `surface` is `VK_NULL_HANDLE`, the values returned in `pPresentModes` will only indicate support for `VK_PRESENT_MODE_FIFO_KHR`, `VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR`, and `VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR`. To query support for any other present mode, a valid handle must be provided in `surface`.

Valid Usage

- VUID-vkGetPhysicalDeviceSurfacePresentModesKHR-surface-06524
  If the `VK_GOOGLE_surfaceless_query` extension is not enabled, `surface` must be a valid `VkSurfaceKHR` handle

- VUID-vkGetPhysicalDeviceSurfacePresentModesKHR-surface-06525
  If `surface` is not `VK_NULL_HANDLE`, it must be supported by `physicalDevice`, as reported by `vkGetPhysicalDeviceSurfaceSupportKHR` or an equivalent platform-specific mechanism
Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceSurfacePresentModesKHR-physicalDevice-parameter
  physicalDevice must be a valid VkPhysicalDevice handle

- VUID-vkGetPhysicalDeviceSurfacePresentModesKHR-surface-parameter
  If surface is not VK_NULL_HANDLE, surface must be a valid VkSurfaceKHR handle

- VUID-vkGetPhysicalDeviceSurfacePresentModesKHR-pPresentModeCount-parameter
  pPresentModeCount must be a valid pointer to a uint32_t value

- VUID-vkGetPhysicalDeviceSurfacePresentModesKHR-pPresentModes-parameter
  If the value referenced by pPresentModeCount is not 0, and pPresentModes is not NULL,
  pPresentModes must be a valid pointer to an array of pPresentModeCount VkPresentModeKHR values

- VUID-vkGetPhysicalDeviceSurfacePresentModesKHR-commonparent
  Both of physicalDevice, and surface that are valid handles of non-ignored parameters
  must have been created, allocated, or retrieved from the same VkInstance

Return Codes

Success

- VK_SUCCESS
- VK_INCOMPLETE

Failure

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_SURFACE_LOST_KHR

Alternatively, to query the supported presentation modes for a surface combined with select other
fixed swapchain creation parameters, call:

```c
// Provided by VK_EXT_full_screen_exclusive
VkResult vkGetPhysicalDeviceSurfacePresentModes2EXT(
    VkPhysicalDevice physicalDevice,
    const VkPhysicalDeviceSurfaceInfo2KHR* pSurfaceInfo,
    uint32_t* pPresentModeCount,
    VkPresentModeKHR* pPresentModes);
```

- physicalDevice is the physical device that will be associated with the swapchain to be created, as
described for vkCreateSwapchainKHR.

- pSurfaceInfo is a pointer to a VkPhysicalDeviceSurfaceInfo2KHR structure describing the
  surface and other fixed parameters that would be consumed by vkCreateSwapchainKHR.

- pPresentModeCount is a pointer to an integer related to the number of presentation modes
available or queried, as described below.

- **pPresentModes** is either **NULL** or a pointer to an array of **VkPresentModeKHR** values, indicating the supported presentation modes.

vkGetPhysicalDeviceSurfacePresentModes2EXT behaves similarly to vkGetPhysicalDeviceSurfacePresentModesKHR, with the ability to specify extended inputs via chained input structures.

**Valid Usage**

- **VUID-vkGetPhysicalDeviceSurfacePresentModes2EXT-pSurfaceInfo-06521**
  If the **VK_GOOGLE_surfaceless_query** extension is not enabled, **pSurfaceInfo->surface** must be a valid **VkSurfaceKHR** handle

- **VUID-vkGetPhysicalDeviceSurfacePresentModes2EXT-pSurfaceInfo-06522**
  If **pSurfaceInfo->surface** is not **VK_NULL_HANDLE**, it must be supported by **physicalDevice**, as reported by vkGetPhysicalDeviceSurfaceSupportKHR or an equivalent platform-specific mechanism

**Valid Usage (Implicit)**

- **VUID-vkGetPhysicalDeviceSurfacePresentModes2EXT-physicalDevice-parameter**
  **physicalDevice** must be a valid **VkPhysicalDevice** handle

- **VUID-vkGetPhysicalDeviceSurfacePresentModes2EXT-pSurfaceInfo-parameter**
  **pSurfaceInfo** must be a valid pointer to a valid **VkPhysicalDeviceSurfaceInfo2KHR** structure

- **VUID-vkGetPhysicalDeviceSurfacePresentModes2EXT-pPresentModeCount-parameter**
  **pPresentModeCount** must be a valid pointer to a **uint32_t** value

- **VUID-vkGetPhysicalDeviceSurfacePresentModes2EXT-pPresentModes-parameter**
  If the value referenced by **pPresentModeCount** is not 0, and **pPresentModes** is not **NULL**, **pPresentModes** must be a valid pointer to an array of **pPresentModeCount** **VkPresentModeKHR** values

**Return Codes**

**Success**

- **VK_SUCCESS**
- **VK_INCOMPLETE**

**Failure**

- **VK_ERROR_OUT_OF_HOST_MEMORY**
- **VK_ERROR_OUT_OF_DEVICE_MEMORY**
- **VK_ERROR_SURFACE_LOST_KHR**
Possible values of elements of the `vkGetPhysicalDeviceSurfacePresentModesKHR::pPresentModes` array, indicating the supported presentation modes for a surface, are:

```c
// Provided by VK_KHR_surface
typedef enum VkPresentModeKHR {
    VK_PRESENT_MODE_IMMEDIATE_KHR = 0,
    VK_PRESENT_MODE_MAILBOX_KHR = 1,
    VK_PRESENT_MODE_FIFO_KHR = 2,
    VK_PRESENT_MODE_FIFO_RELAXED_KHR = 3,
    // Provided by VK_KHR_shared_presentable_image
    VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR = 1000111000,
    // Provided by VK_KHR_shared_presentable_image
    VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR = 1000111001,
} VkPresentModeKHR;
```

- **VK_PRESENT_MODE_IMMEDIATE_KHR** specifies that the presentation engine does not wait for a vertical blanking period to update the current image, meaning this mode may result in visible tearing. No internal queuing of presentation requests is needed, as the requests are applied immediately.

- **VK_PRESENT_MODE_MAILBOX_KHR** specifies that the presentation engine waits for the next vertical blanking period to update the current image. Tearing cannot be observed. An internal single-entry queue is used to hold pending presentation requests. If the queue is full when a new presentation request is received, the new request replaces the existing entry, and any images associated with the prior entry become available for reuse by the application. One request is removed from the queue and processed during each vertical blanking period in which the queue is non-empty.

- **VK_PRESENT_MODE_FIFO_KHR** specifies that the presentation engine waits for the next vertical blanking period to update the current image. Tearing cannot be observed. An internal queue is used to hold pending presentation requests. New requests are appended to the end of the queue, and one request is removed from the beginning of the queue and processed during each vertical blanking period in which the queue is non-empty. This is the only value of `presentMode` that is required to be supported.

- **VK_PRESENT_MODE_FIFO_RELAXED_KHR** specifies that the presentation engine generally waits for the next vertical blanking period to update the current image. If a vertical blanking period has already passed since the last update of the current image then the presentation engine does not wait for another vertical blanking period for the update, meaning this mode may result in visible tearing in this case. This mode is useful for reducing visual stutter with an application that will mostly present a new image before the next vertical blanking period, but may occasionally be late, and present a new image just after the next vertical blanking period. An internal queue is used to hold pending presentation requests. New requests are appended to the end of the queue, and one request is removed from the beginning of the queue and processed during or after each vertical blanking period in which the queue is non-empty.

- **VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR** specifies that the presentation engine and application have concurrent access to a single image, which is referred to as a shared presentable image. The presentation engine is only required to update the current image after a new presentation request is received. Therefore the application must make a presentation
request whenever an update is required. However, the presentation engine may update the current image at any point, meaning this mode may result in visible tearing.

- **VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR** specifies that the presentation engine and application have concurrent access to a single image, which is referred to as a *shared presentable image*. The presentation engine periodically updates the current image on its regular refresh cycle. The application is only required to make one initial presentation request, after which the presentation engine must update the current image without any need for further presentation requests. The application can indicate the image contents have been updated by making a presentation request, but this does not guarantee the timing of when it will be updated. This mode may result in visible tearing if rendering to the image is not timed correctly.

The supported VkImageUsageFlagBits of the presentable images of a swapchain created for a surface may differ depending on the presentation mode, and can be determined as per the table below:

<table>
<thead>
<tr>
<th>Presentation mode</th>
<th>Image usage flags</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_PRESENT_MODE_IMMEDIATE_KHR</td>
<td>VkSurfaceCapabilitiesKHR::supportedUsageFlags</td>
</tr>
<tr>
<td>VK_PRESENT_MODE_MAILBOX_KHR</td>
<td>VkSurfaceCapabilitiesKHR::supportedUsageFlags</td>
</tr>
<tr>
<td>VK_PRESENT_MODE_FIFO_KHR</td>
<td>VkSurfaceCapabilitiesKHR::supportedUsageFlags</td>
</tr>
<tr>
<td>VK_PRESENT_MODE_FIFO_RELAXED_KHR</td>
<td>VkSurfaceCapabilitiesKHR::supportedUsageFlags</td>
</tr>
<tr>
<td>VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR</td>
<td>VkSharedPresentSurfaceCapabilitiesKHR::sharedPresentSupportedUsageFlags</td>
</tr>
<tr>
<td>VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR</td>
<td>VkSharedPresentSurfaceCapabilitiesKHR::sharedPresentSupportedUsageFlags</td>
</tr>
</tbody>
</table>

**Note**

For reference, the mode indicated by **VK_PRESENT_MODE_FIFO_KHR** is equivalent to the behavior of {wgl|glX|egl}SwapBuffers with a swap interval of 1, while the mode indicated by **VK_PRESENT_MODE_FIFO_RELAXED_KHR** is equivalent to the behavior of {wgl|glX}SwapBuffers with a swap interval of -1 (from the {WGL|GLX}_EXT_swap_control_tear extensions).

### 34.6. Full Screen Exclusive Control

Swapchains created with **fullScreenExclusive** set to **VK_FULL_SCREEN_EXCLUSIVE_APPLICATION_CONTROLLED_EXT** must acquire and release exclusive full-screen access explicitly, using the following commands.

To acquire exclusive full-screen access for a swapchain, call:

```c
// Provided by VK_EXT_full_screen-exclusive
VkResult vkAcquireFullScreenExclusiveModeEXT(
```
VkDevice device, VkSwapchainKHR swapchain);

- *device* is the device associated with *swapchain*.
- *swapchain* is the swapchain to acquire exclusive full-screen access for.

### Valid Usage

- VUID-vkAcquireFullScreenExclusiveModeEXT-swapchain-02674
  - *swapchain* must not be in the retired state
- VUID-vkAcquireFullScreenExclusiveModeEXT-swapchain-02675
  - *swapchain* must be a swapchain created with a *VkSurfaceFullScreenExclusiveInfoEXT* structure, with *fullScreenExclusive* set to *VK_FULL_SCREEN_EXCLUSIVE_APPLICATION_CONTROLLED_EXT*
- VUID-vkAcquireFullScreenExclusiveModeEXT-swapchain-02676
  - *swapchain* must not currently have exclusive full-screen access

A return value of *VK_SUCCESS* indicates that the *swapchain* successfully acquired exclusive full-screen access. The swapchain will retain this exclusivity until either the application releases exclusive full-screen access with *vkReleaseFullScreenExclusiveModeEXT*, destroys the swapchain, or if any of the swapchain commands return *VK_ERROR_FULL_SCREEN_EXCLUSIVE_MODE_LOST_EXT* indicating that the mode was lost because of platform-specific changes.

If the swapchain was unable to acquire exclusive full-screen access to the display then *VK_ERROR_INITIALIZATION_FAILED* is returned. An application can attempt to acquire exclusive full-screen access again for the same swapchain even if this command fails, or if *VK_ERROR_FULL_SCREEN_EXCLUSIVE_MODE_LOST_EXT* has been returned by a swapchain command.

### Valid Usage (Implicit)

- VUID-vkAcquireFullScreenExclusiveModeEXT-device-parameter
  - *device* must be a valid *VkDevice* handle
- VUID-vkAcquireFullScreenExclusiveModeEXT-swapchain-parameter
  - *swapchain* must be a valid *VkSwapchainKHR* handle
- VUID-vkAcquireFullScreenExclusiveModeEXT-swapchain-parent
  - *swapchain* must have been created, allocated, or retrieved from *device*

### Return Codes

**Success**
- *VK_SUCCESS*

**Failure**
- *VK_ERROR_OUT_OF_HOST_MEMORY*
To release exclusive full-screen access from a swapchain, call:

```c
// Provided by VK_EXT_full_screen_exclusive
VkResult vkReleaseFullScreenExclusiveModeEXT(
    VkDevice device,
    VkSwapchainKHR swapchain);
```

- `device` is the device associated with `swapchain`.
- `swapchain` is the swapchain to release exclusive full-screen access from.

**Note**
Applications will not be able to present to `swapchain` after this call until exclusive full-screen access is reacquired. This is usually useful to handle when an application is minimised or otherwise intends to stop presenting for a time.

**Valid Usage**

- VUID-vkReleaseFullScreenExclusiveModeEXT-swapchain-02677 `swapchain` must not be in the retired state
- VUID-vkReleaseFullScreenExclusiveModeEXT-swapchain-02678 `swapchain` must be a swapchain created with a `VkSurfaceFullScreenExclusiveInfoEXT` structure, with `fullScreenExclusive` set to `VK_FULL_SCREEN_EXCLUSIVE_APPLICATION_CONTROLLED_EXT`

### 34.7. Device Group Queries

A logical device that represents multiple physical devices may support presenting from images on more than one physical device, or combining images from multiple physical devices.

To query these capabilities, call:

```c
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with VK_KHR_surface
VkResult vkGetDeviceGroupPresentCapabilitiesKHR(
    VkDevice device,
    VkDeviceGroupPresentCapabilitiesKHR* pDeviceGroupPresentCapabilities);
```

- `device` is the logical device.
• `pDeviceGroupPresentCapabilities` is a pointer to a `VkDeviceGroupPresentCapabilitiesKHR` structure in which the device's capabilities are returned.

### Valid Usage (Implicit)

- `VUID-vkGetDeviceGroupPresentCapabilitiesKHR-device-parameter`
  - `device` must be a valid `VkDevice` handle
- `VUID-vkGetDeviceGroupPresentCapabilitiesKHR-pDeviceGroupPresentCapabilities-parameter`
  - `pDeviceGroupPresentCapabilities` must be a valid pointer to a `VkDeviceGroupPresentCapabilitiesKHR` structure

### Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

The `VkDeviceGroupPresentCapabilitiesKHR` structure is defined as:

```c
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with VK_KHR_surface
typedef struct VkDeviceGroupPresentCapabilitiesKHR {
  VkStructureType sType;
  void* pNext;
  uint32_t presentMask[VK_MAX_DEVICE_GROUP_SIZE];
  VkDeviceGroupPresentModeFlagsKHR modes;
} VkDeviceGroupPresentCapabilitiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `presentMask` is an array of `VK_MAX_DEVICE_GROUP_SIZE` `uint32_t` masks, where the mask at element `i` is non-zero if physical device `i` has a presentation engine, and where bit `j` is set in element `i` if physical device `i` can present swapchain images from physical device `j`. If element `i` is non-zero, then bit `i` must be set.
- `modes` is a bitmask of `VkDeviceGroupPresentModeFlagBitsKHR` indicating which device group presentation modes are supported.

`modes` always has `VK_DEVICE_GROUP_PRESENT_MODE_LOCAL_BIT_KHR` set.

The present mode flags are also used when presenting an image, in
VkDeviceGroupPresentInfoKHR::mode.

If a device group only includes a single physical device, then modes must equal VK_DEVICE_GROUP_PRESENT_MODE_LOCAL_BIT_KHR.

Valid Usage (Implicit)

- VUID-VkDeviceGroupPresentCapabilitiesKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_DEVICE_GROUP_PRESENTCapabilities_KHR
- VUID-VkDeviceGroupPresentCapabilitiesKHR-pNext-pNext
  pNext must be NULL

Bits which may be set in VkDeviceGroupPresentCapabilitiesKHR::modes, indicating which device group presentation modes are supported, are:

```c
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with VK_KHR_surface
typedef enum VkDeviceGroupPresentModeFlagBitsKHR {
  VK_DEVICE_GROUP_PRESENT_MODE_LOCAL_BIT_KHR = 0x00000001,
  VK_DEVICE_GROUP_PRESENT_MODE_REMOTE_BIT_KHR = 0x00000002,
  VKDEVICE_GROUP_PRESENT_MODE_SUM_BIT_KHR = 0x00000004,
  VKDEVICE_GROUP_PRESENT_MODE_LOCAL_MULTI_DEVICE_BIT_KHR = 0x00000008,
} VkDeviceGroupPresentModeFlagBitsKHR;
```

- VK_DEVICE_GROUP_PRESENT_MODE_LOCAL_BIT_KHR specifies that any physical device with a presentation engine can present its own swapchain images.
- VK_DEVICE_GROUP_PRESENT_MODE_REMOTE_BIT_KHR specifies that any physical device with a presentation engine can present swapchain images from any physical device in its presentMask.
- VKDEVICE_GROUP_PRESENT_MODE_SUM_BIT_KHR specifies that any physical device with a presentation engine can present the sum of swapchain images from any physical devices in its presentMask.
- VKDEVICE_GROUP_PRESENT_MODE_LOCAL_MULTI_DEVICE_BIT_KHR specifies that multiple physical devices with a presentation engine can each present their own swapchain images.

```c
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with VK_KHR_surface
typedef VkFlags VkDeviceGroupPresentModeFlagsKHR;
```

VkDeviceGroupPresentModeFlagsKHR is a bitmask type for setting a mask of zero or more VkDeviceGroupPresentModeFlagBitsKHR.

Some surfaces may not be capable of using all the device group present modes.

To query the supported device group present modes for a particular surface, call:
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with VK_KHR_surface

VkResult vkGetDeviceGroupSurfacePresentModesKHR(
    VkDevice device,
    VkSurfaceKHR surface,
    VkDeviceGroupPresentModeFlagsKHR* pModes);

- **device** is the logical device.
- **surface** is the surface.
- **pModes** is a pointer to a `VkDeviceGroupPresentModeFlagsKHR` in which the supported device group present modes for the surface are returned.

The modes returned by this command are not invariant, and **may** change in response to the surface being moved, resized, or occluded. These modes **must** be a subset of the modes returned by `vkGetDeviceGroupPresentCapabilitiesKHR`.

**Valid Usage**

- VUID-vkGetDeviceGroupSurfacePresentModesKHR-surface-06212
  - **surface** must be supported by all physical devices associated with **device**, as reported by `vkGetPhysicalDeviceSurfaceSupportKHR` or an equivalent platform-specific mechanism

**Valid Usage (Implicit)**

- VUID-vkGetDeviceGroupSurfacePresentModesKHR-device-parameter
  - **device** must be a valid `VkDevice` handle
- VUID-vkGetDeviceGroupSurfacePresentModesKHR-surface-parameter
  - **surface** must be a valid `VkSurfaceKHR` handle
- VUID-vkGetDeviceGroupSurfacePresentModesKHR-pModes-parameter
  - **pModes** must be a valid pointer to a `VkDeviceGroupPresentModeFlagsKHR` value
- VUID-vkGetDeviceGroupSurfacePresentModesKHR-commonparent
  - Both of **device**, and **surface** must have been created, allocated, or retrieved from the same `VkInstance`

**Host Synchronization**

- Host access to **surface** must be externally synchronized
Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_SURFACE_LOST_KHR

Alternatively, to query the supported device group presentation modes for a surface combined with select other fixed swapchain creation parameters, call:

```c
// Provided by VK_VERSION_1_1 with VK_EXT_full_screen_exclusive, VK_KHR_device_group
// with VK_EXT_full_screen_exclusive
VkResult vkGetDeviceGroupSurfacePresentModes2EXT(
    VkDevice device,
    const VkPhysicalDeviceSurfaceInfo2KHR* pSurfaceInfo,
    VkDeviceGroupPresentModeFlagsKHR* pModes);
```

- `device` is the logical device.
- `pSurfaceInfo` is a pointer to a `VkPhysicalDeviceSurfaceInfo2KHR` structure describing the surface and other fixed parameters that would be consumed by `vkCreateSwapchainKHR`.
- `pModes` is a pointer to a `VkDeviceGroupPresentModeFlagsKHR` in which the supported device group present modes for the surface are returned.

`vkGetDeviceGroupSurfacePresentModes2EXT` behaves similarly to `vkGetDeviceGroupSurfacePresentModesKHR`, with the ability to specify extended inputs via chained input structures.

**Valid Usage**

- **VUID-vkGetDeviceGroupSurfacePresentModes2EXT-pSurfaceInfo-06213**
  - `pSurfaceInfo->surface` must be supported by all physical devices associated with `device`, as reported by `vkGetPhysicalDeviceSurfaceSupportKHR` or an equivalent platform-specific mechanism

**Valid Usage (Implicit)**

- **VUID-vkGetDeviceGroupSurfacePresentModes2EXT-device-parameter**
  - `device` must be a valid `VkDevice` handle
- **VUID-vkGetDeviceGroupSurfacePresentModes2EXT-pSurfaceInfo-parameter**
  - `pSurfaceInfo` must be a valid pointer to a valid `VkPhysicalDeviceSurfaceInfo2KHR`
structure

- VUID-vkGetDeviceGroupSurfacePresentModes2EXT-pModes-parameter
  pModes must be a valid pointer to a VkDeviceGroupPresentModeFlagsKHR value

**Return Codes**

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_SURFACE_LOST_KHR

When using VK_DEVICE_GROUP_PRESENT_MODE_LOCAL_MULTI_DEVICE_BIT_KHR, the application may need to know which regions of the surface are used when presenting locally on each physical device. Presentation of swapchain images to this surface need only have valid contents in the regions returned by this command.

To query a set of rectangles used in presentation on the physical device, call:

```
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with VK_KHR_surface
VkResult vkGetPhysicalDevicePresentRectanglesKHR(
    VkPhysicalDevice physicalDevice,
    VkSurfaceKHR surface,
    uint32_t* pRectCount,
    VkRect2D* pRects);
```

- `physicalDevice` is the physical device.
- `surface` is the surface.
- `pRectCount` is a pointer to an integer related to the number of rectangles available or queried, as described below.
- `pRects` is either NULL or a pointer to an array of VkRect2D structures.

If `pRects` is NULL, then the number of rectangles used when presenting the given `surface` is returned in `pRectCount`. Otherwise, `pRectCount` must point to a variable set by the user to the number of elements in the `pRects` array, and on return the variable is overwritten with the number of structures actually written to `pRects`. If the value of `pRectCount` is less than the number of rectangles, at most `pRectCount` structures will be written, and VK_INCOMPLETE will be returned instead of VK_SUCCESS, to indicate that not all the available rectangles were returned.

The values returned by this command are not invariant, and may change in response to the surface being moved, resized, or occluded.
The rectangles returned by this command must not overlap.

### Valid Usage

- **VUID-vkGetPhysicalDevicePresentRectanglesKHR-surface-06523**
  - `surface` must be a valid `VkSurfaceKHR` handle
- **VUID-vkGetPhysicalDevicePresentRectanglesKHR-surface-06211**
  - `surface` must be supported by `physicalDevice`, as reported by `vkGetPhysicalDeviceSurfaceSupportKHR` or an equivalent platform-specific mechanism

### Valid Usage (Implicit)

- **VUID-vkGetPhysicalDevicePresentRectanglesKHR-physicalDevice-parameter**
  - `physicalDevice` must be a valid `VkPhysicalDevice` handle
- **VUID-vkGetPhysicalDevicePresentRectanglesKHR-surface-parameter**
  - `surface` must be a valid `VkSurfaceKHR` handle
- **VUID-vkGetPhysicalDevicePresentRectanglesKHR-pRectCount-parameter**
  - `pRectCount` must be a valid pointer to a `uint32_t` value
- **VUID-vkGetPhysicalDevicePresentRectanglesKHR-pRects-parameter**
  - If the value referenced by `pRectCount` is not 0, and `pRects` is not NULL, `pRects` must be a valid pointer to an array of `VkRect2D` structures
- **VUID-vkGetPhysicalDevicePresentRectanglesKHR-commonparent**
  - Both of `physicalDevice`, and `surface` must have been created, allocated, or retrieved from the same `VkInstance`

### Host Synchronization

- Host access to `surface` must be externally synchronized

### Return Codes

**Success**

- `VK_SUCCESS`
- `VK_INCOMPLETE`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
34.8. Display Timing Queries

Traditional game and real-time-animation applications frequently use VK_PRESENT_MODE_FIFO_KHR so that presentable images are updated during the vertical blanking period of a given refresh cycle (RC) of the presentation engine’s display. This avoids the visual anomaly known as tearing.

However, synchronizing the presentation of images with the RC does not prevent all forms of visual anomalies. Stuttering occurs when the geometry for each presentable image is not accurately positioned for when that image will be displayed. The geometry may appear to move too little some RCs, and too much for others. Sometimes the animation appears to freeze, when the same image is used for more than one RC.

In order to minimize stuttering, an application needs to correctly position their geometry for when the presentable image will be displayed to the user. To accomplish this, applications need various timing information about the presentation engine’s display. They need to know when presentable images were actually presented, and when they could have been presented. Applications also need to tell the presentation engine to display an image no sooner than a given time. This can allow the application’s animation to look smooth to the user, with no stuttering. The VK_GOOGLE_display_timing extension allows an application to satisfy these needs.

The presentation engine’s display typically refreshes the pixels that are displayed to the user on a periodic basis. The period may be fixed or variable. In many cases, the presentation engine is associated with fixed refresh rate (FRR) display technology, with a fixed refresh rate (RR, e.g. 60Hz). In some cases, the presentation engine is associated with variable refresh rate (VRR) display technology, where each refresh cycle (RC) can vary in length. This extension treats VRR displays as if they are FRR.

To query the duration of a refresh cycle (RC) for the presentation engine’s display, call:

```c
// Provided by VK_GOOGLE_display_timing
VkResult vkGetRefreshCycleDurationGOOGLE(
    VkDevice device,
    VkSwapchainKHR swapchain,
    VkRefreshCycleDurationGOOGLE* pDisplayTimingProperties);
```

- **device** is the device associated with **swapchain**.
- **swapchain** is the swapchain to obtain the refresh duration for.
- **pDisplayTimingProperties** is a pointer to a VkRefreshCycleDurationGOOGLE structure.

**Valid Usage (Implicit)**

- VUID-vkGetRefreshCycleDurationGOOGLE-device-parameter **device** must be a valid VkDevice handle
- VUID-vkGetRefreshCycleDurationGOOGLE-swapchain-parameter **swapchain** must be a valid VkSwapchainKHR handle
- VUID-vkGetRefreshCycleDurationGOOGLE-pDisplayTimingProperties-parameter
pDisplayTimingProperties must be a valid pointer to a VkRefreshCycleDurationGOOGLE structure

- VUID-vkGetRefreshCycleDurationGOOGLE-swapchain-parent swapchain must have been created, allocated, or retrieved from device

### Host Synchronization

- Host access to swapchain must be externally synchronized

### Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_DEVICE_LOST
- VK_ERROR_SURFACE_LOST_KHR

The VkRefreshCycleDurationGOOGLE structure is defined as:

```c
// Provided by VK_GOOGLE_display_timing
typedef struct VkRefreshCycleDurationGOOGLE {
    uint64_t refreshDuration;
} VkRefreshCycleDurationGOOGLE;
```

- refreshDuration is the number of nanoseconds from the start of one refresh cycle to the next.

**Note**

The rate at which an application renders and presents new images is known as the image present rate (IPR, aka frame rate). The inverse of IPR, or the duration between each image present, is the image present duration (IPD). In order to provide a smooth, stutter-free animation, an application will want its IPD to be a multiple of refreshDuration. For example, if a display has a 60Hz refresh rate, refreshDuration will be a value in nanoseconds that is approximately equal to 16.67ms. In such a case, an application will want an IPD of 16.67ms (1X multiplier of refreshDuration), or 33.33ms (2X multiplier of refreshDuration), or 50.0ms (3X multiplier of refreshDuration), etc.

In order to determine a target IPD for a display (i.e. a multiple of refreshDuration), an application needs to determine when its images are actually displayed. Suppose an application has an initial target IPD of 16.67ms (1X multiplier of refreshDuration). It will therefore position the geometry of a new image 16.67ms...
later than the previous image. But suppose this application is running on slower hardware, so that it actually takes 20ms to render each new image. This will create visual anomalies, because the images will not be displayed to the user every 16.67ms, nor every 20ms. In this case, it is better for the application to adjust its target IPD to 33.33ms (i.e. a 2X multiplier of refreshDuration), and tell the presentation engine not to present images any sooner than every 33.33ms. This will allow the geometry to be correctly positioned for each presentable image.

Adjustments to an application’s IPD may be needed because different views of an application’s geometry can take different amounts of time to render. For example, looking at the sky may take less time to render than looking at multiple, complex items in a room. In general, it is good to not frequently change IPD, as that can cause visual anomalies. Adjustments to a larger IPD because of late images should happen quickly, but adjustments to a smaller IPD should only happen if the actualPresentTime and earliestPresentTime members of the VkPastPresentationTimingGOOGLE structure are consistently different, and if presentMargin is consistently large, over multiple images.

The implementation will maintain a limited amount of history of timing information about previous presents. Because of the asynchronous nature of the presentation engine, the timing information for a given vkQueuePresentKHR command will become available some time later. These time values can be asynchronously queried, and will be returned if available. All time values are in nanoseconds, relative to a monotonically-increasing clock (e.g. CLOCK_MONOTONIC (see clock_gettime(2)) on Android and Linux).

To asynchronously query the presentation engine, for newly-available timing information about one or more previous presents to a given swapchain, call:

```c
// Provided by VK_GOOGLE_display_timing
VkResult vkGetPastPresentationTimingGOOGLE(  
    VkDevice device,  
    VkSwapchainKHR swapchain,  
    uint32_t* pPresentationTimingCount,  
    VkPastPresentationTimingGOOGLE* pPresentationTimings);
```

- **device** is the device associated with **swapchain**.
- **swapchain** is the swapchain to obtain presentation timing information duration for.
- **pPresentationTimingCount** is a pointer to an integer related to the number of VkPastPresentationTimingGOOGLE structures to query, as described below.
- **pPresentationTimings** is either NULL or a pointer to an array of VkPastPresentationTimingGOOGLE structures.

If **pPresentationTimings** is NULL, then the number of newly-available timing records for the given swapchain is returned in **pPresentationTimingCount**. Otherwise, **pPresentationTimingCount** must point to a variable set by the user to the number of elements in the **pPresentationTimings** array, and on return the variable is overwritten with the number of structures actually written to **pPresentationTimings**. If the value of **pPresentationTimingCount** is less than the number of newly-
available timing records, at most \texttt{pPresentationTimingCount} structures will be written, and \texttt{VK_INCOMPLETE} will be returned instead of \texttt{VK_SUCCESS}, to indicate that not all the available timing records were returned.

### Valid Usage (Implicit)

- VUID-vkGetPastPresentationTimingGOOGLE-device-parameter \texttt{device} \textbf{must} be a valid \texttt{VkDevice} handle
- VUID-vkGetPastPresentationTimingGOOGLE-swapchain-parameter \texttt{swapchain} \textbf{must} be a valid \texttt{VkSwapchainKHR} handle
- VUID-vkGetPastPresentationTimingGOOGLE-pPresentationTimingCount-parameter \texttt{pPresentationTimingCount} \textbf{must} be a valid pointer to a \texttt{uint32_t} value
- VUID-vkGetPastPresentationTimingGOOGLE-pPresentationTimings-parameter If the value referenced by \texttt{pPresentationTimingCount} is not 0, and \texttt{pPresentationTimings} is not \texttt{NULL}, \texttt{pPresentationTimings} \textbf{must} be a valid pointer to an array of \texttt{pPresentationTimingCount} \texttt{VkPastPresentationTimingGOOGLE} structures
- VUID-vkGetPastPresentationTimingGOOGLE-swapchain-parent \texttt{swapchain} \textbf{must} have been created, allocated, or retrieved from \texttt{device}

### Host Synchronization

- Host access to \texttt{swapchain} \textbf{must} be externally synchronized

### Return Codes

#### Success
- \texttt{VK_SUCCESS}
- \texttt{VK_INCOMPLETE}

#### Failure
- \texttt{VK_ERROR_OUT_OF_HOST_MEMORY}
- \texttt{VK_ERROR_DEVICE_LOST}
- \texttt{VK_ERROR_OUT_OF_DATE_KHR}
- \texttt{VK_ERROR_SURFACE_LOST_KHR}

The \texttt{VkPastPresentationTimingGOOGLE} structure is defined as:

```c
// Provided by VK_GOOGLE_display_timing
typedef struct VkPastPresentationTimingGOOGLE { uint32_t presentID;
    uint64_t desiredPresentTime;
    uint64_t actualPresentTime;
} VkPastPresentationTimingGOOGLE;
```
uint64_t earliestPresentTime;
uint64_t presentMargin;
} VkPastPresentationTimingGOOGLE;

• presentID is an application-provided value that was given to a previous vkQueuePresentKHR command via VkPresentTimeGOOGLE::presentID (see below). It can be used to uniquely identify a previous present with the vkQueuePresentKHR command.

• desiredPresentTime is an application-provided value that was given to a previous vkQueuePresentKHR command via VkPresentTimeGOOGLE::desiredPresentTime. If non-zero, it was used by the application to indicate that an image not be presented any sooner than desiredPresentTime.

• actualPresentTime is the time when the image of the swapchain was actually displayed.

• earliestPresentTime is the time when the image of the swapchain could have been displayed. This may differ from actualPresentTime if the application requested that the image be presented no sooner than VkPresentTimeGOOGLE::desiredPresentTime.

• presentMargin is an indication of how early the vkQueuePresentKHR command was processed compared to how soon it needed to be processed, and still be presented at earliestPresentTime.

The results for a given swapchain and presentID are only returned once from vkGetPastPresentationTimingGOOGLE.

The application can use the VkPastPresentationTimingGOOGLE values to occasionally adjust its timing. For example, if actualPresentTime is later than expected (e.g. one refreshDuration late), the application may increase its target IPD to a higher multiple of refreshDuration (e.g. decrease its frame rate from 60Hz to 30Hz). If actualPresentTime and earliestPresentTime are consistently different, and if presentMargin is consistently large enough, the application may decrease its target IPD to a smaller multiple of refreshDuration (e.g. increase its frame rate from 30Hz to 60Hz). If actualPresentTime and earliestPresentTime are same, and if presentMargin is consistently high, the application may delay the start of its input-render-present loop in order to decrease the latency between user input and the corresponding present (always leaving some margin in case a new image takes longer to render than the previous image). An application that desires its target IPD to always be the same as refreshDuration, can also adjust features until actualPresentTime is never late and presentMargin is satisfactory.

The full VK_GOOGLE_display_timing extension semantics are described for swapchains created with VK_PRESENT_MODE_FIFO_KHR. For example, non-zero values of VkPresentTimeGOOGLE::desiredPresentTime must be honored, and vkGetPastPresentationTimingGOOGLE should return a VkPastPresentationTimingGOOGLE structure with valid values for all images presented with vkQueuePresentKHR. The semantics for other present modes are as follows:

• VK_PRESENT_MODE_IMMEDIATE_KHR. The presentation engine may ignore non-zero values of VkPresentTimeGOOGLE::desiredPresentTime in favor of presenting immediately. The value of VkPastPresentationTimingGOOGLE::earliestPresentTime must be the same as VkPastPresentationTimingGOOGLE::actualPresentTime, which should be when the presentation engine displayed the image.

• VK_PRESENT_MODE_MAILBOX_KHR. The intention of using this present mode with this extension is to
handle cases where an image is presented late, and the next image is presented soon enough to replace it at the next vertical blanking period. For images that are displayed to the user, the value of `VkPastPresentationTimingGOOGLE::actualPresentTime` **must** be when the image was displayed. For images that are not displayed to the user, `vkGetPastPresentationTimingGOOGLE` *may* not return a `VkPastPresentationTimingGOOGLE` structure, or it *may* return a `VkPastPresentationTimingGOOGLE` structure with the value of zero for both `VkPastPresentationTimingGOOGLE::actualPresentTime` and `VkPastPresentationTimingGOOGLE::earliestPresentTime`. It is possible that an application *can* submit images with `VkPresentTimeGOOGLE::desiredPresentTime` values such that new images *may* not be displayed. For example, if `VkPresentTimeGOOGLE::desiredPresentTime` is far enough in the future that an image is not presented before `vkQueuePresentKHR` is called to present another image, the first image will not be displayed to the user. If the application continues to do that, the presentation *may* not display new images.

- **VK_PRESENT_MODE_FIFO_RELAXED_KHR.** For images that are presented in time to be displayed at the next vertical blanking period, the semantics are identical as for **VK_PRESENT_MODE_FIFO_RELAXED_KHR.** For images that are presented late, and are displayed after the start of the vertical blanking period (i.e. with tearing), the values of `VkPastPresentationTimingGOOGLE` *may* be treated as if the image was displayed at the start of the vertical blanking period, or *may* be treated the same as for **VK_PRESENT_MODE_IMMEDIATE_KHR.**

### 34.9. Present Wait

Applications wanting to control the pacing of the application by monitoring when presentation processes have completed to limit the number of outstanding images queued for presentation, need to have a method of being signaled during the presentation process.

Using the **VK_GOOGLE_display_timing** extension applications can discover when images were presented, but only asynchronously.

Providing a mechanism which allows applications to block, waiting for a specific step of the presentation process to complete allows them to control the amount of outstanding work (and hence the potential lag in responding to user input or changes in the rendering environment).

The **VK_KHR_present_wait** extension allows applications to tell the presentation engine at the `vkQueuePresentKHR` call that it plans on waiting for presentation by passing a `VkPresentIdKHR` structure. The `presentId` passed in that structure may then be passed to a future `vkWaitForPresentKHR` call to cause the application to block until that presentation is finished.

### 34.10. WSI Swapchain

A swapchain object (a.k.a. swapchain) provides the ability to present rendering results to a surface. Swapchain objects are represented by `VkSwapchainKHR` handles:

```c
// Provided by VK_KHR_swapchain
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkSwapchainKHR)
```

A swapchain is an abstraction for an array of presentable images that are associated with a surface.
The presentable images are represented by \texttt{VkImage} objects created by the platform. One image (which \textbf{can} be an array image for multiview/stereoscopic-3D surfaces) is displayed at a time, but multiple images \textbf{can} be queued for presentation. An application renders to the image, and then queues the image for presentation to the surface.

A native window \textbf{cannot} be associated with more than one non-retired swapchain at a time. Further, swapchains \textbf{cannot} be created for native windows that have a non-Vulkan graphics API surface associated with them.

\begin{itemize}
\item The presentation engine is an abstraction for the platform's compositor or display engine.
\item The presentation engine \textbf{may} be synchronous or asynchronous with respect to the application and/or logical device.
\item Some implementations \textbf{may} use the device's graphics queue or dedicated presentation hardware to perform presentation.
\end{itemize}

The presentable images of a swapchain are owned by the presentation engine. An application \textbf{can} acquire use of a presentable image from the presentation engine. Use of a presentable image \textbf{must} occur only after the image is returned by \texttt{vkAcquireNextImageKHR}, and before it is released by \texttt{vkQueuePresentKHR}. This includes transitioning the image layout and rendering commands.

An application \textbf{can} acquire use of a presentable image with \texttt{vkAcquireNextImageKHR}. After acquiring a presentable image and before modifying it, the application \textbf{must} use a synchronization primitive to ensure that the presentation engine has finished reading from the image. The application \textbf{can} then transition the image's layout, queue rendering commands to it, etc. Finally, the application presents the image with \texttt{vkQueuePresentKHR}, which releases the acquisition of the image. The application \textbf{can} also release the acquisition of the image through \texttt{vkReleaseSwapchainImagesEXT}, if the image is not in use by the device, and skip the present operation.

The presentation engine controls the order in which presentable images are acquired for use by the application.

\begin{itemize}
\item This allows the platform to handle situations which require out-of-order return of images after presentation. At the same time, it allows the application to generate command buffers referencing all of the images in the swapchain at initialization time, rather than in its main loop.
\end{itemize}

How this all works is described below.

If a swapchain is created with \texttt{presentMode} set to either \texttt{VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR} or \texttt{VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR}, a single presentable image \textbf{can} be acquired, referred to as a shared presentable image. A shared presentable image \textbf{may} be concurrently accessed by the application and the presentation engine, without transitioning the image's layout after it is initially presented.
• With `VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR`, the presentation engine is only required to update to the latest contents of a shared presentable image after a present. The application must call `vkQueuePresentKHR` to guarantee an update. However, the presentation engine may update from it at any time.

• With `VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR`, the presentation engine will automatically present the latest contents of a shared presentable image during every refresh cycle. The application is only required to make one initial call to `vkQueuePresentKHR`, after which the presentation engine will update from it without any need for further present calls. The application can indicate the image contents have been updated by calling `vkQueuePresentKHR`, but this does not guarantee the timing of when updates will occur.

The presentation engine may access a shared presentable image at any time after it is first presented. To avoid tearing, an application should coordinate access with the presentation engine. This requires presentation engine timing information through platform-specific mechanisms and ensuring that color attachment writes are made available during the portion of the presentation engine’s refresh cycle they are intended for.

Note
The `VK_KHR_shared_presentable_image` extension does not provide functionality for determining the timing of the presentation engine’s refresh cycles.

In order to query a swapchain’s status when rendering to a shared presentable image, call:

```c
// Provided by VK_KHR_shared_presentable_image
VkResult vkGetSwapchainStatusKHR(VkDevice device, VkSwapchainKHR swapchain);
```

• `device` is the device associated with `swapchain`.

• `swapchain` is the swapchain to query.

**Valid Usage (Implicit)**

• VUID-vkGetSwapchainStatusKHR-device-parameter
  `device` must be a valid `VkDevice` handle

• VUID-vkGetSwapchainStatusKHR-swapchain-parameter
  `swapchain` must be a valid `VkSwapchainKHR` handle

• VUID-vkGetSwapchainStatusKHR-swapchain-parent
  `swapchain` must have been created, allocated, or retrieved from `device`

**Host Synchronization**

• Host access to `swapchain` must be externally synchronized
The possible return values for `vkGetSwapchainStatusKHR` should be interpreted as follows:

- **VK_SUCCESS** specifies the presentation engine is presenting the contents of the shared presentable image, as per the swapchain’s `VkPresentModeKHR`.

- **VK_SUBOPTIMAL_KHR** the swapchain no longer matches the surface properties exactly, but the presentation engine is presenting the contents of the shared presentable image, as per the swapchain’s `VkPresentModeKHR`.

- **VK_ERROR_OUT_OF_DATE_KHR** the surface has changed in such a way that it is no longer compatible with the swapchain.

- **VK_ERROR_SURFACE_LOST_KHR** the surface is no longer available.

- **VK_ERROR_FULL_SCREEN_EXCLUSIVE_MODE_LOST_EXT**

---

Note

The swapchain state may be cached by implementations, so applications should regularly call `vkGetSwapchainStatusKHR` when using a swapchain with `VkPresentModeKHR` set to `VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR`.

To create a swapchain, call:

```c
// Provided by VK_KHR_swapchain
VkResult vkCreateSwapchainKHR(
    VkDevice device,
    const VkSwapchainCreateInfoKHR* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkSwapchainKHR* pSwapchain);
```

- **device** is the device to create the swapchain for.

- **pCreateInfo** is a pointer to a `VkSwapchainCreateInfoKHR` structure specifying the parameters of the created swapchain.
- **pAllocator** is the allocator used for host memory allocated for the swapchain object when there is no more specific allocator available (see Memory Allocation).

- **pSwapchain** is a pointer to a VkSwapchainKHR handle in which the created swapchain object will be returned.

As mentioned above, if vkCreateSwapchainKHR succeeds, it will return a handle to a swapchain containing an array of at least pCreateInfo->minImageCount presentable images.

While acquired by the application, presentable images can be used in any way that equivalent non-presentable images can be used. A presentable image is equivalent to a non-presentable image created with the following VkImageCreateInfo parameters:

<table>
<thead>
<tr>
<th>VkImageCreateInfo Field</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>flags</td>
<td>VK_IMAGE_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT is set if VK_SWAPCHAIN_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT_KHR is set</td>
</tr>
<tr>
<td></td>
<td>VK_IMAGE_CREATE_PROTECTED_BIT is set if VK_SWAPCHAIN_CREATE_PROTECTED_BIT_KHR is set</td>
</tr>
<tr>
<td></td>
<td>VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT and VK_IMAGE_CREATE_EXTENDED_USAGE_BIT_KHR are both set if VK_SWAPCHAIN_CREATE_MUTABLE_FORMAT_BIT_KHR is set</td>
</tr>
<tr>
<td></td>
<td>all other bits are unset</td>
</tr>
<tr>
<td>imageType</td>
<td>VK_IMAGE_TYPE_2D</td>
</tr>
<tr>
<td>format</td>
<td>pCreateInfo-&gt;imageFormat</td>
</tr>
<tr>
<td>extent</td>
<td>{pCreateInfo-&gt;imageExtent.width, pCreateInfo-&gt;imageExtent.height, 1}</td>
</tr>
<tr>
<td>mipLevels</td>
<td>1</td>
</tr>
<tr>
<td>arrayLayers</td>
<td>pCreateInfo-&gt;imageArrayLayers</td>
</tr>
<tr>
<td>samples</td>
<td>VK_SAMPLE_COUNT_1_BIT</td>
</tr>
<tr>
<td>tiling</td>
<td>VK_IMAGE_TILING_OPTIMAL</td>
</tr>
<tr>
<td>usage</td>
<td>pCreateInfo-&gt;imageUsage</td>
</tr>
<tr>
<td>sharingMode</td>
<td>pCreateInfo-&gt;imageSharingMode</td>
</tr>
<tr>
<td>queueFamilyIndexCount</td>
<td>pCreateInfo-&gt;queueFamilyIndexCount</td>
</tr>
<tr>
<td>pQueueFamilyIndices</td>
<td>pCreateInfo-&gt;pQueueFamilyIndices</td>
</tr>
<tr>
<td>initialLayout</td>
<td>VK_IMAGE_LAYOUT_UNDEFINED</td>
</tr>
</tbody>
</table>

The pCreateInfo->surface must not be destroyed until after the swapchain is destroyed.

If oldSwapchain is VK_NULL_HANDLE, and the native window referred to by pCreateInfo->surface is
already associated with a Vulkan swapchain, **VK_ERROR_NATIVE_WINDOW_IN_USE_KHR** must be returned.

If the native window referred to by `pCreateInfo->surface` is already associated with a non-Vulkan graphics API surface, **VK_ERROR_NATIVE_WINDOW_IN_USE_KHR** must be returned.

The native window referred to by `pCreateInfo->surface` must not become associated with a non-Vulkan graphics API surface before all associated Vulkan swapchains have been destroyed.

`vkCreateSwapchainKHR` will return **VK_ERROR_DEVICE_LOST** if the logical device was lost. The `VkSwapchainKHR` is a child of the device, and must be destroyed before the device. However, `VkSurfaceKHR` is not a child of any `VkDevice` and is not affected by the lost device. After successfully recreating a `VkDevice`, the same `VkSurfaceKHR` can be used to create a new `VkSwapchainKHR`, provided the previous one was destroyed.

If the `oldSwapchain` parameter of `pCreateInfo` is a valid swapchain, which has exclusive full-screen access, that access is released from `pCreateInfo->oldSwapchain`. If the command succeeds in this case, the newly created swapchain will automatically acquire exclusive full-screen access from `pCreateInfo->oldSwapchain`.

**Note**

This implicit transfer is intended to avoid exiting and entering full-screen exclusive mode, which may otherwise cause unwanted visual updates to the display.

In some cases, swapchain creation may fail if exclusive full-screen mode is requested for application control, but for some implementation-specific reason exclusive full-screen access is unavailable for the particular combination of parameters provided. If this occurs, **VK_ERROR_INITIALIZATION_FAILED** will be returned.

**Note**

In particular, it will fail if the `imageExtent` member of `pCreateInfo` does not match the extents of the monitor. Other reasons for failure may include the app not being set as high-dpi aware, or if the physical device and monitor are not compatible in this mode.

If the `pNext` chain of `VkSwapchainCreateInfoKHR` includes a `VkSwapchainPresentBarrierCreateInfoNV` structure, then that structure includes additional swapchain creation parameters specific to the present barrier. Swapchain creation may fail if the state of the current system restricts the usage of the present barrier feature `VkSurfaceCapabilitiesPresentBarrierNV`, or a swapchain itself does not satisfy all the required conditions. In this scenario **VK_ERROR_INITIALIZATION_FAILED** is returned.

When the `VkSurfaceKHR` in `VkSwapchainCreateInfoKHR` is a display surface, then the `VkDisplayModeKHR` in display surface’s `VkDisplaySurfaceCreateInfoKHR` is associated with a particular `VkDisplayKHR`. Swapchain creation may fail if that `VkDisplayKHR` is not acquired by the application. In this scenario **VK_ERROR_INITIALIZATION_FAILED** is returned.
Valid Usage (Implicit)

- VUID-vkCreateSwapchainKHR-device-parameter
device must be a valid VkDevice handle

- VUID-vkCreateSwapchainKHR-pCreateInfo-parameter
pCreateInfo must be a valid pointer to a valid VkSwapchainCreateInfoKHR structure

- VUID-vkCreateSwapchainKHR-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkCreateSwapchainKHR-pSwapchain-parameter
pSwapchain must be a valid pointer to a VkSwapchainKHR handle

Host Synchronization

- Host access to pCreateInfo->surface must be externally synchronized
- Host access to pCreateInfo->oldSwapchain must be externally synchronized

Return Codes

Success
  - VK_SUCCESS

Failure
  - VK_ERROR_OUT_OF_HOST_MEMORY
  - VK_ERROR_OUT_OF_DEVICE_MEMORY
  - VK_ERROR_DEVICE_LOST
  - VK_ERROR_SURFACE_LOST_KHR
  - VK_ERROR_NATIVE_WINDOW_IN_USE_KHR
  - VK_ERROR_INITIALIZATION_FAILED
  - VK_ERROR_COMPRESSION_EXHAUSTED_EXT

The VkSwapchainCreateInfoKHR structure is defined as:

```c
// Provided by VK_KHR_swapchain
typedef struct VkSwapchainCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkSwapchainCreateFlagsKHR flags;
    VkSurfaceKHR surface;
    uint32_t minImageCount;
    VkFormat imageFormat;
} VkSwapchainCreateInfoKHR;
```
VkColorSpaceKHR
VkExtent2D
uint32_t
VkImageUsageFlags
VkSharingMode
const uint32_t*
VkSurfaceTransformFlagBitsKHR
VkCompositeAlphaFlagBitsKHR
VkPresentModeKHR
VkBool32
VkSwapchainKHR
} VkSwapchainCreateInfoKHR;

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is a bitmask of *VkSwapchainCreateFlagBitsKHR* indicating parameters of the swapchain creation.
- **surface** is the surface onto which the swapchain will present images. If the creation succeeds, the swapchain becomes associated with *surface*.
- **minImageCount** is the minimum number of presentable images that the application needs. The implementation will either create the swapchain with at least that many images, or it will fail to create the swapchain.
- **imageFormat** is a *VkFormat* value specifying the format the swapchain image(s) will be created with.
- **imageColorSpace** is a *VkColorSpaceKHR* value specifying the way the swapchain interprets image data.
- **imageExtent** is the size (in pixels) of the swapchain image(s). The behavior is platform-dependent if the image extent does not match the surface’s *currentExtent* as returned by `vkGetPhysicalDeviceSurfaceCapabilitiesKHR`.

**Note**

On some platforms, it is normal that *maxImageExtent* may become (0, 0), for example when the window is minimized. In such a case, it is not possible to create a swapchain due to the Valid Usage requirements, unless scaling is selected through *VkSwapchainPresentScalingCreateInfoEXT*, if supported.

- **imageArrayLayers** is the number of views in a multiview/stereo surface. For non-stereoscopic-3D applications, this value is 1.
- **imageUsage** is a bitmask of *VkImageUsageFlagBits* describing the intended usage of the (acquired) swapchain images.
- **imageSharingMode** is the sharing mode used for the image(s) of the swapchain.
- **queueFamilyIndexCount** is the number of queue families having access to the image(s) of the swapchain when imageSharingMode is *VK_SHARING_MODE_CONCURRENT*. 
• `pQueueFamilyIndices` is a pointer to an array of queue family indices having access to the images(s) of the swapchain when `imageSharingMode` is `VK_SHARING_MODE_CONCURRENT`.

• `preTransform` is a `VkSurfaceTransformFlagBitsKHR` value describing the transform, relative to the presentation engine's natural orientation, applied to the image content prior to presentation. If it does not match the `currentTransform` value returned by `vkGetPhysicalDeviceSurfaceCapabilitiesKHR`, the presentation engine will transform the image content as part of the presentation operation.

• `compositeAlpha` is a `VkCompositeAlphaFlagBitsKHR` value indicating the alpha compositing mode to use when this surface is composited together with other surfaces on certain window systems.

• `presentMode` is the presentation mode the swapchain will use. A swapchain's present mode determines how incoming present requests will be processed and queued internally.

• `clipped` specifies whether the Vulkan implementation is allowed to discard rendering operations that affect regions of the surface that are not visible.
  
  ◦ If set to `VK_TRUE`, the presentable images associated with the swapchain may not own all of their pixels. Pixels in the presentable images that correspond to regions of the target surface obscured by another window on the desktop, or subject to some other clipping mechanism will have undefined content when read back. Fragment shaders may not execute for these pixels, and thus any side effects they would have had will not occur. Setting `VK_TRUE` does not guarantee any clipping will occur, but allows more efficient presentation methods to be used on some platforms.
  
  ◦ If set to `VK_FALSE`, presentable images associated with the swapchain will own all of the pixels they contain.

  **Note**
  Applications should set this value to `VK_TRUE` if they do not expect to read back the content of presentable images before presenting them or after reacquiring them, and if their fragment shaders do not have any side effects that require them to run for all pixels in the presentable image.

• `oldSwapchain` is `VK_NULL_HANDLE`, or the existing non-retired swapchain currently associated with `surface`. Providing a valid `oldSwapchain` may aid in the resource reuse, and also allows the application to still present any images that are already acquired from it.

Upon calling `vkCreateSwapchainKHR` with an `oldSwapchain` that is not `VK_NULL_HANDLE`, `oldSwapchain` is retired — even if creation of the new swapchain fails. The new swapchain is created in the non-retired state whether or not `oldSwapchain` is `VK_NULL_HANDLE`.

Upon calling `vkCreateSwapchainKHR` with an `oldSwapchain` that is not `VK_NULL_HANDLE`, any images from `oldSwapchain` that are not acquired by the application may be freed by the implementation, which may occur even if creation of the new swapchain fails. The application can destroy `oldSwapchain` to free all memory associated with `oldSwapchain`.

  **Note**
  Multiple retired swapchains can be associated with the same `VkSurfaceKHR` through multiple uses of `oldSwapchain` that outnumber calls to `vkDestroySwapchainKHR`.
After oldSwapchain is retired, the application can pass to vkQueuePresentKHR any images it had already acquired from oldSwapchain. E.g., an application may present an image from the old swapchain before an image from the new swapchain is ready to be presented. As usual, vkQueuePresentKHR may fail if oldSwapchain has entered a state that causes VK_ERROR_OUT_OF_DATE_KHR to be returned.

The application can continue to use a shared presentable image obtained from oldSwapchain until a presentable image is acquired from the new swapchain, as long as it has not entered a state that causes it to return VK_ERROR_OUT_OF_DATE_KHR.

Valid Usage

- VUID-VkSwapchainCreateInfoKHR-surface-01270
  surface must be a surface that is supported by the device as determined using vkGetPhysicalDeviceSurfaceSupportKHR

- VUID-VkSwapchainCreateInfoKHR-minImageCount-01272
  minImageCount must be less than or equal to the value returned in the maxImageCount member of the VkSurfaceCapabilitiesKHR structure returned by vkGetPhysicalDeviceSurfaceCapabilitiesKHR for the surface if the returned maxImageCount is not zero

- VUID-VkSwapchainCreateInfoKHR-presentMode-02839
  If presentMode is not VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR nor VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR, then minImageCount must be greater than or equal to the value returned in the minImageCount member of theVkSurfaceCapabilitiesKHR structure returned by vkGetPhysicalDeviceSurfaceCapabilitiesKHR for the surface

- VUID-VkSwapchainCreateInfoKHR-minImageCount-01383
  minImageCount must be 1 if presentMode is either VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR or VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR

- VUID-VkSwapchainCreateInfoKHR-imageFormat-01273
  imageFormat and imageColorSpace must match the format and colorSpace members, respectively, of one of the VkSurfaceFormatKHR structures returned by vkGetPhysicalDeviceSurfaceFormatsKHR for the surface

- VUID-VkSwapchainCreateInfoKHR-pNext-07781
  If a VkSwapchainPresentScalingCreateInfoEXT structure was not included in the pNext chain, or it is included and VkSwapchainPresentScalingCreateInfoEXT::scalingBehavior is zero then imageExtent must be between minImageExtent and maxImageExtent, inclusive, where minImageExtent and maxImageExtent are members of the VkSurfaceCapabilitiesKHR structure returned by vkGetPhysicalDeviceSurfaceCapabilitiesKHR for the surface

- VUID-VkSwapchainCreateInfoKHR-pNext-07782
  If a VkSwapchainPresentScalingCreateInfoEXT structure was included in the pNext chain and VkSwapchainPresentScalingCreateInfoEXT::scalingBehavior is not zero then imageExtent must be between minScaledImageExtent and maxScaledImageExtent, inclusive, where minScaledImageExtent and maxScaledImageExtent are members of the
VkSurfacePresentScalingCapabilitiesEXT structure returned by
vkGetPhysicalDeviceSurfaceCapabilities2KHR for the surface and presentMode

• VUID-VkSwapchainCreateInfoKHR-imageExtent-01689
  imageExtent members width and height must both be non-zero

• VUID-VkSwapchainCreateInfoKHR-imageArrayLayers-01275
  imageArrayLayers must be greater than 0 and less than or equal to the maxImageArrayLayers
  member of the VkSurfaceCapabilitiesKHR structure returned by
  vkGetPhysicalDeviceSurfaceCapabilitiesKHR for the surface

• VUID-VkSwapchainCreateInfoKHR-presentMode-01427
  If presentMode is VK_PRESENT_MODE_IMMEDIATE_KHR, VK_PRESENT_MODE_MAILBOX_KHR,
  VK_PRESENT_MODE_FIFO_KHR or VK_PRESENT_MODE_FIFO_RELAXED_KHR, imageUsage must be a
  subset of the supported usage flags present in the supportedUsageFlags member of the
  VkSurfaceCapabilitiesKHR structure returned by
  vkGetPhysicalDeviceSurfaceCapabilitiesKHR for surface

• VUID-VkSwapchainCreateInfoKHR-imageUsage-01384
  If presentMode is VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR or
  VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR, imageUsage must be a subset of the
  supported usage flags present in the sharedPresentSupportedUsageFlags member of the
  VkSharedPresentSurfaceCapabilitiesKHR structure returned by
  vkGetPhysicalDeviceSurfaceCapabilities2KHR for surface

• VUID-VkSwapchainCreateInfoKHR-imageSharingMode-01277
  If imageSharingMode is VK_SHARING_MODE_CONCURRENT, pQueueFamilyIndices must be a valid
  pointer to an array of queueFamilyIndexCount uint32_t values

• VUID-VkSwapchainCreateInfoKHR-imageSharingMode-01278
  If imageSharingMode is VK_SHARING_MODE_CONCURRENT, queueFamilyIndexCount must be greater
  than 1

• VUID-VkSwapchainCreateInfoKHR-imageSharingMode-01428
  If imageSharingMode is VK_SHARING_MODE_CONCURRENT, each element of pQueueFamilyIndices
  must be unique and must be less than pQueueFamilyPropertyCount returned by either
  vkGetPhysicalDeviceQueueFamilyProperties
  or
  vkGetPhysicalDeviceQueueFamilyProperties2 for the physicalDevice that was used to
  create device

• VUID-VkSwapchainCreateInfoKHR-preTransform-01279
  preTransform must be one of the bits present in the supportedTransforms member of the
  VkSurfaceCapabilitiesKHR structure returned by
  vkGetPhysicalDeviceSurfaceCapabilitiesKHR for the surface

• VUID-VkSwapchainCreateInfoKHR-compositeAlpha-01280
  compositeAlpha must be one of the bits present in the supportedCompositeAlpha member of
  the VkSurfaceCapabilitiesKHR structure returned by
  vkGetPhysicalDeviceSurfaceCapabilitiesKHR for the surface

• VUID-VkSwapchainCreateInfoKHR-presentMode-01281
  presentMode must be one of the VkPresentModeKHR values returned by
  vkGetPhysicalDeviceSurfacePresentModesKHR for the surface
If the logical device was created with `VkDeviceGroupDeviceCreateInfo`::physicalDeviceCount equal to 1, flags must not contain `VK_SWAPCHAIN_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT_KHR`.

If `oldSwapchain` is not `VK_NULL_HANDLE`, `oldSwapchain` must be a non-retired swapchain associated with native window referred to by `surface`.

The implied image creation parameters of the swapchain must be supported as reported by `vkGetPhysicalDeviceImageFormatProperties`.

If `flags` contains `VK_SWAPCHAIN_CREATE_MUTABLE_FORMAT_BIT_KHR` then the `pNext` chain must include a `VkImageFormatListCreateInfo` structure with a `viewFormatCount` greater than zero and `pViewFormats` must have an element equal to `imageFormat`.

If a `VkImageFormatListCreateInfo` structure was included in the `pNext` chain and `VkImageFormatListCreateInfo`::`viewFormatCount` is not zero then all of the formats in `VkImageFormatListCreateInfo`::`pViewFormats` must be compatible with the `format` as described in the compatibility table.

If `flags` do not contain `VK_SWAPCHAIN_CREATE_MUTABLE_FORMAT_BIT_KHR` and the `pNext` chain include a `VkImageFormatListCreateInfo` structure then `VkImageFormatListCreateInfo`::`viewFormatCount` must be 0 or 1.

If `flags` contains `VK_SWAPCHAIN_CREATE_PROTECTED_BIT_KHR`, then `VkSurfaceProtectedCapabilitiesKHR`::`supportsProtected` must be `VK_TRUE` in the `VkSurfaceProtectedCapabilitiesKHR` structure returned by `vkGetPhysicalDeviceSurfaceCapabilities2KHR` for `surface`.

If the `pNext` chain includes a `VkSurfaceFullScreenExclusiveInfoEXT` structure with its `fullScreenExclusive` member set to `VK_FULL_SCREEN_EXCLUSIVE_APPLICATION_CONTROLLED_EXT`, and `surface` was created using `vkCreateWin32SurfaceKHR`, a `VkSurfaceFullScreenExclusiveWin32InfoEXT` structure must be included in the `pNext` chain.

If the `imageCompressionControlSwapchain` feature is not enabled, the `pNext` chain must not include an `VkImageCompressionControlEXT` structure.

**Valid Usage (Implicit)**

- `VK_STRUCTURE_TYPE_SWAPCHAIN_CREATE_INFO_KHR` must be `sType`.
- `VK_STRUCTURE_TYPE_SWAPCHAIN_CREATE_INFO_KHR` must be `pNext`.
- `VK_STRUCTURE_TYPE_SWAPCHAIN_CREATE_INFO_KHR` must be `sType`.
- `VK_STRUCTURE_TYPE_SWAPCHAIN_CREATE_INFO_KHR` must be `pNext`.
Each `pNext` member of any structure (including this one) in the `pNext` chain **must** be either `NULL` or a pointer to a valid instance of `VkDeviceGroupSwapchainCreateInfoKHR`, `VkImageCompressionControlEXT`, `VkImageFormatListCreateInfo`, `VkSurfaceFullScreenExclusiveInfoEXT`, `VkSurfaceFullScreenExclusiveWin32InfoEXT`, `VkSwapchainCounterCreateInfoEXT`, `VkSwapchainDisplayNativeHdrCreateInfoAMD`, `VkSwapchainPresentBarrierCreateInfoNV`, `VkSwapchainPresentModesCreateInfoEXT`, or `VkSwapchainPresentScalingCreateInfoEXT`.

- **VUID-VkSwapchainCreateInfoKHR-sType-unique**
  The `sType` value of each struct in the `pNext` chain **must** be unique.

- **VUID-VkSwapchainCreateInfoKHR-flags-parameter**
  `flags` **must** be a valid combination of `VkSwapchainCreateFlagBitsKHR` values.

- **VUID-VkSwapchainCreateInfoKHR-surface-parameter**
  `surface` **must** be a valid `VkSurfaceKHR` handle.

- **VUID-VkSwapchainCreateInfoKHR-imageFormat-parameter**
  `imageFormat` **must** be a valid `VkFormat` value.

- **VUID-VkSwapchainCreateInfoKHR-imageColorSpace-parameter**
  `imageColorSpace` **must** be a valid `VkColorSpaceKHR` value.

- **VUID-VkSwapchainCreateInfoKHR-imageUsage-parameter**
  `imageUsage` **must** be a valid combination of `VkImageUsageFlagBits` values.

- **VUID-VkSwapchainCreateInfoKHR-imageUsage-requiredbitmask**
  `imageUsage` **must** not be `0`.

- **VUID-VkSwapchainCreateInfoKHR-imageSharingMode-parameter**
  `imageSharingMode` **must** be a valid `VkSharingMode` value.

- **VUID-VkSwapchainCreateInfoKHR-preTransform-parameter**
  `preTransform` **must** be a valid `VkSurfaceTransformFlagBitsKHR` value.

- **VUID-VkSwapchainCreateInfoKHR-compositeAlpha-parameter**
  `compositeAlpha` **must** be a valid `VkCompositeAlphaFlagBitsKHR` value.

- **VUID-VkSwapchainCreateInfoKHR-presentMode-parameter**
  `presentMode` **must** be a valid `VkPresentModeKHR` value.

- **VUID-VkSwapchainCreateInfoKHR-oldSwapchain-parameter**
  If `oldSwapchain` is not `VK_NULL_HANDLE`, `oldSwapchain` **must** be a valid `VkSwapchainKHR` handle.

- **VUID-VkSwapchainCreateInfoKHR-commonparent**
  Both of `oldSwapchain`, and `surface` that are valid handles of non-ignored parameters **must** have been created, allocated, or retrieved from the same `VkInstance`.

Bits which **can** be set in `VkSwapchainCreateInfoKHR::flags`, specifying parameters of swapchain creation, are:

```c
// Provided by VK_KHR_swapchain
typedef enum VkSwapchainCreateFlagBitsKHR {
    // Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with
```

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VK_KHR_swapchain

VK_SWAPCHAIN_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT_KHR = 0x00000001,
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain
VK_SWAPCHAIN_CREATE_PROTECTED_BIT_KHR = 0x00000002,
// Provided by VK_KHR_swapchain_mutable_format
VK_SWAPCHAIN_CREATE_MUTABLE_FORMAT_BIT_KHR = 0x00000004,
// Provided by VK_EXT_swapchain_maintenance1
VK_SWAPCHAIN_CREATE_DEFERRED_MEMORY_ALLOCATION_BIT_EXT = 0x00000008,
} VkSwapchainCreateFlagBitsKHR;

- VK_SWAPCHAIN_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT_KHR specifies that images created from the swapchain (i.e. with the swapchain member of VkImageSwapchainCreateInfoKHR set to this swapchain's handle) must use VK_IMAGE_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT.
- VK_SWAPCHAIN_CREATE_PROTECTED_BIT_KHR specifies that images created from the swapchain are protected images.
- VK_SWAPCHAIN_CREATE_MUTABLE_FORMAT_BIT_KHR specifies that the images of the swapchain can be used to create a VkImageView with a different format than what the swapchain was created with. The list of allowed image view formats is specified by adding a VkImageFormatListCreateInfo structure to the pNext chain of VkSwapchainCreateInfoKHR. In addition, this flag also specifies that the swapchain can be created with usage flags that are not supported for the format the swapchain is created with but are supported for at least one of the allowed image view formats.
- VK_SWAPCHAIN_CREATE_DEFERRED_MEMORY_ALLOCATION_BIT_EXT specifies that the implementation may defer allocation of memory associated with each swapchain image until its index is to be returned from vkAcquireNextImageKHR or vkAcquireNextImage2KHR for the first time.

typedef VkFlags VkSwapchainCreateFlagsKHR;

VkSwapchainCreateFlagsKHR is a bitmask type for setting a mask of zero or more VkSwapchainCreateFlagBitsKHR.

If the pNext chain of VkSwapchainCreateInfoKHR includes a VkDeviceGroupSwapchainCreateInfoKHR structure, then that structure includes a set of device group present modes that the swapchain can be used with.

The VkDeviceGroupSwapchainCreateInfoKHR structure is defined as:

typedef struct VkDeviceGroupSwapchainCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkDeviceGroupPresentModeFlagsKHR modes;
} VkDeviceGroupSwapchainCreateInfoKHR;

- sType is a VkStructureType value identifying this structure.
• `pNext` is NULL or a pointer to a structure extending this structure.

• `modes` is a bitfield of modes that the swapchain can be used with.

If this structure is not present, `modes` is considered to be `VK_DEVICE_GROUP_PRESENT_MODE_LOCAL_BIT_KHR`.

### Valid Usage (Implicit)

- **VUID-VkDeviceGroupSwapchainCreateInfoKHR-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_DEVICE_GROUP_SWAPCHAIN_CREATE_INFO_KHR`

- **VUID-VkDeviceGroupSwapchainCreateInfoKHR-modes-parameter**
  
  `modes` must be a valid combination of `VkDeviceGroupPresentModeFlagBitsKHR` values

- **VUID-VkDeviceGroupSwapchainCreateInfoKHR-modes-requiredbitset**
  
  `modes` must not be 0

If the `pNext` chain of `VkSwapchainCreateInfoKHR` includes a `VkSwapchainDisplayNativeHdrCreateInfoAMD` structure, then that structure includes additional swapchain creation parameters specific to display native HDR support.

The `VkSwapchainDisplayNativeHdrCreateInfoAMD` structure is defined as:

```c
// Provided by VK_AMD_display_native_hdr
typedef struct VkSwapchainDisplayNativeHdrCreateInfoAMD {
    VkStructureType sType;
    const void* pNext;
    VkBool32 localDimmingEnable;
} VkSwapchainDisplayNativeHdrCreateInfoAMD;
```

- `sType` is a `VkStructureType` value identifying this structure.

- `pNext` is NULL or a pointer to a structure extending this structure.

- `localDimmingEnable` specifies whether local dimming is enabled for the swapchain.

If the `pNext` chain of `VkSwapchainCreateInfoKHR` does not include this structure, the default value for `localDimmingEnable` is `VK_TRUE`, meaning local dimming is initially enabled for the swapchain.

### Valid Usage (Implicit)

- **VUID-VkSwapchainDisplayNativeHdrCreateInfoAMD-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_SWAPCHAIN_DISPLAY_NATIVE_HDR_CREATE_INFO_AMD`

### Valid Usage

- **VUID-VkSwapchainDisplayNativeHdrCreateInfoAMD-localDimmingEnable-04449**
  
  It is only valid to set `localDimmingEnable` to `VK_TRUE` if
The local dimming HDR setting may also be changed over the life of a swapchain by calling:

```c
// Provided by VK_AMD_display_native_hdr
void vkSetLocalDimmingAMD(
    VkDevice device,
    VkSwapchainKHR swapChain,
    VkBool32 localDimmingEnable);
```

- `device` is the device associated with `swapChain`.
- `swapChain` handle to enable local dimming.
- `localDimmingEnable` specifies whether local dimming is enabled for the swapchain.

### Valid Usage (Implicit)

- VUID-vkSetLocalDimmingAMD-device-parameter
  - `device` must be a valid `VkDevice` handle
- VUID-vkSetLocalDimmingAMD-swapChain-parameter
  - `swapChain` must be a valid `VkSwapchainKHR` handle
- VUID-vkSetLocalDimmingAMD-swapChain-parent
  - `swapChain` must have been created, allocated, or retrieved from `device`

### Valid Usage

- VUID-vkSetLocalDimmingAMD-localDimmingSupport-04618
  - ` VkDisplayNativeHdrSurfaceCapabilitiesAMD::localDimmingSupport` must be supported

If the `pNext` chain of `VkSwapchainCreateInfoKHR` includes a `VkSurfaceFullScreenExclusiveInfoEXT` structure, then that structure specifies the application’s preferred full-screen presentation behavior. If this structure is not present, `fullscreenExclusive` is considered to be `VK_FULL_SCREEN_EXCLUSIVE_DEFAULT_EXT`.

To enable surface counters when creating a swapchain, add a `VkSwapchainCounterCreateInfoEXT` structure to the `pNext` chain of `VkSwapchainCreateInfoKHR`. `VkSwapchainCounterCreateInfoEXT` is defined as:

```c
// Provided by VK_EXT_display_control
typedef struct VkSwapchainCounterCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkSurfaceCounterFlagsEXT surfaceCounters;
} VkSwapchainCounterCreateInfoEXT;
```
• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **surfaceCounters** is a bitmask of `VkSurfaceCounterFlagBitsEXT` specifying surface counters to enable for the swapchain.

---

**Valid Usage**

- VUID-VkSwapchainCounterCreateInfoEXT-surfaceCounters-01244
  The bits in `surfaceCounters` must be supported by `VkSwapchainCreateInfoKHR::surface`, as reported by `vkGetPhysicalDeviceSurfaceCapabilities2EXT`.

---

**Valid Usage (Implicit)**

- VUID-VkSwapchainCounterCreateInfoEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_SWAPCHAIN_COUNTER_CREATE_INFO_EXT`.

- VUID-VkSwapchainCounterCreateInfoEXT-surfaceCounters-parameter
  `surfaceCounters` must be a valid combination of `VkSurfaceCounterFlagBitsEXT` values.

---

The requested counters become active when the first presentation command for the associated swapchain is processed by the presentation engine. To query the value of an active counter, use:

```c
// Provided by VK_EXT_display_control
VkResult vkGetSwapchainCounterEXT(
    VkDevice device,
    VkSwapchainKHR swapchain,
    VkSurfaceCounterFlagBitsEXT counter,
    uint64_t* pCounterValue);
```

• **device** is the `VkDevice` associated with `swapchain`.

• **swapchain** is the swapchain from which to query the counter value.

• **counter** is a `VkSurfaceCounterFlagBitsEXT` value specifying the counter to query.

• **pCounterValue** will return the current value of the counter.

If a counter is not available because the swapchain is out of date, the implementation may return `VK_ERROR_OUT_OF_DATE_KHR`.

---

**Valid Usage**

- VUID-vkGetSwapchainCounterEXT-swapchain-01245
  One or more present commands on `swapchain` must have been processed by the presentation engine.
Valid Usage (Implicit)

- VUID-vkGetSwapchainCounterEXT-device-parameter
  
  *device must* be a valid `VkDevice` handle

- VUID-vkGetSwapchainCounterEXT-swapchain-parameter
  
  *swapchain must* be a valid `VkSwapchainKHR` handle

- VUID-vkGetSwapchainCounterEXT-counter-parameter
  
  *counter must* be a valid `VkSurfaceCounterFlagBitsEXT` value

- VUID-vkGetSwapchainCounterEXT-pCounterValue-parameter
  
  *pCounterValue must* be a valid pointer to a `uint64_t` value

- VUID-vkGetSwapchainCounterEXT-swapchain-parent
  
  *swapchain must* have been created, allocated, or retrieved from `device`

Return Codes

Success

- `VK_SUCCESS`

Failure

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_DEVICE_LOST`
- `VK_ERROR_OUT_OF_DATE_KHR`

To specify compression properties for the swapchain images in this swapchain, add a `VkImageCompressionControlEXT` structure to the `pNext` chain of the `VkSwapchainCreateInfoKHR` structure.

Applications can modify the presentation mode used by the swapchain on a per-presentation basis. However, all presentation modes the application intends to use with the swapchain must be specified at swapchain creation time. To specify more than one presentation mode when creating a swapchain, include the `VkSwapchainPresentModesCreateInfoEXT` structure in the `pNext` chain of the `VkSwapchainCreateInfoKHR` structure.

The `VkSwapchainPresentModesCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_swapchain_maintenance1
typedef struct VkSwapchainPresentModesCreateInfoEXT {
    VkStructureType          sType;
    const void*              pNext;
    uint32_t                 presentModeCount;
    const VkPresentModeKHR*   pPresentModes;
} VkSwapchainPresentModesCreateInfoEXT;
```
• **sType** is a `VkStructureType` value identifying this structure.
• **pNext** is `NULL` or a pointer to a structure extending this structure.
• **presentModeCount** is the number of presentation modes provided.
• **pPresentModes** is a list of presentation modes with `presentModeCount` entries

### Valid Usage

- **VUID-VkSwapchainPresentModesCreateInfoEXT-None-07762**
  Each entry in `pPresentModes` **must** be one of the `VkPresentModeKHR` values returned by `vkGetPhysicalDeviceSurfacePresentModesKHR` for the surface.

- **VUID-VkSwapchainPresentModesCreateInfoEXT-pPresentModes-07763**
  The entries in `pPresentModes` **must** be a subset of the present modes returned in `VkSurfacePresentModeCompatibilityEXT::pPresentModes`, given `VkSwapchainCreateInfoKHR::presentMode` in `VkSurfacePresentModeEXT`.

- **VUID-VkSwapchainPresentModesCreateInfoEXT-presentMode-07764**
  `VkSwapchainCreateInfoKHR::presentMode` **must** be included in `pPresentModes`.

### Valid Usage (Implicit)

- **VUID-VkSwapchainPresentModesCreateInfoEXT-sType-sType**
  `sType` **must** be `VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_MODES_CREATE_INFO_EXT`.

- **VUID-VkSwapchainPresentModesCreateInfoEXT-pPresentModes-parameter**
  `pPresentModes` **must** be a valid pointer to an array of `presentModeCount` valid `VkPresentModeKHR` values.

- **VUID-VkSwapchainPresentModesCreateInfoEXT-presentModeCount-arraylength**
  `presentModeCount` **must** be greater than `0`.

When an application presents a swapchain image with dimensions different than those of the target surface, different behavior is possible on different platforms per their respective specifications:

- Presentation fails and `VK_ERROR_OUT_OF_DATE_KHR` is returned.
- Scaling is done and `VK_SUCCESS` or `VK_SUBOPTIMAL_KHR` is returned.
- Unspecified scaling using an arbitrary combination of stretching, centering and/or clipping.

Applications **can** define specific behavior when creating a swapchain by including the `VkSwapchainPresentScalingCreateInfoEXT` structure in the `pNext` chain of the `VkSwapchainCreateInfoKHR` structure.

The `VkSwapchainPresentScalingCreateInfoEXT` structure is defined as:

```c
typedef struct VkSwapchainPresentScalingCreateInfoEXT {
```
VkStructureType sType;
const void* pNext;
VkPresentScalingFlagsEXT scalingBehavior;
VkPresentGravityFlagsEXT presentGravityX;
VkPresentGravityFlagsEXT presentGravityY;
} VkSwapchainPresentScalingCreateInfoEXT;

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **scalingBehavior** is 0 or the scaling method to use when the dimensions of the surface and swapchain images differ.
- **presentGravityX** is 0 or the x-axis direction in which swapchain image pixels gravitate relative to the surface when **scalingBehavior** does not result in a one-to-one pixel mapping between the scaled swapchain image and the surface.
- **presentGravityY** is 0 or the y-axis direction in which swapchain image pixels gravitate relative to the surface when **scalingBehavior** does not result in a one-to-one pixel mapping between the scaled swapchain image and the surface.

If **scalingBehavior** is 0, the result of presenting a swapchain image with dimensions that do not match the surface dimensions is implementation and platform-dependent. If **presentGravityX** or **presentGravityY** are 0, the presentation gravity must match that defined by the native platform surface on platforms which define surface gravity.

### Valid Usage

- VUID-VkSwapchainPresentScalingCreateInfoEXT-presentGravityX-07765
  If **presentGravityX** is 0, **presentGravityY** must be 0
- VUID-VkSwapchainPresentScalingCreateInfoEXT-presentGravityX-07766
  If **presentGravityX** is not 0, **presentGravityY** must not be 0
- VUID-VkSwapchainPresentScalingCreateInfoEXT-scalingBehavior-07767
  **scalingBehavior** must not have more than one bit set
- VUID-VkSwapchainPresentScalingCreateInfoEXT-presentGravityX-07768
  **presentGravityX** must not have more than one bit set
- VUID-VkSwapchainPresentScalingCreateInfoEXT-presentGravityY-07769
  **presentGravityY** must not have more than one bit set
- VUID-VkSwapchainPresentScalingCreateInfoEXT-scalingBehavior-07770
  **scalingBehavior** must be a valid scaling method for the surface as returned in VkSurfacePresentScalingCapabilitiesEXT::supportedPresentScaling, given VkSwapchainCreateInfoKHR::presentMode in VkSurfacePresentModeEXT
- VUID-VkSwapchainPresentScalingCreateInfoEXT-scalingBehavior-07771
  If the swapchain is created with VkSwapchainPresentModesCreateInfoEXT, **scalingBehavior** must be a valid scaling method for the surface as returned in VkSurfacePresentScalingCapabilitiesEXT::supportedPresentScaling, given each present mode in VkSwapchainPresentModesCreateInfoEXT::pPresentModes in
**VkSurfacePresentModeEXT**

- VUID-VkSwapchainPresentScalingCreateInfoEXT-presentGravityX-07772
  `presentGravityX` **must** be a valid x-axis present gravity for the surface as returned in `VkSurfacePresentScalingCapabilitiesEXT::supportedPresentGravityX`, given `VkSwapchainCreateInfoKHR::presentMode` in `VkSurfacePresentModeEXT`

- VUID-VkSwapchainPresentScalingCreateInfoEXT-presentGravityX-07773
  If the swapchain is created with `VkSwapchainPresentModesCreateInfoEXT`, `presentGravityX` **must** be a valid x-axis present gravity for the surface as returned in `VkSurfacePresentScalingCapabilitiesEXT::supportedPresentGravityX`, given each present mode in `VkSwapchainPresentModesCreateInfoEXT::pPresentModes` in `VkSurfacePresentModeEXT`

- VUID-VkSwapchainPresentScalingCreateInfoEXT-presentGravityY-07774
  `presentGravityY` **must** be a valid y-axis present gravity for the surface as returned in `VkSurfacePresentScalingCapabilitiesEXT::supportedPresentGravityY`, given `VkSwapchainCreateInfoKHR::presentMode` in `VkSurfacePresentModeEXT`

- VUID-VkSwapchainPresentScalingCreateInfoEXT-presentGravityY-07775
  If the swapchain is created with `VkSwapchainPresentModesCreateInfoEXT`, `presentGravityY` **must** be a valid y-axis present gravity for the surface as returned in `VkSurfacePresentScalingCapabilitiesEXT::supportedPresentGravityY`, given each present mode in `VkSwapchainPresentModesCreateInfoEXT::pPresentModes` in `VkSurfacePresentModeEXT`

**Valid Usage (Implicit)**

- VUID-VkSwapchainPresentScalingCreateInfoEXT-sType-sType
  `sType` **must** be `VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_SCALING_CREATE_INFO_EXT`

- VUID-VkSwapchainPresentScalingCreateInfoEXT-scalingBehavior-parameter
  `scalingBehavior` **must** be a valid combination of `VkPresentScalingFlagBitsEXT` values

- VUID-VkSwapchainPresentScalingCreateInfoEXT-presentGravityX-parameter
  `presentGravityX` **must** be a valid combination of `VkPresentGravityFlagBitsEXT` values

- VUID-VkSwapchainPresentScalingCreateInfoEXT-presentGravityY-parameter
  `presentGravityY` **must** be a valid combination of `VkPresentGravityFlagBitsEXT` values

To destroy a swapchain object call:

```c
// Provided by VK_KHR_swapchain
void vkDestroySwapchainKHR(
  VkDevice device,
  VkSwapchainKHR swapchain,
  const VkAllocationCallbacks* pAllocator);
```

- `device` is the `VkDevice` associated with `swapchain`. 
• **swapchain** is the swapchain to destroy.
• **pAllocator** is the allocator used for host memory allocated for the swapchain object when there is no more specific allocator available (see Memory Allocation).

The application **must** not destroy a swapchain until after completion of all outstanding operations on images that were acquired from the swapchain. **swapchain** and all associated VkImage handles are destroyed, and **must** not be acquired or used any more by the application. The memory of each VkImage will only be freed after that image is no longer used by the presentation engine. For example, if one image of the swapchain is being displayed in a window, the memory for that image **may** not be freed until the window is destroyed, or another swapchain is created for the window. Destroying the swapchain does not invalidate the parent VkSurfaceKHR, and a new swapchain **can** be created with it.

When a swapchain associated with a display surface is destroyed, if the image most recently presented to the display surface is from the swapchain being destroyed, then either any display resources modified by presenting images from any swapchain associated with the display surface **must** be reverted by the implementation to their state prior to the first present performed on one of these swapchains, or such resources **must** be left in their current state.

If **swapchain** has exclusive full-screen access, it is released before the swapchain is destroyed.

### Valid Usage

- VUID-vkDestroySwapchainKHR-swapchain-01282
  All uses of presentable images acquired from **swapchain** **must** have completed execution

- VUID-vkDestroySwapchainKHR-swapchain-01283
  If VkAllocationCallbacks were provided when **swapchain** was created, a compatible set of callbacks **must** be provided here

- VUID-vkDestroySwapchainKHR-swapchain-01284
  If no VkAllocationCallbacks were provided when **swapchain** was created, **pAllocator** **must** be NULL

### Valid Usage (Implicit)

- VUID-vkDestroySwapchainKHR-device-parameter
  **device** **must** be a valid VkDevice handle

- VUID-vkDestroySwapchainKHR-swapchain-parameter
  If **swapchain** is not VK_NULL_HANDLE, **swapchain** **must** be a valid VkSwapchainKHR handle

- VUID-vkDestroySwapchainKHR-pAllocator-parameter
  If **pAllocator** is not NULL, **pAllocator** **must** be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkDestroySwapchainKHR-swapchain-parent
  If **swapchain** is a valid handle, it **must** have been created, allocated, or retrieved from **device**
Host Synchronization

- Host access to swapchain must be externally synchronized

When the VK_KHR_display_swapchain extension is enabled, multiple swapchains that share presentable images are created by calling:

```c
// Provided by VK_KHR_display_swapchain
VkResult vkCreateSharedSwapchainsKHR(
    VkDevice device,
    uint32_t swapchainCount,
    const VkSwapchainCreateInfoKHR* pCreateInfos,
    const VkAllocationCallbacks* pAllocator,
    VkSwapchainKHR* pSwapchains);
```

- device is the device to create the swapchains for.
- swapchainCount is the number of swapchains to create.
- pCreateInfos is a pointer to an array of VkSwapchainCreateInfoKHR structures specifying the parameters of the created swapchains.
- pAllocator is the allocator used for host memory allocated for the swapchain objects when there is no more specific allocator available (see Memory Allocation).
- pSwapchains is a pointer to an array of VkSwapchainKHR handles in which the created swapchain objects will be returned.

vkCreateSharedSwapchainsKHR is similar to vkCreateSwapchainKHR, except that it takes an array of VkSwapchainCreateInfoKHR structures, and returns an array of swapchain objects.

The swapchain creation parameters that affect the properties and number of presentable images must match between all the swapchains. If the displays used by any of the swapchains do not use the same presentable image layout or are incompatible in a way that prevents sharing images, swapchain creation will fail with the result code VK_ERROR_INCOMPATIBLE_DISPLAY_KHR. If any error occurs, no swapchains will be created. Images presented to multiple swapchains must be re-acquired from all of them before being modified. After destroying one or more of the swapchains, the remaining swapchains and the presentable images can continue to be used.

Valid Usage (Implicit)

- VUID-vkCreateSharedSwapchainsKHR-device-parameter
  device must be a valid VkDevice handle
- VUID-vkCreateSharedSwapchainsKHR-pCreateInfos-parameter
  pCreateInfos must be a valid pointer to an array of swapchainCount valid VkSwapchainCreateInfoKHR structures
- VUID-vkCreateSharedSwapchainsKHR-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid
**VkAllocationCallbacks** structure

- VUID-vkCreateSharedSwapchainsKHR-pSwapchains-parameter
  
  pSwapchains **must** be a valid pointer to an array of `swapchainCount` `VkSwapchainKHR` handles

- VUID-vkCreateSharedSwapchainsKHR-swapchainCount-arraylength
  
  `swapchainCount` **must** be greater than 0

---

### Host Synchronization

- Host access to `pCreateInfos[].surface` **must** be externally synchronized
- Host access to `pCreateInfos[].oldSwapchain` **must** be externally synchronized

---

### Return Codes

**Success**

- VK_SUCCESS

**Failure**

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_INCOMPATIBLE_DISPLAY_KHR
- VK_ERROR_DEVICE_LOST
- VK_ERROR_SURFACE_LOST_KHR

---

To obtain the array of presentable images associated with a swapchain, call:

```c
// Provided by VK_KHR_swapchain

VkResult vkGetSwapchainImagesKHR(
    VkDevice device,          
    VkSwapchainKHR swapchain, 
    uint32_t* pSwapchainImageCount, 
    VkImage* pSwapchainImages);
```

- `device` is the device associated with `swapchain`.
- `swapchain` is the swapchain to query.
- `pSwapchainImageCount` is a pointer to an integer related to the number of presentable images available or queried, as described below.
- `pSwapchainImages` is either `NULL` or a pointer to an array of `VkImage` handles.

If `pSwapchainImages` is `NULL`, then the number of presentable images for `swapchain` is returned in `pSwapchainImageCount`. Otherwise, `pSwapchainImageCount` **must** point to a variable set by the user to
the number of elements in the `pSwapchainImages` array, and on return the variable is overwritten with the number of structures actually written to `pSwapchainImages`. If the value of `pSwapchainImageCount` is less than the number of presentable images for `swapchain`, at most `pSwapchainImageCount` structures will be written, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available presentable images were returned.

### Valid Usage (Implicit)

- **VUID-vkGetSwapchainImagesKHR-device-parameter**
  - `device` must be a valid `VkDevice` handle
- **VUID-vkGetSwapchainImagesKHR-swapchain-parameter**
  - `swapchain` must be a valid `VkSwapchainKHR` handle
- **VUID-vkGetSwapchainImagesKHR-pSwapchainImageCount-parameter**
  - `pSwapchainImageCount` must be a valid pointer to a `uint32_t` value
- **VUID-vkGetSwapchainImagesKHR-pSwapchainImages-parameter**
  - If the value referenced by `pSwapchainImageCount` is not 0, and `pSwapchainImages` is not NULL, `pSwapchainImages` must be a valid pointer to an array of `pSwapchainImageCount` `VkImage` handles
- **VUID-vkGetSwapchainImagesKHR-swapchain-parent**
  - `swapchain` must have been created, allocated, or retrieved from `device`

### Return Codes

**Success**

- `VK_SUCCESS`
- `VK_INCOMPLETE`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

**Note**

By knowing all presentable images used in the swapchain, the application can create command buffers that reference these images prior to entering its main rendering loop. However, command buffers are not allowed to reference presentable images created with `VK_SWAPCHAIN_CREATE_DEFERRED_MEMORY_ALLOCATION_BIT_EXT` until their indices have been returned from `vkAcquireNextImageKHR` at least once.

Images returned by `vkGetSwapchainImagesKHR` are fully backed by memory before they are passed to the application, as if they are each bound completely and contiguously to a single `VkDeviceMemory` object, unless the swapchain is created with the `VK_SWAPCHAIN_CREATE_DEFERRED_MEMORY_ALLOCATION_BIT_EXT` flag. All presentable images are initially...
in the `VK_IMAGE_LAYOUT_UNDEFINED` layout, thus before using presentable images, the application must transition them to a valid layout for the intended use.

Further, the lifetime of presentable images is controlled by the implementation, so applications must not destroy a presentable image. See `vkDestroySwapchainKHR` for further details on the lifetime of presentable images.

Images can also be created by using `vkCreateImage` with `VkImageSwapchainCreateInfoKHR` and bound to swapchain memory using `vkBindImageMemory2` with `VkBindImageMemorySwapchainInfoKHR`. These images can be used anywhere swapchain images are used, and are useful in logical devices with multiple physical devices to create peer memory bindings of swapchain memory. These images and bindings have no effect on what memory is presented. Unlike images retrieved from `vkGetSwapchainImagesKHR`, these images must be destroyed with `vkDestroyImage`.

To acquire an available presentable image to use, and retrieve the index of that image, call:

```c
// Provided by VK_KHR_swapchain
VkResult vkAcquireNextImageKHR(
    VkDevice device,
    VkSwapchainKHR swapchain,
    uint64_t timeout,
    VkSemaphore semaphore,
    VkFence fence,
    uint32_t* pImageIndex);
```

- **device** is the device associated with **swapchain**.
- **swapchain** is the non-retired swapchain from which an image is being acquired.
- **timeout** specifies how long the function waits, in nanoseconds, if no image is available.
- **semaphore** is **VK_NULL_HANDLE** or a semaphore to signal.
- **fence** is **VK_NULL_HANDLE** or a fence to signal.
- **pImageIndex** is a pointer to a `uint32_t` in which the index of the next image to use (i.e. an index into the array of images returned by `vkGetSwapchainImagesKHR`) is returned.

If the **swapchain** has been created with the `VK_SWAPCHAIN_CREATE_DEFERRED_MEMORY_ALLOCATION_BIT_EXT` flag, the image whose index is returned in **pImageIndex** will be fully backed by memory before this call returns to the application, as if it is bound completely and contiguously to a single `VkDeviceMemory` object.

**Valid Usage**

- VUID-vkAcquireNextImageKHR-swapchain-01285
  **swapchain** must not be in the retired state

- VUID-vkAcquireNextImageKHR-semaphore-01286
  If **semaphore** is not **VK_NULL_HANDLE** it must be unsigned
• VUID-vkAcquireNextImageKHR-semaphore-01779
  If semaphore is not VK_NULL_HANDLE it must not have any uncompleted signal or wait operations pending

• VUID-vkAcquireNextImageKHR-fence-01287
  If fence is not VK_NULL_HANDLE it must be unsignaled and must not be associated with any other queue command that has not yet completed execution on that queue

• VUID-vkAcquireNextImageKHR-semaphore-01780
  semaphore and fence must not both be equal to VK_NULL_HANDLE

• VUID-vkAcquireNextImageKHR-surface-07783
  If forward progress cannot be guaranteed for the surface used to create the swapchain member of pAcquireInfo, the timeout member of pAcquireInfo must not be UINT64_MAX

• VUID-vkAcquireNextImageKHR-semaphore-03265
  semaphore must have a VkSemaphoreType of VK_SEMAPHORE_TYPE_BINARY

Valid Usage (Implicit)

• VUID-vkAcquireNextImageKHR-device-parameter
  device must be a valid VkDevice handle

• VUID-vkAcquireNextImageKHR-swapchain-parameter
  swapchain must be a valid VkSwapchainKHR handle

• VUID-vkAcquireNextImageKHR-semaphore-parameter
  If semaphore is not VK_NULL_HANDLE, semaphore must be a valid VkSemaphore handle

• VUID-vkAcquireNextImageKHR-fence-parameter
  If fence is not VK_NULL_HANDLE, fence must be a valid VkFence handle

• VUID-vkAcquireNextImageKHR-pImageIndex-parameter
  pImageIndex must be a valid pointer to a uint32_t value

• VUID-vkAcquireNextImageKHR-swapchain-parent
  swapchain must have been created, allocated, or retrieved from device

• VUID-vkAcquireNextImageKHR-semaphore-parent
  If semaphore is a valid handle, it must have been created, allocated, or retrieved from device

• VUID-vkAcquireNextImageKHR-fence-parent
  If fence is a valid handle, it must have been created, allocated, or retrieved from device

Host Synchronization

• Host access to swapchain must be externally synchronized
• Host access to semaphore must be externally synchronized
• Host access to fence must be externally synchronized
Return Codes

Success
- VK_SUCCESS
- VK_TIMEOUT
- VK_NOT_READY
- VK_SUBOPTIMAL_KHR

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_DEVICE_LOST
- VK_ERROR_OUT_OF_DATE_KHR
- VK_ERROR_SURFACE_LOST_KHR
- VK_ERROR_FULL_SCREEN_EXCLUSIVE_MODE_LOST_EXT

If an image is acquired successfully, `vkAcquireNextImageKHR` must either return VK_SUCCESS or VK_SUBOPTIMAL_KHR. The implementation may return VK_SUBOPTIMAL_KHR if the swapchain no longer matches the surface properties exactly, but can still be used for presentation.

When successful, `vkAcquireNextImageKHR` acquires a presentable image from `swapchain` that an application can use, and sets `pImageIndex` to the index of that image within the swapchain. The presentation engine may not have finished reading from the image at the time it is acquired, so the application must use `semaphore` and/or `fence` to ensure that the image layout and contents are not modified until the presentation engine reads have completed. Once `vkAcquireNextImageKHR` successfully acquires an image, the semaphore signal operation referenced by `semaphore`, if not VK_NULL_HANDLE, and the fence signal operation referenced by `fence`, if not VK_NULL_HANDLE, are submitted for execution. If `vkAcquireNextImageKHR` does not successfully acquire an image, `semaphore` and `fence` are unaffected. The order in which images are acquired is implementation-dependent, and may be different than the order the images were presented.

If `timeout` is zero, then `vkAcquireNextImageKHR` does not wait, and will either successfully acquire an image, or fail and return VK_NOT_READY if no image is available.

If the specified timeout period expires before an image is acquired, `vkAcquireNextImageKHR` returns VK_TIMEOUT. If `timeout` is UINT64_MAX, the timeout period is treated as infinite, and `vkAcquireNextImageKHR` will block until an image is acquired or an error occurs.

Let S be the number of images in `swapchain`. If `swapchain` is created with VkSwapchainPresentModesCreateInfoEXT, let M be the maximum of the values in VkSurfaceCapabilitiesKHR::minImageCount when queried with each present mode in VkSwapchainPresentModesCreateInfoEXT::pPresentModes in VkSurfacePresentModeEXT. Otherwise, let M be the value of VkSurfaceCapabilitiesKHR::minImageCount without a VkSurfacePresentModeEXT as part of the query input.
vkAcquireNextImageKHR **should** not be called if the number of images that the application has currently acquired is greater than \( S-M \). If \( \text{vkAcquireNextImageKHR} \) is called when the number of images that the application has currently acquired is less than or equal to \( S-M \), \( \text{vkAcquireNextImageKHR} \) **must** return in finite time with an allowed VkResult code.

**Note**

Returning a result in finite time guarantees that the implementation cannot deadlock an application, or suspend its execution indefinitely with correct API usage. Acquiring too many images at once may block indefinitely, which is covered by valid usage when attempting to use UINT64_MAX. For example, a scenario here is when a compositor holds on to images which are currently being presented, and there are not any vacant images left to be acquired.

**Note**

\( \text{VK_SUBOPTIMAL_KHR} \) **may** happen, for example, if the platform surface has been resized but the platform is able to scale the presented images to the new size to produce valid surface updates. It is up to the application to decide whether it prefers to continue using the current swapchain in this state, or to re-create the swapchain to better match the platform surface properties.

If the swapchain images no longer match native surface properties, either \( \text{VK_SUBOPTIMAL_KHR} \) or \( \text{VK_ERROR_OUT_OF_DATE_KHR} \) **must** be returned. If \( \text{VK_ERROR_OUT_OF_DATE_KHR} \) is returned, no image is acquired and attempts to present previously acquired images to the swapchain will also fail with \( \text{VK_ERROR_OUT_OF_DATE_KHR} \). Applications need to create a new swapchain for the surface to continue presenting if \( \text{VK_ERROR_OUT_OF_DATE_KHR} \) is returned.

If device loss occurs (see Lost Device) before the timeout has expired, \( \text{vkAcquireNextImageKHR} \) **must** return in finite time with either one of the allowed success codes, or \( \text{VK_ERROR_DEVICE_LOST} \).

If semaphore is not \( \text{VK_NULL_HANDLE} \), the semaphore **must** be unsignaled, with no signal or wait operations pending. It will become signaled when the application can use the image.

**Note**

Use of semaphore allows rendering operations to be recorded and submitted before the presentation engine has completed its use of the image.

If fence is not equal to \( \text{VK_NULL_HANDLE} \), the fence **must** be unsignaled, with no signal operations pending. It will become signaled when the application can use the image.

**Note**

Applications **should** not rely on \( \text{vkAcquireNextImageKHR} \) blocking in order to meter their rendering speed. The implementation **may** return from this function immediately regardless of how many presentation requests are queued, and regardless of when queued presentation requests will complete relative to the call. Instead, applications **can** use fence to meter their frame generation work to match the presentation rate.
An application must wait until either the semaphore or fence is signaled before accessing the image’s data.

**Note**

When the presentable image will be accessed by some stage S, the recommended idiom for ensuring correct synchronization is:

- The VkSubmitInfo used to submit the image layout transition for execution includes vkAcquireNextImageKHR:semaphore in its pWaitSemaphores member, with the corresponding element of pWaitDstStageMask including S.
- The synchronization command that performs any necessary image layout transition includes S in both the srcStageMask and dstStageMask.

After a successful return, the image indicated by pImageIndex and its data will be unmodified compared to when it was presented.

**Note**

Exclusive ownership of presentable images corresponding to a swapchain created with VK_SHARING_MODE_EXCLUSIVE as defined in Resource Sharing is not altered by a call to vkAcquireNextImageKHR. That means upon the first acquisition from such a swapchain presentable images are not owned by any queue family, while at subsequent acquisitions the presentable images remain owned by the queue family the image was previously presented on.

The possible return values for vkAcquireNextImageKHR depend on the timeout provided:

- **VK_SUCCESS** is returned if an image became available.
- **VK_ERROR_SURFACE_LOST_KHR** is returned if the surface becomes no longer available.
- **VK_NOT_READY** is returned if timeout is zero and no image was available.
- **VK_TIMEOUT** is returned if timeout is greater than zero and less than UINT64_MAX, and no image became available within the time allowed.
- **VK_SUBOPTIMAL_KHR** is returned if an image became available, and the swapchain no longer matches the surface properties exactly, but can still be used to present to the surface successfully.

**Note**

This may happen, for example, if the platform surface has been resized but the platform is able to scale the presented images to the new size to produce valid surface updates. It is up to the application to decide whether it prefers to continue using the current swapchain indefinitely or temporarily in this state, or to re-create the swapchain to better match the platform surface properties.

- **VK_ERROR_OUT_OF_DATE_KHR** is returned if the surface has changed in such a way that it is no longer compatible with the swapchain, and further presentation requests using the swapchain will fail. Applications must query the new surface properties and recreate their swapchain if
they wish to continue presenting to the surface.

If the native surface and presented image sizes no longer match, presentation may fail unless the swapchain is created with a non-zero value in `VkSwapchainPresentScalingCreateInfoEXT::scalingBehavior`. If presentation does succeed, the mapping from the presented image to the native surface is defined by the `VkSwapchainPresentScalingCreateInfoEXT` structure if provided. Otherwise it is implementation-defined. It is the application’s responsibility to detect surface size changes and react appropriately. If presentation fails because of a mismatch in the surface and presented image sizes, a `VK_ERROR_OUT_OF_DATE_KHR` error will be returned.

Note

For example, consider a 4x3 window/surface that gets resized to be 3x4 (taller than wider). On some window systems, the portion of the window/surface that was previously and still is visible (the 3x3 part) will contain the same contents as before, while the remaining parts of the window will have undefined contents. Other window systems may squash/stretch the image to fill the new window size without any undefined contents, or apply some other mapping.

To acquire an available presentable image to use, and retrieve the index of that image, call:

```c
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with VK_KHR_swapchain
VkResult vkAcquireNextImage2KHR(
    VkDevice device,
    const VkAcquireNextImageInfoKHR* pAcquireInfo,
    uint32_t* pImageIndex);
```

- `device` is the device associated with `swapchain`.
- `pAcquireInfo` is a pointer to a `VkAcquireNextImageInfoKHR` structure containing parameters of the acquire.
- `pImageIndex` is a pointer to a `uint32_t` that is set to the index of the next image to use.

If the `swapchain` has been created with the `VK_SWAPCHAIN_CREATE_DEFERRED_MEMORY_ALLOCATION_BIT_EXT` flag, the image whose index is returned in `pImageIndex` will be fully backed by memory before this call returns to the application.

**Valid Usage**

- VUID-vkAcquireNextImage2KHR-surface-07784
  If forward progress cannot be guaranteed for the surface used to create `swapchain`, the `timeout` member of `pAcquireInfo` must not be `UINT64_MAX`

**Valid Usage (Implicit)**

- VUID-vkAcquireNextImage2KHR-device-parameter
device must be a valid VkDevice handle

- VUID-vkAcquireNextImage2KHR-pAcquireInfo-parameter
  pAcquireInfo must be a valid pointer to a valid VkAcquireNextImageInfoKHR structure

- VUID-vkAcquireNextImage2KHR-pImageIndex-parameter
  pImageIndex must be a valid pointer to a uint32_t value

### Return Codes

**Success**
- VK_SUCCESS
- VK_TIMEOUT
- VK_NOT_READY
- VK_SUBOPTIMAL_KHR

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_DEVICE_LOST
- VK_ERROR_OUT_OF_DATE_KHR
- VK_ERROR_SURFACE_LOST_KHR
- VK_ERROR_FULL_SCREEN_EXCLUSIVE_MODE_LOST_EXT

The VkAcquireNextImageInfoKHR structure is defined as:

```c
typedef struct VkAcquireNextImageInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkSwapchainKHR swapchain;
    uint64_t timeout;
    VkSemaphore semaphore;
    VkFence fence;
    uint32_t deviceMask;
} VkAcquireNextImageInfoKHR;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **swapchain** is a non-retired swapchain from which an image is acquired.
- **timeout** specifies how long the function waits, in nanoseconds, if no image is available.
- **semaphore** is VK_NULL_HANDLE or a semaphore to signal.
• fence is VK_NULL_HANDLE or a fence to signal.
• deviceMask is a mask of physical devices for which the swapchain image will be ready to use when the semaphore or fence is signaled.

If vkAcquireNextImageKHR is used, the device mask is considered to include all physical devices in the logical device.

Note

vkAcquireNextImage2KHR signals at most one semaphore, even if the application requests waiting for multiple physical devices to be ready via the deviceMask. However, only a single physical device can wait on that semaphore, since the semaphore becomes unsignaled when the wait succeeds. For other physical devices to wait for the image to be ready, it is necessary for the application to submit semaphore signal operation(s) to that first physical device to signal additional semaphore(s) after the wait succeeds, which the other physical device(s) can wait upon.

Valid Usage

• VUID-VkAcquireNextImageInfoKHR-swapchain-01675
  swapchain must not be in the retired state

• VUID-VkAcquireNextImageInfoKHR-semaphore-01288
  If semaphore is not VK_NULL_HANDLE it must be unsignaled

• VUID-VkAcquireNextImageInfoKHR-semaphore-01781
  If semaphore is not VK_NULL_HANDLE it must not have any uncompleted signal or wait operations pending

• VUID-VkAcquireNextImageInfoKHR-fence-01289
  If fence is not VK_NULL_HANDLE it must be unsignaled and must not be associated with any other queue command that has not yet completed execution on that queue

• VUID-VkAcquireNextImageInfoKHR-semaphore-01782
  semaphore and fence must not both be equal to VK_NULL_HANDLE

• VUID-VkAcquireNextImageInfoKHR-deviceMask-01290
  deviceMask must be a valid device mask

• VUID-VkAcquireNextImageInfoKHR-deviceMask-01291
  deviceMask must not be zero

• VUID-VkAcquireNextImageInfoKHR-semaphore-03266
  semaphore must have a VkSemaphoreType of VK_SEMAPHORE_TYPE_BINARY

Valid Usage (Implicit)

• VUID-VkAcquireNextImageInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_ACQUIRE_NEXT_IMAGE_INFO_KHR
• VUID-VkAcquireNextImageInfoKHR-pNext-pNext
  pNext must be NULL

• VUID-VkAcquireNextImageInfoKHR-swapchain-parameter
  swapchain must be a valid VkSwapchainKHR handle

• VUID-VkAcquireNextImageInfoKHR-semaphore-parameter
  If semaphore is not VK_NULL_HANDLE, semaphore must be a valid VkSemaphore handle

• VUID-VkAcquireNextImageInfoKHR-fence-parameter
  If fence is not VK_NULL_HANDLE, fence must be a valid VkFence handle

• VUID-VkAcquireNextImageInfoKHR-commonparent
  Each of fence, semaphore, and swapchain that are valid handles of non-ignored parameters
  must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

• Host access to swapchain must be externally synchronized
• Host access to semaphore must be externally synchronized
• Host access to fence must be externally synchronized

After queueing all rendering commands and transitioning the image to the correct layout, to queue
an image for presentation, call:

// Provided by VK_KHR_swapchain
VkResult vkQueuePresentKHR(
  VkQueue queue,
  const VkPresentInfoKHR* pPresentInfo);

• queue is a queue that is capable of presentation to the target surface’s platform on the same
device as the image’s swapchain.
• pPresentInfo is a pointer to a VkPresentInfoKHR structure specifying parameters of the
  presentation.

Note
There is no requirement for an application to present images in the same order
that they were acquired - applications can arbitrarily present any image that is
currently acquired.

Valid Usage

• VUID-vkQueuePresentKHR-pSwapchains-01292
  Each element of pSwapchains member of pPresentInfo must be a swapchain that is created
  for a surface for which presentation is supported from queue as determined using a call to
  vkGetPhysicalDeviceSurfaceSupportKHR
Any writes to memory backing the images referenced by the `pImageIndices` and `pSwapchains` members of `pPresentInfo`, that are available before `vkQueuePresentKHR` is executed, are automatically made visible to the read access performed by the presentation engine. This automatic visibility operation for an image happens-after the semaphore signal operation, and happens-before the presentation engine accesses the image.

Queueing an image for presentation defines a set of queue operations, including waiting on the semaphores and submitting a presentation request to the presentation engine. However, the scope of this set of queue operations does not include the actual processing of the image by the presentation engine.

**Note**

The origin of the native orientation of the surface coordinate system is not specified in the Vulkan specification; it depends on the platform. For most platforms the origin is by default upper-left, meaning the pixel of the presented `VkImage` at coordinates (0,0) would appear at the upper left pixel of the platform surface (assuming `VK_SURFACE_TRANSFORM_IDENTITY_BIT_KHR`, and the display standing the right way up).

If `vkQueuePresentKHR` fails to enqueue the corresponding set of queue operations, it may return `VK_ERROR_OUT_OF_HOST_MEMORY` or `VK_ERROR_OUT_OF_DEVICE_MEMORY`. If it does, the implementation must ensure that the state and contents of any resources or synchronization primitives referenced is unaffected by the call or its failure.

If `vkQueuePresentKHR` fails in such a way that the implementation is unable to make that guarantee, the implementation must return `VK_ERROR_DEVICE_LOST`.

However, if the presentation request is rejected by the presentation engine with an error `VK_ERROR_OUT_OF_DATE_KHR`, `VK_ERROR_FULL_SCREEN_EXCLUSIVE_MODE_LOST_EXT`, or `VK_ERROR_SURFACE_LOST_KHR`, the set of queue operations are still considered to be enqueued and thus any semaphore wait operation specified in `VkPresentInfoKHR` will execute when the corresponding
queue operation is complete.

Calls to `vkQueuePresentKHR` may block, but must return in finite time.

If any swapchain member of `pPresentInfo` was created with `VK_FULL_SCREEN_EXCLUSIVE_APPLICATION_CONTROLLED_EXT`, `VK_ERROR_FULL_SCREEN_EXCLUSIVE_MODE_LOST_EXT` will be returned if that swapchain does not have exclusive full-screen access, possibly for implementation-specific reasons outside of the application’s control.

---

**Valid Usage (Implicit)**

- VUID-vkQueuePresentKHR-queue-parameter
  queue must be a valid `VkQueue` handle
- VUID-vkQueuePresentKHR-pPresentInfo-parameter
  `pPresentInfo` must be a valid pointer to a valid `VkPresentInfoKHR` structure

---

**Host Synchronization**

- Host access to queue must be externally synchronized
- Host access to `pPresentInfo->pWaitSemaphores[]` must be externally synchronized
- Host access to `pPresentInfo->pSwapchains[]` must be externally synchronized

---

**Command Properties**

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---

**Return Codes**

**Success**

- `VK_SUCCESS`
- `VK_SUBOPTIMAL_KHR`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_DEVICE_LOST`
- `VK_ERROR_OUT_OF_DATE_KHR`
- `VK_ERROR_SURFACE_LOST_KHR`
The `VkPresentInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_swapchain
typedef struct VkPresentInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t waitSemaphoreCount;
    const VkSemaphore* pWaitSemaphores;
    uint32_t swapchainCount;
    const VkSwapchainKHR* pSwapchains;
    const uint32_t* pImageIndices;
    VkResult* pResults;
} VkPresentInfoKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **waitSemaphoreCount** is the number of semaphores to wait for before issuing the present request. The number may be zero.
- **pWaitSemaphores** is NULL or a pointer to an array of `VkSemaphore` objects with `waitSemaphoreCount` entries, and specifies the semaphores to wait for before issuing the present request.
- **swapchainCount** is the number of swapchains being presented to by this command.
- **pSwapchains** is a pointer to an array of `VkSwapchainKHR` objects with `swapchainCount` entries.
- **pImageIndices** is a pointer to an array of indices into the array of each swapchain’s presentable images, with `swapchainCount` entries. Each entry in this array identifies the image to present on the corresponding entry in the `pSwapchains` array.
- **pResults** is a pointer to an array of `VkResult` typed elements with `swapchainCount` entries. Applications that do not need per-swapchain results can use NULL for `pResults`. If non-NULL, each entry in `pResults` will be set to the `VkResult` for presenting the swapchain corresponding to the same index in `pSwapchains`.

Before an application can present an image, the image’s layout must be transitioned to the `VK_IMAGE_LAYOUT_PRESENT_SRC_KHR` layout, or for a shared presentable image the `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR` layout.

**Note**

When transitioning the image to `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR` or `VK_IMAGE_LAYOUT_PRESENT_SRC_KHR`, there is no need to delay subsequent processing, or perform any visibility operations (as `vkQueuePresentKHR` performs automatic visibility operations). To achieve this, the `dstAccessMask` member of the `VkImageMemoryBarrier` should be set to 0, and the `dstStageMask` parameter should be set to `VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT`.
Valid Usage

- **VUID-VkPresentInfoKHR-pSwapchain-09231**
  Elements of `pSwapchain` must be unique

- **VUID-VkPresentInfoKHR-pImageIndices-01430**
  Each element of `pImageIndices` must be the index of a presentable image acquired from the swapchain specified by the corresponding element of the `pSwapchains` array, and the presented image subresource must be in the `VK_IMAGE_LAYOUT_PRESENT_SRC_KHR` or `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR` layout at the time the operation is executed on a `VkDevice`

- **VUID-VkPresentInfoKHR-pNext-06235**
  If a `VkPresentIdKHR` structure is included in the `pNext` chain, and the `presentId` feature is not enabled, each `presentIds` entry in that structure must be NULL

- **VUID-VkPresentInfoKHR-pSwapchains-09199**
  If any element of the `pSwapchains` array has been created with `VkSwapchainPresentModesCreateInfoEXT`, all of the elements of this array must be created with `VkSwapchainPresentModesCreateInfoEXT`

Valid Usage (Implicit)

- **VUID-VkPresentInfoKHR-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_PRESENT_INFO_KHR`

- **VUID-VkPresentInfoKHR-pNext-pNext**
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either NULL or a pointer to a valid instance of `VkDeviceGroupPresentInfoKHR`, `VkDisplayPresentInfoKHR`, `VkFrameBoundaryEXT`, `VkPresentFrameTokenGGP`, `VkPresentIdKHR`, `VkPresentRegionsKHR`, `VkPresentTimesInfoGOOGLE`, `VkSwapchainPresentFenceInfoEXT`, or `VkSwapchainPresentModeInfoEXT`

- **VUID-VkPresentInfoKHR-sType-unique**
  The `sType` value of each struct in the `pNext` chain must be unique

- **VUID-VkPresentInfoKHR-pWaitSemaphores-parameter**
  If `waitSemaphoreCount` is not 0, `pWaitSemaphores` must be a valid pointer to an array of `waitSemaphoreCount` valid `VkSemaphore` handles

- **VUID-VkPresentInfoKHR-pSwapchains-parameter**
  `pSwapchains` must be a valid pointer to an array of `swapchainCount` valid `VkSwapchainKHR` handles

- **VUID-VkPresentInfoKHR-pImageIndices-parameter**
  `pImageIndices` must be a valid pointer to an array of `swapchainCount` `uint32_t` values

- **VUID-VkPresentInfoKHR-pResults-parameter**
  If `pResults` is not NULL, `pResults` must be a valid pointer to an array of `swapchainCount` `VkResult` values

- **VUID-VkPresentInfoKHR-swapchainCount-arraylength**
  2978
**swapchainCount** must be greater than 0

- VUID-VkPresentInfoKHR-commonparent
  Both of the elements of `pSwapchains`, and the elements of `pWaitSemaphores` that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same `VkDevice`

When the `VK_KHR_incremental_present` extension is enabled, additional fields can be specified that allow an application to specify that only certain rectangular regions of the presentable images of a swapchain are changed. This is an optimization hint that a presentation engine may use to only update the region of a surface that is actually changing. The application still must ensure that all pixels of a presented image contain the desired values, in case the presentation engine ignores this hint. An application can provide this hint by adding a `VkPresentRegionsKHR` structure to the `pNext` chain of the `VkPresentInfoKHR` structure.

The ` VkPresentRegionsKHR` structure is defined as:

```c
// Provided by VK_KHR_incremental_present
typedef struct VkPresentRegionsKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t swapchainCount;
    const VkPresentRegionKHR* pRegions;
} VkPresentRegionsKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `swapchainCount` is the number of swapchains being presented to by this command.
- `pRegions` is `NULL` or a pointer to an array of `VkPresentRegionKHR` elements with `swapchainCount` entries. If not `NULL`, each element of `pRegions` contains the region that has changed since the last present to the swapchain in the corresponding entry in the `VkPresentInfoKHR::pSwapchains` array.

### Valid Usage

- VUID-VkPresentRegionsKHR-swapchainCount-01260
  `swapchainCount` must be the same value as `VkPresentInfoKHR::swapchainCount`, where `VkPresentInfoKHR` is included in the `pNext` chain of this `VkPresentRegionsKHR` structure

### Valid Usage (Implicit)

- VUID-VkPresentRegionsKHR-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_PRESENT_REGIONS_KHR`

- VUID-VkPresentRegionsKHR-pRegions-parameter
  If `pRegions` is not `NULL`, `pRegions` must be a valid pointer to an array of `swapchainCount` valid `VkPresentRegionKHR` structures
For a given image and swapchain, the region to present is specified by the `VkPresentRegionKHR` structure, which is defined as:

```c
// Provided by VK_KHR_incremental_present
typedef struct VkPresentRegionKHR {
    uint32_t rectangleCount;
    const VkRectLayerKHR* pRectangles;
} VkPresentRegionKHR;
```

- `rectangleCount` is the number of rectangles in `pRectangles`, or zero if the entire image has changed and should be presented.
- `pRectangles` is either `NULL` or a pointer to an array of `VkRectLayerKHR` structures. The `VkRectLayerKHR` structure is the framebuffer coordinates, plus layer, of a portion of a presentable image that has changed and must be presented. If non-`NULL`, each entry in `pRectangles` is a rectangle of the given image that has changed since the last image was presented to the given swapchain. The rectangles must be specified relative to `VkSurfaceCapabilitiesKHR::currentTransform`, regardless of the swapchain’s `preTransform`. The presentation engine will apply the `preTransform` transformation to the rectangles, along with any further transformation it applies to the image content.

### Valid Usage (Implicit)

- VUID-VkPresentRegionKHR-pRectangles-parameter
  
  If `rectangleCount` is not 0, and `pRectangles` is not `NULL`, `pRectangles` must be a valid pointer to an array of `rectangleCount` valid `VkRectLayerKHR` structures.

The `VkRectLayerKHR` structure is defined as:

```c
// Provided by VK_KHR_incremental_present
typedef struct VkRectLayerKHR {
    VkOffset2D offset;
    VkExtent2D extent;
    uint32_t layer;
} VkRectLayerKHR;
```

- `offset` is the origin of the rectangle, in pixels.
- `extent` is the size of the rectangle, in pixels.
- `layer` is the layer of the image. For images with only one layer, the value of `layer` must be 0.

Some platforms allow the size of a surface to change, and then scale the pixels of the image to fit the surface. `VkRectLayerKHR` specifies pixels of the swapchain’s image(s), which will be constant for
the life of the swapchain.

Valid Usage

- VUID-VkRectLayerKHR-offset-04864
  The sum of `offset` and `extent`, after being transformed according to the `preTransform` member of the `VkSwapchainCreateInfoKHR` structure, **must** be no greater than the `imageExtent` member of the `VkSwapchainCreateInfoKHR` structure passed to `vkCreateSwapchainKHR`

- VUID-VkRectLayerKHR-layer-01262
  `layer` **must** be less than the `imageArrayLayers` member of the `VkSwapchainCreateInfoKHR` structure passed to `vkCreateSwapchainKHR`

When the `VK_KHR_display_swapchain` extension is enabled, additional fields **can** be specified when presenting an image to a swapchain by setting `VkPresentInfoKHR::pNext` to point to a `VkDisplayPresentInfoKHR` structure.

The `VkDisplayPresentInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_display_swapchain
typedef struct VkDisplayPresentInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkRect2D srcRect;
    VkRect2D dstRect;
    VkBool32 persistent;
} VkDisplayPresentInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `srcRect` is a rectangular region of pixels to present. It **must** be a subset of the image being presented. If `VkDisplayPresentInfoKHR` is not specified, this region will be assumed to be the entire presentable image.
- `dstRect` is a rectangular region within the visible region of the swapchain’s display mode. If `VkDisplayPresentInfoKHR` is not specified, this region will be assumed to be the entire visible region of the swapchain’s mode. If the specified rectangle is a subset of the display mode’s visible region, content from display planes below the swapchain’s plane will be visible outside the rectangle. If there are no planes below the swapchain’s, the area outside the specified rectangle will be black. If portions of the specified rectangle are outside of the display’s visible region, pixels mapping only to those portions of the rectangle will be discarded.
- `persistent`: If this is `VK_TRUE`, the display engine will enable buffered mode on displays that support it. This allows the display engine to stop sending content to the display until a new image is presented. The display will instead maintain a copy of the last presented image. This allows less power to be used, but **may** increase presentation latency. If `VkDisplayPresentInfoKHR` is not specified, persistent mode will not be used.
If the extent of the `srcRect` and `dstRect` are not equal, the presented pixels will be scaled accordingly.

### Valid Usage

- **VUID-VkDisplayPresentInfoKHR-srcRect-01257**
  `srcRect` **must** specify a rectangular region that is a subset of the image being presented

- **VUID-VkDisplayPresentInfoKHR-dstRect-01258**
  `dstRect` **must** specify a rectangular region that is a subset of the `visibleRegion` parameter of the display mode the swapchain being presented uses

- **VUID-VkDisplayPresentInfoKHR-persistentContent-01259**
  If the `persistentContent` member of the `VkDisplayPropertiesKHR` structure returned by `vkGetPhysicalDeviceDisplayPropertiesKHR` for the display the present operation targets is `VK_FALSE`, then `persistent` **must** be `VK_FALSE`

### Valid Usage (Implicit)

- **VUID-VkDisplayPresentInfoKHR-sType-sType**
  `sType` **must** be `VK_STRUCTURE_TYPE_DISPLAY_PRESENT_INFO_KHR`

If the `pNext` chain of `VkPresentInfoKHR` includes a `VkDeviceGroupPresentInfoKHR` structure, then that structure includes an array of device masks and a device group present mode.

The `VkDeviceGroupPresentInfoKHR` structure is defined as:

```c
// Provided by VK_VERSION_1_1 with VK_KHR_swapchain, VK_KHR_device_group with VK_KHR_swapchain
typedef struct VkDeviceGroupPresentInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t swapchainCount;
    const uint32_t* pDeviceMasks;
    VkDeviceGroupPresentModeFlagBitsKHR mode;
} VkDeviceGroupPresentInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `swapchainCount` is zero or the number of elements in `pDeviceMasks`.
- `pDeviceMasks` is a pointer to an array of device masks, one for each element of `VkPresentInfoKHR::pSwapchains`.
- `mode` is a `VkDeviceGroupPresentModeFlagBitsKHR` value specifying the device group present mode that will be used for this present.

If `mode` is `VKDEVICEGROUP_PRESENTMODE_LOCAL_BIT_KHR`, then each element of `pDeviceMasks` selects
which instance of the swapchain image is presented. Each element of \texttt{pDeviceMasks} must have exactly one bit set, and the corresponding physical device must have a presentation engine as reported by \texttt{VkDeviceGroupPresentCapabilitiesKHR}.

If \texttt{mode} is \texttt{VK\_DEVICE\_GROUP\_PRESENT\_MODE\_REMOTE\_BIT\_KHR}, then each element of \texttt{pDeviceMasks} selects which instance of the swapchain image is presented. Each element of \texttt{pDeviceMasks} must have exactly one bit set, and some physical device in the logical device must include that bit in its \texttt{VkDeviceGroupPresentCapabilitiesKHR::presentMask}.

If \texttt{mode} is \texttt{VK\_DEVICE\_GROUP\_PRESENT\_MODE\_SUM\_BIT\_KHR}, then each element of \texttt{pDeviceMasks} selects which instances of the swapchain image are component-wise summed and the sum of those images is presented. If the sum in any component is outside the representable range, the value of that component is undefined. Each element of \texttt{pDeviceMasks} must have a value for which all set bits are set in one of the elements of \texttt{VkDeviceGroupPresentCapabilitiesKHR::presentMask}.

If \texttt{mode} is \texttt{VK\_DEVICE\_GROUP\_PRESENT\_MODE\_LOCAL\_MULTI\_DEVICE\_BIT\_KHR}, then each element of \texttt{pDeviceMasks} selects which instance(s) of the swapchain images are presented. For each bit set in each element of \texttt{pDeviceMasks}, the corresponding physical device must have a presentation engine as reported by \texttt{VkDeviceGroupPresentCapabilitiesKHR}.

If \texttt{VkDeviceGroupPresentInfoKHR} is not provided or \texttt{swapchainCount} is zero then the masks are considered to be 1. If \texttt{VkDeviceGroupPresentInfoKHR} is not provided, \texttt{mode} is considered to be \texttt{VK\_DEVICE\_GROUP\_PRESENT\_MODE\_LOCAL\_BIT\_KHR}.

### Valid Usage

- **VUID-VkDeviceGroupPresentInfoKHR-swapchainCount-01297**
  \texttt{swapchainCount} must equal 0 or \texttt{VkPresentInfoKHR::swapchainCount}

- **VUID-VkDeviceGroupPresentInfoKHR-mode-01298**
  If \texttt{mode} is \texttt{VK\_DEVICE\_GROUP\_PRESENT\_MODE\_LOCAL\_BIT\_KHR}, then each element of \texttt{pDeviceMasks} must have exactly one bit set, and the corresponding element of \texttt{VkDeviceGroupPresentCapabilitiesKHR::presentMask} must be non-zero

- **VUID-VkDeviceGroupPresentInfoKHR-mode-01299**
  If \texttt{mode} is \texttt{VK\_DEVICE\_GROUP\_PRESENT\_MODE\_REMOTE\_BIT\_KHR}, then each element of \texttt{pDeviceMasks} must have exactly one bit set, and some physical device in the logical device must include that bit in its \texttt{VkDeviceGroupPresentCapabilitiesKHR::presentMask}

- **VUID-VkDeviceGroupPresentInfoKHR-mode-01300**
  If \texttt{mode} is \texttt{VK\_DEVICE\_GROUP\_PRESENT\_MODE\_SUM\_BIT\_KHR}, then each element of \texttt{pDeviceMasks} must have a value for which all set bits are set in one of the elements of \texttt{VkDeviceGroupPresentCapabilitiesKHR::presentMask}

- **VUID-VkDeviceGroupPresentInfoKHR-mode-01301**
  If \texttt{mode} is \texttt{VK\_DEVICE\_GROUP\_PRESENT\_MODE\_LOCAL\_MULTI\_DEVICE\_BIT\_KHR}, then for each bit set in each element of \texttt{pDeviceMasks}, the corresponding element of \texttt{VkDeviceGroupPresentCapabilitiesKHR::presentMask} must be non-zero

- **VUID-VkDeviceGroupPresentInfoKHR-pDeviceMasks-01302**
  The value of each element of \texttt{pDeviceMasks} must be equal to the device mask passed in
VkAcquireNextImageInfoKHR::deviceMask when the image index was last acquired

- VUID-VkDeviceGroupPresentInfoKHR-mode-01303
  mode must have exactly one bit set, and that bit must have been included in VkDeviceGroupSwapchainCreateInfoKHR::modes

Valid Usage (Implicit)

- VUID-VkDeviceGroupPresentInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_DEVICE_GROUP_PRESENT_INFO_KHR

- VUID-VkDeviceGroupPresentInfoKHR-pDeviceMasks-parameter
  If swapchainCount is not 0, pDeviceMasks must be a valid pointer to an array of swapchainCount uint32_t values

- VUID-VkDeviceGroupPresentInfoKHR-mode-parameter
  mode must be a valid VkDeviceGroupPresentModeFlagBitsKHR value

When the VK_GOOGLE_display_timing extension is enabled, additional fields can be specified that allow an application to specify the earliest time that an image should be displayed. This allows an application to avoid stutter that is caused by an image being displayed earlier than planned. Such stuttering can occur with both fixed and variable-refresh-rate displays, because stuttering occurs when the geometry is not correctly positioned for when the image is displayed. An application can instruct the presentation engine that an image should not be displayed earlier than a specified time by adding a VkPresentTimesInfoGOOGLE structure to the pNext chain of the VkPresentInfoKHR structure.

The VkPresentTimesInfoGOOGLE structure is defined as:

```c
// Provided by VK_GOOGLE_display_timing
typedef struct VkPresentTimesInfoGOOGLE {
    VkStructureType sType;
    const void* pNext;
    uint32_t swapchainCount;
    const VkPresentTimeGOOGLE* pTimes;
} VkPresentTimesInfoGOOGLE;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- swapchainCount is the number of swapchains being presented to by this command.
- pTimes is NULL or a pointer to an array of VkPresentTimeGOOGLE elements with swapchainCount entries. If not NULL, each element of pTimes contains the earliest time to present the image corresponding to the entry in the VkPresentInfoKHR::pImageIndices array.

Valid Usage

- VUID-VkPresentTimesInfoGOOGLE-swapchainCount-01247
The `VkPresentTimeGOOGLE` structure is defined as:

```c
// Provided by VK_GOOGLE_display_timing
typedef struct VkPresentTimeGOOGLE {
    uint32_t presentID;
    uint64_t desiredPresentTime;
} VkPresentTimeGOOGLE;
```

- **presentID** is an application-provided identification value, that can be used with the results of `vkGetPastPresentationTimingGOOGLE`, in order to uniquely identify this present. In order to be useful to the application, it should be unique within some period of time that is meaningful to the application.

- **desiredPresentTime** specifies that the image given should not be displayed to the user any earlier than this time. `desiredPresentTime` is a time in nanoseconds, relative to a monotonically-increasing clock (e.g. `CLOCK_MONOTONIC` (see `clock_gettime(2)`) on Android and Linux). A value of zero specifies that the presentation engine may display the image at any time. This is useful when the application desires to provide `presentID`, but does not need a specific `desiredPresentTime`.

The `VkPresentIdKHR` structure is defined as:

```c
// Provided by VK_KHR_present_id
typedef struct VkPresentIdKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t swapchainCount;
    const uint64_t* pPresentIds;
} VkPresentIdKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.

- **pNext** is `NULL` or a pointer to a structure extending this structure.
• **swapchainCount** is the number of swapchains being presented to the `vkQueuePresentKHR` command.

• **pPresentIds** is NULL or a pointer to an array of `uint64_t` with `swapchainCount` entries. If not NULL, each non-zero value in `pPresentIds` specifies the present id to be associated with the presentation of the swapchain with the same index in the `vkQueuePresentKHR` call.

For applications to be able to reference specific presentation events queued by a call to `vkQueuePresentKHR`, an identifier needs to be associated with them. When the `presentId` feature is enabled, applications **can** include the `VkPresentIdKHR` structure in the `pNext` chain of the `VkPresentInfoKHR` structure to supply identifiers.

Each `VkSwapchainKHR` has a `presentId` associated with it. This value is initially set to zero when the `VkSwapchainKHR` is created.

When a `VkPresentIdKHR` structure with a non-NULL `pPresentIds` is included in the `pNext` chain of a `VkPresentInfoKHR` structure, each `pSwapchains` entry has a presentId associated in the `pPresentIds` array at the same index as the swapchain in the `pSwapchains` array. If this `presentId` is non-zero, then the application **can** later use this value to refer to that image presentation. A value of zero indicates that this presentation has no associated `presentId`. A non-zero `presentId` **must** be greater than any non-zero `presentId` passed previously by the application for the same swapchain.

There is no requirement for any precise timing relationship between the presentation of the image to the user and the update of the `presentId` value, but implementations **should** make this as close as possible to the presentation of the first pixel in the new image to the user.

---

### Valid Usage

- **VUID-VkPresentIdKHR-swapchainCount-04998**
  - `swapchainCount` **must** be the same value as `VkPresentInfoKHR::swapchainCount`, where this `VkPresentIdKHR` is in the `pNext` chain of the `VkPresentInfoKHR` structure

- **VUID-VkPresentIdKHR-presentIds-04999**
  - Each `presentIds` entry **must** be greater than any previous `presentIds` entry passed for the associated `pSwapchains` entry

---

### Valid Usage (Implicit)

- **VUID-VkPresentIdKHR-sType-sType**
  - `sType` **must** be `VK_STRUCTURE_TYPE_PRESENT_ID_KHR`

- **VUID-VkPresentIdKHR-pPresentIds-parameter**
  - If `pPresentIds` is not NULL, `pPresentIds` **must** be a valid pointer to an array of `swapchainCount uint64_t` values

- **VUID-VkPresentIdKHR-swapchainCount-arraylength**
  - `swapchainCount` **must** be greater than 0

---

When the `presentWait` feature is enabled, an application **can** wait for an image to be presented to
the user by first specifying a presentId for the target presentation by adding a `VkPresentIdKHR` structure to the `pNext` chain of the `VkPresentInfoKHR` structure and then waiting for that presentation to complete by calling:

```c
// Provided by VK_KHR_present_wait
VkResult vkWaitForPresentKHR(
    VkDevice device,
    VkSwapchainKHR swapchain,
    uint64_t presentId,
    uint64_t timeout);
```

- `device` is the device associated with `swapchain`.
- `swapchain` is the non-retired swapchain on which an image was queued for presentation.
- `presentId` is the presentation presentId to wait for.
- `timeout` is the timeout period in units of nanoseconds. `timeout` is adjusted to the closest value allowed by the implementation-dependent timeout accuracy, which may be substantially longer than one nanosecond, and may be longer than the requested period.

`vkWaitForPresentKHR` waits for the presentId associated with `swapchain` to be increased in value so that it is at least equal to `presentId`.

For `VK_PRESENT_MODE_MAILBOX_KHR` (or other present mode where images may be replaced in the presentation queue) any wait of this type associated with such an image must be signaled no later than a wait associated with the replacing image would be signaled.

When the presentation has completed, the presentId associated with the related `pSwapchains` entry will be increased in value so that it is at least equal to the value provided in the `VkPresentIdKHR` structure.

There is no requirement for any precise timing relationship between the presentation of the image to the user and the update of the presentId value, but implementations should make this as close as possible to the presentation of the first pixel in the next image being presented to the user.

The call to `vkWaitForPresentKHR` will block until either the presentId associated with `swapchain` is greater than or equal to `presentId`, or `timeout` nanoseconds passes. When the swapchain becomes OUT_OF_DATE, the call will either return `VK_SUCCESS` (if the image was delivered to the presentation engine and may have been presented to the user) or will return early with status `VK_ERROR_OUT_OF_DATE_KHR` (if the image was not presented to the user).

As an exception to the normal rules for objects which are externally synchronized, the `swapchain` passed to `vkWaitForPresentKHR` may be simultaneously used by other threads in calls to functions other than `vkDestroySwapchainKHR`. Access to the swapchain data associated with this extension must be atomic within the implementation.

**Valid Usage**

- VUID-vkWaitForPresentKHR-swapchain-04997
**swapchain** must not be in the retired state

- VUID-vkWaitForPresentKHR-presentWait-06234
  The `presentWait` feature must be enabled

---

### Valid Usage (Implicit)

- VUID-vkWaitForPresentKHR-device-parameter
  `device` must be a valid `VkDevice` handle

- VUID-vkWaitForPresentKHR-swapchain-parameter
  `swapchain` must be a valid `VkSwapchainKHR` handle

- VUID-vkWaitForPresentKHR-swapchain-parent
  `swapchain` must have been created, allocated, or retrieved from `device`

---

### Host Synchronization

- Host access to `swapchain` must be externally synchronized

---

### Return Codes

#### Success

- `VK_SUCCESS`
- `VK_TIMEOUT`
- `VK_SUBOPTIMAL_KHR`

#### Failure

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_DEVICE_LOST`
- `VK_ERROR_OUT_OF_DATE_KHR`
- `VK_ERROR_SURFACE_LOST_KHR`
- `VK_ERROR_FULL_SCREEN_EXCLUSIVE_MODE_LOST_EXT`

---

When the `VK_GGP_frame_token` extension is enabled, a Google Games Platform frame token can be specified when presenting an image to a swapchain by adding a `VkPresentFrameTokenGGP` structure to the `pNext` chain of the `VkPresentInfoKHR` structure.

The `VkPresentFrameTokenGGP` structure is defined as:

```c
// Provided by VK_GGP_frame_token
typedef struct VkPresentFrameTokenGGP {
```
The `VkPresentFrameTokenGGP` structure is defined as:

```c
typedef struct VkPresentFrameTokenGGP {
    VkStructureType sType;
    const void* pNext;
    GgpFrameToken frameToken;
} VkPresentFrameTokenGGP;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **frameToken** is the Google Games Platform frame token.

### Valid Usage

- VUID-VkPresentFrameTokenGGP-frameToken-02680
  frameToken must be a valid `GgpFrameToken`

### Valid Usage (Implicit)

- VUID-VkPresentFrameTokenGGP-sType-sType
  **sType** must be `VK_STRUCTURE_TYPE_PRESENT_FRAME_TOKEN_GGP`

The `VkSwapchainPresentModeInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_swapchain_maintenance1
typedef struct VkSwapchainPresentModeInfoEXT {
    VkStructureType sType;
    const void* pNext;
    uint32_t swapchainCount;
    const VkPresentModeKHR* pPresentModes;
} VkSwapchainPresentModeInfoEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **swapchainCount** is the number of swapchains being presented to by this command.
- **pPresentModes** is a list of presentation modes with `swapchainCount` entries.

If the **pNext** chain of `VkPresentInfoKHR` includes a `VkSwapchainPresentModeInfoEXT` structure, then that structure defines the presentation modes used for the current and subsequent presentation operations.

When the application changes present modes with `VkSwapchainPresentModeInfoEXT`, images that have already been queued for presentation will continue to be presented according to the previous present mode. The current image being queued for presentation and subsequent images will be presented according to the new present mode. The behavior during the transition between the two modes is defined as follows.
• Transition from VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR to VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR: the presentation engine updates the shared presentable image according to the behavior of VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR.

• Transition from VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR to VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR: the presentation engine may update the shared presentable image or defer that to its regular refresh cycle, according to the behavior of VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR.

• Transition between VK_PRESENT_MODE_FIFO_KHR and VK_PRESENT_MODE_FIFO_RELAXED_KHR: Images continue to be appended to the same FIFO queue, and the behavior with respect to waiting for vertical blanking period will follow the new mode for current and subsequent images.

• Transition from VK_PRESENT_MODE_IMMEDIATE_KHR to VK_PRESENT_MODE_FIFO_KHR or VK_PRESENT_MODE_FIFO_RELAXED_KHR: As all prior present requests in the VK_PRESENT_MODE_IMMEDIATE_KHR mode are applied immediately, there are no outstanding present operations in this mode, and current and subsequent images are appended to the FIFO queue and presented according to the new mode.

• Transition from VK_PRESENT_MODE_MAILBOX_KHR to VK_PRESENT_MODE_FIFO_KHR or VK_PRESENT_MODE_FIFO_RELAXED_KHR: Presentation in both modes require waiting for the next vertical blanking period, with VK_PRESENT_MODE_MAILBOX_KHR allowing the pending present operation to be replaced by a new one. In this case, the current present operation will replace the pending present operation and is applied according to the new mode.

• Transition from VK_PRESENT_MODE_FIFO_KHR or VK_PRESENT_MODE_FIFO_RELAXED_KHR to VK_PRESENT_MODE_IMMEDIATE_KHR or VK_PRESENT_MODE_MAILBOX_KHR: If the FIFO queue is empty, presentation is done according to the behavior of the new mode. If there are present operations in the FIFO queue, once the last present operation is performed based on the respective vertical blanking period, the current and subsequent updates are applied according to the new mode.

• The behavior during transition between any other present modes, if possible, is implementation defined.

Valid Usage

• VUID-VkSwapchainPresentModeInfoEXT-swapchainCount-07760
  swapchainCount must be equal to VkPresentInfoKHR::swapchainCount

• VUID-VkSwapchainPresentModeInfoEXT-pPresentModes-07761
  Each entry in pPresentModes must be a presentation mode specified in VkSwapchainPresentModesCreateInfoEXT::pPresentModes when creating the entry’s corresponding swapchain

Valid Usage (Implicit)

• VUID-VkSwapchainPresentModeInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_MODE_INFO_EXT

• VUID-VkSwapchainPresentModeInfoEXT-pPresentModes-parameter
  pPresentModes must be a valid pointer to an array of swapchainCount valid
The `VkSwapchainPresentFenceInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_swapchain_maintenance1
typedef struct VkSwapchainPresentFenceInfoEXT {
    VkStructureType sType;
    const void* pNext;
    uint32_t swapchainCount;
    const VkFence* pFences;
} VkSwapchainPresentFenceInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `swapchainCount` is the number of swapchains being presented to by this command.
- `pFences` is a list of fences with `swapchainCount` entries. Each entry must be `VK_NULL_HANDLE` or the handle of a fence to signal when the relevant operations on the associated swapchain have completed.

The set of *queue operations* defined by queuing an image for presentation, as well as operations performed by the presentation engine access the payloads of objects associated with the presentation operation. The associated objects include:

- The swapchain image, its implicitly bound memory, and any other resources bound to that memory.
- The wait semaphores specified when queuing the image for presentation.

The application can provide a fence that the implementation will signal when all such queue operations have completed and the presentation engine has taken a reference to the payload of any objects it accesses as part of the present operation. For all binary wait semaphores imported by the presentation engine using the equivalent of reference transference, as described in *Importing Semaphore Payloads*, this fence must not signal until all such semaphore payloads have been reset by the presentation engine.

The application can destroy the wait semaphores associated with a given presentation operation when at least one of the associated fences is signaled, and can destroy the swapchain when the fences associated with all past presentation requests referring to that swapchain have signaled.

Fences associated with presentations to the same swapchain on the same `VkQueue` must be signaled in the same order as the present operations.

To specify a fence for each swapchain in a present operation, include the `VkSwapchainPresentFenceInfoEXT` structure in the `pNext` chain of the `VkPresentInfoKHR` structure.
Valid Usage

• VUID-VkSwapchainPresentFenceInfoEXT-swapchainCount-07757
  swapchainCount must be equal to VkPresentInfoKHR::swapchainCount

• VUID-VkSwapchainPresentFenceInfoEXT-pFences-07758
  Each element of pFences must be unsignaled

• VUID-VkSwapchainPresentFenceInfoEXT-pFences-07759
  Each element of pFences must not be associated with any other queue command that has not yet completed execution on that queue

Valid Usage (Implicit)

• VUID-VkSwapchainPresentFenceInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_FENCE_INFO_EXT

• VUID-VkSwapchainPresentFenceInfoEXT-pFences-parameter
  pFences must be a valid pointer to an array of swapchainCount valid VkFence handles

• VUID-VkSwapchainPresentFenceInfoEXT-swapchainCount-arraylength
  swapchainCount must be greater than 0

vkQueuePresentKHR releases the acquisition of the images referenced by imageIndices. The queue family corresponding to the queue vkQueuePresentKHR is executed on must have ownership of the presented images as defined in Resource Sharing. vkQueuePresentKHR does not alter the queue family ownership, but the presented images must not be used again before they have been reacquired using vkAcquireNextImageKHR.

The processing of the presentation happens in issue order with other queue operations, but semaphores have to be used to ensure that prior rendering and other commands in the specified queue complete before the presentation begins. The presentation command itself does not delay processing of subsequent commands on the queue, however, presentation requests sent to a particular queue are always performed in order. Exact presentation timing is controlled by the semantics of the presentation engine and native platform in use.

If an image is presented to a swapchain created from a display surface, the mode of the associated display will be updated, if necessary, to match the mode specified when creating the display surface. The mode switch and presentation of the specified image will be performed as one atomic operation.

The result codes VK_ERROR_OUT_OF_DATE_KHR and VK_SUBOPTIMAL_KHR have the same meaning when returned by vkQueuePresentKHR as they do when returned by vkAcquireNextImageKHR. If multiple swapchains are presented, the result code is determined applying the following rules in order:

• If the device is lost, VK_ERROR_DEVICE_LOST is returned.

• If any of the target surfaces are no longer available the error VK_ERROR_SURFACE_LOST_KHR is returned.
• If any of the presents would have a result of `VK_ERROR_OUT_OF_DATE_KHR` if issued separately then `VK_ERROR_OUT_OF_DATE_KHR` is returned.

• If any of the presents would have a result of `VK_ERROR_FULL_SCREEN_EXCLUSIVE_MODE_LOST_EXT` if issued separately then `VK_ERROR_FULL_SCREEN_EXCLUSIVE_MODE_LOST_EXT` is returned.

• If any of the presents would have a result of `VK_SUBOPTIMAL_KHR` if issued separately then `VK_SUBOPTIMAL_KHR` is returned.

• Otherwise `VK_SUCCESS` is returned.

Presentation is a read-only operation that will not affect the content of the presentable images. Upon reacquiring the image and transitioning it away from the `VK_IMAGE_LAYOUT_PRESENT_SRC_KHR` layout, the contents will be the same as they were prior to transitioning the image to the present source layout and presenting it. However, if a mechanism other than Vulkan is used to modify the platform window associated with the swapchain, the content of all presentable images in the swapchain becomes undefined.

**Note**
The application can continue to present any acquired images from a retired swapchain as long as the swapchain has not entered a state that causes `vkQueuePresentKHR` to return `VK_ERROR_OUT_OF_DATE_KHR`.

To release images previously acquired through `vkAcquireNextImage2KHR` or `vkAcquireNextImageKHR`, call:

```c
// Provided by VK_EXT_swapchain_maintenance1
VkResult vkReleaseSwapchainImagesEXT(
    VkDevice device,
    const VkReleaseSwapchainImagesInfoEXT* pReleaseInfo);
```

• `device` is the device associated with `VkReleaseSwapchainImagesInfoEXT::swapchain`.

• `pReleaseInfo` is a pointer to a `VkReleaseSwapchainImagesInfoEXT` structure containing parameters of the release.

Only images that are not in use by the device can be released.

Releasing images is a read-only operation that will not affect the content of the released images. Upon reacquiring the image, the image contents and its layout will be the same as they were prior to releasing it. However, if a mechanism other than Vulkan is used to modify the platform window associated with the swapchain, the content of all presentable images in the swapchain becomes undefined.

**Note**
This functionality is useful during swapchain recreation, where acquired images from the old swapchain can be released instead of presented.
Valid Usage (Implicit)

- VUID-vkReleaseSwapchainImagesEXT-device-parameter
device must be a valid VkDevice handle

- VUID-vkReleaseSwapchainImagesEXT-pReleaseInfo-parameter
pReleaseInfo must be a valid pointer to a valid VkReleaseSwapchainImagesInfoEXT structure

Return Codes

Success
  - VK_SUCCESS

Failure
  - VK_ERROR_SURFACE_LOST_KHR

The VkReleaseSwapchainImagesInfoEXT structure is defined as:

```c
// Provided by VK_EXT_swapchain_maintenance1
typedef struct VkReleaseSwapchainImagesInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkSwapchainKHR swapchain;
    uint32_t imageIndexCount;
    const uint32_t* pImageIndices;
} VkReleaseSwapchainImagesInfoEXT;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- swapchain is a swapchain to which images are being released.
- imageIndexCount is the number of image indices to be released.
- pImageIndices is a pointer to an array of indices into the array of swapchain's presentable images, with imageIndexCount entries.

Valid Usage

- VUID-VkReleaseSwapchainImagesInfoEXT-pImageIndices-07785
  Each element of pImageIndices must be the index of a presentable image acquired from the swapchain specified by swapchain

- VUID-VkReleaseSwapchainImagesInfoEXT-pImageIndices-07786
  All uses of presentable images identified by elements of pImageIndices must have completed execution
Valid Usage (Implicit)

- VUID-VkReleaseSwapchainImagesInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_RELEASE_SWAPCHAIN_IMAGES_INFO_EXT
- VUID-VkReleaseSwapchainImagesInfoEXT-pNext-pNext
  pNext must be NULL
- VUID-VkReleaseSwapchainImagesInfoEXT-swapchain-parameter
  swapchain must be a valid VkSwapchainKHR handle
- VUID-VkReleaseSwapchainImagesInfoEXT-pImageIndices-parameter
  pImageIndices must be a valid pointer to an array of imageIndexCount uint32_t values
- VUID-VkReleaseSwapchainImagesInfoEXT-imageIndexCount-arraylength
  imageIndexCount must be greater than 0

Host Synchronization

- Host access to swapchain must be externally synchronized

34.11. Hdr Metadata

This section describes how to improve color reproduction of content to better reproduce colors as seen on the reference monitor. Definitions below are from the associated SMPTE 2086, CTA 861.3 and CIE 15:2004 specifications.

To provide Hdr metadata to an implementation, call:

```c
// Provided by VK_EXT_hdr_metadata
void vkSetHdrMetadataEXT(  
    VkDevice          device,  
    uint32_t          swapchainCount,  
    const VkSwapchainKHR* pSwapchains,  
    const VkHdrMetadataEXT* pMetadata);
```

- `device` is the logical device where the swapchain(s) were created.
- `swapchainCount` is the number of swapchains included in `pSwapchains`.
- `pSwapchains` is a pointer to an array of `swapchainCount` VkSwapchainKHR handles.
- `pMetadata` is a pointer to an array of `swapchainCount` VkHdrMetadataEXT structures.

The metadata will be applied to the specified VkSwapchainKHR objects at the next vkQueuePresentKHR call using that VkSwapchainKHR object. The metadata will persist until a subsequent vkSetHdrMetadataEXT changes it.
Valid Usage (Implicit)

- VUID-vkSetHdrMetadataEXT-device-parameter
  
  `device` must be a valid `VkDevice` handle

- VUID-vkSetHdrMetadataEXT-pSwapchains-parameter
  
  `pSwapchains` must be a valid pointer to an array of `swapchainCount` valid `VkSwapchainKHR` handles

- VUID-vkSetHdrMetadataEXT-pMetadata-parameter
  
  `pMetadata` must be a valid pointer to an array of `swapchainCount` valid `VkHdrMetadataEXT` structures

- VUID-vkSetHdrMetadataEXT-swapchainCount-arraylength
  
  `swapchainCount` must be greater than 0

- VUID-vkSetHdrMetadataEXT-pSwapchains-parent
  
  Each element of `pSwapchains` must have been created, allocated, or retrieved from `device`

The `VkHdrMetadataEXT` structure is defined as:

```c
// Provided by VK_EXT_hdr_metadata
typedef struct VkHdrMetadataEXT {
    VkStructureType sType;
    const void* pNext;
    VkXYColorEXT displayPrimaryRed;
    VkXYColorEXT displayPrimaryGreen;
    VkXYColorEXT displayPrimaryBlue;
    VkXYColorEXT whitePoint;
    float maxLuminance;
    float minLuminance;
    float maxContentLightLevel;
    float maxFrameAverageLightLevel;
} VkHdrMetadataEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `displayPrimaryRed` is a `VkXYColorEXT` structure specifying the reference monitor’s red primary in chromaticity coordinates
- `displayPrimaryGreen` is a `VkXYColorEXT` structure specifying the reference monitor’s green primary in chromaticity coordinates
- `displayPrimaryBlue` is a `VkXYColorEXT` structure specifying the reference monitor’s blue primary in chromaticity coordinates
- `whitePoint` is a `VkXYColorEXT` structure specifying the reference monitor’s white-point in chromaticity coordinates
- `maxLuminance` is the maximum luminance of the reference monitor in nits
• **minLuminance** is the minimum luminance of the reference monitor in nits
• **maxContentLightLevel** is content’s maximum luminance in nits
• **maxFrameAverageLightLevel** is the maximum frame average light level in nits

### Valid Usage (Implicit)

- VUID-VkHdrMetadataEXT-sType-sType
  - `sType` **must** be `VK_STRUCTURE_TYPE_HDR_METADATA_EXT`
- VUID-VkHdrMetadataEXT-pNext-pNext
  - `pNext` **must** be `NULL`

![Note]
The validity and use of this data is outside the scope of Vulkan.

The **VkXYColorEXT** structure is defined as:

```c
// Provided by VK_EXT_hdr_metadata
typedef struct VkXYColorEXT {
  float x;
  float y;
} VkXYColorEXT;
```

- **x** is the x chromaticity coordinate.
- **y** is the y chromaticity coordinate.

Chromaticity coordinates are as specified in CIE 15:2004 “Calculation of chromaticity coordinates” (Section 7.3) and are limited to between 0 and 1 for real colors for the reference monitor.

### 34.12. Present Barrier

The **VK_NV_present_barrier** extension allows applications to synchronize corresponding presentation requests across multiple swapchains using the **present barrier**. A swapchain is said to be using the **present barrier** if the swapchain is created by adding a `VkSwapchainPresentBarrierCreateInfoNV` structure to the `pNext` chain of the `VkSwapchainCreateInfoKHR` structure, and setting `VkSwapchainPresentBarrierCreateInfoNV::presentBarrierEnable` to true.

A set of corresponding presentation requests is defined as exactly one queued presentation request associated with each swapchain using the present barrier, whether or not that queued request has executed. A given presentation request is added, when created by calling `vkQueuePresentKHR` and specifying a swapchain using the present barrier, either to the oldest existing set of corresponding requests for which there is no existing member associated with the request’s swapcahin, or to a new set of corresponding requests if no such set exists.

A set of corresponding requests is said to be **full** when it contains one request from each swapchain.
using the present barrier. Queued presentation of an image to a swapchain using the present barrier is deferred by the implementation until the set of corresponding requests is full, and the visibility operations associated with all requests in that set, as described by vkQueuePresentKHR, have completed.

Additionally, the set of swapchains using the present barrier can be in the same process, or different processes running under the same operating system. And if the required synchronization hardware is connected and correctly configured, this extension also supports applications to synchronize corresponding presentation requests using the present barrier across distributed systems. However, the configuration mechanism of the required hardware is outside the scope of the Vulkan specification and this extension.

The VkSwapchainPresentBarrierCreateInfoNV structure is defined as:

```c
// Provided by VK_NV_present_barrier
typedef struct VkSwapchainPresentBarrierCreateInfoNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 presentBarrierEnable;
} VkSwapchainPresentBarrierCreateInfoNV;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **presentBarrierEnable** is a boolean value indicating a request for using the present barrier.

If the pNext chain of VkSwapchainCreateInfoKHR does not include this structure, the default value for presentBarrierEnable is VK_FALSE, meaning the swapchain does not request to use the present barrier. Additionally, when recreating a swapchain that was using the present barrier, and the pNext chain of VkSwapchainCreateInfoKHR does not include this structure, it means the swapchain will stop using the present barrier.

**Valid Usage (Implicit)**

- VUID-VkSwapchainPresentBarrierCreateInfoNV-sType-sType
  
  **sType** must be VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_BARRIER_CREATE_INFO_NV

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Chapter 35. Deferred Host Operations

Certain Vulkan commands are inherently expensive for the host CPU to execute. It is often desirable to offload such work onto background threads, and to parallelize the work across multiple CPUs. The concept of deferred operations allows applications and drivers to coordinate the execution of expensive host commands using an application-managed thread pool.

The VK_KHR_deferred_host_operations extension defines the infrastructure and usage patterns for deferrable commands, but does not specify any commands as deferrable. This is left to additional dependent extensions. Commands must not be deferred unless the deferral is specifically allowed by another extension which depends on VK_KHR_deferred_host_operations. This specification will refer to such extensions as deferral extensions.

35.1. Requesting Deferral

When an application requests an operation deferral, the implementation may defer the operation. When deferral is requested and the implementation defers any operation, the implementation must return VK_OPERATION_DEFERRED_KHR as the success code if no errors occurred. When deferral is requested, the implementation should defer the operation when the workload is significant, however if the implementation chooses not to defer any of the requested operations and instead executes all of them immediately, the implementation must return VK_OPERATION_NOT_DEFERRED_KHR as the success code if no errors occurred.

A deferred operation is created complete with an initial result value of VK_SUCCESS. The deferred operation becomes pending when an operation has been successfully deferred with that deferred operation object.

A deferred operation is considered pending until the deferred operation completes. A pending deferred operation becomes complete when it has been fully executed by one or more threads. Pending deferred operations will never complete until they are joined by an application thread, using vkDeferredOperationJoinKHR. Applications can join multiple threads to the same deferred operation, enabling concurrent execution of subtasks within that operation.

The application can query the status of a VkDeferredOperationKHR using the vkGetDeferredOperationMaxConcurrencyKHR or vkGetDeferredOperationResultKHR commands.

Parameters to the command requesting a deferred operation may be accessed by the implementation at any time until the deferred operation enters the complete state. The application must obey the following rules while a deferred operation is pending:

- Externally synchronized parameters must not be accessed.
- Pointer parameters must not be modified (e.g. reallocated/freed).
- The contents of pointer parameters which may be read by the command must not be modified.
- The contents of pointer parameters which may be written by the command must not be read.
- Vulkan object parameters must not be passed as externally synchronized parameters to any other command.
When the deferred operation is complete, the application should call `vkGetDeferredOperationResultKHR` to obtain the `VkResult` indicating success or failure of the operation. The `VkResult` value returned will be one of the values that the command requesting the deferred operation is able to return. Writes to output parameters of the requesting command will happen-before the deferred operation is complete.

When a deferral is requested for a command, the implementation may perform memory management operations on the allocator supplied to `vkCreateDeferredOperationKHR` for the deferred operation object, as described in the Memory Allocation chapter. Such allocations must occur on the thread which requests deferral.

If an allocator was supplied for the deferred command at the time of the deferral request, then the implementation may perform memory management operations on this allocator during the execution of `vkDeferredOperationJoinKHR`. These operations may occur concurrently and may be performed by any joined thread. The application must ensure that the supplied allocator is able to operate correctly under these conditions.

### 35.2. Deferred Host Operations API

The `VkDeferredOperationKHR` handle is defined as:

```c
// Provided by VK_KHR_deferred_host_operations
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkDeferredOperationKHR)
```

This handle refers to a tracking structure which manages the execution state for a deferred command.

To construct the tracking object for a deferred command, call:

```c
// Provided by VK_KHR_deferred_host_operations
VkResult vkCreateDeferredOperationKHR(
    VkDevice device,
    const VkAllocationCallbacks* pAllocator,
    VkDeferredOperationKHR* pDeferredOperation);
```

- `device` is the device which owns operation.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pDeferredOperation` is a pointer to a handle in which the created `VkDeferredOperationKHR` is returned.

#### Valid Usage (Implicit)

- VUID-vkCreateDeferredOperationKHR-device-parameter
  - `device` must be a valid `VkDevice` handle
- VUID-vkCreateDeferredOperationKHR-pAllocator-parameter
If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkCreateDeferredOperationKHR-pDeferredOperation-parameter pDeferredOperation must be a valid pointer to a VkDeferredOperationKHR handle

---

## Return Codes

### Success
- VK_SUCCESS

### Failure
- VK_ERROR_OUT_OF_HOST_MEMORY

To assign a thread to a deferred operation, call:

```c
// Provided by VK_KHR_deferred_host_operations
VkResult vkDeferredOperationJoinKHR(
    VkDevice device,
    VkDeferredOperationKHR operation);
```

- `device` is the device which owns `operation`.
- `operation` is the deferred operation that the calling thread should work on.

The `vkDeferredOperationJoinKHR` command will execute a portion of the deferred operation on the calling thread.

The return value will be one of the following:

- A return value of `VK_SUCCESS` indicates that `operation` is complete. The application should use `vkGetDeferredOperationResultKHR` to retrieve the result of `operation`.
- A return value of `VK_THREAD_DONE_KHR` indicates that the deferred operation is not complete, but there is no work remaining to assign to threads. Future calls to `vkDeferredOperationJoinKHR` are not necessary and will simply harm performance. This situation may occur when other threads executing `vkDeferredOperationJoinKHR` are about to complete `operation`, and the implementation is unable to partition the workload any further.
- A return value of `VK_THREAD_IDLE_KHR` indicates that the deferred operation is not complete, and there is no work for the thread to do at the time of the call. This situation may occur if the operation encounters a temporary reduction in parallelism. By returning `VK_THREAD_IDLE_KHR`, the implementation is signaling that it expects that more opportunities for parallelism will emerge as execution progresses, and that future calls to `vkDeferredOperationJoinKHR` can be beneficial. In the meantime, the application can perform other work on the calling thread.

Implementations must guarantee forward progress by enforcing the following invariants:

1. If only one thread has invoked `vkDeferredOperationJoinKHR` on a given operation, that thread
**Valid Usage (Implicit)**

- VUID-vkDeferredOperationJoinKHR-device-parameter
  
  *device* must be a valid *VkDevice* handle

- VUID-vkDeferredOperationJoinKHR-operation-parameter
  
  *operation* must be a valid *VkDeferredOperationKHR* handle

- VUID-vkDeferredOperationJoinKHR-operation-parent
  
  *operation* must have been created, allocated, or retrieved from *device*

**Return Codes**

**Success**

- VK_SUCCESS
- VK_THREAD_DONE_KHR
- VK_THREAD_IDLE_KHR

**Failure**

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

When a deferred operation is completed, the application can destroy the tracking object by calling:

```
// Provided by VK_KHR_deferred_host_operations
void vkDestroyDeferredOperationKHR(
    VkDevice device,  // device is the device which owns operation.
    VkDeferredOperationKHR operation,  // operation is the completed operation to be destroyed.
    const VkAllocationCallbacks* pAllocator);  // pAllocator controls host memory allocation as described in the Memory Allocation chapter.
```

**Valid Usage**

- VUID-vkDestroyDeferredOperationKHR-operation-03434
  
  If *VkAllocationCallbacks* were provided when *operation* was created, a compatible set of callbacks must be provided here

- VUID-vkDestroyDeferredOperationKHR-operation-03435
If no `VkAllocationCallbacks` were provided when `operation` was created, `pAllocator` must be `NULL`.

- VUID-vkDestroyDeferredOperationKHR-operation-03436
  `operation` must be completed

Valid Usage (Implicit)

- VUID-vkDestroyDeferredOperationKHR-device-parameter
  `device` must be a valid `VkDevice` handle

- VUID-vkDestroyDeferredOperationKHR-operation-parameter
  If `operation` is not `VK_NULL_HANDLE`, `operation` must be a valid `VkDeferredOperationKHR` handle

- VUID-vkDestroyDeferredOperationKHR-pAllocator-parameter
  If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

- VUID-vkDestroyDeferredOperationKHR-operation-parent
  If `operation` is a valid handle, it must have been created, allocated, or retrieved from `device`.

Host Synchronization

- Host access to `operation` must be externally synchronized.

To query the number of additional threads that can usefully be joined to a deferred operation, call:

```c
// Provided by VK_KHR_deferred_host_operations
uint32_t vkGetDeferredOperationMaxConcurrencyKHR(
    VkDevice device,
    VkDeferredOperationKHR operation);
```

- `device` is the device which owns `operation`.
- `operation` is the deferred operation to be queried.

The returned value is the maximum number of threads that can usefully execute a deferred operation concurrently, reported for the state of the deferred operation at the point this command is called. This value is intended to be used to better schedule work onto available threads. Applications can join any number of threads to the deferred operation and expect it to eventually complete, though excessive joins may return `VK_THREAD_DONE_KHR` immediately, performing no useful work.

If `operation` is complete, `vkGetDeferredOperationMaxConcurrencyKHR` returns zero.

If `operation` is currently joined to any threads, the value returned by this command may
immediately be out of date.

If operation is pending, implementations **must** not return zero unless at least one thread is currently executing `vkDeferredOperationJoinKHR` on operation. If there are such threads, the implementation **should** return an estimate of the number of additional threads which it could profitably use.

Implementations **may** return 2\(^{32}\)-1 to indicate that the maximum concurrency is unknown and cannot be easily derived. Implementations **may** return values larger than the maximum concurrency available on the host CPU. In these situations, an application **should** clamp the return value rather than oversubscribing the machine.

**Note**

The recommended usage pattern for applications is to query this value once, after deferral, and schedule no more than the specified number of threads to join the operation. Each time a joined thread receives `VK_THREAD_IDLE_KHR`, the application should schedule an additional join at some point in the future, but is not required to do so.

---

**Valid Usage (Implicit)**

- VUID-vkGetDeferredOperationMaxConcurrencyKHR-device-parameter
  - `device` **must** be a valid `VkDevice` handle
- VUID-vkGetDeferredOperationMaxConcurrencyKHR-operation-parameter
  - `operation` **must** be a valid `VkDeferredOperationKHR` handle
- VUID-vkGetDeferredOperationMaxConcurrencyKHR-operation-parent
  - `operation` **must** have been created, allocated, or retrieved from `device`

---

The `vkGetDeferredOperationResultKHR` function is defined as:

```c
// Provided by VK_KHR_deferred_host_operations
VkResult vkGetDeferredOperationResultKHR(
    VkDevice device,
    VkDeferredOperationKHR operation);
```

- `device` is the device which owns `operation`.
- `operation` is the operation whose deferred result is being queried.

If no command has been deferred on `operation`, `vkGetDeferredOperationResultKHR` returns `VK_SUCCESS`.

If the deferred operation is pending, `vkGetDeferredOperationResultKHR` returns `VK_NOT_READY`.

If the deferred operation is complete, it returns the appropriate return value from the original command. This value **must** be one of the `VkResult` values which could have been returned by the original command if the operation had not been deferred.
Valid Usage (Implicit)

- VUID-vkGetDeferredOperationResultKHR-device-parameter
  device must be a valid VkDevice handle

- VUID-vkGetDeferredOperationResultKHR-operation-parameter
  operation must be a valid VkDeferredOperationKHR handle

- VUID-vkGetDeferredOperationResultKHR-operation-parent
  operation must have been created, allocated, or retrieved from device

Return Codes

Success
- VK_SUCCESS
- VK_NOT_READY
Chapter 36. Private Data

The private data extension provides a way for users to associate arbitrary user-defined data with Vulkan objects. This association is accomplished by storing 64-bit unsigned integers of user-defined data in private data slots. A private data slot represents a storage allocation for one data item for each child object of the device.

An application can reserve private data slots at device creation. To reserve private data slots, insert a `VkDevicePrivateDataCreateInfo` in the `pNext` chain in `VkDeviceCreateInfo` before device creation. Multiple `VkDevicePrivateDataCreateInfo` structures can be chained together, and the sum of the requested slots will be reserved. This is an exception to the specified valid usage for structure pointer chains. Reserving slots in this manner is not strictly necessary but it may improve performance.

Private data slots are represented by `VkPrivateDataSlot` handles:

```c
// Provided by VK_VERSION_1_3
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkPrivateDataSlot)
```

or the equivalent

```c
// Provided by VK_EXT_private_data
typedef VkPrivateDataSlot VkPrivateDataSlotEXT;
```

To create a private data slot, call:

```c
// Provided by VK_VERSION_1_3
VkResult vkCreatePrivateDataSlot(
    VkDevice device,
    const VkPrivateDataSlotCreateInfo* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
   VkPrivateDataSlot* pPrivateDataSlot);
```

or the equivalent command

```c
// Provided by VK_EXT_private_data
VkResult vkCreatePrivateDataSlotEXT( 
    VkDevice device, 
    const VkPrivateDataSlotCreateInfo* pCreateInfo, 
    const VkAllocationCallbacks* pAllocator, 
    VkPrivateDataSlot* pPrivateDataSlot);
```

- `device` is the logical device associated with the creation of the object(s) holding the private data slot.
• `pCreateInfo` is a pointer to a `VkPrivateDataSlotCreateInfo`.
• `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
• `pPrivateDataSlot` is a pointer to a `VkPrivateDataSlot` handle in which the resulting private data slot is returned.

### Valid Usage

- **VUID-vkCreatePrivateDataSlot-privateData-04564**
  The privateData feature must be enabled.

### Valid Usage (Implicit)

- **VUID-vkCreatePrivateDataSlot-device-parameter**
  `device` must be a valid `VkDevice` handle.
- **VUID-vkCreatePrivateDataSlot-pCreateInfo-parameter**
  `pCreateInfo` must be a valid pointer to a valid `VkPrivateDataSlotCreateInfo` structure.
- **VUID-vkCreatePrivateDataSlot-pAllocator-parameter**
  If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure.
- **VUID-vkCreatePrivateDataSlot-pPrivateDataSlot-parameter**
  `pPrivateDataSlot` must be a valid pointer to a `VkPrivateDataSlot` handle.

### Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`

The `VkPrivateDataSlotCreateInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPrivateDataSlotCreateInfo {
    VkStructureType sType;
    const void* pNext;
    VkPrivateDataSlotCreateFlags flags;
} VkPrivateDataSlotCreateInfo;
```

or the equivalent

```c
// Provided by VK_EXT_private_data
```
typedef VkPrivateDataSlotCreateInfo VkPrivateDataSlotCreateInfoEXT;

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is reserved for future use.

**Valid Usage (Implicit)**

- VUID-VkPrivateDataSlotCreateInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_PRIVATE_DATA_SLOT_CREATE_INFO
- VUID-VkPrivateDataSlotCreateInfo-pNext-pNext
  pNext must be NULL
- VUID-VkPrivateDataSlotCreateInfo-flags-zerobitmask
  flags must be 0

// Provided by VK_VERSION_1_3
typedef VkFlags VkPrivateDataSlotCreateFlags;

or the equivalent

// Provided by VK_EXT_private_data
typedef VkPrivateDataSlotCreateFlags VkPrivateDataSlotCreateFlagsEXT;

**VkPrivateDataSlotCreateFlags** is a bitmask type for setting a mask, but is currently reserved for future use.

To destroy a private data slot, call:

// Provided by VK_VERSION_1_3
void vkDestroyPrivateDataSlot(
    VkDevice device,
    VkPrivateDataSlot privateDataSlot,
    const VkAllocationCallbacks* pAllocator);

or the equivalent command

// Provided by VK_EXT_private_data
void vkDestroyPrivateDataSlotEXT(
    VkDevice device,
    VkPrivateDataSlot privateDataSlot,
    const VkAllocationCallbacks* pAllocator);
• **device** is the logical device associated with the creation of the object(s) holding the private data slot.
• **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
• **privateDataSlot** is the private data slot to destroy.

### Valid Usage

- **VUID-vkDestroyPrivateDataSlot-privateDataSlot-04062**
  If `VkAllocationCallbacks` were provided when `privateDataSlot` was created, a compatible set of callbacks **must** be provided here.

- **VUID-vkDestroyPrivateDataSlot-privateDataSlot-04063**
  If no `VkAllocationCallbacks` were provided when `privateDataSlot` was created, `pAllocator` **must** be `NULL`.

### Valid Usage (Implicit)

- **VUID-vkDestroyPrivateDataSlot-device-parameter**
  `device` **must** be a valid `VkDevice` handle.

- **VUID-vkDestroyPrivateDataSlot-privateDataSlot-parameter**
  If `privateDataSlot` is not `VK_NULL_HANDLE`, `privateDataSlot` **must** be a valid `VkPrivateDataSlot` handle.

- **VUID-vkDestroyPrivateDataSlot-pAllocator-parameter**
  If `pAllocator` is not `NULL`, `pAllocator` **must** be a valid pointer to a valid `VkAllocationCallbacks` structure.

- **VUID-vkDestroyPrivateDataSlot-privateDataSlot-parent**
  If `privateDataSlot` is a valid handle, it **must** have been created, allocated, or retrieved from `device`.

### Host Synchronization

- Host access to `privateDataSlot` **must** be externally synchronized.

To store user defined data in a slot associated with a Vulkan object, call:

```c
// Provided by VK_VERSION_1_3
VkResult vkSetPrivateData(
    VkDevice device,
    VkObjectType objectType,
    uint64_t objectHandle,
    VkPrivateDataSlot privateDataSlot,
    uint64_t data);
```
or the equivalent command

```c
// Provided by VK_EXT_private_data
VkResult vkSetPrivateDataEXT(
    VkDevice device,
    VkObjectType objectType,
    uint64_t objectHandle,
    VkPrivateDataSlot privateDataSlot,
    uint64_t data);
```

- `device` is the device that created the object.
- `objectType` is a `VkObjectType` specifying the type of object to associate data with.
- `objectHandle` is a handle to the object to associate data with.
- `privateDataSlot` is a handle to a `VkPrivateDataSlot` specifying location of private data storage.
- `data` is user defined data to associate the object with. This data will be stored at `privateDataSlot`.

### Valid Usage

- **VUID-vkSetPrivateData-objectHandle-04016**
  - `objectHandle` must be `device` or a child of `device`

- **VUID-vkSetPrivateData-objectHandle-04017**
  - `objectHandle` must be a valid handle to an object of type `objectType`

### Valid Usage (Implicit)

- **VUID-vkSetPrivateData-device-parameter**
  - `device` must be a valid `VkDevice` handle

- **VUID-vkSetPrivateData-objectType-parameter**
  - `objectType` must be a valid `VkObjectType` value

- **VUID-vkSetPrivateData-privateDataSlot-parameter**
  - `privateDataSlot` must be a valid `VkPrivateDataSlot` handle

- **VUID-vkSetPrivateData-privateDataSlot-parent**
  - `privateDataSlot` must have been created, allocated, or retrieved from `device`

### Return Codes

**Success**
- **VK_SUCCESS**

**Failure**
- **VK_ERROR_OUT_OF_HOST_MEMORY**
To retrieve user defined data from a slot associated with a Vulkan object, call:

```c
// Provided by VK_VERSION_1_3
void vkGetPrivateData(
    VkDevice device,
    VkObjectType objectType,
    uint64_t objectHandle,
    VkPrivateDataSlot privateDataSlot,
    uint64_t* pData);
```

or the equivalent command

```c
// Provided by VK_EXT_private_data
void vkGetPrivateDataEXT(
    VkDevice device,
    VkObjectType objectType,
    uint64_t objectHandle,
    VkPrivateDataSlot privateDataSlot,
    uint64_t* pData);
```

- `device` is the device that created the object
- `objectType` is a `VkObjectType` specifying the type of object data is associated with.
- `objectHandle` is a handle to the object data is associated with.
- `privateDataSlot` is a handle to a `VkPrivateDataSlot` specifying location of private data pointer storage.
- `pData` is a pointer to specify where user data is returned. 0 will be written in the absence of a previous call to `vkSetPrivateData` using the object specified by `objectHandle`.

**Note**
Due to platform details on Android, implementations might not be able to reliably return 0 from calls to `vkGetPrivateData` for `VkSwapchainKHR` objects on which `vkSetPrivateData` has not previously been called. This erratum is exclusive to the Android platform and objects of type `VkSwapchainKHR`.

**Valid Usage**

- VUID-vkGetPrivateData-objectType-04018
  `objectType` must be `VK_OBJECT_TYPE_DEVICE`, or an object type whose parent is `VkDevice`

**Valid Usage (Implicit)**

- VUID-vkGetPrivateData-device-parameter
  `device` must be a valid `VkDevice` handle
• VUID-vkGetPrivateData-objectType-parameter
  
  **objectType** must be a valid **VkObjectType** value

• VUID-vkGetPrivateData-privateDataSlot-parameter
  
  **privateDataSlot** must be a valid **VkPrivateDataSlot** handle

• VUID-vkGetPrivateData-pData-parameter
  
  **pData** must be a valid pointer to a **uint64_t** value

• VUID-vkGetPrivateData-privateDataSlot-parent
  
  **privateDataSlot** must have been created, allocated, or retrieved from **device**
Chapter 37. Acceleration Structures

37.1. Acceleration Structures

 Acceleration structures are data structures used by the implementation to efficiently manage scene geometry as it is traversed during a ray tracing query. The application is responsible for managing acceleration structure objects (see Acceleration Structures), including allocation, destruction, executing builds or updates, and synchronizing resources used during ray tracing queries.

There are two types of acceleration structures, top level acceleration structures and bottom level acceleration structures.

An acceleration structure is considered to be constructed if an acceleration structure build command or copy command has been executed with the given acceleration structure as the destination.

![Diagram showing the relationship between top and bottom level acceleration structures.](image)

Figure 27. Acceleration Structure

**Caption**

The diagram shows the relationship between top and bottom level acceleration structures.

37.1.1. Geometry

Geometries refer to a triangle or axis-aligned bounding box.
37.1.2. Top Level Acceleration Structures

Opaque acceleration structure for an array of instances. The descriptor or device address referencing this is the starting point for traversal.

The top level acceleration structure takes a reference to any bottom level acceleration structure referenced by its instances. Those bottom level acceleration structure objects must be valid when the top level acceleration structure is accessed.

37.1.3. Bottom Level Acceleration Structures

Opaque acceleration structure for an array of geometries.

37.1.4. Acceleration Structure Update Rules

The API defines two types of operations to produce acceleration structures from geometry:

- A build operation is used to construct an acceleration structure.
- An update operation is used to modify an existing acceleration structure.

An update operation imposes certain constraints on the input, in exchange for considerably faster execution. When performing an update, the application is required to provide a full description of the acceleration structure, but is prohibited from changing anything other than instance definitions, transform matrices, and vertex or AABB positions. All other aspects of the description must exactly match the one from the original build.

More precisely, the application must not use an update operation to do any of the following:

- Change primitives or instances from active to inactive, or vice versa (as defined in Inactive Primitives and Instances).
- Change the index or vertex formats of triangle geometry.
- Change triangle geometry transform pointers from null to non-null or vice versa.
- Change the number of geometries or instances in the structure.
- Change the geometry flags for any geometry in the structure.
- Change the number of vertices or primitives for any geometry in the structure.

If the original acceleration structure was built using opacity micromaps and VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_OPACITY_MICROMAP_DATA_UPDATE_EXT was set in flags, the application must provide the corresponding micromap information to the update operation. The application is prohibited from changing anything other than the specific opacity values assigned to the triangles.

More precisely, the application must not use an update operation to do any of the following:

- Remove micromaps or VkOpacityMicromapSpecialIndexEXT values from a geometry which previously had them, or vice versa.
- Change between use of VkOpacityMicromapSpecialIndexEXT values and explicit micro-map
triangles.

• Change the subdivision level or format of the micromap triangle associated with any acceleration-structure triangle.

If the original acceleration structure was built using opacity micromaps and VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_OPACITY_MICROMAP_UPDATE_EXT was set in flags, the application must provide a micromap to the update operation.

If the original acceleration structure was built using opacity micromaps and neither opacity micromap update flag is set the application must provide the original micromap to the update operation.

If the original acceleration structure was built using displacement micromaps and VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_DISPLACEMENT_MICROMAP_UPDATE_NV was set in flags, the application must provide a displacement micromap to the update operation.

If the original acceleration structure was built using displacement micromaps and the displacement micromap update flag is not set the application must provide the original micromap to the update operation.

37.1.5. Inactive Primitives and Instances

Acceleration structures allow the use of particular input values to signal inactive primitives or instances.

An inactive triangle is one for which the first (X) component of any vertex is NaN. If any other vertex component is NaN, and the first is not, the behavior is undefined. If the vertex format does not have a NaN representation, then all triangles are considered active.

An inactive instance is one whose acceleration structure reference is 0.

An inactive AABB is one for which the minimum X coordinate is NaN. If any other component is NaN, and the first is not, the behavior is undefined.

In the above definitions, “NaN” refers to any type of NaN. Signaling, non-signaling, quiet, loud, or otherwise.

An inactive object is considered invisible to all rays, and should not be represented in the acceleration structure. Implementations should ensure that the presence of inactive objects does not seriously degrade traversal performance.

Inactive objects are counted in the auto-generated index sequences which are provided to shaders via InstanceId and PrimitiveId SPIR-V decorations. This allows objects in the scene to change freely between the active and inactive states, without affecting the layout of any arrays which are being indexed using the ID values.

Any transition between the active and inactive states requires a full acceleration structure rebuild. Applications must not perform an acceleration structure update where an object is active in the source acceleration structure but would be inactive in the destination, or vice versa.
37.1.6. Building Acceleration Structures

To build an acceleration structure call:

```c
// Provided by VK_NV_ray_tracing
void vkCmdBuildAccelerationStructureNV(
    VkCommandBuffer commandBuffer,
    const VkAccelerationStructureInfoNV* pInfo,
    VkBuffer instanceData,
    VkDeviceSize instanceOffset,
    VkBool32 update,
    VkAccelerationStructureNV dst,
    VkAccelerationStructureNV src,
    VkBuffer scratch,
    VkDeviceSize scratchOffset);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `pInfo` contains the shared information for the acceleration structure's structure.
- `instanceData` is the buffer containing an array of `VkAccelerationStructureInstanceKHR` structures defining acceleration structures. This parameter must be `NULL` for bottom level acceleration structures.
- `instanceOffset` is the offset in bytes (relative to the start of `instanceData`) at which the instance data is located.
- `update` specifies whether to update the `dst` acceleration structure with the data in `src`.
- `dst` is a pointer to the target acceleration structure for the build.
- `src` is a pointer to an existing acceleration structure that is to be used to update the `dst` acceleration structure.
- `scratch` is the `VkBuffer` that will be used as scratch memory for the build.
- `scratchOffset` is the offset in bytes relative to the start of `scratch` that will be used as a scratch memory.

Accesses to `dst`, `src`, and `scratch` must be synchronized with the `VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR` pipeline stage and an access type of `VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR` or `VK_ACCESS_ACCELERATION_STRUCTURE_WRITE_BIT_KHR`.

**Valid Usage**

- VUID-vkCmdBuildAccelerationStructureNV-geometryCount-02241
  
  `geometryCount` must be less than or equal to `VkPhysicalDeviceRayTracingPropertiesNV::maxGeometryCount`

- VUID-vkCmdBuildAccelerationStructureNV-dst-02488
  
  `dst` must have been created with compatible `VkAccelerationStructureInfoNV` where `VkAccelerationStructureInfoNV::type` and `VkAccelerationStructureInfoNV::flags` are identical, and `VkAccelerationStructureInfoNV::instanceCount`
**VkAccelerationStructureInfoNV**::`geometryCount` for `dst` are greater than or equal to the build size and each geometry in `VkAccelerationStructureInfoNV`::`pGeometries` for `dst` has greater than or equal to the number of vertices, indices, and AABBs

- **VUID-vkCmdBuildAccelerationStructureNV-update-02489**
  If `update` is `VK_TRUE`, `src` **must** not be `VK_NULL_HANDLE`

- **VUID-vkCmdBuildAccelerationStructureNV-update-02490**
  If `update` is `VK_TRUE`, `src` **must** have previously been constructed with `VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_UPDATE_BIT_NV` set in `VkAccelerationStructureInfoNV`::`flags` in the original build

- **VUID-vkCmdBuildAccelerationStructureNV-update-02491**
  If `update` is `VK_FALSE`, the `size` member of the `VkMemoryRequirements` structure returned from a call to `vkGetAccelerationStructureMemoryRequirementsNV` with `VkAccelerationStructureMemoryRequirementsInfoNV`::`accelerationStructure` set to `dst` and `VkAccelerationStructureMemoryRequirementsInfoNV`::`type` set to `VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_BUILD_SCRATCH_NV` **must** be less than or equal to the size of `scratch` minus `scratchOffset`

- **VUID-vkCmdBuildAccelerationStructureNV-update-02492**
  If `update` is `VK_TRUE`, the `size` member of the `VkMemoryRequirements` structure returned from a call to `vkGetAccelerationStructureMemoryRequirementsNV` with `VkAccelerationStructureMemoryRequirementsInfoNV`::`accelerationStructure` set to `dst` and `VkAccelerationStructureMemoryRequirementsInfoNV`::`type` set to `VK_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_TYPE_UPDATE_SCRATCH_NV` **must** be less than or equal to the size of `scratch` minus `scratchOffset`

- **VUID-vkCmdBuildAccelerationStructureNV-scratch-03522**
  `scratch` **must** have been created with `VK_BUFFER_USAGE_RAY_TRACING_BIT_NV` usage flag

- **VUID-vkCmdBuildAccelerationStructureNV-instanceData-03523**
  If `instanceData` is not `VK_NULL_HANDLE`, `instanceData` **must** have been created with `VK_BUFFER_USAGE_RAY_TRACING_BIT_NV` usage flag

- **VUID-vkCmdBuildAccelerationStructureNV-accelerationStructureReference-03786**
  Each `VkAccelerationStructureInstanceKHR`::`accelerationStructureReference` value in `instanceData` **must** be a valid device address containing a value obtained from `vkGetAccelerationStructureHandleNV`

- **VUID-vkCmdBuildAccelerationStructureNV-update-03524**
  If `update` is `VK_TRUE`, then objects that were previously active **must** not be made inactive as per **Inactive Primitives and Instances**

- **VUID-vkCmdBuildAccelerationStructureNV-update-03525**
  If `update` is `VK_TRUE`, then objects that were previously inactive **must** not be made active as per **Inactive Primitives and Instances**

- **VUID-vkCmdBuildAccelerationStructureNV-update-03526**
  If `update` is `VK_TRUE`, the `src` and `dst` objects **must** either be the same object or not have any memory aliasing

- **VUID-vkCmdBuildAccelerationStructureNV-dst-07787**
  `dst` **must** be bound completely and contiguously to a single `VkDeviceMemory` object via
Valid Usage (Implicit)

- VUID-vkCmdBuildAccelerationStructureNV-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdBuildAccelerationStructureNV-pInfo-parameter
  pInfo must be a valid pointer to a valid VkAccelerationStructureInfoNV structure

- VUID-vkCmdBuildAccelerationStructureNV-instanceData-parameter
  If instanceData is not VK_NULL_HANDLE, instanceData must be a valid VkBuffer handle

- VUID-vkCmdBuildAccelerationStructureNV-dst-parameter
  dst must be a valid VkAccelerationStructureNV handle

- VUID-vkCmdBuildAccelerationStructureNV-src-parameter
  If src is not VK_NULL_HANDLE, src must be a valid VkAccelerationStructureNV handle

- VUID-vkCmdBuildAccelerationStructureNV-scratch-parameter
  scratch must be a valid VkBuffer handle

- VUID-vkCmdBuildAccelerationStructureNV-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdBuildAccelerationStructureNV-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support compute operations

- VUID-vkCmdBuildAccelerationStructureNV-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdBuildAccelerationStructureNV-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdBuildAccelerationStructureNV-commonparent
  Each of commandBuffer, dst, instanceData, scratch, and src that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
To build acceleration structures call:

```c
void vkCmdBuildAccelerationStructuresKHR(
    VkCommandBuffer commandBuffer,
    uint32_t infoCount,
    const VkAccelerationStructureBuildGeometryInfoKHR* pInfos,
    const VkAccelerationStructureBuildRangeInfoKHR* const* ppBuildRangeInfos);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `infoCount` is the number of acceleration structures to build. It specifies the number of the `pInfos` structures and `ppBuildRangeInfos` pointers that must be provided.
- `pInfos` is a pointer to an array of `infoCount` `VkAccelerationStructureBuildGeometryInfoKHR` structures defining the geometry used to build each acceleration structure.
- `ppBuildRangeInfos` is a pointer to an array of `infoCount` pointers to arrays of `VkAccelerationStructureBuildRangeInfoKHR` structures. Each `ppBuildRangeInfos[i]` is a pointer to an array of `pInfos[i].geometryCount` `VkAccelerationStructureBuildRangeInfoKHR` structures defining dynamic offsets to the addresses where geometry data is stored, as defined by `pInfos[i].`.

The `vkCmdBuildAccelerationStructuresKHR` command provides the ability to initiate multiple acceleration structures builds, however there is no ordering or synchronization implied between any of the individual acceleration structure builds.

**Note**

This means that an application cannot build a top-level acceleration structure in the same `vkCmdBuildAccelerationStructuresKHR` call as the associated bottom-level or instance acceleration structures are being built. There also cannot be any memory aliasing between any acceleration structure memories or scratch memories being used by any of the builds.

Accesses to the acceleration structure scratch buffers as identified by the `VkAccelerationStructureBuildGeometryInfoKHR::scratchData` buffer device addresses must be synchronized with the `VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR` pipeline stage and an access type of `(VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR | VK_ACCESS_ACCELERATION_STRUCTURE_WRITE_BIT_KHR)`. Accesses to each `VkAccelerationStructureBuildGeometryInfoKHR::srcAccelerationStructure` and `VkAccelerationStructureBuildGeometryInfoKHR::dstAccelerationStructure` must be synchronized.
with the `VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR` pipeline stage and an access type of `VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR` or `VK_ACCESS_ACCELERATION_STRUCTURE_WRITE_BIT_KHR`, as appropriate.

Accesses to other input buffers as identified by any used values of `VkAccelerationStructureGeometryMotionTrianglesDataNV::vertexData`, `VkAccelerationStructureGeometryTrianglesDataKHR::vertexData`, `VkAccelerationStructureGeometryTrianglesDataKHR::indexData`, `VkAccelerationStructureGeometryTrianglesDataKHR::transformData`, `VkAccelerationStructureGeometryAabbsDataKHR::data`, and `VkAccelerationStructureGeometryInstancesDataKHR::data` must be synchronized with the `VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR` pipeline stage and an access type of `VK_ACCESS_SHADER_READ_BIT`.

### Valid Usage

- **VUID-vkCmdBuildAccelerationStructuresKHR-accelerationStructure-08923**
  The `VkPhysicalDeviceAccelerationStructureFeaturesKHR::accelerationStructure` feature must be enabled.

- **VUID-vkCmdBuildAccelerationStructuresKHR-mode-04628**
  The `mode` member of each element of `pInfos` must be a valid `VkBuildAccelerationStructureModeKHR` value.

- **VUID-vkCmdBuildAccelerationStructuresKHR-srcAccelerationStructure-04629**
  If the `srcAccelerationStructure` member of any element of `pInfos` is not `VK_NULL_HANDLE`, the `srcAccelerationStructure` member must be a valid `VkAccelerationStructureKHR` handle.

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-04630**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, its `srcAccelerationStructure` member must not be `VK_NULL_HANDLE`.

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03403**
  The `srcAccelerationStructure` member of any element of `pInfos` must not be the same acceleration structure as the `dstAccelerationStructure` member of any other element of `pInfos`.

- **VUID-vkCmdBuildAccelerationStructuresKHR-dstAccelerationStructure-03698**
  The `dstAccelerationStructure` member of any element of `pInfos` must not be the same acceleration structure as the `dstAccelerationStructure` member of any other element of `pInfos`.

- **VUID-vkCmdBuildAccelerationStructuresKHR-dstAccelerationStructure-03800**
  The `dstAccelerationStructure` member of any element of `pInfos` must be a valid `VkAccelerationStructureKHR` handle.

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03699**
  For each element of `pInfos`, if its `type` member is `VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_KHR`, its `dstAccelerationStructure` member...
must have been created with a value of VkAccelerationStructureCreateInfoKHR::type equal to either VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_KHR or VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR

• VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03700
  For each element of pInfos, if its type member is VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_KHR, its dstAccelerationStructure member must have been created with a value of VkAccelerationStructureCreateInfoKHR::type equal to either VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_KHR or VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR

• VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03663
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, inactive primitives in its srcAccelerationStructure member must not be made active

• VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03664
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, active primitives in its srcAccelerationStructure member must not be made inactive

• VUID-vkCmdBuildAccelerationStructuresKHR-None-03407
  The dstAccelerationStructure member of any element of pInfos must not be referenced by the geometry.instances.data member of any element of pGeometries or ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR in any other element of pInfos

• VUID-vkCmdBuildAccelerationStructuresKHR-dstAccelerationStructure-03701
  The range of memory backing the dstAccelerationStructure member of any element of pInfos that is accessed by this command must not overlap the memory backing the srcAccelerationStructure member of any other element of pInfos with a mode equal to VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, which is accessed by this command

• VUID-vkCmdBuildAccelerationStructuresKHR-dstAccelerationStructure-03702
  The range of memory backing the dstAccelerationStructure member of any element of pInfos that is accessed by this command must not overlap the memory backing the dstAccelerationStructure member of any other element of pInfos, which is accessed by this command

• VUID-vkCmdBuildAccelerationStructuresKHR-dstAccelerationStructure-03703
  The range of memory backing the dstAccelerationStructure member of any element of pInfos that is accessed by this command must not overlap the memory backing the scratchData member of any element of pInfos (including the same element), which is accessed by this command

• VUID-vkCmdBuildAccelerationStructuresKHR-scratchData-03704
  The range of memory backing the scratchData member of any element of pInfos that is accessed by this command must not overlap the memory backing the scratchData member of any other element of pInfos, which is accessed by this command

• VUID-vkCmdBuildAccelerationStructuresKHR-scratchData-03705
  The range of memory backing the scratchData member of any element of pInfos that is accessed by this command must not overlap the memory backing the srcAccelerationStructure member of any element of pInfos with a mode equal to
VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR (including the same element), which is accessed by this command

- **VUID-vkCmdBuildAccelerationStructuresKHR-dstAccelerationStructure-03706**
The range of memory backing the dstAccelerationStructure member of any element of pInfos that is accessed by this command must not overlap the memory backing any acceleration structure referenced by the geometry.instances.data member of any element of pGeometries or ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR in any other element of pInfos, which is accessed by this command

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03667**
For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, its srcAccelerationStructure member must have previously been constructed with VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_UPDATE_BIT_KHR set in VkAccelerationStructureBuildGeometryInfoKHR::flags in the build

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03668**
For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, its srcAccelerationStructure and dstAccelerationStructure members must either be the same VkAccelerationStructureKHR, or not have any memory aliasing

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03758**
For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, its geometryCount member must have the same value which was specified when srcAccelerationStructure was last built

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03759**
For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, its flags member must have the same value which was specified when srcAccelerationStructure was last built

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03760**
For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, its type member must have the same value which was specified when srcAccelerationStructure was last built

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03761**
For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, then for each VkAccelerationStructureGeometryKHR structure referred to by its pGeometries or ppGeometries members, its geometryType member must have the same value which was specified when srcAccelerationStructure was last built

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03762**
For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, then for each VkAccelerationStructureGeometryKHR structure referred to by its pGeometries or ppGeometries members, its flags member must have the same value which was specified when srcAccelerationStructure was last built

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03763**
For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, then for each `VkAccelerationStructureGeometryKHR` structure referred to by its `pGeometries` or `ppGeometries` members, if `geometryType` is `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, its `geometry.triangles.vertexFormat` member **must** have the same value which was specified when `srcAccelerationStructure` was last built

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03764**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, then for each `VkAccelerationStructureGeometryKHR` structure referred to by its `pGeometries` or `ppGeometries` members, if `geometryType` is `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, its `geometry.triangles.maxVertex` member **must** have the same value which was specified when `srcAccelerationStructure` was last built

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03765**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, then for each `VkAccelerationStructureGeometryKHR` structure referred to by its `pGeometries` or `ppGeometries` members, if `geometryType` is `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, its `geometry.triangles.transformData` address was NULL when `srcAccelerationStructure` was last built, then it **must** be NULL

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03766**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, then for each `VkAccelerationStructureGeometryKHR` structure referred to by its `pGeometries` or `ppGeometries` members, if `geometryType` is `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if its `geometry.triangles.transformData` address was not NULL when `srcAccelerationStructure` was last built, then it **must** not be NULL

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03767**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, then for each `VkAccelerationStructureGeometryKHR` structure referred to by its `pGeometries` or `ppGeometries` members, if `geometryType` is `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, and `geometry.triangles.indexType` is not `VK_INDEX_TYPE_NONE_KHR`, then the value of each index referenced **must** be the same as the corresponding index value when `srcAccelerationStructure` was last built

- **VUID-vkCmdBuildAccelerationStructuresKHR-primitiveCount-03769**
  For each `VkAccelerationStructureBuildRangeInfoKHR` referenced by this command, its `primitiveCount` member **must** have the same value which was specified when
**srcAccelerationStructure** was last built

- **VUID-vkCmdBuildAccelerationStructuresKHR-firstVertex-03770**
  For each `VkAccelerationStructureBuildRangeInfoKHR` referenced by this command, if the corresponding geometry uses indices, its `firstVertex` member must have the same value which was specified when `srcAccelerationStructure` was last built

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03801**
  For each element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_INSTANCES_KHR`, the corresponding `ppBuildRangeInfos[i][j].primitiveCount` must be less than or equal to `VkPhysicalDeviceAccelerationStructurePropertiesKHR::maxInstanceCount`

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03707**
  For each element of `pInfos`, the buffer used to create its `dstAccelerationStructure` member must be bound to device memory

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03708**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR` the buffer used to create its `srcAccelerationStructure` member must be bound to device memory

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03709**
  For each element of `pInfos`, the buffer used to create each acceleration structure referenced by the `geometry.instances.data` member of any element of `pGeometries` or `ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_INSTANCES_KHR` must be bound to device memory

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03671**
  If `pInfos[i].mode` is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_BUILD_KHR`, all addresses between `pInfos[i].scratchData.deviceAddress` and `pInfos[i].scratchData.deviceAddress + N - 1` must be in the buffer device address range of the same buffer, where N is given by the `buildScratchSize` member of the `VkAccelerationStructureBuildSizesInfoKHR` structure returned from a call to `vkGetAccelerationStructureBuildSizesKHR` with an identical `VkAccelerationStructureBuildGeometryInfoKHR` structure and primitive count

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03672**
  If `pInfos[i].mode` is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, all addresses between `pInfos[i].scratchData.deviceAddress` and `pInfos[i].scratchData.deviceAddress + N - 1` must be in the buffer device address range of the same buffer, where N is given by the `updateScratchSize` member of the `VkAccelerationStructureBuildSizesInfoKHR` structure returned from a call to `vkGetAccelerationStructureBuildSizesKHR` with an identical `VkAccelerationStructureBuildGeometryInfoKHR` structure and primitive count

- **VUID-vkCmdBuildAccelerationStructuresKHR-geometry-03673**
  The buffers from which the buffer device addresses for all of the `geometry.triangles.vertexData`, `geometry.triangles.indexData`, `geometry.triangles.transformData`, `geometry.aabbs.data`, and `geometry.instances.data` members of all `pInfos[i].pGeometries` and `pInfos[i].ppGeometries` are queried must have been created with the `VK_BUFFER_USAGE_ACCELERATION_STRUCTURE_BUILD_INPUT_READ_ONLY_BIT_KHR` usage flag
The buffer from which the buffer device address `pInfos[i].scratchData.deviceAddress` is queried **must** have been created with `VK_BUFFER_USAGE_STORAGE_BUFFER_BIT` usage flag

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03802**  
  For each element of `pInfos`, its `scratchData.deviceAddress` member **must** be a valid device address obtained from `vkGetBufferDeviceAddress`

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03803**  
  For each element of `pInfos`, if `scratchData.deviceAddress` is the address of a non-sparse buffer then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03710**  
  For each element of `pInfos`, its `scratchData.deviceAddress` member **must** be a multiple of `VkPhysicalDeviceAccelerationStructurePropertiesKHR::minAccelerationStructureScratchOffsetAlignment`

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03804**  
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, `geometry.triangles.vertexData.deviceAddress` **must** be a valid device address obtained from `vkGetBufferDeviceAddress`

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03805**  
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if `geometry.triangles.vertexData.deviceAddress` is the address of a non-sparse buffer then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03806**  
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if `geometry.triangles.indexType` is not `VK_INDEX_TYPE_NONE_KHR`, `geometry.triangles.indexData.deviceAddress` **must** be aligned to the size in bytes of the type in `indexType`

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03807**  
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if `geometry.triangles.indexType` is not `VK_INDEX_TYPE_NONE_KHR`, if `geometry.triangles.indexData.deviceAddress` is the address of a non-sparse buffer then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03712**  
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, and with `geometry.triangles.indexType` not equal to `VK_INDEX_TYPE_NONE_KHR`, `geometry.triangles.indexData.deviceAddress` **must** be aligned to the size in bytes of the type in `indexType`

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03808**  
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of...
VK_GEOMETRY_TYPE_TRIANGLES_KHR, if `geometry.triangles.transformData.deviceAddress` is not 0, it **must** be a valid device address obtained from `vkGetBufferDeviceAddress`

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03809**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if `geometry.triangles.transformData.deviceAddress` is not 0, it **must** be bound completely and contiguously to a single `VkDeviceMemory` object.

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03810**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if `geometry.triangles.transformData.deviceAddress` is not 0, it **must** be aligned to 16 bytes.

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03811**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_AABBS_KHR`, `geometry.aabbs.data.deviceAddress` **must** be a valid device address obtained from `vkGetBufferDeviceAddress`.

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03812**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_AABBS_KHR`, if `geometry.aabbs.data.deviceAddress` is the address of a non-sparse buffer then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object.

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03714**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_INSTANCES_KHR`, if `geometry.arrayOfPointers` is `VK_FALSE`, `geometry.instances.data.deviceAddress` **must** be aligned to 16 bytes.

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03715**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_INSTANCES_KHR`, if `geometry.arrayOfPointers` is `VK_TRUE`, each element of `geometry.instances.data.deviceAddress` in device memory **must** be aligned to 16 bytes.

- **VUID-vkCmdBuildAccelerationStructuresKHR-pInfos-03813**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_INSTANCES_KHR`, if `geometry.instances.data.deviceAddress` is the address of a non-sparse buffer then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object.
For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_INSTANCES_KHR`, each `VkAccelerationStructureInstanceKHR::accelerationStructureReference` value in `geometry.instances.data.deviceAddress` must be a valid device address containing a value obtained from `vkGetAccelerationStructureDeviceAddressKHR` or 0.

For each `pInfos[i]`, `dstAccelerationStructure` must have been created with a value of `VkAccelerationStructureCreateInfoKHR::size` greater than or equal to the memory size required by the build operation, as returned by `vkGetAccelerationStructureBuildSizesKHR` with `pBuildInfo = pInfos[i]` and with each element of the `pMaxPrimitiveCounts` array greater than or equal to the equivalent `ppBuildRangeInfos[i][j].primitiveCount` values for `j` in `[0, pInfos[i].geometryCount)`.

Each element of `ppBuildRangeInfos[i]` must be a valid pointer to an array of `pInfos[i].geometryCount` `VkAccelerationStructureBuildRangeInfoKHR` structures.

**Valid Usage (Implicit)**

- `commandBuffer` must be a valid `VkCommandBuffer` handle.
- `pInfos` must be a valid pointer to an array of `infoCount` valid `VkAccelerationStructureBuildGeometryInfoKHR` structures.
- `ppBuildRangeInfos` must be a valid pointer to an array of `infoCount` `VkAccelerationStructureBuildRangeInfoKHR` structures.
- `commandBuffer` must be in the recording state.
- The `VkCommandPool` that `commandBuffer` was allocated from must support compute operations.
- This command must only be called outside of a render pass instance.
- This command must only be called outside of a video coding scope.
- `infoCount` must be greater than 0.

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized.
Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized.

### Command Properties

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To build acceleration structures with some parameters sourced on the device call:

```c
// Provided by VK_KHR_acceleration_structure
void vkCmdBuildAccelerationStructuresIndirectKHR(
    VkCommandBuffer commandBuffer,
    uint32_t infoCount,
    const VkAccelerationStructureBuildGeometryInfoKHR* pInfos,
    const VkDeviceAddress* pIndirectDeviceAddresses,
    const uint32_t* pIndirectStrides,
    const uint32_t* const* ppMaxPrimitiveCounts);
```

- **commandBuffer** is the command buffer into which the command will be recorded.
- **infoCount** is the number of acceleration structures to build.
- **pInfos** is a pointer to an array of **infoCount** VkAccelerationStructureBuildGeometryInfoKHR structures defining the geometry used to build each acceleration structure.
- **pIndirectDeviceAddresses** is a pointer to an array of **infoCount** buffer device addresses which point to pInfos[i].geometryCount VkAccelerationStructureBuildRangeInfoKHR structures defining dynamic offsets to the addresses where geometry data is stored, as defined by pInfos[i].
- **pIndirectStrides** is a pointer to an array of **infoCount** byte strides between elements of pIndirectDeviceAddresses.
- **ppMaxPrimitiveCounts** is a pointer to an array of **infoCount** pointers to arrays of pInfos[i].geometryCount values indicating the maximum number of primitives that will be built by this command for each geometry.

Accesses to acceleration structures, scratch buffers, vertex buffers, index buffers, and instance buffers must be synchronized as with vkCmdBuildAccelerationStructuresKHR.

Accesses to any element of pIndirectDeviceAddresses must be synchronized with the VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR pipeline stage and an access type of VK_ACCESS_INDIRECT_COMMAND_READ_BIT.

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Valid Usage

- **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-accelerationStructureIndirectBuild-03650**
  The `VkPhysicalDeviceAccelerationStructureFeaturesKHR::accelerationStructureIndirectBuild` feature must be enabled.

- **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-mode-04628**
  The `mode` member of each element of `pInfos` must be a valid `VkBuildAccelerationStructureModeKHR` value.

- **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-srcAccelerationStructure-04629**
  If the `srcAccelerationStructure` member of any element of `pInfos` is not `VK_NULL_HANDLE`, the `srcAccelerationStructure` member must be a valid `VkAccelerationStructureKHR` handle.

- **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-04630**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, its `srcAccelerationStructure` member must not be `VK_NULL_HANDLE`.

- **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03403**
  The `srcAccelerationStructure` member of any element of `pInfos` must not be the same acceleration structure as the `dstAccelerationStructure` member of any other element of `pInfos`.

- **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-dstAccelerationStructure-03698**
  The `dstAccelerationStructure` member of any element of `pInfos` must not be the same acceleration structure as the `dstAccelerationStructure` member of any other element of `pInfos`.

- **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-dstAccelerationStructure-03800**
  The `dstAccelerationStructure` member of any element of `pInfos` must be a valid `VkAccelerationStructureKHR` handle.

- **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03699**
  For each element of `pInfos`, if its `type` member is `VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_KHR`, its `dstAccelerationStructure` member must have been created with a value of `VkAccelerationStructureCreateInfoKHR::type` equal to either `VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_KHR` or `VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR`.

- **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03700**
  For each element of `pInfos`, if its `type` member is `VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_KHR`, its `dstAccelerationStructure` member must have been created with a value of `VkAccelerationStructureCreateInfoKHR::type` equal to either `VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_KHR` or `VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR`.

- **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03663**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, inactive primitives in its
srcAccelerationStructure member must not be made active

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03664
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, active primitives in its srcAccelerationStructure member must not be made inactive.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-None-03407
  The dstAccelerationStructure member of any element of pInfos must not be referenced by the geometry.instances.data member of any element of pGeometries or ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR in any other element of pInfos.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-dstAccelerationStructure-03701
  The range of memory backing the dstAccelerationStructure member of any element of pInfos that is accessed by this command must not overlap the memory backing the srcAccelerationStructure member of any other element of pInfos with a mode equal to VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, which is accessed by this command.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-dstAccelerationStructure-03702
  The range of memory backing the dstAccelerationStructure member of any element of pInfos that is accessed by this command must not overlap the memory backing the dstAccelerationStructure member of any other element of pInfos, which is accessed by this command.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-dstAccelerationStructure-03703
  The range of memory backing the dstAccelerationStructure member of any element of pInfos that is accessed by this command must not overlap the memory backing the scratchData member of any element of pInfos (including the same element), which is accessed by this command.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-scratchData-03704
  The range of memory backing the scratchData member of any element of pInfos that is accessed by this command must not overlap the memory backing the scratchData member of any other element of pInfos, which is accessed by this command.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-scratchData-03705
  The range of memory backing the scratchData member of any element of pInfos that is accessed by this command must not overlap the memory backing the srcAccelerationStructure member of any element of pInfos with a mode equal to VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR (including the same element), which is accessed by this command.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-dstAccelerationStructure-03706
  The range of memory backing the dstAccelerationStructure member of any element of pInfos that is accessed by this command must not overlap the memory backing any acceleration structure referenced by the geometry.instances.data member of any element of pGeometries or ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR in any other element of pInfos, which is accessed by this command.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03667
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, its srcAccelerationStructure member must have previously been constructed with
VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_UPDATE_BIT_KHR set in VkAccelerationStructureBuildGeometryInfoKHR::flags in the build

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03668
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, its srcAccelerationStructure and dstAccelerationStructure members must either be the same VkAccelerationStructureKHR, or not have any memory aliasing.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03758
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, its geometryCount member must have the same value which was specified when srcAccelerationStructure was last built.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03759
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, its flags member must have the same value which was specified when srcAccelerationStructure was last built.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03760
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, its type member must have the same value which was specified when srcAccelerationStructure was last built.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03761
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, then for each VkAccelerationStructureGeometryKHR structure referred to by its pGeometries or ppGeometries members, its geometryType member must have the same value which was specified when srcAccelerationStructure was last built.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03762
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, then for each VkAccelerationStructureGeometryKHR structure referred to by its pGeometries or ppGeometries members, its flags member must have the same value which was specified when srcAccelerationStructure was last built.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03763
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, then for each VkAccelerationStructureGeometryKHR structure referred to by its pGeometries or ppGeometries members, if geometryType is VK_GEOMETRY_TYPE_TRIANGLES_KHR, its geometry.triangles.vertexFormat member must have the same value which was specified when srcAccelerationStructure was last built.

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03764
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, then for each VkAccelerationStructureGeometryKHR structure referred to by its pGeometries or ppGeometries members, if geometryType is VK_GEOMETRY_TYPE_TRIANGLES_KHR, its geometry.triangles.maxVertex member must have the same value which was specified when srcAccelerationStructure was last built.
For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, then for each `VkAccelerationStructureGeometryKHR` structure referred to by its `pGeometries` or `ppGeometries` members, if `geometryType` is `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, its `geometry.triangles.indexType` member **must** have the same value which was specified when `srcAccelerationStructure` was last built.

For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, then for each `VkAccelerationStructureGeometryKHR` structure referred to by its `pGeometries` or `ppGeometries` members, if `geometryType` is `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, its `geometry.triangles.transformData` address was **NULL** when `srcAccelerationStructure` was last built, then it **must** be **NULL**.

For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, then for each `VkAccelerationStructureGeometryKHR` structure referred to by its `pGeometries` or `ppGeometries` members, if `geometryType` is `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if its `geometry.triangles.transformData` address was not **NULL** when `srcAccelerationStructure` was last built, then it **must** not be **NULL**.

For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, then for each `VkAccelerationStructureGeometryKHR` structure referred to by its `pGeometries` or `ppGeometries` members, if `geometryType` is `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, and `geometry.triangles.indexType` is not `VK_INDEX_TYPE_NONE_KHR`, then the value of each index referenced **must** be the same as the corresponding index value when `srcAccelerationStructure` was last built.

For each `VkAccelerationStructureBuildRangeInfoKHR` referenced by this command, its `primitiveCount` member **must** have the same value which was specified when `srcAccelerationStructure` was last built.

For each `VkAccelerationStructureBuildRangeInfoKHR` referenced by this command, if the corresponding geometry uses indices, its `firstVertex` member **must** have the same value which was specified when `srcAccelerationStructure` was last built.

For each element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_INSTANCES_KHR`, the corresponding `ppMaxPrimitiveCounts[i][j]` **must** be less than or equal to `VkPhysicalDeviceAccelerationStructurePropertiesKHR::maxInstanceCount`.

For each element of `pInfos`, the buffer used to create its `dstAccelerationStructure` member **must** be bound to device memory.
For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR` the buffer used to create its `srcAccelerationStructure` member must be bound to device memory.

For each element of `pInfos`, the buffer used to create each acceleration structure referenced by the `geometry.instances.data` member of any element of `pGeometries` or `ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_INSTANCES_KHR` must be bound to device memory.

If `pInfos[i].mode` is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_BUILD_KHR`, all addresses between `pInfos[i].scratchData.deviceAddress` and `pInfos[i].scratchData.deviceAddress + N - 1` must be in the buffer device address range of the same buffer, where `N` is given by the `buildScratchSize` member of the `VkAccelerationStructureBuildSizesInfoKHR` structure returned from a call to `vkGetAccelerationStructureBuildSizesKHR` with an identical `VkAccelerationStructureBuildGeometryInfoKHR` structure and primitive count.

If `pInfos[i].mode` is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, all addresses between `pInfos[i].scratchData.deviceAddress` and `pInfos[i].scratchData.deviceAddress + N - 1` must be in the buffer device address range of the same buffer, where `N` is given by the `updateScratchSize` member of the `VkAccelerationStructureBuildSizesInfoKHR` structure returned from a call to `vkGetAccelerationStructureBuildSizesKHR` with an identical `VkAccelerationStructureBuildGeometryInfoKHR` structure and primitive count.

The buffers from which the buffer device addresses for all of the `geometry.triangles.vertexData`, `geometry.triangles.indexData`, `geometry.triangles.transformData`, `geometry.aabbs.data`, and `geometry.instances.data` members of all `pInfos[i].pGeometries` and `pInfos[i].ppGeometries` are queried must have been created with the `VK_BUFFER_USAGE_ACCELERATION_STRUCTURE_BUILD_INPUT_READ_ONLY_BIT_KHR` usage flag.

The buffer from which the buffer device address `pInfos[i].scratchData.deviceAddress` is queried must have been created with `VK_BUFFER_USAGE_STORAGE_BUFFER_BIT` usage flag.

For each element of `pInfos`, its `scratchData.deviceAddress` member must be a valid device address obtained from `vkGetBufferDeviceAddress`.

For each element of `pInfos`, if `scratchData.deviceAddress` is the address of a non-sparse buffer then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

For each element of `pInfos`, its `scratchData.deviceAddress` member must be a multiple of `VkPhysicalDeviceAccelerationStructurePropertiesKHR::minAccelerationStructureScratchOffsetAlignment`.

```
• **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03804**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, `geometry.triangles.vertexData.deviceAddress` must be a valid device address obtained from `vkGetBufferDeviceAddress`.

• **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03805**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if `geometry.triangles.vertexData.deviceAddress` is the address of a non-sparse buffer then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

• **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03711**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, `geometry.triangles.vertexData.deviceAddress` must be aligned to the size in bytes of the smallest component of the format in `vertexFormat`.

• **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03806**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if `geometry.triangles.indexData.deviceAddress` is not `VK_INDEX_TYPE_NONE_KHR`, `geometry.triangles.indexData.deviceAddress` must be a valid device address obtained from `vkGetBufferDeviceAddress`.

• **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03807**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if `geometry.triangles.indexData.deviceAddress` is the address of a non-sparse buffer then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

• **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03808**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if `geometry.triangles.transformData.deviceAddress` is not `0`, it must be a valid device address obtained from `vkGetBufferDeviceAddress`.

• **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03809**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if `geometry.triangles.transformData.deviceAddress` is the address of a non-sparse buffer then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

• **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03810**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if `geometry.triangles.transformData.deviceAddress` is not `0`, it must be aligned to 16 bytes.

• **VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03811**
  For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of...
VK_GEOMETRY_TYPE_AABBS_KHR, geometry.aabbs.data.deviceAddress must be a valid device address obtained from vkGetBufferDeviceAddress

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03812
  For any element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_AABBS_KHR, if geometry.aabbs.data.deviceAddress is the address of a non-sparse buffer then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03714
  For any element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_AABBS_KHR, geometry.aabbs.data.deviceAddress must be aligned to 8 bytes

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03715
  For any element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR, if geometry.arrayOfPointers is VK_FALSE, geometry.instances.data.deviceAddress must be aligned to 16 bytes

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03716
  For any element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR, if geometry.arrayOfPointers is VK_TRUE, geometry.instances.data.deviceAddress must be aligned to 8 bytes

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03717
  For any element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR, if geometry.arrayOfPointers is VK_TRUE, each element of geometry.instances.data.deviceAddress in device memory must be aligned to 16 bytes

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03813
  For any element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR, geometry.instances.data.deviceAddress must be a valid device address obtained from vkGetBufferDeviceAddress

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03814
  For any element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR, if geometry.instances.data.deviceAddress is the address of a non-sparse buffer then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-06707
  For any element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR, each VkAccelerationStructureInstanceKHR::accelerationStructureReference value in geometry.instances.data.deviceAddress must be a valid device address containing a value obtained from vkGetAccelerationStructureDeviceAddressKHR or 0

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pIndirectDeviceAddresses-03645
  For any element of pIndirectDeviceAddresses, if the buffer from which it was queried is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pIndirectDeviceAddresses-03646
  For any element of pIndirectDeviceAddresses[i], all device addresses between pIndirectDeviceAddresses[i] and pIndirectDeviceAddresses[i] + (pInfos[i].geometryCount × 3035) must be valid.
pIndirectStrides[i]) - 1 must be in the buffer device address range of the same buffer

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pIndirectDeviceAddresses-03647
  For any element of pIndirectDeviceAddresses, the buffer from which it was queried must have been created with the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT bit set

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pIndirectDeviceAddresses-03648
  Each element of pIndirectDeviceAddresses must be a multiple of 4

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pIndirectDeviceAddresses-03649
  Each element of pIndirectDeviceAddresses must be a multiple of 4

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pIndirectDeviceAddresses-03651
  Each VkAccelerationStructureBuildRangeInfoKHR structure referenced by any element of pIndirectDeviceAddresses must be a valid VkAccelerationStructureBuildRangeInfoKHR structure

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-03652
  pInfos[i].dstAccelerationStructure must have been created with a value of VkAccelerationStructureCreateInfoKHR::size greater than or equal to the memory size required by the build operation, as returned by vkGetAccelerationStructureBuildSizesKHR with pBuildInfo = pInfos[i] and pMaxPrimitiveCounts = ppMaxPrimitiveCounts[i]

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-ppMaxPrimitiveCounts-03653
  Each ppMaxPrimitiveCounts[i][j][] must be greater than or equal to the primitiveCount value specified by the VkAccelerationStructureBuildRangeInfoKHR structure located at pIndirectDeviceAddresses[i] + (j × pIndirectStrides[i])

Valid Usage (Implicit)

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pInfos-parameter
  pInfos must be a valid pointer to an array of infoCount valid VkAccelerationStructureBuildGeometryInfoKHR structures

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pIndirectDeviceAddresses-parameter
  pIndirectDeviceAddresses must be a valid pointer to an array of infoCount VkDeviceAddress values

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-pIndirectStrides-parameter
  pIndirectStrides must be a valid pointer to an array of infoCount uint32_t values

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-ppMaxPrimitiveCounts-parameter
  ppMaxPrimitiveCounts must be a valid pointer to an array of infoCount uint32_t values

- VUID-vkCmdBuildAccelerationStructuresIndirectKHR-commandBuffer-recording
  commandBuffer must be in the recording state
The \textit{VkCommandPool} that \textit{commandBuffer} was allocated from \textbf{must} support compute operations.

This command \textbf{must} only be called outside of a render pass instance.

This command \textbf{must} only be called outside of a video coding scope.

\textbf{infoCount} \textbf{must} be greater than 0.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
Command Buffer Levels & Render Pass Scope & Video Coding Scope & Supported Queue Types & Command Type \\
\hline
Primary & Outside & Outside & Compute & Action \\
Secondary & Outside & Outside & Compute & Action \\
\hline
\end{tabular}
\end{table}

The \textit{VkAccelerationStructureBuildGeometryInfoKHR} structure is defined as:

\begin{verbatim}
// Provided by VK_KHR_acceleration_structure
typedef struct VkAccelerationStructureBuildGeometryInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkAccelerationStructureTypeKHR type;
    VkBuildAccelerationStructureFlagsKHR flags;
    VkBuildAccelerationStructureModeKHR mode;
    VkAccelerationStructureKHR srcAccelerationStructure;
    VkAccelerationStructureKHR dstAccelerationStructure;
    uint32_t geometryCount;
    const VkAccelerationStructureGeometryKHR* pGeometries;
    const VkAccelerationStructureGeometryKHR* const* ppGeometries;
    VkDeviceOrHostAddressKHR scratchData;
} VkAccelerationStructureBuildGeometryInfoKHR;
\end{verbatim}

- \textbf{sType} is a \textit{VkStructureType} value identifying this structure.
- \textbf{pNext} is \textbf{NULL} or a pointer to a structure extending this structure.
• **type** is a `VkAccelerationStructureTypeKHR` value specifying the type of acceleration structure being built.

• **flags** is a bitmask of `VkBuildAccelerationStructureFlagBitsKHR` specifying additional parameters of the acceleration structure.

• **mode** is a `VkBuildAccelerationStructureModeKHR` value specifying the type of operation to perform.

• **srcAccelerationStructure** is a pointer to an existing acceleration structure that is to be used to update the `dst` acceleration structure when `mode` is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`.

• **dstAccelerationStructure** is a pointer to the target acceleration structure for the build.

• **geometryCount** specifies the number of geometries that will be built into `dstAccelerationStructure`.

• **pGeometries** is a pointer to an array of `VkAccelerationStructureGeometryKHR` structures.

• **ppGeometries** is a pointer to an array of pointers to `VkAccelerationStructureGeometryKHR` structures.

• **scratchData** is the device or host address to memory that will be used as scratch memory for the build.

Only one of `pGeometries` or `ppGeometries` can be a valid pointer, the other must be NULL. Each element of the non-NULL array describes the data used to build each acceleration structure geometry.

The index of each element of the `pGeometries` or `ppGeometries` members of `VkAccelerationStructureBuildGeometryInfoKHR` is used as the geometry index during ray traversal. The geometry index is available in ray shaders via the `RayGeometryIndexKHR` built-in, and is used to determine hit and intersection shaders executed during traversal. The geometry index is available to ray queries via the `OpRayQueryGetIntersectionGeometryIndexKHR` instruction.

Setting `VK_BUILD_ACCELERATION_STRUCTURE_MOTION_BIT_NV` in `flags` indicates that this build is a motion top level acceleration structure. A motion top level uses instances of format `VkAccelerationStructureMotionInstanceNV` if `VkAccelerationStructureGeometryInstancesDataKHR::arrayOfPointers` is `VK_FALSE`.

If `VkAccelerationStructureGeometryInstancesDataKHR::arrayOfPointers` is `VK_TRUE`, the pointer for each element of the array of instance pointers consists of 4 bits of `VkAccelerationStructureMotionInstanceTypeNV` in the low 4 bits of the pointer identifying the type of structure at the pointer. The device address accessed is the value in the array with the low 4 bits set to zero. The structure at the pointer is one of `VkAccelerationStructureInstanceKHR`, `VkAccelerationStructureMatrixMotionInstanceNV` or `VkAccelerationStructureSRTMotionInstanceNV`, depending on the type value encoded in the low 4 bits.

A top level acceleration structure with either motion instances or vertex motion in its instances must set `VK_BUILD_ACCELERATION_STRUCTURE_MOTION_BIT_NV` in `flags`.

Members `srcAccelerationStructure` and `dstAccelerationStructure` may be the same or different for
an update operation (when `mode` is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`). If they are the same, the update happens in-place. Otherwise, the target acceleration structure is updated and the source is not modified.

### Valid Usage

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-type-03654**
  - `type` must not be `VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR`

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-pGeometries-03788**
  - Only one of `pGeometries` or `ppGeometries` can be a valid pointer, the other must be `NULL`

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-type-03789**
  - If `type` is `VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_KHR`, the `geometryType` member of elements of either `pGeometries` or `ppGeometries` must be `VK_GEOMETRY_TYPE_INSTANCES_KHR`

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-type-03790**
  - If `type` is `VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_KHR`, `geometryCount` must be `1`

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-type-03791**
  - If `type` is `VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_KHR`, the `geometryType` member of each geometry in either `pGeometries` or `ppGeometries` must not be `VK_GEOMETRY_TYPE_INSTANCES_KHR`

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-type-03792**
  - If `type` is `VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_KHR`, then `geometryType` member of each geometry in either `pGeometries` or `ppGeometries` must be the same

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-type-03793**
  - If `type` is `VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_KHR`, then `geometryCount` must be less than or equal to `VkPhysicalDeviceAccelerationStructurePropertiesKHR::maxGeometryCount`

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-type-03794**
  - If `type` is `VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_KHR` and the `geometryType` member of either `pGeometries` or `ppGeometries` is `VK_GEOMETRY_TYPE_AABBS_KHR`, the total number of AABBs in all geometries must be less than or equal to `VkPhysicalDeviceAccelerationStructurePropertiesKHR::maxPrimitiveCount`

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-type-03795**
  - If `type` is `VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_KHR` and the `geometryType` member of either `pGeometries` or `ppGeometries` is `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, the total number of triangles in all geometries must be less than or equal to `VkPhysicalDeviceAccelerationStructurePropertiesKHR::maxPrimitiveCount`

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-flags-03796**
  - If `flags` has the `VK_BUILD_ACCELERATION_STRUCTURE_PREFER_FAST_TRACE_BIT_KHR` bit set, then it must not have the `VK_BUILD_ACCELERATION_STRUCTURE_PREFER_FAST_BUILD_BIT_KHR` bit set

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-dstAccelerationStructure-04927**
  - If `dstAccelerationStructure` was created with `VK_ACCELERATION_STRUCTURE_CREATE_MOTION_BIT_NV` set in `VkAccelerationStructureCreateInfoKHR::flags`,
**Valid Usage (Implicit)**

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-sType-sType**  
  
  *sType* **must** be *VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_BUILD_GEOMETRY_INFO_KHR*

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-pNext-pNext**  
  
  *pNext* **must** be NULL

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-type-parameter**  
  
  *type* **must** be a valid *VkAccelerationStructureTypeKHR* value

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-flags-parameter**  
  
  *flags* **must** be a valid combination of *VkBuildAccelerationStructureFlagBitsKHR* values

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-pGeometries-parameter**  
  
  If *geometryCount* is not 0, and *pGeometries* is not NULL, *pGeometries* **must** be a valid pointer to an array of *geometryCount* valid *VkAccelerationStructureGeometryKHR* structures

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-ppGeometries-parameter**  
  
  If *geometryCount* is not 0, and *ppGeometries* is not NULL, *ppGeometries* **must** be a valid pointer to an array of *geometryCount* valid pointers to valid *VkAccelerationStructureGeometryKHR* structures

- **VUID-VkAccelerationStructureBuildGeometryInfoKHR-commonparent**  
  
  Both of *dstAccelerationStructure*, and *srcAccelerationStructure* that are valid handles of non-ignored parameters **must** have been created, allocated, or retrieved from the same *VkDevice*

The *VkBuildAccelerationStructureModeKHR* enumeration is defined as:

```c
// Provided by VK_KHR_acceleration_structure
typedef enum VkBuildAccelerationStructureModeKHR {
    VK_BUILD_ACCELERATION_STRUCTURE_MODE_BUILD_KHR = 0,
    VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR = 1,
} VkBuildAccelerationStructureModeKHR;
```
• \texttt{VK\_BUILD\_ACCELERATION\_STRUCTURE\_MODE\_BUILD\_KHR} specifies that the destination acceleration structure will be built using the specified geometries.

• \texttt{VK\_BUILD\_ACCELERATION\_STRUCTURE\_MODE\_UPDATE\_KHR} specifies that the destination acceleration structure will be built using data in a source acceleration structure, updated by the specified geometries.

The \texttt{VkDeviceOrHostAddressKHR} union is defined as:

\begin{verbatim}
// Provided by VK_KHR_acceleration_structure
typedef union VkDeviceOrHostAddressKHR {
    VkDeviceAddress deviceAddress;
    void* hostAddress;
} VkDeviceOrHostAddressKHR;
\end{verbatim}

• \texttt{deviceAddress} is a buffer device address as returned by the \texttt{vkGetBufferDeviceAddressKHR} command.

• \texttt{hostAddress} is a host memory address.

The \texttt{VkDeviceOrHostAddressConstKHR} union is defined as:

\begin{verbatim}
// Provided by VK_KHR_acceleration_structure
typedef union VkDeviceOrHostAddressConstKHR {
    VkDeviceAddress deviceAddress;
    const void* hostAddress;
} VkDeviceOrHostAddressConstKHR;
\end{verbatim}

• \texttt{deviceAddress} is a buffer device address as returned by the \texttt{vkGetBufferDeviceAddressKHR} command.

• \texttt{hostAddress} is a const host memory address.

The \texttt{VkAccelerationStructureGeometryKHR} structure is defined as:

\begin{verbatim}
// Provided by VK_KHR_acceleration_structure
typedef struct VkAccelerationStructureGeometryKHR {
    VkStructureType sType;
    const void* pNext;
    VkGeometryTypeKHR geometryType;
    VkAccelerationStructureGeometryDataKHR geometry;
    VkGeometryFlagsKHR flags;
} VkAccelerationStructureGeometryKHR;
\end{verbatim}

• \texttt{sType} is a \texttt{VkStructureType} value identifying this structure.

• \texttt{pNext} is \texttt{NULL} or a pointer to a structure extending this structure.

• \texttt{geometryType} describes which type of geometry this \texttt{VkAccelerationStructureGeometryKHR} refers to.
• **geometry** is a `VkAccelerationStructureGeometryDataKHR` union describing the geometry data for the relevant geometry type.

• **flags** is a bitmask of `VkGeometryFlagBitsKHR` values describing additional properties of how the geometry should be built.

### Valid Usage (Implicit)

- **VUID-VkAccelerationStructureGeometryKHR-sType-sType**
  
  - *sType must be* `VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_GEOMETRY_KHR`

- **VUID-VkAccelerationStructureGeometryKHR-pNext-pNext**
  
  - *pNext must be* `NULL`

- **VUID-VkAccelerationStructureGeometryKHR-geometryType-parameter**
  
  - *geometryType must be a valid `VkGeometryTypeKHR` value*

- **VUID-VkAccelerationStructureGeometryKHR-triangles-parameter**
  
  - If `geometryType` is `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, the `triangles` member of `geometry` must be a valid `VkAccelerationStructureGeometryTrianglesDataKHR` structure

- **VUID-VkAccelerationStructureGeometryKHR-aabbs-parameter**
  
  - If `geometryType` is `VK_GEOMETRY_TYPE_AABBS_KHR`, the `aabbs` member of `geometry` must be a valid `VkAccelerationStructureGeometryAabbsDataKHR` structure

- **VUID-VkAccelerationStructureGeometryKHR-instances-parameter**
  
  - If `geometryType` is `VK_GEOMETRY_TYPE_INSTANCES_KHR`, the `instances` member of `geometry` must be a valid `VkAccelerationStructureGeometryInstancesDataKHR` structure

- **VUID-VkAccelerationStructureGeometryKHR-flags-parameter**
  
  - *flags must be a valid combination of `VkGeometryFlagBitsKHR` values*

The `VkAccelerationStructureGeometryDataKHR` union is defined as:

```cpp
// Provided by VK_KHR_acceleration_structure
typedef union VkAccelerationStructureGeometryDataKHR {
  VkAccelerationStructureGeometryTrianglesDataKHR triangles;
  VkAccelerationStructureGeometryAabbsDataKHR aabbs;
  VkAccelerationStructureGeometryInstancesDataKHR instances;
} VkAccelerationStructureGeometryDataKHR;
```

• **triangles** is a `VkAccelerationStructureGeometryTrianglesDataKHR` structure.

• **aabbs** is a `VkAccelerationStructureGeometryAabbsDataKHR` structure.

• **instances** is a `VkAccelerationStructureGeometryInstancesDataKHR` structure.

The `VkAccelerationStructureGeometryTrianglesDataKHR` structure is defined as:

```cpp
// Provided by VK_KHR_acceleration_structure
typedef struct VkAccelerationStructureGeometryTrianglesDataKHR {
  VkStructureType sType;
} VkAccelerationStructureGeometryTrianglesDataKHR;
```
const void* getNext;
VkFormat vertexFormat;
VkDeviceOrHostAddressConstKHR vertexData;
VkDeviceSize vertexStride;
uint32_t maxVertex;
VkIndexType indexType;
VkDeviceOrHostAddressConstKHR indexData;
VkDeviceOrHostAddressConstKHR transformData;
} VkAccelerationStructureGeometryTrianglesDataKHR;

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **vertexFormat** is the *VkFormat* of each vertex element.
- **vertexData** is a device or host address to memory containing vertex data for this geometry.
- **maxVertex** is the highest index of a vertex that will be addressed by a build command using this structure.
- **vertexStride** is the stride in bytes between each vertex.
- **indexType** is the *VkIndexType* of each index element.
- **indexData** is a device or host address to memory containing index data for this geometry.
- **transformData** is a device or host address to memory containing an optional reference to a *VkTransformMatrixKHR* structure describing a transformation from the space in which the vertices in this geometry are described to the space in which the acceleration structure is defined.

**Note**

Unlike the stride for vertex buffers in *VkVertexInputBindingDescription* for graphics pipelines which must not exceed *maxVertexInputBindingStride*, **vertexStride** for acceleration structure geometry is instead restricted to being a 32-bit value.

**Valid Usage**

- **VUID-VkAccelerationStructureGeometryTrianglesDataKHR-vertexStride-03735**
  vertexStride **must** be a multiple of the size in bytes of the smallest component of vertexFormat

- **VUID-VkAccelerationStructureGeometryTrianglesDataKHR-vertexStride-03819**
  vertexStride **must** be less than or equal to $2^{32} - 1$

- **VUID-VkAccelerationStructureGeometryTrianglesDataKHR-vertexFormat-03797**
  The format features of vertexFormat **must** contain VK_FORMAT_FEATURE_ACCELERATION_STRUCTURE_VERTEX_BUFFER_BIT_KHR

- **VUID-VkAccelerationStructureGeometryTrianglesDataKHR-indexType-03798**
  indexType **must** be VK_INDEX_TYPE_UINT16, VK_INDEX_TYPE_UINT32, or VK_INDEX_TYPE_NONE_KHR
Valid Usage (Implicit)

- VUID-VkAccelerationStructureGeometryTrianglesDataKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_GEOMETRY_TRIANGLES_DATA_KHR

- VUID-VkAccelerationStructureGeometryTrianglesDataKHR-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkAccelerationStructureGeometryMotionTrianglesDataNV, VkAccelerationStructureTrianglesDisplacementMicromapNV, VkAccelerationStructureTrianglesOpacityMicromapEXT

- VUID-VkAccelerationStructureGeometryTrianglesDataKHR-sType-unique
  The sType value of each struct in the pNext chain must be unique

- VUID-VkAccelerationStructureGeometryTrianglesDataKHR-vertexFormat-parameter
  vertexFormat must be a valid VkFormat value

- VUID-VkAccelerationStructureGeometryTrianglesDataKHR-indexType-parameter
  indexType must be a valid VkIndexType value

The VkAccelerationStructureGeometryMotionTrianglesDataNV structure is defined as:

```c
// Provided by VK_NV_ray_tracing_motion_blur
typedef struct VkAccelerationStructureGeometryMotionTrianglesDataNV {
    VkStructureType sType;
    const void* pNext;
    VkDeviceOrHostAddressConstKHR vertexData;
} VkAccelerationStructureGeometryMotionTrianglesDataNV;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- vertexData is a pointer to vertex data for this geometry at time 1.0

If VkAccelerationStructureGeometryMotionTrianglesDataNV is included in the pNext chain of a VkAccelerationStructureGeometryTrianglesDataKHR structure, the basic vertex positions are used for the position of the triangles in the geometry at time 0.0 and the vertexData in VkAccelerationStructureGeometryMotionTrianglesDataNV is used for the vertex positions at time 1.0, with positions linearly interpolated at intermediate times.

Indexing for VkAccelerationStructureGeometryMotionTrianglesDataNV vertexData is equivalent to the basic vertex position data.

Valid Usage (Implicit)

- VUID-VkAccelerationStructureGeometryMotionTrianglesDataNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_GEOMETRY_MOTION_TRIANGLES_DATA_NV
The `VkAccelerationStructureTrianglesOpacityMicromapEXT` structure is defined as:

```c
// Provided by VK_EXT_opacity_micromap
typedef struct VkAccelerationStructureTrianglesOpacityMicromapEXT {
    VkStructureType sType;
    void* pNext;
    VkIndexType indexType;
    VkDeviceOrHostAddressConstKHR indexBuffer;
    VkDeviceSize indexStride;
    uint32_t baseTriangle;
    uint32_t usageCountsCount;
    const VkMicromapUsageEXT* pUsageCounts;
    const VkMicromapUsageEXT* const* ppUsageCounts;
    VkMicromapEXT micromap;
} VkAccelerationStructureTrianglesOpacityMicromapEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **indexType** is the type of triangle indices used when indexing this micromap.
- **indexBuffer** is the address containing the triangle indices.
- **indexStride** is the byte stride between triangle indices.
- **baseTriangle** is the base value added to the non-negative triangle indices.
- **usageCountsCount** specifies the number of usage counts structures that will be used to determine the size of this micromap.
- **pUsageCounts** is a pointer to an array of `VkMicromapUsageEXT` structures.
- **ppUsageCounts** is a pointer to an array of pointers to `VkMicromapUsageEXT` structures.
- **micromap** is the handle to the micromap object to include in this geometry.

If `VkAccelerationStructureTrianglesOpacityMicromapEXT` is included in the `pNext` chain of a `VkAccelerationStructureGeometryTrianglesDataKHR` structure, that geometry will reference that micromap.

For each triangle in the geometry, the acceleration structure build fetches an index from `indexBuffer` using `indexType` and `indexStride`. If that value is the unsigned cast of one of the values from `VkOpacityMicromapSpecialIndexEXT` then that triangle behaves as described for that special value in Ray Opacity Micromap. Otherwise that triangle uses the opacity micromap information from `micromap` at that index plus `baseTriangle`.

Only one of `pUsageCounts` or `ppUsageCounts` can be a valid pointer, the other must be `NULL`. The elements of the non-`NULL` array describe the total count used to build this geometry. For a given format and subdivisionLevel the number of triangles in this geometry matching those values after indirection and special index handling must be equal to the sum of matching `count` provided.

If `micromap` is `VK_NULL_HANDLE`, then every value read from `indexBuffer` must be one of the values in `VkOpacityMicromapSpecialIndexEXT`. 


Valid Usage

- VUID-VkAccelerationStructureTrianglesOpacityMicromapEXT-pUsageCounts-07335
  Only one of `pUsageCounts` or `ppUsageCounts` can be a valid pointer, the other must be `NULL`.

Valid Usage (Implicit)

- VUID-VkAccelerationStructureTrianglesOpacityMicromapEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_TRIANGLES_OPACITY_MICROMAP_EXT`.
- VUID-VkAccelerationStructureTrianglesOpacityMicromapEXT-indexType-parameter
  `indexType` must be a valid `VkIndexType` value.
- VUID-VkAccelerationStructureTrianglesOpacityMicromapEXT-pUsageCounts-parameter
  If `usageCountsCount` is not 0, and `pUsageCounts` is not `NULL`, `pUsageCounts` must be a valid pointer to an array of `usageCountsCount` `VkMicromapUsageEXT` structures.
- VUID-VkAccelerationStructureTrianglesOpacityMicromapEXT-ppUsageCounts-parameter
  If `usageCountsCount` is not 0, and `ppUsageCounts` is not `NULL`, `ppUsageCounts` must be a valid pointer to an array of `usageCountsCount` valid pointers to `VkMicromapUsageEXT` structures.
- VUID-VkAccelerationStructureTrianglesOpacityMicromapEXT-micromap-parameter
  If `micromap` is not `VK_NULL_HANDLE`, `micromap` must be a valid `VkMicromapEXT` handle.

The `VkOpacityMicromapSpecialIndexEXT` enumeration is defined as:

```c
// Provided by VK_EXT_opacity_micromap
typedef enum VkOpacityMicromapSpecialIndexEXT {
    VK_OPACITY_MICROMAP_SPECIAL_INDEX_FULLY_TRANSPARENT_EXT = -1,
    VK_OPACITY_MICROMAP_SPECIAL_INDEX_FULLY_OPAQUE_EXT = -2,
    VK_OPACITY_MICROMAP_SPECIAL_INDEX_FULLY_UNKNOWN_TRANSPARENT_EXT = -3,
    VK_OPACITY_MICROMAP_SPECIAL_INDEX_FULLY_UNKNOWN_OPAQUE_EXT = -4,
} VkOpacityMicromapSpecialIndexEXT;
```

- `VK_OPACITY_MICROMAP_SPECIAL_INDEX_FULLY_TRANSPARENT_EXT` specifies that the entire triangle is fully transparent.
- `VK_OPACITY_MICROMAP_SPECIAL_INDEX_FULLY_OPAQUE_EXT` specifies that the entire triangle is fully opaque.
- `VK_OPACITY_MICROMAP_SPECIAL_INDEX_FULLY_UNKNOWN_TRANSPARENT_EXT` specifies that the entire triangle is unknown-transparent.
- `VK_OPACITY_MICROMAP_SPECIAL_INDEX_FULLY_UNKNOWN_OPAQUE_EXT` specifies that the entire triangle is unknown-opaque.

The `VkAccelerationStructureTrianglesDisplacementMicromapNV` structure is defined as:

```c
// Provided by VK_NV_displacement_micromap
```
typedef struct VkAccelerationStructureTrianglesDisplacementMicromapNV {
    VkStructureType sType;
    void* pNext;
    VkFormat displacementBiasAndScaleFormat;
    VkFormat displacementVectorFormat;
    VkDeviceOrHostAddressConstKHR displacementBiasAndScaleBuffer;
    VkDeviceSize displacementBiasAndScaleStride;
    VkDeviceOrHostAddressConstKHR displacementVectorBuffer;
    VkDeviceSize displacementVectorStride;
    VkDeviceOrHostAddressConstKHR displacedMicromapPrimitiveFlags;
    VkDeviceSize displacedMicromapPrimitiveFlagsStride;
    VkIndexType indexType;
    VkDeviceOrHostAddressConstKHR indexBuffer;
    VkDeviceSize indexStride;
    uint32_t baseTriangle;
    uint32_t usageCountsCount;
    const VkMicromapUsageEXT* pUsageCounts;
    const VkMicromapUsageEXT* const* ppUsageCounts;
    VkMicromapEXT micromap;
} VkAccelerationStructureTrianglesDisplacementMicromapNV;

• **sType** is a **VkStructureType** value identifying this structure.
• **pNext** is **NULL** or a pointer to a structure extending this structure.
• **displacementBiasAndScaleFormat** is the format of displacement bias and scale used in this displacement micromap reference.
• **displacementVectorFormat** is the format of displacement vector used in this displacement micromap reference.
• **displacementBiasAndScaleBuffer** is the address containing the bias and scale.
• **displacementBiasAndScaleStride** is the byte stride between bias and scale values.
• **displacementVectorBuffer** is the address containing the displacement vector values.
• **displacementVectorStride** is the byte stride between displacement vector values.
• **displacedMicromapPrimitiveFlags** is the address containing the primitive flags.
• **displacedMicromapPrimitiveFlagsStride** is the byte stride between primitive flag values.
• **indexType** is the type of triangle indices used when indexing this micromap.
• **indexBuffer** is the address containing the triangle indices.
• **indexStride** is the byte stride between triangle indices.
• **baseTriangle** is the base value added to the non-negative triangle indices.
• **usageCountsCount** specifies the number of usage counts structures that will be used to determine the size of this micromap.
• **pUsageCounts** is a pointer to an array of **VkMicromapUsageEXT** structures.
• **ppUsageCounts** is a pointer to an array of pointers to **VkMicromapUsageEXT** structures.
• **micromap** is the handle to the micromap object to include in this geometry.
If `VkAccelerationStructureTrianglesDisplacementMicromapNV` is included in the `pNext` chain of a `VkAccelerationStructureGeometryTrianglesDataKHR` structure, that geometry will reference that micromap.

For each triangle in the geometry, the acceleration structure build fetches an index from `indexBuffer` using `indexType` and `indexStride`. That triangle uses the displacement micromap information from `micromap` at that index plus `baseTriangle`.

Only one of `pUsageCounts` or `ppUsageCounts` can be a valid pointer, the other must be `NULL`. The elements of the non-`NULL` array describe the total count used to build this geometry. For a given `format` and `subdivisionLevel` the number of triangles in this geometry matching those values after indirection must be equal to the sum of matching `count` provided.

**Valid Usage**

- VUID-VkAccelerationStructureTrianglesDisplacementMicromapNV-pUsageCounts-07992
  Only one of `pUsageCounts` or `ppUsageCounts` can be a valid pointer, the other must be `NULL`.

**Valid Usage (Implicit)**

- VUID-VkAccelerationStructureTrianglesDisplacementMicromapNV-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_TRIANGLES_DISPLACEMENT_MICROMAP_NV`.

- VUID-VkAccelerationStructureTrianglesDisplacementMicromapNV-displacementBiasAndScaleFormat-parameter
  `displacementBiasAndScaleFormat` must be a valid `VkFormat` value.

- VUID-VkAccelerationStructureTrianglesDisplacementMicromapNV-displacementVectorFormat-parameter
  `displacementVectorFormat` must be a valid `VkFormat` value.

- VUID-VkAccelerationStructureTrianglesDisplacementMicromapNV-indexType-parameter
  `indexType` must be a valid `VkIndexType` value.

- VUID-VkAccelerationStructureTrianglesDisplacementMicromapNV-pUsageCounts-parameter
  If `usageCountsCount` is not `0`, and `pUsageCounts` is not `NULL`, `pUsageCounts` must be a valid pointer to an array of `usageCountsCount` `VkMicromapUsageEXT` structures.

- VUID-VkAccelerationStructureTrianglesDisplacementMicromapNV-ppUsageCounts-parameter
  If `usageCountsCount` is not `0`, and `ppUsageCounts` is not `NULL`, `ppUsageCounts` must be a valid pointer to an array of `usageCountsCount` valid pointers to `VkMicromapUsageEXT` structures.

- VUID-VkAccelerationStructureTrianglesDisplacementMicromapNV-micromap-parameter
  If `micromap` is not `VK_NULL_HANDLE`, `micromap` must be a valid `VkMicromapEXT` handle.

The `VkTransformMatrixKHR` structure is defined as:

---

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// Provided by VK_KHR_acceleration_structure

typedef struct VkTransformMatrixKHR {
    float matrix[3][4];
} VkTransformMatrixKHR;

or the equivalent

// Provided by VK_NV_ray_tracing

typedef VkTransformMatrixKHR VkTransformMatrixNV;

• matrix is a 3x4 row-major affine transformation matrix.

Valid Usage

• VUID-VkTransformMatrixKHR-matrix-03799
The first three columns of matrix must define an invertible 3x3 matrix

The VkAccelerationStructureGeometryAabbsDataKHR structure is defined as:

// Provided by VK_KHR_acceleration_structure

typedef struct VkAccelerationStructureGeometryAabbsDataKHR {
    VkStructureType sType;
    const void* pNext;
    VkDeviceOrHostAddressConstKHR data;
    VkDeviceSize stride;
} VkAccelerationStructureGeometryAabbsDataKHR;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• data is a device or host address to memory containing VkAabbPositionsKHR structures containing position data for each axis-aligned bounding box in the geometry.
• stride is the stride in bytes between each entry in data. The stride must be a multiple of 8.

Valid Usage

• VUID-VkAccelerationStructureGeometryAabbsDataKHR-stride-03545
  stride must be a multiple of 8
• VUID-VkAccelerationStructureGeometryAabbsDataKHR-stride-03820
  stride must be less than or equal to $2^{32} - 1$
Valid Usage (Implicit)

• VUID-VkAccelerationStructureGeometryAabbsDataKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_GEOMETRY_AABBS_DATA_KHR

• VUID-VkAccelerationStructureGeometryAabbsDataKHR-pNext-pNext
  pNext must be NULL

The VkAabbPositionsKHR structure is defined as:

```c
// Provided by VK_KHR_acceleration_structure
typedef struct VkAabbPositionsKHR {
    float minX;
    float minY;
    float minZ;
    float maxX;
    float maxY;
    float maxZ;
} VkAabbPositionsKHR;
```

or the equivalent

```c
// Provided by VK_NV_ray_tracing
typedef VkAabbPositionsKHR VkAabbPositionsNV;
```

• minX is the x position of one opposing corner of a bounding box.
• minY is the y position of one opposing corner of a bounding box.
• minZ is the z position of one opposing corner of a bounding box.
• maxX is the x position of the other opposing corner of a bounding box.
• maxY is the y position of the other opposing corner of a bounding box.
• maxZ is the z position of the other opposing corner of a bounding box.

Valid Usage

• VUID-VkAabbPositionsKHR-minX-03546
  minX must be less than or equal to maxX

• VUID-VkAabbPositionsKHR-minY-03547
  minY must be less than or equal to maxY

• VUID-VkAabbPositionsKHR-minZ-03548
  minZ must be less than or equal to maxZ

The VkAccelerationStructureGeometryInstancesDataKHR structure is defined as:
// Provided by VK_KHR_acceleration_structure
typedef struct VkAccelerationStructureGeometryInstancesDataKHR {
    VkStructureType sType;
    const void* pNext;
    VkBool32 arrayOfPointers;
    VkDeviceOrHostAddressConstKHR data;
} VkAccelerationStructureGeometryInstancesDataKHR;

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **arrayOfPointers** specifies whether **data** is used as an array of addresses or just an array.
- **data** is either the address of an array of device or host addresses referencing individual VkAccelerationStructureInstanceKHR structures or packed motion instance information as described in motion instances if **arrayOfPointers** is VK_TRUE, or the address of an array of VkAccelerationStructureInstanceKHR or VkAccelerationStructureMotionInstanceNV structures. Addresses and VkAccelerationStructureInstanceKHR structures are tightly packed. VkAccelerationStructureMotionInstanceNV structures have a stride of 160 bytes.

Valid Usage (Implicit)
- VUID-VkAccelerationStructureGeometryInstancesDataKHR-sType-sType
  **sType** must be VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_GEOMETRY_INSTANCES_DATA_KHR
- VUID-VkAccelerationStructureGeometryInstancesDataKHR-pNext-pNext
  **pNext** must be NULL

Acceleration structure instances **can** be built into top-level acceleration structures. Each acceleration structure instance is a separate entry in the top-level acceleration structure which includes all the geometry of a bottom-level acceleration structure at a transformed location. Multiple instances **can** point to the same bottom level acceleration structure.

An acceleration structure instance is defined by the structure:

// Provided by VK_KHR_acceleration_structure
typedef struct VkAccelerationStructureInstanceKHR {
    VkTransformMatrixKHR transform;
    uint32_t instanceCustomIndex:24;
    uint32_t mask:8;
    uint32_t instanceShaderBindingTableRecordOffset:24;
    VkGeometryInstanceFlagsKHR flags:8;
    uint64_t accelerationStructureReference;
} VkAccelerationStructureInstanceKHR;

or the equivalent
typedef VkAccelerationStructureInstanceKHR VkAccelerationStructureInstanceNV;

- **transform** is a `VkTransformMatrixKHR` structure describing a transformation to be applied to the acceleration structure.

- **instanceCustomIndex** is a 24-bit user-specified index value accessible to ray shaders in the `InstanceCustomIndexKHR` built-in.

- **mask** is an 8-bit visibility mask for the geometry. The instance may only be hit if `Cull Mask & instance.mask != 0`

- **instanceShaderBindingTableRecordOffset** is a 24-bit offset used in calculating the hit shader binding table index.

- **flags** is an 8-bit mask of `VkGeometryInstanceFlagBitsKHR` values to apply to this instance.

- **accelerationStructureReference** is either:
  - a device address containing the value obtained from `vkGetAccelerationStructureDeviceAddressKHR` or `vkGetAccelerationStructureHandleNV` (used by device operations which reference acceleration structures) or,
  - a ` VkAccelerationStructureKHR` object (used by host operations which reference acceleration structures).

The C language specification does not define the ordering of bit-fields, but in practice, this struct produces the correct layout with existing compilers. The intended bit pattern is for the following:

- **instanceCustomIndex** and **mask** occupy the same memory as if a single `uint32_t` was specified in their place
  - **instanceCustomIndex** occupies the 24 least significant bits of that memory
  - **mask** occupies the 8 most significant bits of that memory

- **instanceShaderBindingTableRecordOffset** and **flags** occupy the same memory as if a single `uint32_t` was specified in their place
  - **instanceShaderBindingTableRecordOffset** occupies the 24 least significant bits of that memory
  - **flags** occupies the 8 most significant bits of that memory

If a compiler produces code that diverges from that pattern, applications must employ another method to set values according to the correct bit pattern.

### Valid Usage (Implicit)

- **VUID-VkAccelerationStructureInstanceKHR-flags-parameter**
  - **flags** must be a valid combination of `VkGeometryInstanceFlagBitsKHR` values

Possible values of **flags** in the instance modifying the behavior of that instance are:
typedef enum VkGeometryInstanceFlagBitsKHR {
    VK_GEOMETRY_INSTANCE_TRIANGLE_FACING_CULL_DISABLE_BIT_KHR = 0x00000001,
    VK_GEOMETRY_INSTANCE_TRIANGLE_FLIP_FACING_BIT_KHR = 0x00000002,
    VK_GEOMETRY_INSTANCE_FORCE_OPAQUE_BIT_KHR = 0x00000004,
    VK_GEOMETRY_INSTANCE_FORCE_NO_OPAQUE_BIT_KHR = 0x00000008,
    VK_GEOMETRY_INSTANCE_FORCE_OPAQUE_BIT_NV
        = VK_GEOMETRY_INSTANCE_FORCE_OPAQUE_BIT_KHR,
    VK_GEOMETRY_INSTANCE_FORCE_NO_OPAQUE_BIT_NV
        = VK_GEOMETRY_INSTANCE_FORCE_NO_OPAQUE_BIT_KHR,
    VK_GEOMETRY_INSTANCE_DISABLE_OPACITY_MICROMAPS_EXT = 0x00000020,
    VK_GEOMETRY_INSTANCE_FORCE_OPACITY_MICROMAP_2_STATE_EXT = 0x00000010,
    VK_GEOMETRY_INSTANCE_TRIANGLE_FACING_CULL_DISABLE_BIT_KHR
        = VK_GEOMETRY_INSTANCE_TRIANGLE_FACING_CULL_DISABLE_BIT_KHR,
    VK_GEOMETRY_INSTANCE_TRIANGLE_FRONT_COUNTERCLOCKWISE_BIT_NV
        = VK_GEOMETRY_INSTANCE_TRIANGLE_FRONT_COUNTERCLOCKWISE_BIT_KHR,
    VK_GEOMETRY_INSTANCE_TRIANGLE_FRONT_COUNTERCLOCKWISE_BIT_KHR
        = VK_GEOMETRY_INSTANCE_TRIANGLE_FRONT_COUNTERCLOCKWISE_BIT_KHR,
    VK_GEOMETRY_INSTANCE_FORCE_OPAQUE_BIT_NV
        = VK_GEOMETRY_INSTANCE_FORCE_OPAQUE_BIT_KHR,
    VK_GEOMETRY_INSTANCE_FORCE_NO_OPAQUE_BIT_NV
        = VK_GEOMETRY_INSTANCE_FORCE_NO_OPAQUE_BIT_KHR,
} VkGeometryInstanceFlagBitsKHR;

• VK_GEOMETRY_INSTANCE_TRIANGLE_FACING_CULL_DISABLE_BIT_KHR disables face culling for this instance.

• VK_GEOMETRY_INSTANCE_TRIANGLE_FLIP_FACING_BIT_KHR indicates that the facing determination for geometry in this instance is inverted. Because the facing is determined in object space, an instance transform does not change the winding, but a geometry transform does.

• VK_GEOMETRY_INSTANCE_FORCE_OPAQUE_BIT_KHR causes this instance to act as though VK_GEOMETRY_OPAQUE_BIT_KHR were specified on all geometries referenced by this instance. This behavior can be overridden by the SPIR-V NoOpaqueKHR ray flag.

• VK_GEOMETRY_INSTANCE_FORCE_NO_OPAQUE_BIT_KHR causes this instance to act as though VK_GEOMETRY_OPAQUE_BIT_KHR were not specified on all geometries referenced by this instance. This behavior can be overridden by the SPIR-V OpaqueKHR ray flag.

VK_GEOMETRY_INSTANCE_FORCE_NO_OPAQUE_BIT_KHR and VK_GEOMETRY_INSTANCE_FORCE_OPAQUE_BIT_KHR must not be used in the same flag.
VkGeometryInstanceFlagsKHR is a bitmask type for setting a mask of zero or more VkGeometryInstanceFlagBitsKHR.

Acceleration structure motion instances can be built into top-level acceleration structures. Each acceleration structure instance is a separate entry in the top-level acceleration structure which includes all the geometry of a bottom-level acceleration structure at a transformed location including a type of motion and parameters to determine the motion of the instance over time.

An acceleration structure motion instance is defined by the structure:

```c
// Provided by VK_NV_ray_tracing_motion_blur
typedef struct VkAccelerationStructureMotionInstanceNV {
    VkAccelerationStructureMotionInstanceTypeNV type;
    VkAccelerationStructureMotionInstanceFlagsNV flags;
    VkAccelerationStructureMotionInstanceDataNV data;
} VkAccelerationStructureMotionInstanceNV;
```

- **type** is a VkAccelerationStructureMotionInstanceTypeNV enumerant identifying which type of motion instance this is and which type of the union is valid.
- **flags** is currently unused, but is required to keep natural alignment of **data**.
- **data** is a VkAccelerationStructureMotionInstanceDataNV containing motion instance data for this instance.

**Note**

If writing this other than with a standard C compiler, note that the final structure should be 152 bytes in size.

**Valid Usage (Implicit)**

- **VUID-VkAccelerationStructureMotionInstanceNV-type-parameter**
  type must be a valid VkAccelerationStructureMotionInstanceTypeNV value
- **VUID-VkAccelerationStructureMotionInstanceNV-flags-zerobitmask**
  flags must be 0
- **VUID-VkAccelerationStructureMotionInstanceNV-staticInstance-parameter**
  If type is VK_ACCELERATION_STRUCTURE_MOTION_INSTANCE_TYPE_STATIC_NV, the staticInstance...
member of `data` must be a valid `VkAccelerationStructureInstanceKHR` structure

- VUID-VkAccelerationStructureMotionInstanceNV-matrixMotionInstance-parameter
  If `type` is `VK_ACCELERATION_STRUCTURE_MOTION_INSTANCE_TYPE_MATRIX_MOTION_NV`, the `matrixMotionInstance` member of `data` must be a valid `VkAccelerationStructureMatrixMotionInstanceNV` structure

- VUID-VkAccelerationStructureMotionInstanceNV-srtMotionInstance-parameter
  If `type` is `VK_ACCELERATION_STRUCTURE_MOTION_INSTANCE_TYPE_SRT_MOTION_NV`, the `srtMotionInstance` member of `data` must be a valid `VkAccelerationStructureSRTMotionInstanceNV` structure

Acceleration structure motion instance is defined by the union:

```c
// Provided by VK_NV_ray_tracing_motion_blur
typedef union VkAccelerationStructureMotionInstanceDataNV {
    VkAccelerationStructureInstanceKHR staticInstance;
    VkAccelerationStructureMatrixMotionInstanceNV matrixMotionInstance;
    VkAccelerationStructureSRTMotionInstanceNV srtMotionInstance;
} VkAccelerationStructureMotionInstanceDataNV;
```

- `staticInstance` is a `VkAccelerationStructureInstanceKHR` structure containing data for a static instance.
- `matrixMotionInstance` is a `VkAccelerationStructureMatrixMotionInstanceNV` structure containing data for a matrix motion instance.
- `srtMotionInstance` is a `VkAccelerationStructureSRTMotionInstanceNV` structure containing data for an SRT motion instance.

```c
// Provided by VK_NV_ray_tracing_motion_blur
typedef VkFlags VkAccelerationStructureMotionInstanceFlagsNV;
```

`VkAccelerationStructureMotionInstanceFlagsNV` is a bitmask type for setting a mask, but is currently reserved for future use.

The `VkAccelerationStructureMotionInstanceTypeNV` enumeration is defined as:

```c
// Provided by VK_NV_ray_tracing_motion_blur
typedef enum VkAccelerationStructureMotionInstanceTypeNV {
    VK_ACCELERATION_STRUCTURE_MOTION_INSTANCE_TYPE_STATIC_NV = 0,
    VK_ACCELERATION_STRUCTURE_MOTION_INSTANCE_TYPE_MATRIX_MOTION_NV = 1,
    VK_ACCELERATION_STRUCTURE_MOTION_INSTANCE_TYPE_SRT_MOTION_NV = 2,
} VkAccelerationStructureMotionInstanceTypeNV;
```

- `VK_ACCELERATION_STRUCTURE_MOTION_INSTANCE_TYPE_STATIC_NV` specifies that the instance is a static instance with no instance motion.
- `VK_ACCELERATION_STRUCTURE_MOTION_INSTANCE_TYPE_MATRIX_MOTION_NV` specifies that the instance is
a motion instance with motion specified by interpolation between two matrices.

- **VK_ACCELERATION_STRUCTURE MOTION INSTANCE TYPE SRT MOTION NV** specifies that the instance is a motion instance with motion specified by interpolation in the SRT decomposition.

An acceleration structure matrix motion instance is defined by the structure:

```c
// Provided by VK_NV_ray_tracing_motion_blur
typedef struct VkAccelerationStructureMatrixMotionInstanceNV {
    VkTransformMatrixKHR transformT0;
    VkTransformMatrixKHR transformT1;
    uint32_t instanceCustomIndex:24;
    uint32_t mask:8;
    uint32_t instanceShaderBindingTableRecordOffset:24;
    VkGeometryInstanceFlagsKHR flags:8;
    uint64_t accelerationStructureReference;
} VkAccelerationStructureMatrixMotionInstanceNV;
```

- **transformT0** is a VkTransformMatrixKHR structure describing a transformation to be applied to the acceleration structure at time 0.

- **transformT1** is a VkTransformMatrixKHR structure describing a transformation to be applied to the acceleration structure at time 1.

- **instanceCustomIndex** is a 24-bit user-specified index value accessible to ray shaders in the InstanceCustomIndexKHR built-in.

- **mask** is an 8-bit visibility mask for the geometry. The instance may only be hit if Cull Mask & instance.mask != 0

- **instanceShaderBindingTableRecordOffset** is a 24-bit offset used in calculating the hit shader binding table index.

- **flags** is an 8-bit mask of VkGeometryInstanceFlagBitsKHR values to apply to this instance.

- **accelerationStructureReference** is either:
  - a device address containing the value obtained from vkGetAccelerationStructureDeviceAddressKHR or vkGetAccelerationStructureHandleNV (used by device operations which reference acceleration structures) or,
  - a VkAccelerationStructureKHR object (used by host operations which reference acceleration structures).

The C language specification does not define the ordering of bit-fields, but in practice, this struct produces the correct layout with existing compilers. The intended bit pattern is for the following:

- **instanceCustomIndex** and **mask** occupy the same memory as if a single uint32_t was specified in their place
  - **instanceCustomIndex** occupies the 24 least significant bits of that memory
  - **mask** occupies the 8 most significant bits of that memory

- **instanceShaderBindingTableRecordOffset** and **flags** occupy the same memory as if a single
If a compiler produces code that diverges from that pattern, applications must employ another method to set values according to the correct bit pattern.

The transform for a matrix motion instance at a point in time is derived by component-wise linear interpolation of the two transforms. That is, for a time in [0,1] the resulting transform is

\[
\text{transformT0} \times (1 - \text{time}) + \text{transformT1} \times \text{time}
\]

Valid Usage (Implicit)

- VUID-VkAccelerationStructureMatrixMotionInstanceNV-flags-parameter
  - flags must be a valid combination of \text{VkGeometryInstanceFlagBitsKHR} values

An acceleration structure SRT motion instance is defined by the structure:

```c
// Provided by VK_NV_ray_tracing_motion_blur
typedef struct VkAccelerationStructureSRTMotionInstanceNV {
    VkSRTDataNV transformT0;
    VkSRTDataNV transformT1;
    uint32_t instanceCustomIndex:24;
    uint32_t mask:8;
    uint32_t instanceShaderBindingTableRecordOffset:24;
    VkGeometryInstanceFlagsKHR flags:8;
    uint64_t accelerationStructureReference;
} VkAccelerationStructureSRTMotionInstanceNV;
```

- transformT0 is a \text{VkSRTDataNV} structure describing a transformation to be applied to the acceleration structure at time 0.
- transformT1 is a \text{VkSRTDataNV} structure describing a transformation to be applied to the acceleration structure at time 1.
- instanceCustomIndex is a 24-bit user-specified index value accessible to ray shaders in the \text{InstanceCustomIndexKHR} built-in.
- mask is an 8-bit visibility mask for the geometry. The instance may only be hit if \text{Cull Mask} & instance.mask != 0
- instanceShaderBindingTableRecordOffset is a 24-bit offset used in calculating the hit shader binding table index.
- flags is an 8-bit mask of \text{VkGeometryInstanceFlagBitsKHR} values to apply to this instance.
- accelerationStructureReference is either:
  - a device address containing the value obtained from
The C language specification does not define the ordering of bit-fields, but in practice, this struct produces the correct layout with existing compilers. The intended bit pattern is for the following:

- **instanceCustomIndex** and **mask** occupy the same memory as if a single **uint32_t** was specified in their place
  - **instanceCustomIndex** occupies the 24 least significant bits of that memory
  - **mask** occupies the 8 most significant bits of that memory

- **instanceShaderBindingTableRecordOffset** and **flags** occupy the same memory as if a single **uint32_t** was specified in their place
  - **instanceShaderBindingTableRecordOffset** occupies the 24 least significant bits of that memory
  - **flags** occupies the 8 most significant bits of that memory

If a compiler produces code that diverges from that pattern, applications **must** employ another method to set values according to the correct bit pattern.

The transform for a SRT motion instance at a point in time is derived from component-wise linear interpolation of the two SRT transforms. That is, for a **time** in [0,1] the resulting transform is

\[
\text{transformT0} \times (1 - \text{time}) + \text{transformT1} \times \text{time}
\]

**Valid Usage (Implicit)**

- VUID-VkAccelerationStructureSRTMotionInstanceNV-flags-parameter
  - **flags** must be a valid combination of **VkGeometryInstanceFlagBitsKHR** values

An acceleration structure SRT transform is defined by the structure:

```c
// Provided by VK_NV_ray_tracing_motion_blur
typedef struct VkSRTDataNV {
    float sx;
    float a;
    float b;
    float pxv;
    float sy;
    float c;
    float pvy;
    float sz;
    float pvz;
    float qx;
    float qy;
};
```
float qz;
float qw;
float tx;
float ty;
float tz;
} VkSRTDataNV;

- sx is the x component of the scale of the transform
- a is one component of the shear for the transform
- b is one component of the shear for the transform
- px is the x component of the pivot point of the transform
- sy is the y component of the scale of the transform
- c is one component of the shear for the transform
- pv is the y component of the pivot point of the transform
- sz is the z component of the scale of the transform
- pvz is the z component of the pivot point of the transform
- qx is the x component of the rotation quaternion
- qy is the y component of the rotation quaternion
- qz is the z component of the rotation quaternion
- qw is the w component of the rotation quaternion
- tx is the x component of the post-rotation translation
- ty is the y component of the post-rotation translation
- tz is the z component of the post-rotation translation

This transform decomposition consists of three elements. The first is a matrix S, consisting of a scale, shear, and translation, usually used to define the pivot point of the following rotation. This matrix is constructed from the parameters above by:

\[
S = \begin{pmatrix}
sx & a & b & px \\
0 & sy & c & pv \\
0 & 0 & sz & pvz \\
\end{pmatrix}
\]

The rotation quaternion is defined as:

\[
R = [ qx, qy, qz, qw ]
\]

This is a rotation around a conceptual normalized axis [ ax, ay, az ] of amount theta such that:

\[
[ qx, qy, qz ] = \sin(\theta/2) \times [ ax, ay, az ]
\]

and
qw = \cos(\theta/2)

Finally, the transform has a translation \( T \) constructed from the parameters above by:

\[
T = \begin{pmatrix}
1 & 0 & 0 & tx \\
0 & 1 & 0 & ty \\
0 & 0 & 1 & tz
\end{pmatrix}
\]

The effective derived transform is then given by

\( T \times R \times S \)

\textit{VkAccelerationStructureBuildRangeInfoKHR} is defined as:

```c
// Provided by VK_KHR_acceleration_structure
typedef struct VkAccelerationStructureBuildRangeInfoKHR {
    uint32_t primitiveCount;
    uint32_t primitiveOffset;
    uint32_t firstVertex;
    uint32_t transformOffset;
} VkAccelerationStructureBuildRangeInfoKHR;
```

- \texttt{primitiveCount} defines the number of primitives for a corresponding acceleration structure geometry.
- \texttt{primitiveOffset} defines an offset in bytes into the memory where primitive data is defined.
- \texttt{firstVertex} is the index of the first vertex to build from for triangle geometry.
- \texttt{transformOffset} defines an offset in bytes into the memory where a transform matrix is defined.

The primitive count and primitive offset are interpreted differently depending on the \textit{VkGeometryTypeKHR} used:

- For geometries of type \texttt{VK_GEOMETRY_TYPE_TRIANGLES_KHR}, \texttt{primitiveCount} is the number of triangles to be built, where each triangle is treated as 3 vertices.
  - If the geometry uses indices, \texttt{primitiveCount} \times 3 indices are consumed from \texttt{VkAccelerationStructureGeometryTrianglesDataKHR::indexData}, starting at an offset of \texttt{primitiveOffset}. The value of \texttt{firstVertex} is added to the index values before fetching vertices.
  - If the geometry does not use indices, \texttt{primitiveCount} \times 3 vertices are consumed from \texttt{VkAccelerationStructureGeometryTrianglesDataKHR::vertexData}, starting at an offset of \texttt{primitiveOffset} + \texttt{VkAccelerationStructureGeometryTrianglesDataKHR::vertexStride} \times \texttt{firstVertex}.
  - If \texttt{VkAccelerationStructureGeometryTrianglesDataKHR::transformData} is not \texttt{NULL}, a single \texttt{VkTransformMatrixKHR} structure is consumed from \texttt{VkAccelerationStructureGeometryTrianglesDataKHR::transformData}, at an offset of
transformOffset. This matrix describes a transformation from the space in which the vertices for all triangles in this geometry are described to the space in which the acceleration structure is defined.

- For geometries of type `VK_GEOMETRY_TYPE_AABBS_KHR`, `primitiveCount` is the number of axis-aligned bounding boxes. `primitiveCount` `VkAabbPositionsKHR` structures are consumed from `VkAccelerationStructureGeometryAabbsDataKHR::data`, starting at an offset of `primitiveOffset`.

- For geometries of type `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, `primitiveCount` is the number of acceleration structures. `primitiveCount` `VkAccelerationStructureInstanceKHR` or `VkAccelerationStructureMotionInstanceNV` structures are consumed from `VkAccelerationStructureGeometryInstancesDataKHR::data`, starting at an offset of `primitiveOffset`.

**Valid Usage**

- VUID-VkAccelerationStructureBuildRangeInfoKHR-primitiveOffset-03656
  For geometries of type `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if the geometry uses indices, the offset `primitiveOffset` from `VkAccelerationStructureGeometryTrianglesDataKHR::indexData` must be a multiple of the element size of `VkAccelerationStructureGeometryTrianglesDataKHR::indexType`

- VUID-VkAccelerationStructureBuildRangeInfoKHR-primitiveOffset-03657
  For geometries of type `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, if the geometry does not use indices, the offset `primitiveOffset` from `VkAccelerationStructureGeometryTrianglesDataKHR::vertexData` must be a multiple of the component size of `VkAccelerationStructureGeometryTrianglesDataKHR::vertexFormat`

- VUID-VkAccelerationStructureBuildRangeInfoKHR-transformOffset-03658
  For geometries of type `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, the offset `transformOffset` from `VkAccelerationStructureGeometryTrianglesDataKHR::transformData` must be a multiple of 16

- VUID-VkAccelerationStructureBuildRangeInfoKHR-primitiveOffset-03659
  For geometries of type `VK_GEOMETRY_TYPE_AABBS_KHR`, the offset `primitiveOffset` from `VkAccelerationStructureGeometryAabbsDataKHR::data` must be a multiple of 8

- VUID-VkAccelerationStructureBuildRangeInfoKHR-primitiveOffset-03660
  For geometries of type `VK_GEOMETRY_TYPE_INSTANCES_KHR`, the offset `primitiveOffset` from `VkAccelerationStructureGeometryInstancesDataKHR::data` must be a multiple of 16

### 37.1.7. Copying Acceleration Structures

An additional command exists for copying acceleration structures without updating their contents. The acceleration structure object can be compacted in order to improve performance. Before copying, an application must query the size of the resulting acceleration structure.

To query acceleration structure size parameters call:

```c
// Provided by VK_KHR_acceleration_structure
```
void vkCmdWriteAccelerationStructuresPropertiesKHR(
    VkCommandBuffer commandBuffer,
    uint32_t accelerationStructureCount,
    const VkAccelerationStructureKHR* pAccelerationStructures,
    VkQueryType queryType,
    VkQueryPool queryPool,
    uint32_t firstQuery);

- commandBuffer is the command buffer into which the command will be recorded.
- accelerationStructureCount is the count of acceleration structures for which to query the property.
- pAccelerationStructures is a pointer to an array of existing previously built acceleration structures.
- queryType is a VkQueryType value specifying the type of queries managed by the pool.
- queryPool is the query pool that will manage the results of the query.
- firstQuery is the first query index within the query pool that will contain the accelerationStructureCount number of results.

Accesses to any of the acceleration structures listed in pAccelerationStructures must be synchronized with the VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR pipeline stage or the VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR pipeline stage, and an access type of VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR.

- If queryType is VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_KHR, then the value written out is the number of bytes required by a compacted acceleration structure.
- If queryType is VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_SIZE_KHR, then the value written out is the number of bytes required by a serialized acceleration structure.

Valid Usage

- VUID-vkCmdWriteAccelerationStructuresPropertiesKHR-accelerationStructure-08924
  The VkPhysicalDeviceAccelerationStructureFeaturesKHR::accelerationStructure feature must be enabled
- VUID-vkCmdWriteAccelerationStructuresPropertiesKHR-queryPool-02493
  queryPool must have been created with a queryType matching queryType
- VUID-vkCmdWriteAccelerationStructuresPropertiesKHR-queryPool-02494
  The queries identified by queryPool and firstQuery must be unavailable
- VUID-vkCmdWriteAccelerationStructuresPropertiesKHR-buffer-03736
  The buffer used to create each acceleration structure in pAccelerationStructures must be bound to device memory
- VUID-vkCmdWriteAccelerationStructuresPropertiesKHR-query-04880
  The sum of query plus accelerationStructureCount must be less than or equal to the number of queries in queryPool
All acceleration structures in `pAccelerationStructures` must have been built prior to the execution of this command.

All acceleration structures in `pAccelerationStructures` must have been built with `VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_COMPACTION_BIT_KHR` if `queryType` is `VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_KHR`.

`queryType` must be `VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SIZE_KHR`, `VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_BOTTOM_LEVEL_POINTERS_KHR`, `VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_KHR` or `VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_SIZE_KHR`.

Valid Usage (Implicit)

- `commandBuffer` must be a valid `VkCommandBuffer` handle.
- `pAccelerationStructures` must be a valid pointer to an array of `accelerationStructureCount` valid `VkAccelerationStructureKHR` handles.
- `queryType` must be a valid `VkQueryType` value.
- `queryPool` must be a valid `VkQueryPool` handle.
- `commandBuffer` must be in the recording state.
- The `VkCommandPool` that `commandBuffer` was allocated from must support compute operations.
- This command must only be called outside of a render pass instance.
- This command must only be called outside of a video coding scope.
- `accelerationStructureCount` must be greater than 0.
- Each of `commandBuffer`, `queryPool`, and the elements of `pAccelerationStructures` must have been created, allocated, or retrieved from the same `VkDevice`.

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Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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<tbody>
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<td>Outside</td>
<td>Outside</td>
<td>Compute</td>
<td>Action</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To query acceleration structure size parameters call:

```c
// Provided by VK_NV_ray_tracing
void vkCmdWriteAccelerationStructuresPropertiesNV(
    VkCommandBuffer commandBuffer,
    uint32_t accelerationStructureCount,
    const VkAccelerationStructureNV* pAccelerationStructures,
    VkQueryType queryType,
    VkQueryPool queryPool,
    uint32_t firstQuery);
```

- commandBuffer is the command buffer into which the command will be recorded.
- accelerationStructureCount is the count of acceleration structures for which to query the property.
- pAccelerationStructures is a pointer to an array of existing previously built acceleration structures.
- queryType is a VkQueryType value specifying the type of queries managed by the pool.
- queryPool is the query pool that will manage the results of the query.
- firstQuery is the first query index within the query pool that will contain the accelerationStructureCount number of results.

Accesses to any of the acceleration structures listed in pAccelerationStructures must be synchronized with the VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR pipeline stage and an access type of VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR.

Valid Usage

- VUID-vkCmdWriteAccelerationStructuresPropertiesNV-queryPool-03755 queryPool must have been created with a queryType matching queryType
The queries identified by `queryPool` and `firstQuery` **must** be unavailable.

`accelerationStructure` **must** be bound completely and contiguously to a single `VkDeviceMemory` object via `vkBindAccelerationStructureMemoryNV`.

All acceleration structures in `pAccelerationStructures` **must** have been built prior to the execution of this command.

All acceleration structures in `pAccelerationStructures` **must** have been built with `VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_COMPACTION_BIT_KHR` if `queryType` is `VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_NV`.

`queryType` **must** be `VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_NV`.

---

**Valid Usage (Implicit)**

- `commandBuffer` **must** be a valid `VkCommandBuffer` handle.
- `pAccelerationStructures` **must** be a valid pointer to an array of `accelerationStructureCount` valid `VkAccelerationStructureNV` handles.
- `queryType` **must** be a valid `VkQueryType` value.
- `queryPool` **must** be a valid `VkQueryPool` handle.
- `commandBuffer` **must** be in the recording state.
- The `VkCommandPool` that `commandBuffer` was allocated from **must** support compute operations.
- This command **must** only be called outside of a render pass instance.
- This command **must** only be called outside of a video coding scope.
- `accelerationStructureCount` **must** be greater than 0.
- Each of `commandBuffer`, `queryPool`, and the elements of `pAccelerationStructures` **must** have been created, allocated, or retrieved from the same `VkDevice`.
Host Synchronization

• Host access to `commandBuffer` must be externally synchronized
• Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

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</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To copy an acceleration structure call:

```c
// Provided by VK_NV_ray_tracing
void vkCmdCopyAccelerationStructureNV(
    VkCommandBuffer commandBuffer,
    VkAccelerationStructureNV dst,
    VkAccelerationStructureNV src,
    VkCopyAccelerationStructureModeKHR mode);
```

• `commandBuffer` is the command buffer into which the command will be recorded.
• `dst` is the target acceleration structure for the copy.
• `src` is the source acceleration structure for the copy.
• `mode` is a `VkCopyAccelerationStructureModeKHR` value specifying additional operations to perform during the copy.

Accesses to `src` and `dst` must be synchronized with the `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR` pipeline stage or the `VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR` pipeline stage, and an access type of `VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR` or `VK_ACCESS_ACCELERATION_STRUCTURE_WRITE_BIT_KHR` as appropriate.

Valid Usage

• VUID-vkCmdCopyAccelerationStructureNV-mode-03410
  `mode` must be `VK_COPY_ACCELERATION_STRUCTURE_MODE_COMPACT_KHR` or `VK_COPY_ACCELERATION_STRUCTURE_MODE_CLONE_KHR`

• VUID-vkCmdCopyAccelerationStructureNV-src-04963
  The source acceleration structure `src` must have been constructed prior to the execution of this command
• VUID-vkCmdCopyAccelerationStructureNV-src-03411
  If \texttt{mode} is \texttt{VK\_COPY\_ACCELERATION\_STRUCTURE\_MODE\_COMPACT\_KHR}, \texttt{src} must have been constructed with \texttt{VK\_BUILD\_ACCELERATION\_STRUCTURE\_ALLOW\_COMPACT\_BIT\_KHR} in the build.

• VUID-vkCmdCopyAccelerationStructureNV-buffer-03718
  The \texttt{buffer} used to create \texttt{src} must be bound to device memory.

• VUID-vkCmdCopyAccelerationStructureNV-buffer-03719
  The \texttt{buffer} used to create \texttt{dst} must be bound to device memory.

• VUID-vkCmdCopyAccelerationStructureNV-dst-07791
  The range of memory backing \texttt{dst} that is accessed by this command must not overlap the memory backing \texttt{src} that is accessed by this command.

• VUID-vkCmdCopyAccelerationStructureNV-dst-07792
  \texttt{dst} must be bound completely and contiguously to a single \texttt{VkDeviceMemory} object via \texttt{vkBindAccelerationStructureMemoryNV}.

\begin{section}{Valid Usage (Implicit)}

• VUID-vkCmdCopyAccelerationStructureNV-commandBuffer-parameter
  \texttt{commandBuffer} must be a valid \texttt{VkCommandBuffer} handle.

• VUID-vkCmdCopyAccelerationStructureNV-dst-parameter
  \texttt{dst} must be a valid \texttt{VkAccelerationStructureNV} handle.

• VUID-vkCmdCopyAccelerationStructureNV-src-parameter
  \texttt{src} must be a valid \texttt{VkAccelerationStructureNV} handle.

• VUID-vkCmdCopyAccelerationStructureNV-mode-parameter
  \texttt{mode} must be a valid \texttt{VkCopyAccelerationStructureModeKHR} value.

• VUID-vkCmdCopyAccelerationStructureNV-commandBuffer-recording
  \texttt{commandBuffer} must be in the recording state.

• VUID-vkCmdCopyAccelerationStructureNV-commandBuffer-cmdpool
  The \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from must support compute operations.

• VUID-vkCmdCopyAccelerationStructureNV-renderpass
  This command must only be called outside of a render pass instance.

• VUID-vkCmdCopyAccelerationStructureNV-videocoding
  This command must only be called outside of a video coding scope.

• VUID-vkCmdCopyAccelerationStructureNV-commonparent
  Each of \texttt{commandBuffer}, \texttt{dst}, and \texttt{src} must have been created, allocated, or retrieved from the same \texttt{VkDevice}.
\end{section}

\begin{section}{Host Synchronization}

• Host access to \texttt{commandBuffer} must be externally synchronized.
\end{section}
Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized.

---

### Command Properties

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</tbody>
</table>

---

To copy an acceleration structure call:

```c
// Provided by VK_KHR_acceleration_structure
void vkCmdCopyAccelerationStructureKHR(
    VkCommandBuffer commandBuffer,
    const VkCopyAccelerationStructureInfoKHR* pInfo);
```

- commandBuffer is the command buffer into which the command will be recorded.
- pInfo is a pointer to a VkCopyAccelerationStructureInfoKHR structure defining the copy operation.

This command copies the pInfo->src acceleration structure to the pInfo->dst acceleration structure in the manner specified by pInfo->mode.

Accesses to pInfo->src and pInfo->dst must be synchronized with the VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR pipeline stage or the VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR pipeline stage, and an access type of VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR or VK_ACCESS_ACCELERATION_STRUCTURE_WRITE_BIT_KHR as appropriate.

---

### Valid Usage

- VUID-vkCmdCopyAccelerationStructureKHR-accelerationStructure-08925
  - The VkPhysicalDeviceAccelerationStructureFeaturesKHR::accelerationStructure feature must be enabled

- VUID-vkCmdCopyAccelerationStructureKHR-buffer-03737
  - The buffer used to create pInfo->src must be bound to device memory

- VUID-vkCmdCopyAccelerationStructureKHR-buffer-03738
  - The buffer used to create pInfo->dst must be bound to device memory

---

### Valid Usage (Implicit)

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- **VUID-vkCmdCopyAccelerationStructureKHR-commandBuffer-parameter**
  
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- **VUID-vkCmdCopyAccelerationStructureKHR-pInfo-parameter**
  
  `pInfo` must be a valid pointer to a valid `VkCopyAccelerationStructureInfoKHR` structure.

- **VUID-vkCmdCopyAccelerationStructureKHR-commandBuffer-recording**
  
  `commandBuffer` must be in the recording state.

- **VUID-vkCmdCopyAccelerationStructureKHR-commandBuffer-cmdpool**
  
  The `VkCommandPool` that `commandBuffer` was allocated from must support compute operations.

- **VUID-vkCmdCopyAccelerationStructureKHR-renderpass**
  
  This command must only be called outside of a render pass instance.

- **VUID-vkCmdCopyAccelerationStructureKHR-videocoding**
  
  This command must only be called outside of a video coding scope.

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

### Command Properties

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</tr>
</tbody>
</table>

The `VkCopyAccelerationStructureInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_acceleration_structure
typedef struct VkCopyAccelerationStructureInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkAccelerationStructureKHR src;
    VkAccelerationStructureKHR dst;
    VkCopyAccelerationStructureModeKHR mode;
} VkCopyAccelerationStructureInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `src` is the source acceleration structure for the copy.
• ```dst``` is the target acceleration structure for the copy.
• ```mode``` is a ```VkCopyAccelerationStructureModeKHR``` value specifying additional operations to perform during the copy.

### Valid Usage

- **VUID-VkCopyAccelerationStructureInfoKHR-mode-03410**
  ```mode``` **must** be ```VK_COPY_ACCELERATION_STRUCTURE_MODE_COMPACT_KHR``` or ```VK_COPY_ACCELERATION_STRUCTURE_MODE_CLONE_KHR```.

- **VUID-VkCopyAccelerationStructureInfoKHR-src-04963**
The source acceleration structure ```src``` **must** have been constructed prior to the execution of this command.

- **VUID-VkCopyAccelerationStructureInfoKHR-src-03411**
  If ```mode``` is ```VK_COPY_ACCELERATION_STRUCTURE_MODE_COMPACT_KHR```, ```src``` **must** have been constructed with ```VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_COMPACTION_BIT_KHR``` in the build.

- **VUID-VkCopyAccelerationStructureInfoKHR-buffer-03718**
The buffer used to create ```src``` **must** be bound to device memory.

- **VUID-VkCopyAccelerationStructureInfoKHR-buffer-03719**
The buffer used to create ```dst``` **must** be bound to device memory.

- **VUID-VkCopyAccelerationStructureInfoKHR-dst-07791**
The range of memory backing ```dst``` that is accessed by this command **must** not overlap the memory backing ```src``` that is accessed by this command.

- **VUID-VkCopyAccelerationStructureInfoKHR-dst-07792**
  ```dst``` **must** be bound completely and contiguously to a single ```VkDeviceMemory``` object via ```vkBindAccelerationStructureMemoryNV```.

### Valid Usage (Implicit)

- **VUID-VkCopyAccelerationStructureInfoKHR-sType-sType**
  ```sType``` **must** be ```VK_STRUCTURE_TYPE_COPY_ACCELERATION_STRUCTURE_INFO_KHR```.

- **VUID-VkCopyAccelerationStructureInfoKHR-pNext-pNext**
  ```pNext``` **must** be ```NULL```.

- **VUID-VkCopyAccelerationStructureInfoKHR-src-parameter**
  ```src``` **must** be a valid ```VkAccelerationStructureKHR``` handle.

- **VUID-VkCopyAccelerationStructureInfoKHR-dst-parameter**
  ```dst``` **must** be a valid ```VkAccelerationStructureKHR``` handle.

- **VUID-VkCopyAccelerationStructureInfoKHR-mode-parameter**
  ```mode``` **must** be a valid ```VkCopyAccelerationStructureModeKHR``` value.

- **VUID-VkCopyAccelerationStructureInfoKHR-commonparent**
  Both of ```dst```, and ```src``` **must** have been created, allocated, or retrieved from the same ```VkDevice```.
Possible values of `mode` specifying additional operations to perform during the copy, are:

```c
// Provided by VK_KHR_acceleration_structure
typedef enum VkCopyAccelerationStructureModeKHR {
    VK_COPY_ACCELERATION_STRUCTURE_MODE_CLONE_KHR = 0,
    VK_COPY_ACCELERATION_STRUCTURE_MODE_COMPACT_KHR = 1,
    VK_COPY_ACCELERATION_STRUCTURE_MODE_SERIALIZE_KHR = 2,
    VK_COPY_ACCELERATION_STRUCTURE_MODE_DESERIALIZE_KHR = 3,
} VkCopyAccelerationStructureModeKHR;
```

or the equivalent

```c
// Provided by VK_NV_ray_tracing
typedef VkCopyAccelerationStructureModeKHR VkCopyAccelerationStructureModeNV;
```

- **VK_COPY_ACCELERATION_STRUCTURE_MODE_CLONE_KHR** creates a direct copy of the acceleration structure specified in `src` into the one specified by `dst`. The `dst` acceleration structure **must** have been created with the same parameters as `src`. If `src` contains references to other acceleration structures, `dst` will reference the same acceleration structures.

- **VK_COPY_ACCELERATION_STRUCTURE_MODE_COMPACT_KHR** creates a more compact version of an acceleration structure `src` into `dst`. The acceleration structure `dst` **must** have been created with a size at least as large as that returned by `vkCmdWriteAccelerationStructuresPropertiesKHR` or `vkWriteAccelerationStructuresPropertiesKHR` after the build of the acceleration structure specified by `src`. If `src` contains references to other acceleration structures, `dst` will reference the same acceleration structures.

- **VK_COPY_ACCELERATION_STRUCTURE_MODE_SERIALIZE_KHR** serializes the acceleration structure to a semi-opaque format which can be reloaded on a compatible implementation.

- **VK_COPY_ACCELERATION_STRUCTURE_MODE_DESERIALIZE_KHR** deserializes the semi-opaque serialization format in the buffer to the acceleration structure.

To copy an acceleration structure to device memory call:

```c
// Provided by VK_KHR_acceleration_structure
void vkCmdCopyAccelerationStructureToMemoryKHR(
    VkCommandBuffer commandBuffer, 
    const VkCopyAccelerationStructureToMemoryInfoKHR* pInfo);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `pInfo` is an a pointer to a `VkCopyAccelerationStructureToMemoryInfoKHR` structure defining
the copy operation.

Accesses to pInfo->src must be synchronized with the 
VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR pipeline stage or the 
VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR pipeline stage, and an access type of 
VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR. Accesses to the buffer indicated by pInfo->dst.deviceAddress must be synchronized with the 
VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR pipeline stage or the 
VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR pipeline stage, and an and an access type of VK_ACCESS_TRANSFER_WRITE_BIT.

This command produces the same results as vkCopyAccelerationStructureToMemoryKHR, but writes its result to a device address, and is executed on the device rather than the host. The output may not necessarily be bit-for-bit identical, but it can be equally used by either vkCmdCopyMemoryToAccelerationStructureKHR or vkCopyMemoryToAccelerationStructureKHR.

The defined header structure for the serialized data consists of:

- VK_UUID_SIZE bytes of data matching VkPhysicalDeviceIDProperties::driverUUID
- VK_UUID_SIZE bytes of data identifying the compatibility for comparison using vkGetDeviceAccelerationStructureCompatibilityKHR
- A 64-bit integer of the total size matching the value queried using VK_QUERY_TYPE_ACCELERATION_STRUCTURE.Serialization_SIZE_KHR
- A 64-bit integer of the deserialized size to be passed in to VkAccelerationStructureCreateInfoKHR::size
- A 64-bit integer of the count of the number of acceleration structure handles following. This value matches the value queried using VK_QUERY_TYPE_ACCELERATION_STRUCTURE.Serialization.BOTTOMLEVEL.POINTERS_KHR. This will be zero for a bottom-level acceleration structure. For top-level acceleration structures this number is implementation-dependent; the number of and ordering of the handles may not match the instance descriptions which were used to build the acceleration structure.

The corresponding handles matching the values returned by vkGetAccelerationStructureDeviceAddressKHR or vkGetAccelerationStructureHandleNV are tightly packed in the buffer following the count. The application is expected to store a mapping between those handles and the original application-generated bottom-level acceleration structures to provide when deserializing. The serialized data is written to the buffer (or read from the buffer) according to the host endianness.

Valid Usage

- VUID-vkCmdCopyAccelerationStructureToMemoryKHR-accelerationStructure-08926
  The VkPhysicalDeviceAccelerationStructureFeaturesKHR::accelerationStructure feature must be enabled
- VUID-vkCmdCopyAccelerationStructureToMemoryKHR-pInfo-03739
  pInfo->dst.deviceAddress must be a valid device address for a buffer bound to device memory
• VUID-vkCmdCopyAccelerationStructureToMemoryKHR-pInfo-03740
  pInfo->dst.deviceAddress must be aligned to 256 bytes

• VUID-vkCmdCopyAccelerationStructureToMemoryKHR-pInfo-03741
  If the buffer pointed to by pInfo->dst.deviceAddress is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

• VUID-vkCmdCopyAccelerationStructureToMemoryKHR-None-03559
  The buffer used to create pInfo->src must be bound to device memory

**Valid Usage (Implicit)**

• VUID-vkCmdCopyAccelerationStructureToMemoryKHR-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

• VUID-vkCmdCopyAccelerationStructureToMemoryKHR-pInfo-parameter
  pInfo must be a valid pointer to a valid VkCopyAccelerationStructureToMemoryInfoKHR structure

• VUID-vkCmdCopyAccelerationStructureToMemoryKHR-commandBuffer-recording
  commandBuffer must be in the recording state

• VUID-vkCmdCopyAccelerationStructureToMemoryKHR-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support compute operations

• VUID-vkCmdCopyAccelerationStructureToMemoryKHR-renderpass
  This command must only be called outside of a render pass instance

• VUID-vkCmdCopyAccelerationStructureToMemoryKHR-videocoding
  This command must only be called outside of a video coding scope

**Host Synchronization**

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

**Command Properties**

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</table>

// Provided by VK_KHR_acceleration_structure
typedef struct VkCopyAccelerationStructureToMemoryInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkAccelerationStructureKHR src;
    VkDeviceOrHostAddressKHR dst;
    VkCopyAccelerationStructureModeKHR mode;
} VkCopyAccelerationStructureToMemoryInfoKHR;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **src** is the source acceleration structure for the copy
- **dst** is the device or host address to memory which is the target for the copy
- **mode** is a `VkCopyAccelerationStructureModeKHR` value specifying additional operations to perform during the copy.

### Valid Usage

- **VUID-VkCopyAccelerationStructureToMemoryInfoKHR-src-04959**
  The source acceleration structure `src` must have been constructed prior to the execution of this command

- **VUID-VkCopyAccelerationStructureToMemoryInfoKHR-dst-03561**
  The memory pointed to by `dst` must be at least as large as the serialization size of `src`, as reported by `vkWriteAccelerationStructuresPropertiesKHR` or `vkCmdWriteAccelerationStructuresPropertiesKHR` with a query type of `VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_SIZE_KHR`

- **VUID-VkCopyAccelerationStructureToMemoryInfoKHR-mode-03412**
  `mode` must be `VK_COPY_ACCELERATION_STRUCTURE_MODE_SERIALIZE_KHR`

### Valid Usage (Implicit)

- **VUID-VkCopyAccelerationStructureToMemoryInfoKHR-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_COPY_ACCELERATION_STRUCTURE_TO_MEMORY_INFO_KHR`

- **VUID-VkCopyAccelerationStructureToMemoryInfoKHR-pNext-pNext**
  `pNext` must be NULL

- **VUID-VkCopyAccelerationStructureToMemoryInfoKHR-src-parameter**
  `src` must be a valid `VkAccelerationStructureKHR` handle

- **VUID-VkCopyAccelerationStructureToMemoryInfoKHR-mode-parameter**
  `mode` must be a valid `VkCopyAccelerationStructureModeKHR` value

To copy device memory to an acceleration structure call:

```c
// Provided by VK_KHR_acceleration_structure
```
void vkCmdCopyMemoryToAccelerationStructureKHR(
    VkCommandBuffer commandBuffer,
    const VkCopyMemoryToAccelerationStructureInfoKHR* pInfo);

- **commandBuffer** is the command buffer into which the command will be recorded.
- **pInfo** is a pointer to a `VkCopyMemoryToAccelerationStructureInfoKHR` structure defining the copy operation.

Accesses to `pInfo->dst` must be synchronized with the `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR` pipeline stage or the `VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR` pipeline stage, and an access type of `VK_ACCESS_ACCELERATION_STRUCTURE_WRITE_BIT_KHR`. Accesses to the buffer indicated by `pInfo->src.deviceAddress` must be synchronized with the `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR` pipeline stage or the `VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR` pipeline stage, and an access type of `VK_ACCESS_TRANSFER_READ_BIT`.

This command can accept acceleration structures produced by either `vkCmdCopyAccelerationStructureToMemoryKHR` or `vkCopyAccelerationStructureToMemoryKHR`.

The structure provided as input to deserialize is as described in `vkCmdCopyAccelerationStructureToMemoryKHR`, with any acceleration structure handles filled in with the newly-queried handles to bottom level acceleration structures created before deserialization. These do not need to be built at deserialize time, but must be created.

### Valid Usage

- **VUID-vkCmdCopyMemoryToAccelerationStructureKHR-accelerationStructure-08927**
  The `VkPhysicalDeviceAccelerationStructureFeaturesKHR::accelerationStructure` feature must be enabled

- **VUID-vkCmdCopyMemoryToAccelerationStructureKHR-pInfo-03742**
  `pInfo->src.deviceAddress` must be a valid device address for a buffer bound to device memory

- **VUID-vkCmdCopyMemoryToAccelerationStructureKHR-pInfo-03743**
  `pInfo->src.deviceAddress` must be aligned to 256 bytes

- **VUID-vkCmdCopyMemoryToAccelerationStructureKHR-pInfo-03744**
  If the buffer pointed to by `pInfo->src.deviceAddress` is non-sparse then it must be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdCopyMemoryToAccelerationStructureKHR-buffer-03745**
  The buffer used to create `pInfo->dst` must be bound to device memory

### Valid Usage (Implicit)

- **VUID-vkCmdCopyMemoryToAccelerationStructureKHR-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle
• VUID-vkCmdCopyMemoryToAccelerationStructureKHR-pInfo-parameter pInfo must be a valid pointer to a valid VkCopyMemoryToAccelerationStructureInfoKHR structure

• VUID-vkCmdCopyMemoryToAccelerationStructureKHR-commandBuffer-recording commandBuffer must be in the recording state

• VUID-vkCmdCopyMemoryToAccelerationStructureKHR-commandBuffer-cmdpool The VkCommandPool that commandBuffer was allocated from must support compute operations

• VUID-vkCmdCopyMemoryToAccelerationStructureKHR-renderpass This command must only be called outside of a render pass instance

• VUID-vkCmdCopyMemoryToAccelerationStructureKHR-videocoding This command must only be called outside of a video coding scope

Host Synchronization

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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The VkCopyMemoryToAccelerationStructureInfoKHR structure is defined as:

```c
// Provided by VK_KHR_acceleration_structure
typedef struct VkCopyMemoryToAccelerationStructureInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkDeviceOrHostAddressConstKHR src;
    VkAccelerationStructureKHR dst;
    VkCopyAccelerationStructureModeKHR mode;
} VkCopyMemoryToAccelerationStructureInfoKHR;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• src is the device or host address to memory containing the source data for the copy.
• dst is the target acceleration structure for the copy.
• mode is a VkCopyAccelerationStructureModeKHR value specifying additional operations to perform during the copy.

Valid Usage

• VUID-VkCopyMemoryToAccelerationStructureInfoKHR-src-04960
The source memory pointed to by src must contain data previously serialized using vkCmdCopyAccelerationStructureToMemoryKHR, potentially modified to relocate acceleration structure references as described in that command

• VUID-VkCopyMemoryToAccelerationStructureInfoKHR-mode-03413
mode must be VK_COPY_ACCELERATION_STRUCTURE_MODE_DESERIALIZE_KHR

• VUID-VkCopyMemoryToAccelerationStructureInfoKHR-pInfo-03414
The data in src must have a format compatible with the destination physical device as returned by vkGetDeviceAccelerationStructureCompatibilityKHR

• VUID-VkCopyMemoryToAccelerationStructureInfoKHR-dst-03746
dst must have been created with a size greater than or equal to that used to serialize the data in src

Valid Usage (Implicit)

• VUID-VkCopyMemoryToAccelerationStructureInfoKHR-sType-sType
sType must be VK_STRUCTURE_TYPE_COPY_MEMORY_TO_ACCELERATION_STRUCTURE_INFO_KHR

• VUID-VkCopyMemoryToAccelerationStructureInfoKHR-pNext-pNext
pNext must be NULL

• VUID-VkCopyMemoryToAccelerationStructureInfoKHR-dst-parameter
dst must be a valid VkAccelerationStructureKHR handle

• VUID-VkCopyMemoryToAccelerationStructureInfoKHR-mode-parameter
mode must be a valid VkCopyAccelerationStructureModeKHR value

To check if a serialized acceleration structure is compatible with the current device call:

```c
// Provided by VK_KHR_acceleration_structure
void vkGetDeviceAccelerationStructureCompatibilityKHR(
    VkDevice device,
    const VkAccelerationStructureVersionInfoKHR* pVersionInfo,
    VkAccelerationStructureCompatibilityKHR* pCompatibility);
```

• device is the device to check the version against.

• pVersionInfo is a pointer to a VkAccelerationStructureVersionInfoKHR structure specifying version information to check against the device.

• pCompatibility is a pointer to a VkAccelerationStructureCompatibilityKHR value in which compatibility information is returned.
Valid Usage

- VUID-vkGetDeviceAccelerationStructureCompatibilityKHR-accelerationStructure-08928
  The `VkPhysicalDeviceAccelerationStructureFeaturesKHR::accelerationStructure` feature must be enabled.

Valid Usage (Implicit)

- VUID-vkGetDeviceAccelerationStructureCompatibilityKHR-device-parameter
device must be a valid `VkDevice` handle

- VUID-vkGetDeviceAccelerationStructureCompatibilityKHR-pVersionInfo-parameter
  pVersionInfo must be a valid pointer to a valid `VkAccelerationStructureVersionInfoKHR` structure

- VUID-vkGetDeviceAccelerationStructureCompatibilityKHR-pCompatibility-parameter
  pCompatibility must be a valid pointer to a `VkAccelerationStructureCompatibilityKHR` value

The `VkAccelerationStructureVersionInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_acceleration_structure
typedef struct VkAccelerationStructureVersionInfoKHR {
    VkStructureType sType;
    const void* pNext;
    const uint8_t* pVersionData;
} VkAccelerationStructureVersionInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `pVersionData` is a pointer to the version header of an acceleration structure as defined in `vkCmdCopyAccelerationStructureToMemoryKHR`

Note

`pVersionData` is a pointer to an array of 2×`VK_UUID_SIZE` uint8_t values instead of two `VK_UUID_SIZE` arrays as the expected use case for this member is to be pointed at the header of a previously serialized acceleration structure (via `vkCmdCopyAccelerationStructureToMemoryKHR` or `vkCopyAccelerationStructureToMemoryKHR`) that is loaded in memory. Using arrays would necessitate extra memory copies of the UUIDs.

Valid Usage (Implicit)

- VUID-VkAccelerationStructureVersionInfoKHR-sType-sType
  sType must be `VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_VERSION_INFO_KHR`
Possible values of \texttt{pCompatibility} returned by \texttt{vkGetDeviceAccelerationStructureCompatibilityKHR} are:

// Provided by VK_KHR_acceleration_structure

typedef enum VkAccelerationStructureCompatibilityKHR {
  VK_ACCELERATION_STRUCTURE_COMPATIBILITY_COMPATIBLE_KHR = 0,
  VK_ACCELERATION_STRUCTURE_COMPATIBILITY_INCOMPATIBLE_KHR = 1,
} VkAccelerationStructureCompatibilityKHR;

- \texttt{VK_ACCELERATION_STRUCTURE_COMPATIBILITY_COMPATIBLE_KHR} if the \texttt{pVersionData} version acceleration structure is compatible with \texttt{device}.
- \texttt{VK_ACCELERATION_STRUCTURE_COMPATIBILITY_INCOMPATIBLE_KHR} if the \texttt{pVersionData} version acceleration structure is not compatible with \texttt{device}.

### 37.2. Host Acceleration Structure Operations

Implementations are also required to provide host implementations of the acceleration structure operations if the \texttt{accelerationStructureHostCommands} feature is enabled:

- \texttt{vkBuildAccelerationStructuresKHR} corresponding to \texttt{vkCmdBuildAccelerationStructuresKHR}
- \texttt{vkCopyAccelerationStructureKHR} corresponding to \texttt{vkCmdCopyAccelerationStructureKHR}
- \texttt{vkCopyAccelerationStructureToMemoryKHR} corresponding to \texttt{vkCmdCopyAccelerationStructureToMemoryKHR}
- \texttt{vkCopyMemoryToAccelerationStructureKHR} corresponding to \texttt{vkCmdCopyMemoryToAccelerationStructureKHR}
- \texttt{vkWriteAccelerationStructuresPropertiesKHR} corresponding to \texttt{vkCmdWriteAccelerationStructuresPropertiesKHR}

These commands are functionally equivalent to their device counterparts, except that they are executed on the host timeline, rather than being enqueued into command buffers.

All acceleration structures used by the host commands \textbf{must} be bound to host-visible memory, and all input data for acceleration structure builds \textbf{must} be referenced using host addresses instead of device addresses. Applications are not required to map acceleration structure memory when using the host commands.

\textit{Note}

The \texttt{vkBuildAccelerationStructuresKHR} and \texttt{vkCmdBuildAccelerationStructuresKHR} \textbf{may} use different algorithms, and thus
are not required to produce identical structures. The structures produced by these two commands may exhibit different memory footprints or traversal performance, but should strive to be similar where possible.

Apart from these details, the host and device operations are interchangeable. For example, an application can use `vkBuildAccelerationStructuresKHR` to build a structure, compact it on the device using `vkCmdCopyAccelerationStructureKHR`, and serialize the result using `vkCopyAccelerationStructureToMemoryKHR`.

**Note**
For efficient execution, acceleration structures manipulated using these commands should always be bound to host cached memory, as the implementation may need to repeatedly read and write this memory during the execution of the command.

To build acceleration structures on the host, call:

```c
// Provided by VK_KHR_acceleration_structure
VkResult vkBuildAccelerationStructuresKHR(
    VkDevice device,               // VkDevice for which the acceleration structures are being built.
    VkDeferredOperationKHR deferredOperation, // Optional VkDeferredOperationKHR to request deferral for this command.
    uint32_t infoCount,            // Number of acceleration structures to build. Specifies the number of the pInfos structures and ppBuildRangeInfos pointers that must be provided.
    const VkAccelerationStructureBuildGeometryInfoKHR* pInfos,  // Pointer to an array of infoCount VkAccelerationStructureBuildGeometryInfoKHR structures defining the geometry used to build each acceleration structure.
    const VkAccelerationStructureBuildRangeInfoKHR* const* ppBuildRangeInfos); // Pointer to an array of infoCount pointers to arrays of VkAccelerationStructureBuildRangeInfoKHR structures defining dynamic offsets to the addresses where geometry data is stored, as defined by pInfos[i].
```

- `device` is the `VkDevice` for which the acceleration structures are being built.
- `deferredOperation` is an optional `VkDeferredOperationKHR` to request deferral for this command.
- `infoCount` is the number of acceleration structures to build. It specifies the number of the `pInfos` structures and `ppBuildRangeInfos` pointers that must be provided.
- `pInfos` is a pointer to an array of `infoCount` `VkAccelerationStructureBuildGeometryInfoKHR` structures defining the geometry used to build each acceleration structure.
- `ppBuildRangeInfos` is a pointer to an array of `infoCount` pointers to arrays of `VkAccelerationStructureBuildRangeInfoKHR` structures. Each `ppBuildRangeInfos[i]` is a pointer to an array of `pInfos[i].geometryCount` `VkAccelerationStructureBuildRangeInfoKHR` structures defining dynamic offsets to the addresses where geometry data is stored, as defined by `pInfos[i]`.

This command fulfills the same task as `vkCmdBuildAccelerationStructuresKHR` but is executed by the host.

The `vkBuildAccelerationStructuresKHR` command provides the ability to initiate multiple acceleration structures builds, however there is no ordering or synchronization implied between any of the individual acceleration structure builds.

**Note**
This means that an application cannot build a top-level acceleration structure in
the same `vkBuildAccelerationStructuresKHR` call as the associated bottom-level or instance acceleration structures are being built. There also cannot be any memory aliasing between any acceleration structure memories or scratch memories being used by any of the builds.

### Valid Usage

- **VUID-vkBuildAccelerationStructuresKHR-accelerationStructureHostCommands-03581**
  The `VkPhysicalDeviceAccelerationStructureFeaturesKHR::accelerationStructureHostCommands` feature must be enabled.

- **VUID-vkBuildAccelerationStructuresKHR-mode-04628**
  The `mode` member of each element of `pInfos` must be a valid `VkBuildAccelerationStructureModeKHR` value.

- **VUID-vkBuildAccelerationStructuresKHR-srcAccelerationStructure-04629**
  If the `srcAccelerationStructure` member of any element of `pInfos` is not `VK_NULL_HANDLE`, the `srcAccelerationStructure` member must be a valid `VkAccelerationStructureKHR` handle.

- **VUID-vkBuildAccelerationStructuresKHR-pInfos-04630**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, its `srcAccelerationStructure` member must not be `VK_NULL_HANDLE`.

- **VUID-vkBuildAccelerationStructuresKHR-pInfos-03403**
  The `srcAccelerationStructure` member of any element of `pInfos` must not be the same acceleration structure as the `dstAccelerationStructure` member of any other element of `pInfos`.

- **VUID-vkBuildAccelerationStructuresKHR-dstAccelerationStructure-03698**
  The `dstAccelerationStructure` member of any element of `pInfos` must not be the same acceleration structure as the `dstAccelerationStructure` member of any other element of `pInfos`.

- **VUID-vkBuildAccelerationStructuresKHR-pInfos-03699**
  For each element of `pInfos`, if its `type` member is `VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_KHR`, its `dstAccelerationStructure` member must have been created with a value of `VkAccelerationStructureCreateInfoKHR::type` equal to either `VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_KHR` or `VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR`.

- **VUID-vkBuildAccelerationStructuresKHR-pInfos-03700**
  For each element of `pInfos`, if its `type` member is `VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_KHR`, its `dstAccelerationStructure` member must have been created with a value of `VkAccelerationStructureCreateInfoKHR::type` equal to either `VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_KHR` or `VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR`.
For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, inactive primitives in its `srcAccelerationStructure` member must not be made active.

For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, active primitives in its `srcAccelerationStructure` member must not be made inactive.

The `dstAccelerationStructure` member of any element of `pInfos` must not be referenced by the `geometry.instances.data` member of any element of `pGeometries` or `ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_INSTANCES_KHR` in any other element of `pInfos`.

The range of memory backing the `dstAccelerationStructure` member of any element of `pInfos` that is accessed by this command must not overlap the memory backing the `srcAccelerationStructure` member of any other element of `pInfos` with a `mode` equal to `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, which is accessed by this command.

The range of memory backing the `dstAccelerationStructure` member of any other element of `pInfos` that is accessed by this command must not overlap the memory backing the `dstAccelerationStructure` member of any other element of `pInfos`, which is accessed by this command.

The range of memory backing the `scratchData` member of any element of `pInfos` that is accessed by this command must not overlap the memory backing the `scratchData` member of any other element of `pInfos`, which is accessed by this command.

The range of memory backing the `scratchData` member of any element of `pInfos` that is accessed by this command must not overlap the memory backing the `scratchData` member of any other element of `pInfos`, which is accessed by this command.

The range of memory backing the `scratchData` member of any element of `pInfos` that is accessed by this command must not overlap the memory backing any acceleration structure referenced by the `geometry.instances.data` member of any element of `pGeometries` or `ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_INSTANCES_KHR` in any other element of `pInfos`, which is accessed by this command.

The range of memory backing the `dstAccelerationStructure` member of any element of `pInfos` that is accessed by this command must not overlap the memory backing any acceleration structure referenced by the `geometry.instances.data` member of any element of `pGeometries` or `ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_INSTANCES_KHR` in any other element of `pInfos`, which is accessed by this command.
For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, its `srcAccelerationStructure` member must have previously been constructed with `VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_UPDATE_BIT_KHR` set in `VkAccelerationStructureBuildGeometryInfoKHR::flags` in the build.

- **VUID-vkBuildAccelerationStructuresKHR-pInfos-03668**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, its `srcAccelerationStructure` and `dstAccelerationStructure` members must either be the same `VkAccelerationStructureKHR`, or not have any memory aliasing.

- **VUID-vkBuildAccelerationStructuresKHR-pInfos-03758**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, its `geometryCount` member must have the same value which was specified when `srcAccelerationStructure` was last built.

- **VUID-vkBuildAccelerationStructuresKHR-pInfos-03759**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, its `flags` member must have the same value which was specified when `srcAccelerationStructure` was last built.

- **VUID-vkBuildAccelerationStructuresKHR-pInfos-03760**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, its `type` member must have the same value which was specified when `srcAccelerationStructure` was last built.

- **VUID-vkBuildAccelerationStructuresKHR-pInfos-03761**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, then for each `VkAccelerationStructureGeometryKHR` structure referred to by its `pGeometries` or `ppGeometries` members, its `geometryType` member must have the same value which was specified when `srcAccelerationStructure` was last built.

- **VUID-vkBuildAccelerationStructuresKHR-pInfos-03762**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, then for each `VkAccelerationStructureGeometryKHR` structure referred to by its `pGeometries` or `ppGeometries` members, its `flags` member must have the same value which was specified when `srcAccelerationStructure` was last built.

- **VUID-vkBuildAccelerationStructuresKHR-pInfos-03763**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, then for each `VkAccelerationStructureGeometryKHR` structure referred to by its `pGeometries` or `ppGeometries` members, if `geometryType` is `VK_GEOMETRY_TYPE_TRIANGLES_KHR`, its `geometry.triangles.vertexFormat` member must have the same value which was specified when `srcAccelerationStructure` was last built.

- **VUID-vkBuildAccelerationStructuresKHR-pInfos-03764**
  For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, then for each `VkAccelerationStructureGeometryKHR` structure referred to by its `pGeometries` or...
ppGeometries members, if geometryType is VK_GEOMETRY_TYPE_TRIANGLES_KHR, its geometry.triangles.maxVertex member must have the same value which was specified when srcAccelerationStructure was last built.

- VUID-vkBuildAccelerationStructuresKHR-pInfos-03765
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, then for each VkAccelerationStructureGeometryKHR structure referred to by its pGeometries or ppGeometries members, if geometryType is VK_GEOMETRY_TYPE_TRIANGLES_KHR, its geometry.triangles.indexType member must have the same value which was specified when srcAccelerationStructure was last built.

- VUID-vkBuildAccelerationStructuresKHR-pInfos-03766
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, then for each VkAccelerationStructureGeometryKHR structure referred to by its pGeometries or ppGeometries members, if geometryType is VK_GEOMETRY_TYPE_TRIANGLES_KHR, its geometry.triangles.transformData address was NULL when srcAccelerationStructure was last built, then it must be NULL.

- VUID-vkBuildAccelerationStructuresKHR-pInfos-03767
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR, then for each VkAccelerationStructureGeometryKHR structure referred to by its pGeometries or ppGeometries members, if geometryType is VK_GEOMETRY_TYPE_TRIANGLES_KHR, if its geometry.triangles.transformData address was not NULL when srcAccelerationStructure was last built, then it must not be NULL.

- VUID-vkBuildAccelerationStructuresKHR-primitiveCount-03769
  For each VkAccelerationStructureBuildRangeInfoKHR referenced by this command, its primitiveCount member must have the same value which was specified when srcAccelerationStructure was last built.

- VUID-vkBuildAccelerationStructuresKHR-firstVertex-03770
  For each VkAccelerationStructureBuildRangeInfoKHR referenced by this command, if the corresponding geometry uses indices, its firstVertex member must have the same value which was specified when srcAccelerationStructure was last built.

- VUID-vkBuildAccelerationStructuresKHR-pInfos-03801
  For each element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR, the corresponding ppBuildRangeInfos[i][j].primitiveCount must be less than or equal to VkPhysicalDeviceAccelerationStructurePropertiesKHR::maxInstanceCount.
For each `pInfos[i]`, `dstAccelerationStructure` must have been created with a value of `VkAccelerationStructureCreateInfoKHR::size` greater than or equal to the memory size required by the build operation, as returned by `vkGetAccelerationStructureBuildSizesKHR` with `pBuildInfo = pInfos[i]` and with each element of the `pMaxPrimitiveCounts` array greater than or equal to the equivalent `ppBuildRangeInfos[i][j].primitiveCount` values for `j` in `[0, pInfos[i].geometryCount)`

Each element of `ppBuildRangeInfos[i]` must be a valid pointer to an array of `pInfos[i].geometryCount` `VkAccelerationStructureBuildRangeInfoKHR` structures.

If `deferredOperation` is not `VK_NULL_HANDLE`, it must be a valid `VkDeferredOperationKHR` object.

Any previous deferred operation that was associated with `deferredOperation` must be complete.

For each element of `pInfos`, the buffer used to create its `dstAccelerationStructure` member must be bound to host-visible device memory.

For each element of `pInfos`, if its `mode` member is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR` the buffer used to create its `srcAccelerationStructure` member must be bound to host-visible device memory.

For each element of `pInfos`, the buffer used to create each acceleration structure referenced by the `geometry.instances.data` member of any element of `pGeometries` or `ppGeometries` with a `geometryType` of `VK_GEOMETRY_TYPE_INSTANCES_KHR` must be bound to host-visible device memory.

If `pInfos[i].mode` is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_BUILD_KHR`, all addresses between `pInfos[i].scratchData.hostAddress` and `pInfos[i].scratchData.hostAddress + N - 1` must be valid host memory, where `N` is given by the `build ScratchSize` member of the `VkAccelerationStructureBuildSizesInfoKHR` structure returned from a call to `vkGetAccelerationStructureBuildSizesKHR` with an identical `VkAccelerationStructureBuildGeometryInfoKHR` structure and primitive count.

If `pInfos[i].mode` is `VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR`, all addresses between `pInfos[i].scratchData.hostAddress` and `pInfos[i].scratchData.hostAddress + N - 1` must be valid host memory, where `N` is given by the `updateScratchSize` member of the `VkAccelerationStructureBuildSizesInfoKHR` structure returned from a call to `vkGetAccelerationStructureBuildSizesKHR` with an identical `VkAccelerationStructureBuildGeometryInfoKHR` structure and primitive count.

For any element of `pInfos[i].pGeometries` or `pInfos[i].ppGeometries` with a `geometryType` of
VK_GEOMETRY_TYPE_TRIANGLES_KHR, geometry.triangles.vertexData.hostAddress must be a valid host address

- VUID-vkBuildAccelerationStructuresKHR-pInfos-03772
  For any element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_TRIANGLES_KHR, if geometry.triangles.indexType is not VK_INDEX_TYPE_NONE_KHR, geometry.triangles.indexData.hostAddress must be a valid host address

- VUID-vkBuildAccelerationStructuresKHR-pInfos-03773
  For any element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_TRIANGLES_KHR, if geometry.triangles.transformData.hostAddress is not 0, it must be a valid host address

- VUID-vkBuildAccelerationStructuresKHR-pInfos-03774
  For any element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_AABBS_KHR, geometry.aabbs.data.hostAddress must be a valid host address

- VUID-vkBuildAccelerationStructuresKHR-pInfos-03775
  For each element of pInfos, the buffer used to create its dstAccelerationStructure member must be bound to memory that was not allocated with multiple instances

- VUID-vkBuildAccelerationStructuresKHR-pInfos-03776
  For each element of pInfos, if its mode member is VK_BUILD_ACCELERATION_STRUCTURE_MODE_UPDATE_KHR the buffer used to create its srcAccelerationStructure member must be bound to memory that was not allocated with multiple instances

- VUID-vkBuildAccelerationStructuresKHR-pInfos-03777
  For each element of pInfos, the buffer used to create each acceleration structure referenced by the geometry.instances.data member of any element of pGeometries or ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR must be bound to memory that was not allocated with multiple instances

- VUID-vkBuildAccelerationStructuresKHR-pInfos-03778
  For any element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR, geometry.instances.data.hostAddress must be a valid host address

- VUID-vkBuildAccelerationStructuresKHR-pInfos-03779
  For any element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR, each VkAccelerationStructureInstanceKHR::accelerationStructureReference value in geometry.instances.data.hostAddress must be a valid VkAccelerationStructureKHR object

- VUID-vkBuildAccelerationStructuresKHR-pInfos-04930
  For any element of pInfos[i].pGeometries or pInfos[i].ppGeometries with a geometryType of VK_GEOMETRY_TYPE_INSTANCES_KHR with VK_BUILD_ACCELERATION_STRUCTURE_MOTION_BIT_NV set, each accelerationStructureReference in any structure in VkAccelerationStructureMotionInstanceNV value in geometry.instances.data.hostAddress must be a valid VkAccelerationStructureKHR object
Valid Usage (Implicit)

- VUID-vkBuildAccelerationStructuresKHR-device-parameter
  device must be a valid VkDevice handle

- VUID-vkBuildAccelerationStructuresKHR-deferredOperation-parameter
  If deferredOperation is not VK_NULL_HANDLE, deferredOperation must be a valid VkDeferredOperationKHR handle

- VUID-vkBuildAccelerationStructuresKHR-pInfos-parameter
  pInfos must be a valid pointer to an array of infoCount valid VkAccelerationStructureBuildGeometryInfoKHR structures

- VUID-vkBuildAccelerationStructuresKHR-ppBuildRangeInfos-parameter
  ppBuildRangeInfos must be a valid pointer to an array of infoCount VkAccelerationStructureBuildRangeInfoKHR structures

- VUID-vkBuildAccelerationStructuresKHR-infoCount-arraylength
  infoCount must be greater than 0

- VUID-vkBuildAccelerationStructuresKHR-deferredOperation-parent
  If deferredOperation is a valid handle, it must have been created, allocated, or retrieved from device

Return Codes

Success

- VK_SUCCESS
- VK_OPERATION_DEFERRED_KHR
- VK_OPERATION_NOT_DEFERRED_KHR

Failure

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

To copy or compact an acceleration structure on the host, call:

```c
// Provided by VK_KHR_acceleration_structure
VkResult vkCopyAccelerationStructureKHR(
    VkDevice device,
    VkDeferredOperationKHR deferredOperation,
    const VkCopyAccelerationStructureInfoKHR* pInfo);
```

- device is the device which owns the acceleration structures.
- deferredOperation is an optional VkDeferredOperationKHR to request deferral for this command.
• pInfo is a pointer to a VkCopyAccelerationStructureInfoKHR structure defining the copy operation.

This command fulfills the same task as vkCmdCopyAccelerationStructureKHR but is executed by the host.

Valid Usage

• VUID-vkCopyAccelerationStructureKHR-accelerationStructureHostCommands-03582
  The VkPhysicalDeviceAccelerationStructureFeaturesKHR::accelerationStructureHostCommands

• VUID-vkCopyAccelerationStructureKHR-deferredOperation-03677
  If deferredOperation is not VK_NULL_HANDLE, it must be a valid VkDeferredOperationKHR object

• VUID-vkCopyAccelerationStructureKHR-deferredOperation-03678
  Any previous deferred operation that was associated with deferredOperation must be complete

• VUID-vkCopyAccelerationStructureKHR-buffer-03727
  The buffer used to create pInfo->src must be bound to host-visible device memory

• VUID-vkCopyAccelerationStructureKHR-buffer-03728
  The buffer used to create pInfo->dst must be bound to host-visible device memory feature must be enabled

• VUID-vkCopyAccelerationStructureKHR-buffer-03780
  The buffer used to create pInfo->src must be bound to memory that was not allocated with multiple instances

• VUID-vkCopyAccelerationStructureKHR-buffer-03781
  The buffer used to create pInfo->dst must be bound to memory that was not allocated with multiple instances

Valid Usage (Implicit)

• VUID-vkCopyAccelerationStructureKHR-device-parameter
  device must be a valid VkDevice handle

• VUID-vkCopyAccelerationStructureKHR-deferredOperation-parameter
  If deferredOperation is not VK_NULL_HANDLE, deferredOperation must be a valid VkDeferredOperationKHR handle

• VUID-vkCopyAccelerationStructureKHR-pInfo-parameter
  pInfo must be a valid pointer to a valid VkCopyAccelerationStructureInfoKHR structure

• VUID-vkCopyAccelerationStructureKHR-deferredOperation-parent
  If deferredOperation is a valid handle, it must have been created, allocated, or retrieved from device
Return Codes

Success
• VK_SUCCESS
• VK_OPERATION_DEFERRED_KHR
• VK_OPERATION_NOT_DEFERRED_KHR

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY

To copy host accessible memory to an acceleration structure, call:

```c
// Provided by VK_KHR_acceleration_structure
VkResult vkCopyMemoryToAccelerationStructureKHR(
    VkDevice device,
    VkDeferredOperationKHR deferredOperation,
    const VkCopyMemoryToAccelerationStructureInfoKHR* pInfo);
```

- `device` is the device which owns `pInfo->dst`.
- `deferredOperation` is an optional `VkDeferredOperationKHR` to request deferral for this command.
- `pInfo` is a pointer to a `VkCopyMemoryToAccelerationStructureInfoKHR` structure defining the copy operation.

This command fulfills the same task as `vkCmdCopyMemoryToAccelerationStructureKHR` but is executed by the host.

This command can accept acceleration structures produced by either `vkCmdCopyAccelerationStructureToMemoryKHR` or `vkCopyAccelerationStructureToMemoryKHR`.

Valid Usage

- VUID-vkCopyMemoryToAccelerationStructureKHR-accelerationStructureHostCommands-03583
  The `VkPhysicalDeviceAccelerationStructureFeaturesKHR`::`accelerationStructureHostCommands` feature must be enabled

- VUID-vkCopyMemoryToAccelerationStructureKHR-deferredOperation-03677
  If `deferredOperation` is not `VK_NULL_HANDLE`, it must be a valid `VkDeferredOperationKHR` object

- VUID-vkCopyMemoryToAccelerationStructureKHR-deferredOperation-03678
  Any previous deferred operation that was associated with `deferredOperation` must be complete
Valid Usage (Implicit)

- VUID-vkCopyMemoryToAccelerationStructureKHR-device-parameter
device must be a valid VkDevice handle

- VUID-vkCopyMemoryToAccelerationStructureKHR-deferredOperation-parameter
If deferredOperation is not VK_NULL_HANDLE, deferredOperation must be a valid VkDeferredOperationKHR handle

- VUID-vkCopyMemoryToAccelerationStructureKHR-pInfo-parameter
pInfo must be a valid pointer to a valid VkCopyMemoryToAccelerationStructureInfoKHR structure

- VUID-vkCopyMemoryToAccelerationStructureKHR-deferredOperation-parent
If deferredOperation is a valid handle, it must have been created, allocated, or retrieved from device

Return Codes

Success

- VK_SUCCESS
- VK_OPERATION_DEFERRED_KHR
- VK_OPERATION_NOT_DEFERRED_KHR

Failure

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

To copy an acceleration structure to host accessible memory, call:

```c
// Provided by VK_KHR_acceleration_structure
VkResult vkCopyAccelerationStructureToMemoryKHR(  
    VkDevice device,  
    VkDeferredOperationKHR deferredOperation,
);```
```c
const VkCopyAccelerationStructureToMemoryInfoKHR* pInfo);
```

- **device** is the device which owns `pInfo->src`.
- **deferredOperation** is an optional `VkDeferredOperationKHR` to request deferral for this command.
- **pInfo** is a pointer to a `VkCopyAccelerationStructureToMemoryInfoKHR` structure defining the copy operation.

This command fulfills the same task as `vkCmdCopyAccelerationStructureToMemoryKHR` but is executed by the host.

This command produces the same results as `vkCmdCopyAccelerationStructureToMemoryKHR`, but writes its result directly to a host pointer, and is executed on the host rather than the device. The output may not necessarily be bit-for-bit identical, but it can be equally used by either `vkCmdCopyMemoryToAccelerationStructureKHR` or `vkCopyMemoryToAccelerationStructureKHR`.

### Valid Usage

- **VUID-vkCopyAccelerationStructureToMemoryKHR-accelerationStructureHostCommands-03584**
  The `VkPhysicalDeviceAccelerationStructureFeaturesKHR`::`accelerationStructureHostCommands` feature must be enabled.

- **VUID-vkCopyAccelerationStructureToMemoryKHR-deferredOperation-03677**
  If `deferredOperation` is not `VK_NULL_HANDLE`, it must be a valid `VkDeferredOperationKHR` object.

- **VUID-vkCopyAccelerationStructureToMemoryKHR-deferredOperation-03678**
  Any previous deferred operation that was associated with `deferredOperation` must be complete.

- **VUID-vkCopyAccelerationStructureToMemoryKHR-buffer-03731**
  The buffer used to create `pInfo->src` must be bound to host-visible device memory.

- **VUID-vkCopyAccelerationStructureToMemoryKHR-pInfo-03732**
  `pInfo->dst.hostAddress` must be a valid host pointer.

- **VUID-vkCopyAccelerationStructureToMemoryKHR-pInfo-03751**
  `pInfo->dst.hostAddress` must be aligned to 16 bytes.

- **VUID-vkCopyAccelerationStructureToMemoryKHR-buffer-03783**
  The buffer used to create `pInfo->src` must be bound to memory that was not allocated with multiple instances.

### Valid Usage (Implicit)

- **VUID-vkCopyAccelerationStructureToMemoryKHR-device-parameter**
  `device` must be a valid `VkDevice` handle.

3091
If `deferredOperation` is not `VK_NULL_HANDLE`, `deferredOperation` must be a valid `VkDeferredOperationKHR` handle.

`pInfo` must be a valid pointer to a valid `VkCopyAccelerationStructureToMemoryInfoKHR` structure.

If `deferredOperation` is a valid handle, it must have been created, allocated, or retrieved from `device`.

**Return Codes**

**Success**
- `VK_SUCCESS`
- `VK_OPERATION_DEFERRED_KHR`
- `VK_OPERATION_NOT_DEFERRED_KHR`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

To query acceleration structure size parameters on the host, call:

```c
// Provided by VK_KHR_acceleration_structure
VkResult vkWriteAccelerationStructuresPropertiesKHR(
    VkDevice device,
    uint32_t accelerationStructureCount,
    const VkAccelerationStructureKHR* pAccelerationStructures,
    VkQueryType queryType,
    size_t dataSize,
    void* pData,
    size_t stride);
```

- `device` is the device which owns the acceleration structures in `pAccelerationStructures`.
- `accelerationStructureCount` is the count of acceleration structures for which to query the property.
- `pAccelerationStructures` is a pointer to an array of existing previously built acceleration structures.
- `queryType` is a `VkQueryType` value specifying the property to be queried.
- `dataSize` is the size in bytes of the buffer pointed to by `pData`.
- `pData` is a pointer to a user-allocated buffer where the results will be written.
- `stride` is the stride in bytes between results for individual queries within `pData`.

3092
This command fulfills the same task as \texttt{vkCmdWriteAccelerationStructuresPropertiesKHR} but is executed by the host.

### Valid Usage

- **VUID-vkWriteAccelerationStructuresPropertiesKHR-accelerationStructureHostCommands-03585**
  The \texttt{VkPhysicalDeviceAccelerationStructureFeaturesKHR} ::\texttt{accelerationStructureHostCommands} feature must be enabled.

- **VUID-vkWriteAccelerationStructuresPropertiesKHR-pAccelerationStructures-04964**
  All acceleration structures in \texttt{pAccelerationStructures} must have been built prior to the execution of this command.

- **VUID-vkWriteAccelerationStructuresPropertiesKHR-accelerationStructures-03431**
  All acceleration structures in \texttt{pAccelerationStructures} must have been built with \texttt{VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_COMPACTION_BIT_KHR} if \texttt{queryType} is \texttt{VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_KHR}.

- **VUID-vkWriteAccelerationStructuresPropertiesKHR-queryType-03448**
  If \texttt{queryType} is \texttt{VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_KHR}, then \texttt{stride} must be a multiple of the size of \texttt{VkDeviceSize}.

- **VUID-vkWriteAccelerationStructuresPropertiesKHR-queryType-03449**
  If \texttt{queryType} is \texttt{VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_KHR}, then \texttt{pData} must point to a \texttt{VkDeviceSize}.

- **VUID-vkWriteAccelerationStructuresPropertiesKHR-queryType-03450**
  If \texttt{queryType} is \texttt{VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_SIZE_KHR}, then \texttt{stride} must be a multiple of the size of \texttt{VkDeviceSize}.

- **VUID-vkWriteAccelerationStructuresPropertiesKHR-queryType-03451**
  If \texttt{queryType} is \texttt{VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_SIZE_KHR}, then \texttt{pData} must point to a \texttt{VkDeviceSize}.

- **VUID-vkWriteAccelerationStructuresPropertiesKHR-queryType-06731**
  If \texttt{queryType} is \texttt{VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SIZE_KHR}, then \texttt{stride} must be a multiple of the size of \texttt{VkDeviceSize}.

- **VUID-vkWriteAccelerationStructuresPropertiesKHR-queryType-06732**
  If \texttt{queryType} is \texttt{VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SIZE_KHR}, then \texttt{pData} must point to a \texttt{VkDeviceSize}.

- **VUID-vkWriteAccelerationStructuresPropertiesKHR-queryType-06733**
  If \texttt{queryType} is \texttt{VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_BOTTOM_LEVEL_POINTERS_KHR}, then \texttt{stride} must be a multiple of the size of \texttt{VkDeviceSize}.
If `queryType` is `VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_BOTTOM_LEVEL_POINTERS_KHR`, then `pData` must point to a `VkDeviceSize`

`dataSize` must be greater than or equal to `accelerationStructureCount * stride`

The buffer used to create each acceleration structure in `pAccelerationStructures` must be bound to host-visible device memory

The buffer used to create each acceleration structure in `pAccelerationStructures` must be bound to memory that was not allocated with multiple instances

### Valid Usage (Implicit)

- `device` must be a valid `VkDevice` handle
- `pAccelerationStructures` must be a valid pointer to an array of `accelerationStructureCount` valid `VkAccelerationStructureKHR` handles
- `queryType` must be a valid `VkQueryType` value
- `pData` must be a valid pointer to an array of `dataSize` bytes
- `accelerationStructureCount` must be greater than 0
- `dataSize` must be greater than 0
- Each element of `pAccelerationStructures` must have been created, allocated, or retrieved from `device`

### Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
Chapter 38. Micromap

38.1. Micromaps

Acceleration structures store and organize geometry for ray tracing, but in some cases it is beneficial to include some information within the geometry, particularly for triangles. A micromap organizes this data around a map of values corresponding to subdivided microtriangles which can be added to a triangle geometry when building a bottom level acceleration structure.

An opacity micromap is a type of micromap which stores information to control intersection opacity as described in Ray Opacity Micromap.

A displacement micromap is a type of micromap which stores information to displace sub-triangle vertices as described in Displacement Micromap.

A micromap is considered to be constructed if a micromap build command or copy command has been executed with the given acceleration structure as the destination.

38.1.1. Building Micromaps

To build micromaps call:

```
// Provided by VK_EXT_opacity_micromap
void vkCmdBuildMicromapsEXT(
    VkCommandBuffer commandBuffer,
    uint32_t infoCount,
    const VkMicromapBuildInfoEXT* pInfos);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `infoCount` is the number of micromaps to build. It specifies the number of the `pInfos` structures that must be provided.
- `pInfos` is a pointer to an array of `infoCount` `VkMicromapBuildInfoEXT` structures defining the data used to build each micromap.

The `vkCmdBuildMicromapsEXT` command provides the ability to initiate multiple micromaps builds, however there is no ordering or synchronization implied between any of the individual micromap builds.

**Note**

This means that there cannot be any memory aliasing between any micromap memories or scratch memories being used by any of the builds.

Accesses to the micromap scratch buffers as identified by the `VkMicromapBuildInfoEXT::scratchData` buffer device addresses must be synchronized with the `VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT` pipeline stage and an access type of `(VK_ACCESS_2_MICROMAP_READ_BIT_EXT | VK_ACCESS_2_MICROMAP_WRITE_BIT_EXT)`. Accesses to
VkMicromapBuildInfoEXT::dstMicromap must be synchronized with the VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT pipeline stage and an access type of VK_ACCESS_2_MICROMAP_WRITE_BIT_EXT.

Accesses to other input buffers as identified by any used values of VkMicromapBuildInfoEXT::data or VkMicromapBuildInfoEXT::triangleArray must be synchronized with the VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT pipeline stage and an access type of VK_ACCESS_SHADER_READ_BIT.

Valid Usage

• VUID-vkCmdBuild MicromapsEXT-pInfos-07461
  For each pInfos[i], dstMicromap must have been created with a value of VkMicromapCreateInfoEXT::size greater than or equal to the memory size required by the build operation, as returned by vkGetMicromapBuildSizesEXT with pBuildInfo = pInfos[i]

• VUID-vkCmdBuild MicromapsEXT-mode-07462
  The mode member of each element of pInfos must be a valid VkBuildMicromapModeEXT value

• VUID-vkCmdBuild MicromapsEXT-dstMicromap-07463
  The dstMicromap member of any element of pInfos must be a valid VkMicromapEXT handle

• VUID-vkCmdBuild MicromapsEXT-pInfos-07464
  For each element of pInfos its type member must match the value of VkMicromapCreateInfoEXT::type when its dstMicromap was created

• VUID-vkCmdBuild MicromapsEXT-dstMicromap-07465
  The range of memory backing the dstMicromap member of any element of pInfos that is accessed by this command must not overlap the memory backing the dstMicromap member of any other element of pInfos, which is accessed by this command

• VUID-vkCmdBuild MicromapsEXT-dstMicromap-07466
  The range of memory backing the dstMicromap member of any element of pInfos that is accessed by this command must not overlap the memory backing the scratchData member of any element of pInfos (including the same element), which is accessed by this command

• VUID-vkCmdBuild MicromapsEXT-scratchData-07467
  The range of memory backing the scratchData member of any element of pInfos that is accessed by this command must not overlap the memory backing the scratchData member of any other element of pInfos, which is accessed by this command

• VUID-vkCmdBuild MicromapsEXT-pInfos-07508
  For each element of pInfos, the buffer used to create its dstMicromap member must be bound to device memory

• VUID-vkCmdBuild MicromapsEXT-pInfos-07509
  If pInfos[i].mode is VK_BUILD_MICROMAP_MODE_BUILD_EXT, all addresses between pInfos[i].scratchData.deviceAddress and pInfos[i].scratchData.deviceAddress + N - 1 must be in
the buffer device address range of the same buffer, where \( N \) is given by the `buildScratchSize` member of the `VkMicromapBuildSizesInfoEXT` structure returned from a call to `vkGetMicromapBuildSizesEXT` with an identical `VkMicromapBuildInfoEXT` structure and primitive count.

- **VUID-vkCmdBuildMicromapsEXT-data-07510**
  The buffers from which the buffer device addresses for all of the data and `triangleArray` members of all `pInfos[i]` are queried must have been created with the `VK_BUFFER_USAGE_MICROMAP_BUILD_INPUT_READ_ONLY_BIT_EXT` usage flag.

- **VUID-vkCmdBuildMicromapsEXT-pInfos-07511**
  For each element of `pInfos[i]` the buffer from which the buffer device address `pInfos[i].scratchData.deviceAddress` is queried must have been created with `VK_BUFFER_USAGE_STORAGE_BUFFER_BIT` usage flag.

- **VUID-vkCmdBuildMicromapsEXT-pInfos-07512**
  For each element of `pInfos`, its `scratchData.deviceAddress`, `data.deviceAddress`, and `triangleArray.deviceAddress` members must be valid device addresses obtained from `vkGetBufferDeviceAddress`.

- **VUID-vkCmdBuildMicromapsEXT-pInfos-07513**
  For each element of `pInfos`, if `scratchData.deviceAddress`, `data.deviceAddress`, or `triangleArray.deviceAddress` is the address of a non-sparse buffer then it must be bound completely and contiguously to a single `VkDeviceMemory` object.

- **VUID-vkCmdBuildMicromapsEXT-pInfos-07514**
  For each element of `pInfos`, its `scratchData.deviceAddress` member must be a multiple of `VkPhysicalDeviceAccelerationStructurePropertiesKHR::minAccelerationStructureScratchOffsetAlignment`.

- **VUID-vkCmdBuildMicromapsEXT-pInfos-07515**
  For each element of `pInfos`, its `triangleArray.deviceAddress` and `data.deviceAddress` members must be a multiple of `256`.

---

**Valid Usage (Implicit)**

- **VUID-vkCmdBuildMicromapsEXT-commandBuffer-parameter**
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- **VUID-vkCmdBuildMicromapsEXT-pInfos-parameter**
  `pInfos` must be a valid pointer to an array of `infoCount` valid `VkMicromapBuildInfoEXT` structures.

- **VUID-vkCmdBuildMicromapsEXT-commandBuffer-recording**
  `commandBuffer` must be in the recording state.

- **VUID-vkCmdBuildMicromapsEXT-commandBuffer-cmdpool**
  The `VkCommandPool` that `commandBuffer` was allocated from must support compute operations.

- **VUID-vkCmdBuildMicromapsEXT-renderpass**
  This command must only be called outside of a render pass instance.
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

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Formats which can be set in `VkMicromapUsageEXT::format` and `VkMicromapTriangleEXT::format` for micromap builds, are:

```c
// Provided by VK_EXT_opacity_micromap
typedef enum VkOpacityMicromapFormatEXT {
    VK_OPACITY_MICROMAP_FORMAT_2_STATE_EXT = 1,
    VK_OPACITY_MICROMAP_FORMAT_4_STATE_EXT = 2,
} VkOpacityMicromapFormatEXT;
```

- `VK_OPACITY_MICROMAP_FORMAT_2_STATE_EXT` indicates that the given micromap format has one bit per subtriangle encoding either fully opaque or fully transparent.
- `VK_OPACITY_MICROMAP_FORMAT_4_STATE_EXT` indicates that the given micromap format has two bits per subtriangle encoding four modes which can be interpreted as described in ray traversal.

Note

For compactness, these values are stored as 16-bit in some structures.

Formats which can be set in `VkMicromapUsageEXT::format` and `VkMicromapTriangleEXT::format` for micromap builds, are:

```c
// Provided by VK_NV_displacement_micromap
typedef enum VkDisplacementMicromapFormatNV {
    VK_DISPLACEMENT_MICROMAP_FORMAT_64_TRIANGLES_64_BYTES_NV = 1,
    VK_DISPLACEMENT_MICROMAP_FORMAT_256_TRIANGLES_128_BYTES_NV = 2,
```


\*\* \* VK_DISPLACEMENT_MICROMAP_FORMAT_1024_TRIANGLES_128_BYTES_NV = 3, \* \*

- **VK_DISPLACEMENT_MICROMAP_FORMAT_64_TRIANGLES_64_BYTES_NV** indicates that the given micromap format encodes 64 micro-triangles worth of displacements in 64 bytes as described in Displacement Micromap Encoding.

- **VK_DISPLACEMENT_MICROMAP_FORMAT_256_TRIANGLES_128_BYTES_NV** indicates that the given micromap format encodes 256 micro-triangles worth of displacements in 128 bytes as described in Displacement Micromap Encoding.

- **VK_DISPLACEMENT_MICROMAP_FORMAT_1024_TRIANGLES_128_BYTES_NV** indicates that the given micromap format encodes 1024 micro-triangles worth of displacements in 128 bytes as described in Displacement Micromap Encoding.

\begin{itemize}
  \item For compactness, these values are stored as 16-bit in some structures.
\end{itemize}

The **VkMicromapBuildInfoEXT** structure is defined as:

```c
// Provided by VK_EXT_opacity_micromap
typedef struct VkMicromapBuildInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkMicromapTypeEXT type;
    VkBuildMicromapFlagsEXT flags;
    VkBuildMicromapModeEXT mode;
    VkMicromapEXT dstMicromap;
    uint32_t usageCountsCount;
    const VkMicromapUsageEXT* pUsageCounts;
    const VkMicromapUsageEXT* const* ppUsageCounts;
    VkDeviceOrHostAddressConstKHR data;
    VkDeviceOrHostAddressKHR scratchData;
    VkDeviceOrHostAddressConstKHR triangleArray;
    VkDeviceSize triangleArrayStride;
} VkMicromapBuildInfoEXT;
```

\begin{itemize}
  \item **sType** is a **VkStructureType** value identifying this structure.
  \item **pNext** is **NULL** or a pointer to a structure extending this structure.
  \item **type** is a **VkMicromapTypeEXT** value specifying the type of micromap being built.
  \item **flags** is a bitmask of **VkBuildMicromapFlagBitsEXT** specifying additional parameters of the micromap.
  \item **mode** is a **VkBuildMicromapModeEXT** value specifying the type of operation to perform.
  \item **dstMicromap** is a pointer to the target micromap for the build.
  \item **usageCountsCount** specifies the number of usage counts structures that will be used to determine the size of this micromap.
\end{itemize}
• **pUsageCounts** is a pointer to an array of `VkMicromapUsageEXT` structures.
• **ppUsageCounts** is a pointer to an array of pointers to `VkMicromapUsageEXT` structures.
• **data** is the device or host address to memory which contains the data for the micromap.
• **scratchData** is the device or host address to memory that will be used as scratch memory for the build.
• **triangleArray** is the device or host address to memory containing the `VkMicromapTriangleEXT` data
• **triangleArrayStride** is the stride in bytes between each element of `triangleArray`

Only one of **pUsageCounts** or **ppUsageCounts** can be a valid pointer, the other must be **NULL**. The elements of the non-NULL array describe the total counts used to build each micromap. Each element contains a **count** which is the number of micromap triangles of that **format** and **subdivisionLevel** contained in the micromap. Multiple elements with the same **format** and **subdivisionLevel** are allowed and the total count for that **format** and **subdivisionLevel** is the sum of the **count** for each element.

Each micromap triangle refers to one element in `triangleArray` which contains the **format** and **subdivisionLevel** for that particular triangle as well as a **dataOffset** in bytes which is the location relative to `data` where that triangle’s micromap data begins. The data at `triangleArray` is laid out as a 4 byte unsigned integer for the **dataOffset** followed by a 2 byte unsigned integer for the subdivision level then a 2 byte unsigned integer for the format. In practice, compilers compile `VkMicromapTriangleEXT` to match this pattern.

For opacity micromaps, the data at `data` is packed as either one bit per element for `VK_OPACITY_MICROMAP_FORMAT_2_STATE_EXT` or two bits per element for `VK_OPACITY_MICROMAP_FORMAT_4_STATE_EXT` and is packed from LSB to MSB in each byte. The data at each index in those bytes is interpreted as discussed in [Ray Opacity Micromap](#).

For displacement micromaps, the data at `data` is interpreted as discussed in [Displacement Micromap Encoding](#).

---

### Valid Usage

- VUID-VkMicromapBuildInfoEXT-pUsageCounts-07516
  
  Only one of **pUsageCounts** or **ppUsageCounts** can be a valid pointer, the other must be **NULL**

- VUID-VkMicromapBuildInfoEXT-type-07517
  
  If **type** is **VK_MICROMAP_TYPE_OPACITY_MICROMAP_EXT** the **format** member of `VkMicromapUsageEXT` must be a valid value from `VkOpacityMicromapFormatEXT`

- VUID-VkMicromapBuildInfoEXT-type-07518
  
  If **type** is **VK_MICROMAP_TYPE_OPACITY_MICROMAP_EXT** the **format** member of `VkMicromapTriangleEXT` must be a valid value from `VkOpacityMicromapFormatEXT`

- VUID-VkMicromapBuildInfoEXT-type-08704
  
  If **type** is **VK_MICROMAP_TYPE_DISPLACEMENT_MICROMAP_NV** the **format** member of `VkMicromapUsageEXT` must be a valid value from `VkDisplacementMicromapFormatNV`

- VUID-VkMicromapBuildInfoEXT-type-08705
If `type` is `VK_MICROMAP_TYPE_DISPLACEMENT_MICROMAP_NV` the `format` member of `VkMicromapTriangleEXT` must be a valid value from `VkDisplacementMicromapFormatNV`.

### Valid Usage (Implicit)

- **VUID-VkMicromapBuildInfoEXT-sType-sType**
  * `sType` must be `VK_STRUCTURE_TYPE_MICROMAP_BUILD_INFO_EXT`

- **VUID-VkMicromapBuildInfoEXT-pNext-pNext**
  * `pNext` must be `NULL`

- **VUID-VkMicromapBuildInfoEXT-type-parameter**
  * `type` must be a valid `VkMicromapTypeEXT` value

- **VUID-VkMicromapBuildInfoEXT-flags-parameter**
  * `flags` must be a valid combination of `VkBuildMicromapFlagBitsEXT` values

- **VUID-VkMicromapBuildInfoEXT-pUsageCounts-parameter**
  * If `usageCountsCount` is not 0, and `pUsageCounts` is not NULL, `pUsageCounts` must be a valid pointer to an array of `usageCountsCount` `VkMicromapUsageEXT` structures

- **VUID-VkMicromapBuildInfoEXT-ppUsageCounts-parameter**
  * If `usageCountsCount` is not 0, and `ppUsageCounts` is not NULL, `ppUsageCounts` must be a valid pointer to an array of `usageCountsCount` valid pointers to `VkMicromapUsageEXT` structures

The `VkBuildMicromapModeEXT` enumeration is defined as:

```c
// Provided by VK_EXT_opacity_micromap
typedef enum VkBuildMicromapModeEXT {
  VK_BUILD_MICROMAP_MODE_BUILD_EXT = 0,
} VkBuildMicromapModeEXT;
```

- `VK_BUILD_MICROMAP_MODE_BUILD_EXT` specifies that the destination micromap will be built using the specified data.

The `VkMicromapUsageEXT` structure is defined as:

```c
// Provided by VK_EXT_opacity_micromap
typedef struct VkMicromapUsageEXT {
  uint32_t count;
  uint32_t subdivisionLevel;
  uint32_t format;
} VkMicromapUsageEXT;
```

- `count` is the number of triangles in the usage format defined by the `subdivisionLevel` and `format` below in the micromap
- `subdivisionLevel` is the subdivision level of this usage format
Valid Usage

- **VUID-VkMicromapUsageEXT-format-07519**
  If the `VkMicromapTypeEXT` of the micromap is `VK_MICROMAP_TYPE_OPACITY_MICROMAP_EXT` then `format` must be `VK_OPACITY_MICROMAP_FORMAT_2_STATE_EXT` or `VK_OPACITY_MICROMAP_FORMAT_4_STATE_EXT`

- **VUID-VkMicromapUsageEXT-format-07520**
  If the `VkMicromapTypeEXT` of the micromap is `VK_MICROMAP_TYPE_OPACITY_MICROMAP_EXT` and `format` is `VK_OPACITY_MICROMAP_FORMAT_2_STATE_EXT` then `subdivisionLevel` must be less than or equal to `VkPhysicalDeviceOpacityMicromapPropertiesEXT::maxOpacity2StateSubdivisionLevel`

- **VUID-VkMicromapUsageEXT-format-07521**
  If the `VkMicromapTypeEXT` of the micromap is `VK_MICROMAP_TYPE_OPACITY_MICROMAP_EXT` and `format` is `VK_OPACITY_MICROMAP_FORMAT_4_STATE_EXT` then `subdivisionLevel` must be less than or equal to `VkPhysicalDeviceOpacityMicromapPropertiesEXT::maxOpacity4StateSubdivisionLevel`

- **VUID-VkMicromapUsageEXT-format-08706**
  If the `VkMicromapTypeEXT` of the micromap is `VK_MICROMAP_TYPE_DISPLACEMENT_MICROMAP_NV` then `format` must be `VK_DISPLACEMENT_MICROMAP_FORMAT_64_TRIANGLES_64_BYTES_NV`, `VK_DISPLACEMENT_MICROMAP_FORMAT_256_TRIANGLES_128_BYTES_NV` or `VK_DISPLACEMENT_MICROMAP_FORMAT_1024_TRIANGLES_128_BYTES_NV`

- **VUID-VkMicromapUsageEXT-subdivisionLevel-08707**
  If the `VkMicromapTypeEXT` of the micromap is `VK_MICROMAP_TYPE_DISPLACEMENT_MICROMAP_NV` then `subdivisionLevel` must be less than or equal to `VkPhysicalDeviceDisplacementMicromapPropertiesNV::maxDisplacementMicromapSubdivisionLevel`

The `format` is interpreted based on the `type` of the micromap using it.

The `VkMicromapTriangleEXT` structure is defined as:

```c
// Provided by VK_EXT_opacity_micromap
typedef struct VkMicromapTriangleEXT {
    uint32_t dataOffset;
    uint16_t subdivisionLevel;
    uint16_t format;
} VkMicromapTriangleEXT;
```

- `dataOffset` is the offset in bytes of the start of the data for this triangle. This is a byte aligned value.
- `subdivisionLevel` is the subdivision level of this triangle
Valid Usage

- VUID-VkMicromapTriangleEXT-format-07522
  If the `VkMicromapTypeEXT` of the micromap is `VK_MICROMAP_TYPE_OPACITY_MICROMAP_EXT` then `format` must be `VK_OPACITY_MICROMAP_FORMAT_2_STATE_EXT` or `VK_OPACITY_MICROMAP_FORMAT_4_STATE_EXT`.

- VUID-VkMicromapTriangleEXT-format-07523
  If the `VkMicromapTypeEXT` of the micromap is `VK_MICROMAP_TYPE_OPACITY_MICROMAP_EXT` and `format` is `VK_OPACITY_MICROMAP_FORMAT_2_STATE_EXT` then `subdivisionLevel` must be less than or equal to `VkPhysicalDeviceOpacityMicromapPropertiesEXT::maxOpacity2StateSubdivisionLevel`.

- VUID-VkMicromapTriangleEXT-format-07524
  If the `VkMicromapTypeEXT` of the micromap is `VK_MICROMAP_TYPE_OPACITY_MICROMAP_EXT` and `format` is `VK_OPACITY_MICROMAP_FORMAT_4_STATE_EXT` then `subdivisionLevel` must be less than or equal to `VkPhysicalDeviceOpacityMicromapPropertiesEXT::maxOpacity4StateSubdivisionLevel`.

- VUID-VkMicromapTriangleEXT-format-08708
  If the `VkMicromapTypeEXT` of the micromap is `VK_MICROMAP_TYPE_DISPLACEMENT_MICROMAP_NV` then `format` must be `VK_DISPLACEMENT_MICROMAP_FORMAT_64_TRIANGLES_64_BYTES_NV`, `VK_DISPLACEMENT_MICROMAP_FORMAT_256_TRIANGLES_128_BYTES_NV` or `VK_DISPLACEMENT_MICROMAP_FORMAT_1024_TRIANGLES_128_BYTES_NV`.

- VUID-VkMicromapTriangleEXT-subdivisionLevel-08709
  If the `VkMicromapTypeEXT` of the micromap is `VK_MICROMAP_TYPE_DISPLACEMENT_MICROMAP_NV` then `subdivisionLevel` must be less than or equal to `VkPhysicalDeviceDisplacementMicromapPropertiesNV::maxDisplacementMicromapSubdivisionLevel`.

The `format` is interpreted based on the `type` of the micromap using it.

38.1.2. Copying Micromaps

An additional command exists for copying micromaps without updating their contents. Before copying, an application must query the size of the resulting micromap.

To query micromap size parameters call:

```c
// Provided by VK_EXT_opacity_micromap
void vkCmdWriteMicromapsPropertiesEXT(
    VkCommandBuffer commandBuffer,    
    uint32_t micromapCount,           
    const VkMicromapEXT* pmicromaps,  
    VkQueryType queryType,            
    VkQueryPool queryPool,            
)
```
uint32_t firstQuery);

- `commandBuffer` is the command buffer into which the command will be recorded.
- `micromapCount` is the count of micromaps for which to query the property.
- `pMicromaps` is a pointer to an array of existing previously built micromaps.
- `queryType` is a `VkQueryType` value specifying the type of queries managed by the pool.
- `queryPool` is the query pool that will manage the results of the query.
- `firstQuery` is the first query index within the query pool that will contain the `micromapCount` number of results.

Accesses to any of the micromaps listed in `pMicromaps` must be synchronized with the `VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT` pipeline stage and an access type of `VK_ACCESS_2_MICROMAP_READ_BIT_EXT`.

- If `queryType` is `VK_QUERY_TYPE_MICROMAP_SERIALIZATION_SIZE_EXT`, then the value written out is the number of bytes required by a serialized micromap.
- If `queryType` is `VK_QUERY_TYPE_MICROMAP_COMPACTED_SIZE_EXT`, then the value written out is the number of bytes required by a compacted micromap.

## Valid Usage

- **VUID-vkCmdWriteMicromapsPropertiesEXT-queryPool-07525**
  - `queryPool` must have been created with a `queryType` matching `queryType`.

- **VUID-vkCmdWriteMicromapsPropertiesEXT-queryPool-07526**
  - The queries identified by `queryPool` and `firstQuery` must be unavailable.

- **VUID-vkCmdWriteMicromapsPropertiesEXT-buffer-07527**
  - The buffer used to create each micromap in `pMicromaps` must be bound to device memory.

- **VUID-vkCmdWriteMicromapsPropertiesEXT-query-07528**
  - The sum of `query` plus `micromapCount` must be less than or equal to the number of queries in `queryPool`.

- **VUID-vkCmdWriteMicromapsPropertiesEXT-pMicromaps-07501**
  - All micromaps in `pMicromaps` must have been constructed prior to the execution of this command.

- **VUID-vkCmdWriteMicromapsPropertiesEXT-pMicromaps-07502**
  - All micromaps in `pMicromaps` must have been constructed with `VK_BUILD_MICROMAP_ALLOW_COMPACTION_BIT_EXT` if `queryType` is `VK_QUERY_TYPE_MICROMAP_COMPACTED_SIZE_EXT`.

- **VUID-vkCmdWriteMicromapsPropertiesEXT-queryType-07503**
  - `queryType` must be `VK_QUERY_TYPE_MICROMAP_COMPACTED_SIZE_EXT` or `VK_QUERY_TYPE_MICROMAP_SERIALIZATION_SIZE_EXT`. 
Valid Usage (Implicit)

- VUID-vkCmdWriteMicromapsPropertiesEXT-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdWriteMicromapsPropertiesEXT-pMicromaps-parameter
  `pMicromaps` must be a valid pointer to an array of `micromapCount` valid `VkMicromapEXT` handles

- VUID-vkCmdWriteMicromapsPropertiesEXT-queryType-parameter
  `queryType` must be a valid `VkQueryType` value

- VUID-vkCmdWriteMicromapsPropertiesEXT-queryPool-parameter
  `queryPool` must be a valid `VkQueryPool` handle

- VUID-vkCmdWriteMicromapsPropertiesEXT-commandBuffer-recording
  `commandBuffer` must be in the recording state

- VUID-vkCmdWriteMicromapsPropertiesEXT-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support compute operations

- VUID-vkCmdWriteMicromapsPropertiesEXT-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdWriteMicromapsPropertiesEXT-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdWriteMicromapsPropertiesEXT-micromapCount-arraylength
  `micromapCount` must be greater than 0

- VUID-vkCmdWriteMicromapsPropertiesEXT-commonparent
  Each of `commandBuffer`, `queryPool`, and the elements of `pMicromaps` must have been created, allocated, or retrieved from the same `VkDevice`

Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

<table>
<thead>
<tr>
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</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To copy a micromap call:
// Provided by VK_EXT_opacity_micromap
void vkCmdCopyMicromapEXT(
    VkCommandBuffer commandBuffer,
    const VkCopyMicromapInfoEXT* pInfo);

• commandBuffer is the command buffer into which the command will be recorded.
• pInfo is a pointer to a VkCopyMicromapInfoEXT structure defining the copy operation.

This command copies the pInfo->src micromap to the pInfo->dst micromap in the manner specified by pInfo->mode.

Accesses to pInfo->src and pInfo->dst must be synchronized with the
VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT pipeline stage and an access type of
VK_ACCESS_2_MICROMAP_READ_BIT_EXT or VK_ACCESS_2_MICROMAP_WRITE_BIT_EXT as appropriate.

Valid Usage

• VUID-vkCmdCopyMicromapEXT-buffer-07529
  The buffer used to create pInfo->src must be bound to device memory

• VUID-vkCmdCopyMicromapEXT-buffer-07530
  The buffer used to create pInfo->dst must be bound to device memory

Valid Usage (Implicit)

• VUID-vkCmdCopyMicromapEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

• VUID-vkCmdCopyMicromapEXT-pInfo-parameter
  pInfo must be a valid pointer to a valid VkCopyMicromapInfoEXT structure

• VUID-vkCmdCopyMicromapEXT-commandBuffer-recording
  commandBuffer must be in the recording state

• VUID-vkCmdCopyMicromapEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support compute operations

• VUID-vkCmdCopyMicromapEXT-renderpass
  This command must only be called outside of a render pass instance

• VUID-vkCmdCopyMicromapEXT-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

• Host access to commandBuffer must be externally synchronized
• Host access to the VkCommandPool that commandBuffer was allocated from must be externally
The `VkCopyMicromapInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_opacity_micromap
typedef struct VkCopyMicromapInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkMicromapEXT src;
    VkMicromapEXT dst;
    VkCopyMicromapModeEXT mode;
} VkCopyMicromapInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `src` is the source micromap for the copy.
- `dst` is the target micromap for the copy.
- `mode` is a `VkCopyMicromapModeEXT` value specifying additional operations to perform during the copy.

### Valid Usage

- VUID-VkCopyMicromapInfoEXT-mode-07531
  mode must be `VK_COPY_MICROMAP_MODE_COMPACT_EXT` or `VK_COPY_MICROMAP_MODE_CLONE_EXT`

- VUID-VkCopyMicromapInfoEXT-src-07532
  The source acceleration structure `src` must have been constructed prior to the execution of this command.

- VUID-VkCopyMicromapInfoEXT-mode-07533
  If `mode` is `VK_COPY_MICROMAP_MODE_COMPACT_EXT`, `src` must have been constructed with `VK_BUILD_MICROMAP_ALLOW_COMPACTION_BIT_EXT` in the build.

- VUID-VkCopyMicromapInfoEXT-buffer-07534
  The `buffer` used to create `src` must be bound to device memory.

- VUID-VkCopyMicromapInfoEXT-buffer-07535
  The `buffer` used to create `dst` must be bound to device memory.
Valid Usage (Implicit)

- **VUID-VkCopyMicromapInfoEXT-sType**: `sType` must be `VK_STRUCTURE_TYPE_COPY_MICROMAP_INFO_EXT`
- **VUID-VkCopyMicromapInfoEXT-pNext**: `pNext` must be `NULL`
- **VUID-VkCopyMicromapInfoEXT-src-parameter**: `src` must be a valid `VkMicromapEXT` handle
- **VUID-VkCopyMicromapInfoEXT-dst-parameter**: `dst` must be a valid `VkMicromapEXT` handle
- **VUID-VkCopyMicromapInfoEXT-mode-parameter**: `mode` must be a valid `VkCopyMicromapModeEXT` value
- **VUID-VkCopyMicromapInfoEXT-commonparent**: Both of `dst` and `src` must have been created, allocated, or retrieved from the same `VkDevice`

Possible values of `mode` specifying additional operations to perform during the copy, are:

```c
// Provided by VK_EXT_opacity_micromap
typedef enum VkCopyMicromapModeEXT {
    VK_COPY_MICROMAP_MODE_CLONE_EXT = 0,
    VK_COPY_MICROMAP_MODE_SERIALIZE_EXT = 1,
    VK_COPY_MICROMAP_MODE_DESERIALIZE_EXT = 2,
    VK_COPY_MICROMAP_MODE_COMPACT_EXT = 3,
} VkCopyMicromapModeEXT;
```

- **VK_COPY_MICROMAP_MODE_CLONE_EXT** creates a direct copy of the micromap specified in `src` into the one specified by `dst`. The `dst` micromap must have been created with the same parameters as `src`.
- **VK_COPY_MICROMAP_MODE_SERIALIZE_EXT** serializes the micromap to a semi-opaque format which can be reloaded on a compatible implementation.
- **VK_COPY_MICROMAP_MODE_DESERIALIZE_EXT** deserializes the semi-opaque serialization format in the buffer to the micromap.
- **VK_COPY_MICROMAP_MODE_COMPACT_EXT** creates a more compact version of a micromap `src` into `dst`. The micromap `dst` must have been created with a size at least as large as that returned by `vkCmdWriteMicromapsPropertiesEXT` after the build of the micromap specified by `src`.

To copy a micromap to device memory call:

```c
// Provided by VK_EXT_opacity_micromap
void vkCmdCopyMicromapToMemoryEXT(
    VkCommandBuffer commandBuffer,
```

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const VkCopyMicromapToMemoryInfoEXT* pInfo);

- `commandBuffer` is the command buffer into which the command will be recorded.
- `pInfo` is an a pointer to a `VkCopyMicromapToMemoryInfoEXT` structure defining the copy operation.

Accesses to `pInfo->src` must be synchronized with the `VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT` pipeline stage and an access type of `VK_ACCESS_2_MICROMAP_READ_BIT_EXT`. Accesses to the buffer indicated by `pInfo->dst.deviceAddress` must be synchronized with the `VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT` pipeline stage and an access type of `VK_ACCESS_TRANSFER_WRITE_BIT`.

This command produces the same results as `vkCopyMicromapToMemoryEXT`, but writes its result to a device address, and is executed on the device rather than the host. The output may not necessarily be bit-for-bit identical, but it can be equally used by either `vkCmdCopyMemoryToMicromapEXT` or `vkCopyMemoryToMicromapEXT`.

The defined header structure for the serialized data consists of:

- `VK_UUID_SIZE` bytes of data matching `VkPhysicalDeviceIDProperties::driverUUID`
- `VK_UUID_SIZE` bytes of data identifying the compatibility for comparison using `vkGetDeviceMicromapCompatibilityEXT` The serialized data is written to the buffer (or read from the buffer) according to the host endianness.

### Valid Usage

- VUID-vkCmdCopyMicromapToMemoryEXT-pInfo-07536
  `pInfo->dst.deviceAddress` must be a valid device address for a buffer bound to device memory
- VUID-vkCmdCopyMicromapToMemoryEXT-pInfo-07537
  `pInfo->dst.deviceAddress` must be aligned to 256 bytes
- VUID-vkCmdCopyMicromapToMemoryEXT-pInfo-07538
  If the buffer pointed to by `pInfo->dst.deviceAddress` is non-sparse then it must be bound completely and contiguously to a single `VkDeviceMemory` object
- VUID-vkCmdCopyMicromapToMemoryEXT-buffer-07539
  The buffer used to create `pInfo->src` must be bound to device memory

### Valid Usage (Implicit)

- VUID-vkCmdCopyMicromapToMemoryEXT-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdCopyMicromapToMemoryEXT-pInfo-parameter
  `pInfo` must be a valid pointer to a valid `VkCopyMicromapToMemoryInfoEXT` structure
- VUID-vkCmdCopyMicromapToMemoryEXT-commandBuffer-recording
The commandBuffer must be in the recording state

- VUID-vkCmdCopyMicromapToMemoryEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support compute operations
- VUID-vkCmdCopyMicromapToMemoryEXT-renderpass
  This command must only be called outside of a render pass instance
- VUID-vkCmdCopyMicromapToMemoryEXT-videocoding
  This command must only be called outside of a video coding scope

### Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

### Command Properties

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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

// Provided by VK_EXT_opacity_micromap
typedef struct VkCopyMicromapToMemoryInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkMicromapEXT src;
    VkDeviceOrHostAddressKHR dst;
    VkCopyMicromapModeEXT mode;
} VkCopyMicromapToMemoryInfoEXT;

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- src is the source micromap for the copy
- dst is the device or host address to memory which is the target for the copy
- mode is a VkCopyMicromapModeEXT value specifying additional operations to perform during the copy.
Valid Usage

• VUID-VkCopyMicromapToMemoryInfoEXT-src-07540
  The source micromap \textit{src} must have been constructed prior to the execution of this command.

• VUID-VkCopyMicromapToMemoryInfoEXT-dst-07541
  The memory pointed to by \textit{dst} must be at least as large as the serialization size of \textit{src}, as reported by \texttt{vkWriteMicromapsPropertiesEXT} or \texttt{vkCmdWriteMicromapsPropertiesEXT} with a query type of \texttt{VK_QUERY_TYPE_MICROMAP_SERIALIZATION_SIZE_EXT}

• VUID-VkCopyMicromapToMemoryInfoEXT-mode-07542
  \textit{mode} must be \texttt{VK_COPY_MICROMAP_MODE_SERIALIZE_EXT}

Valid Usage (Implicit)

• VUID-VkCopyMicromapToMemoryInfoEXT-sType-sType
  \textit{sType} must be \texttt{VK_STRUCTURE_TYPE_COPY_MICROMAP_TO_MEMORY_INFO_EXT}

• VUID-VkCopyMicromapToMemoryInfoEXT-pNext-pNext
  \textit{pNext} must be \texttt{NULL}

• VUID-VkCopyMicromapToMemoryInfoEXT-src-parameter
  \textit{src} must be a valid \texttt{VkMicromapEXT} handle

• VUID-VkCopyMicromapToMemoryInfoEXT-mode-parameter
  \textit{mode} must be a valid \texttt{VkCopyMicromapModeEXT} value

To copy device memory to a micromap call:

```c
// Provided by VK_EXT_opacity_micromap
void vkCmdCopyMemoryToMicromapEXT(
  VkCommandBuffer commandBuffer,
  const VkCopyMicromapToMemoryInfoEXT* pInfo);
```

- \texttt{commandBuffer} is the command buffer into which the command will be recorded.
- \texttt{pInfo} is a pointer to a \texttt{VkCopyMicromapToMemoryInfoEXT} structure defining the copy operation.

Accesses to \texttt{pInfo->dst} must be synchronized with the \texttt{VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT} pipeline stage and an access type of \texttt{VK_ACCESS_2_MICROMAP_READ_BIT_EXT}. Accesses to the buffer indicated by \texttt{pInfo->src.deviceAddress} must be synchronized with the \texttt{VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT} pipeline stage and an access type of \texttt{VK_ACCESS_TRANSFER_READ_BIT}.

This command can accept micromaps produced by either \texttt{vkCmdCopyMicromapToMemoryEXT} or \texttt{vkCopyMicromapToMemoryEXT}. 

Valid Usage

- VUID-vkCmdCopyMemoryToMicromapEXT-pInfo-07543
  pInfo->src.deviceAddress must be a valid device address for a buffer bound to device memory
- VUID-vkCmdCopyMemoryToMicromapEXT-pInfo-07544
  pInfo->src.deviceAddress must be aligned to 256 bytes
- VUID-vkCmdCopyMemoryToMicromapEXT-pInfo-07545
  If the buffer pointed to by pInfo->src.deviceAddress is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object
- VUID-vkCmdCopyMemoryToMicromapEXT-buffer-07546
  The buffer used to create pInfo->dst must be bound to device memory

Valid Usage (Implicit)

- VUID-vkCmdCopyMemoryToMicromapEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle
- VUID-vkCmdCopyMemoryToMicromapEXT-pInfo-parameter
  pInfo must be a valid pointer to a valid VkCopyMemoryToMicromapInfoEXT structure
- VUID-vkCmdCopyMemoryToMicromapEXT-commandBuffer-recording
  commandBuffer must be in the recording state
- VUID-vkCmdCopyMemoryToMicromapEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support compute operations
- VUID-vkCmdCopyMemoryToMicromapEXT-renderpass
  This command must only be called outside of a render pass instance
- VUID-vkCmdCopyMemoryToMicromapEXT-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
The `VkCopyMemoryToMicromapInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_opacity_micromap
typedef struct VkCopyMemoryToMicromapInfoEXT {
VkStructureType                   sType;
const void*                       pNext;
VkDeviceOrHostAddressConstKHR    src;
VkMicromapEXT                     dst;
VkCopyMicromapModeEXT             mode;
} VkCopyMemoryToMicromapInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `src` is the device or host address to memory containing the source data for the copy.
- `dst` is the target micromap for the copy.
- `mode` is a `VkCopyMicromapModeEXT` value specifying additional operations to perform during the copy.

**Valid Usage**

- `VUID-VkCopyMemoryToMicromapInfoEXT-src-07547` The source memory pointed to by `src` must contain data previously serialized using `vkCmdCopyMicromapToMemoryEXT`
- `VUID-VkCopyMemoryToMicromapInfoEXT-mode-07548` `mode` must be `VK_COPY_MICROMAP_MODE_DESERIALIZE_EXT`
- `VUID-VkCopyMemoryToMicromapInfoEXT-src-07549` The data in `src` must have a format compatible with the destination physical device as returned by `vkGetDeviceMicromapCompatibilityEXT`
- `VUID-VkCopyMemoryToMicromapInfoEXT-dst-07550` `dst` must have been created with a size greater than or equal to that used to serialize the data in `src`
Valid Usage (Implicit)

- VUID-VkCopyMemoryToMicromapInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_COPY_MEMORY_TO_MICROMAP_INFO_EXT

- VUID-VkCopyMemoryToMicromapInfoEXT-pNext-pNext
  pNext must be NULL

- VUID-VkCopyMemoryToMicromapInfoEXT-dst-parameter
  dst must be a valid VkMicromapEXT handle

- VUID-VkCopyMemoryToMicromapInfoEXT-mode-parameter
  mode must be a valid VkCopyMicromapModeEXT value

To check if a serialized micromap is compatible with the current device call:

```c
// Provided by VK_EXT_opacity_micromap
void vkGetDeviceMicromapCompatibilityEXT(
    VkDevice device,
    const VkMicromapVersionInfoEXT* pVersionInfo,
    VkAccelerationStructureCompatibilityKHR* pCompatibility);
```

- `device` is the device to check the version against.
- `pVersionInfo` is a pointer to a VkMicromapVersionInfoEXT structure specifying version information to check against the device.
- `pCompatibility` is a pointer to a VkAccelerationStructureCompatibilityKHR value in which compatibility information is returned.

Valid Usage

- VUID-vkGetDeviceMicromapCompatibilityEXT-micromap-07551
  The micromap feature must be enabled

Valid Usage (Implicit)

- VUID-vkGetDeviceMicromapCompatibilityEXT-device-parameter
  device must be a valid VkDevice handle

- VUID-vkGetDeviceMicromapCompatibilityEXT-pVersionInfo-parameter
  pVersionInfo must be a valid pointer to a valid VkMicromapVersionInfoEXT structure

- VUID-vkGetDeviceMicromapCompatibilityEXT-pCompatibility-parameter
  pCompatibility must be a valid pointer to a VkAccelerationStructureCompatibilityKHR value

The VkMicromapVersionInfoEXT structure is defined as:
typedef struct VkMicromapVersionInfoEXT {
  VkStructureType sType;
  const void* pNext;
  const uint8_t* pVersionData;
} VkMicromapVersionInfoEXT;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• pVersionData is a pointer to the version header of a micromap as defined in vkCmdCopyMicromapToMemoryEXT

Note
pVersionData is a pointer to an array of 2×VK_UUID_SIZE uint8_t values instead of two VK_UUID_SIZE arrays as the expected use case for this member is to be pointed at the header of a previously serialized micromap (via vkCmdCopyMicromapToMemoryEXT or vkCopyMicromapToMemoryEXT) that is loaded in memory. Using arrays would necessitate extra memory copies of the UUIDs.

Valid Usage (Implicit)

• VUID-VkMicromapVersionInfoEXT-sType-sType sType must be VK_STRUCTURE_TYPE_MICROMAP_VERSION_INFO_EXT
• VUID-VkMicromapVersionInfoEXT-pNext-pNext pNext must be NULL
• VUID-VkMicromapVersionInfoEXT-pVersionData-parameter pVersionData must be a valid pointer to an array of 2×VK_UUID_SIZE uint8_t values

38.2. Host Micromap Operations

Implementations are also required to provide host implementations of the micromap operations if the micromapHostCommands feature is enabled:

• vkBuildMicromapsEXT corresponding to vkCmdBuildMicromapsEXT
• vkCopyMicromapEXT corresponding to vkCmdCopyMicromapEXT
• vkCopyMicromapToMemoryEXT corresponding to vkCmdCopyMicromapToMemoryEXT
• vkCopyMemoryToMicromapEXT corresponding to vkCmdCopyMemoryToMicromapEXT
• vkWriteMicromapsPropertiesEXT corresponding to vkCmdWriteMicromapsPropertiesEXT

These commands are functionally equivalent to their device counterparts, except that they are executed on the host timeline, rather than being enqueued into command buffers.
All micromaps used by the host commands must be bound to host-visible memory, and all input data for micromap builds must be referenced using host addresses instead of device addresses. Applications are not required to map micromap memory when using the host commands.

Note
The `vkBuildMicromapsEXT` and `vkCmdBuildMicromapsEXT` may use different algorithms, and thus are not required to produce identical structures.

Apart from these details, the host and device operations are interchangeable.

Note
For efficient execution, micromaps manipulated using these commands should always be bound to host cached memory, as the implementation may need to repeatedly read and write this memory during the execution of the command.

To build micromaps on the host, call:

```c
// Provided by VK_EXT_opacity_micromap
VkResult vkBuildMicromapsEXT(
    VkDevice device,
    VkDeferredOperationKHR deferredOperation,
    uint32_t infoCount,
    const VkMicromapBuildInfoEXT* pInfos);
```

- `device` is the `VkDevice` for which the micromaps are being built.
- `deferredOperation` is an optional `VkDeferredOperationKHR` to request deferral for this command.
- `infoCount` is the number of micromaps to build. It specifies the number of the `pInfos` that must be provided.
- `pInfos` is a pointer to an array of `infoCount` `VkMicromapBuildInfoEXT` structures defining the geometry used to build each micromap.

This command fulfills the same task as `vkCmdBuildMicromapsEXT` but is executed by the host.

The `vkBuildMicromapsEXT` command provides the ability to initiate multiple micromaps builds, however there is no ordering or synchronization implied between any of the individual micromap builds.

Note
This means that there cannot be any memory aliasing between any micromap memories or scratch memories being used by any of the builds.

Valid Usage

- VUID-vkBuildMicromapsEXT-pInfos-07461
For each `pInfos[i]`, `dstMicromap` must have been created with a value of `VkMicromapCreateInfoEXT::size` greater than or equal to the memory size required by the build operation, as returned by `vkGetMicromapBuildSizesEXT` with `pBuildInfo = pInfos[i]`.

- **VUID-vkBuildMicromapsEXT-mode-07462**
  The `mode` member of each element of `pInfos` must be a valid `VkBuildMicromapModeEXT` value.

- **VUID-vkBuildMicromapsEXT-dstMicromap-07463**
  The `dstMicromap` member of any element of `pInfos` must be a valid `VkMicromapEXT` handle.

- **VUID-vkBuildMicromapsEXT-pInfos-07464**
  For each element of `pInfos` its `type` member must match the value of `VkMicromapCreateInfoEXT::type` when its `dstMicromap` was created.

- **VUID-vkBuildMicromapsEXT-dstMicromap-07465**
  The range of memory backing the `dstMicromap` member of any element of `pInfos` that is accessed by this command must not overlap the memory backing the `dstMicromap` member of any other element of `pInfos`, which is accessed by this command.

- **VUID-vkBuildMicromapsEXT-dstMicromap-07466**
  The range of memory backing the `scratchData` member of any element of `pInfos` that is accessed by this command must not overlap the memory backing the `scratchData` member of any element of `pInfos` (including the same element), which is accessed by this command.

- **VUID-vkBuildMicromapsEXT-scratchData-07467**
  The range of memory backing the `scratchData` member of any element of `pInfos` that is accessed by this command must not overlap the memory backing the `scratchData` member of any other element of `pInfos`, which is accessed by this command.

- **VUID-vkBuildMicromapsEXT-pInfos-07552**
  For each element of `pInfos`, the buffer used to create its `dstMicromap` member must be bound to host-visible device memory.

- **VUID-vkBuildMicromapsEXT-pInfos-07553**
  For each element of `pInfos`, all referenced addresses of `pInfos[i].data.hostAddress` must be valid host memory.

- **VUID-vkBuildMicromapsEXT-pInfos-07554**
  For each element of `pInfos`, all referenced addresses of `pInfos[i].triangleArray.hostAddress` must be valid host memory.

- **VUID-vkBuildMicromapsEXT-micromapHostCommands-07555**
  The `VkPhysicalDeviceOpacityMicromapFeaturesEXT::micromapHostCommands` feature must be enabled.

- **VUID-vkBuildMicromapsEXT-pInfos-07556**
  If `pInfos[i].mode` is `VK_BUILD_MICROMAP_MODE_BUILD_EXT`, all addresses between `pInfos[i].scratchData.hostAddress` and `pInfos[i].scratchData.hostAddress + N - 1` must be valid host memory, where `N` is given by the `buildScratchSize` member of the `VkMicromapBuildSizesInfoEXT` structure returned from a call to...
vkGetMicromapBuildSizesEXT with an identical VkMicromapBuildInfoEXT structure and primitive count

- VUID-vkBuildMicromapsEXT-pInfos-07557
  For each element of pInfos, the buffer used to create its dstMicromap member must be bound to memory that was not allocated with multiple instances

### Valid Usage (Implicit)

- VUID-vkBuildMicromapsEXT-device-parameter
device must be a valid VkDevice handle

- VUID-vkBuildMicromapsEXT-deferredOperation-parameter
  If deferredOperation is not VK_NULL_HANDLE, deferredOperation must be a valid VkDeferredOperationKHR handle

- VUID-vkBuildMicromapsEXT-pInfos-parameter
  pInfos must be a valid pointer to an array of infoCount valid VkMicromapBuildInfoEXT structures

- VUID-vkBuildMicromapsEXT-infoCount-arraylength
  infoCount must be greater than 0

- VUID-vkBuildMicromapsEXT-deferredOperation-parent
  If deferredOperation is a valid handle, it must have been created, allocated, or retrieved from device

### Return Codes

**Success**

- VK_SUCCESS
- VK_OPERATION_DEFERRED_KHR
- VK_OPERATION_NOT_DEFERRED_KHR

**Failure**

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

To copy or compact a micromap on the host, call:

```c
// Provided by VK_EXT_opacity_micromap
VkResult vkCopyMicromapEXT(
    VkDevice device,
    VkDeferredOperationKHR deferredOperation,
    const VkCopyMicromapInfoEXT* pInfo);
```
• **device** is the device which owns the micromaps.

• **deferredOperation** is an optional `VkDeferredOperationKHR` to request deferral for this command.

• **pInfo** is a pointer to a `VkCopyMicromapInfoEXT` structure defining the copy operation.

This command fulfills the same task as `vkCmdCopyMicromapEXT` but is executed by the host.

### Valid Usage

- **VUID-vkCopyMicromapEXT-deferredOperation-03677**
  If `deferredOperation` is not `VK_NULL_HANDLE`, it **must** be a valid `VkDeferredOperationKHR` object.

- **VUID-vkCopyMicromapEXT-deferredOperation-03678**
  Any previous deferred operation that was associated with `deferredOperation` **must** be complete.

- **VUID-vkCopyMicromapEXT-buffer-07558**
  The **buffer** used to create `pInfo->src` **must** be bound to host-visible device memory.

- **VUID-vkCopyMicromapEXT-buffer-07559**
  The **buffer** used to create `pInfo->dst` **must** be bound to host-visible device memory.

- **VUID-vkCopyMicromapEXT-micromapHostCommands-07560**
  The `VkPhysicalDeviceOpacityMicromapFeaturesEXT::micromapHostCommands` feature **must** be enabled.

- **VUID-vkCopyMicromapEXT-buffer-07561**
  The **buffer** used to create `pInfo->src` **must** be bound to memory that was not allocated with multiple instances.

- **VUID-vkCopyMicromapEXT-buffer-07562**
  The **buffer** used to create `pInfo->dst` **must** be bound to memory that was not allocated with multiple instances.

### Valid Usage (Implicit)

- **VUID-vkCopyMicromapEXT-device-parameter**
  `device` **must** be a valid `VkDevice` handle.

- **VUID-vkCopyMicromapEXT-deferredOperation-parameter**
  If `deferredOperation` is not `VK_NULL_HANDLE`, `deferredOperation` **must** be a valid `VkDeferredOperationKHR` handle.

- **VUID-vkCopyMicromapEXT-pInfo-parameter**
  `pInfo` **must** be a valid pointer to a valid `VkCopyMicromapInfoEXT` structure.

- **VUID-vkCopyMicromapEXT-deferredOperation-parent**
  If `deferredOperation` is a valid handle, it **must** have been created, allocated, or retrieved from `device`.
Return Codes

Success
- VK_SUCCESS
- VK_OPERATION_DEFERRED_KHR
- VK_OPERATION_NOT_DEFERRED_KHR

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

To copy host accessible memory to a micromap, call:

```c
// Provided by VK_EXT_opacity_micromap
VkResult vkCopyMemoryToMicromapEXT(
    VkDevice device,
    VkDeferredOperationKHR deferredOperation,
    const VkCopyMemoryToMicromapInfoEXT* pInfo);
```

- `device` is the device which owns `pInfo->dst`.
- `deferredOperation` is an optional `VkDeferredOperationKHR` to request deferral for this command.
- `pInfo` is a pointer to a `VkCopyMemoryToMicromapInfoEXT` structure defining the copy operation.

This command fulfills the same task as `vkCmdCopyMemoryToMicromapEXT` but is executed by the host.

This command can accept micromaps produced by either `vkCmdCopyMicromapToMemoryEXT` or `vkCopyMicromapToMemoryEXT`.

Valid Usage

- VUID-vkCopyMemoryToMicromapEXT-deferredOperation-03677
  If `deferredOperation` is not `VK_NULL_HANDLE`, it must be a valid `VkDeferredOperationKHR` object
- VUID-vkCopyMemoryToMicromapEXT-deferredOperation-03678
  Any previous deferred operation that was associated with `deferredOperation` must be complete
- VUID-vkCopyMemoryToMicromapEXT-pInfo-07563
  `pInfo->src.hostAddress` must be a valid host pointer
- VUID-vkCopyMemoryToMicromapEXT-pInfo-07564
  `pInfo->src.hostAddress` must be aligned to 16 bytes
The buffer used to create pInfo->dst must be bound to host-visible device memory.

The VkPhysicalDeviceOpacityMicromapFeaturesEXT::micromapHostCommands feature must be enabled.

The buffer used to create pInfo->dst must be bound to memory that was not allocated with multiple instances.

Valid Usage (Implicit)

- VUID-vkCopyMemoryToMicromapEXT-device-parameter
  device must be a valid VkDevice handle

- VUID-vkCopyMemoryToMicromapEXT-deferredOperation-parameter
  If deferredOperation is not VK_NULL_HANDLE, deferredOperation must be a valid VkDeferredOperationKHR handle

- VUID-vkCopyMemoryToMicromapEXT-pInfo-parameter
  pInfo must be a valid pointer to a valid VkCopyMemoryToMicromapInfoEXT structure

- VUID-vkCopyMemoryToMicromapEXT-deferredOperation-parent
  If deferredOperation is a valid handle, it must have been created, allocated, or retrieved from device

Return Codes

Success
- VK_SUCCESS
- VK_OPERATION_DEFERRED_KHR
- VK_OPERATION_NOT_DEFERRED_KHR

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

To copy a micromap to host accessible memory, call:

```c
// Provided by VK_EXT_opacity_micromap
VkResult vkCopyMicromapToMemoryEXT(
  VkDevice device,
  VkDeferredOperationKHR deferredOperation,
  const VkCopyMicromapToMemoryInfoEXT* pInfo);
```
• **device** is the device which owns pInfo->src.

• **deferredOperation** is an optional VkDeferredOperationKHR to request deferral for this command.

• **pInfo** is a pointer to a VkCopyMicromapToMemoryInfoEXT structure defining the copy operation.

This command fulfills the same task as vkCmdCopyMicromapToMemoryEXT but is executed by the host.

This command produces the same results as vkCmdCopyMicromapToMemoryEXT, but writes its result directly to a host pointer, and is executed on the host rather than the device. The output may not necessarily be bit-for-bit identical, but it can be equally used by either vkCmdCopyMemoryToMicromapEXT or vkCopyMemoryToMicromapEXT.

### Valid Usage

- VUID-vkCopyMicromapToMemoryEXT-deferredOperation-03677
  If deferredOperation is not VK_NULL_HANDLE, it must be a valid VkDeferredOperationKHR object

- VUID-vkCopyMicromapToMemoryEXT-deferredOperation-03678
  Any previous deferred operation that was associated with deferredOperation must be complete

- VUID-vkCopyMicromapToMemoryEXT-buffer-07568
  The buffer used to create pInfo->src must be bound to host-visible device memory

- VUID-vkCopyMicromapToMemoryEXT-pInfo-07569
  pInfo->dst.hostAddress must be a valid host pointer

- VUID-vkCopyMicromapToMemoryEXT-pInfo-07570
  pInfo->dst.hostAddress must be aligned to 16 bytes

- VUID-vkCopyMicromapToMemoryEXT-micromapHostCommands-07571
  The VkPhysicalDeviceOpacityMicromapFeaturesEXT::micromapHostCommands feature must be enabled

- VUID-vkCopyMicromapToMemoryEXT-buffer-07572
  The buffer used to create pInfo->src must be bound to memory that was not allocated with multiple instances

### Valid Usage (Implicit)

- VUID-vkCopyMicromapToMemoryEXT-device-parameter
  device must be a valid VkDevice handle

- VUID-vkCopyMicromapToMemoryEXT-deferredOperation-parameter
  If deferredOperation is not VK_NULL_HANDLE, deferredOperation must be a valid VkDeferredOperationKHR handle

- VUID-vkCopyMicromapToMemoryEXT-pInfo-parameter
**pInfo** must be a valid pointer to a valid `VkCopyMicromapToMemoryInfoEXT` structure.

- VUID-vkCopyMicromapToMemoryEXT-deferredOperation-parent
  
  If **deferredOperation** is a valid handle, it must have been created, allocated, or retrieved from **device**.

### Return Codes

**Success**

- **VK_SUCCESS**
- **VK_OPERATION_DEFERRED_KHR**
- **VK_OPERATION_NOT_DEFERRED_KHR**

**Failure**

- **VK_ERROR_OUT_OF_HOST_MEMORY**
- **VK_ERROR_OUT_OF_DEVICE_MEMORY**

To query micromap size parameters on the host, call:

```c
// Provided by VK_EXT_opacity_micromap
VkResult vkWriteMicromapsPropertiesEXT(
    VkDevice device,           // device,                      
    uint32_t micromapCount,    // micromapCount,               
    const VkMicromapEXT* pMicromaps, // pMicromaps,               
    VkQueryType queryType,     // queryType,                  
    size_t dataSize,           // dataSize,                   
    void* pData,               // pData,                      
    size_t stride);            // stride);
```

- **device** is the device which owns the micromaps in **pMicromaps**.
- **micromapCount** is the count of micromaps for which to query the property.
- **pMicromaps** is a pointer to an array of existing previously built micromaps.
- **queryType** is a **VkQueryType** value specifying the property to be queried.
- **dataSize** is the size in bytes of the buffer pointed to by **pData**.
- **pData** is a pointer to a user-allocated buffer where the results will be written.
- **stride** is the stride in bytes between results for individual queries within **pData**.

This command fulfills the same task as `vkCmdWriteMicromapsPropertiesEXT` but is executed by the host.

### Valid Usage

- VUID-vkWriteMicromapsPropertiesEXT-pMicromaps-07501
All micromaps in \texttt{pMicromaps} must have been constructed prior to the execution of this command.

- VUID-vkWriteMicromapsPropertiesEXT-pMicromaps-07502
  All micromaps in \texttt{pMicromaps} must have been constructed with \texttt{VK_BUILD_MICROMAP_ALLOW_COMPACTION_BIT_EXT} if \texttt{queryType} is \texttt{VK_QUERY_TYPE_MICROMAP_COMPACTED_SIZE_EXT}.

- VUID-vkWriteMicromapsPropertiesEXT-queryType-07503
  \texttt{queryType} must be \texttt{VK_QUERY_TYPE_MICROMAP_COMPACTED_SIZE_EXT} or \texttt{VK_QUERY_TYPE_MICROMAP_SERIALIZATION_SIZE_EXT}.

- VUID-vkWriteMicromapsPropertiesEXT-queryType-07573
  If \texttt{queryType} is \texttt{VK_QUERY_TYPE_MICROMAP_SERIALIZATION_SIZE_EXT}, then \texttt{stride} must be a multiple of the size of \texttt{VkDeviceSize}.

- VUID-vkWriteMicromapsPropertiesEXT-queryType-07574
  If \texttt{queryType} is \texttt{VK_QUERY_TYPE_MICROMAP_SERIALIZATION_SIZE_EXT}, then \texttt{pData} must point to a \texttt{VkDeviceSize}.

- VUID-vkWriteMicromapsPropertiesEXT-queryType-07575
  If \texttt{queryType} is \texttt{VK_QUERY_TYPE_MICROMAP_SERIALIZATION_SIZE_EXT}, then \texttt{pData} must point to a \texttt{VkDeviceSize}.

- VUID-vkWriteMicromapsPropertiesEXT-dataSize-07576
  \texttt{dataSize} must be greater than or equal to \texttt{micromapCount*stride}.

- VUID-vkWriteMicromapsPropertiesEXT-buffer-07577
  The buffer used to create each micromap in \texttt{pMicromaps} must be bound to host-visible device memory.

- VUID-vkWriteMicromapsPropertiesEXT-micromapHostCommands-07578
  The \texttt{VkPhysicalDeviceOpacityMicromapFeaturesEXT::micromapHostCommands} feature must be enabled.

- VUID-vkWriteMicromapsPropertiesEXT-buffer-07579
  The buffer used to create each micromap in \texttt{pMicromaps} must be bound to memory that was not allocated with multiple instances.

### Valid Usage (Implicit)

- VUID-vkWriteMicromapsPropertiesEXT-device-parameter
  \texttt{device} must be a valid \texttt{VkDevice} handle.

- VUID-vkWriteMicromapsPropertiesEXT-pMicromaps-parameter
  \texttt{pMicromaps} must be a valid pointer to an array of \texttt{micromapCount} valid \texttt{VkMicromapEXT} handles.

- VUID-vkWriteMicromapsPropertiesEXT-queryType-parameter
  \texttt{queryType} must be a valid \texttt{VkQueryType} value.

- VUID-vkWriteMicromapsPropertiesEXT-pData-parameter
  \texttt{pData} must be a valid pointer to an array of \texttt{dataSize} bytes.

- VUID-vkWriteMicromapsPropertiesEXT-micromapCount-arraylength
  \texttt{micromapCount} must be greater than 0.
38.2.1. Displacement Micromap

A displacement micromap in an acceleration structure includes information in the `VkAccelerationStructureTrianglesDisplacementMicromapNV` to define a base triangle and displacement directions then uses displacement information encoded in the micromap to apply to those values to generate the final position.

**Displacement Base Triangle**

If `displacementBiasAndScaleBuffer` is provided the bias and scale are fetched from that buffer. If `displacementBiasAndScaleBuffer` is zero the bias and scale are assumed to be 0.0 and 1.0, respectively.

Given an input position from the geometry, the base position and displacement vector used by the displacement are computed by:

\[
\text{basePosition} = \text{inputPosition} + \text{displacementVector} \times \text{bias}
\]

\[
\text{baseDisplacementVector} = \text{displacementVector} \times \text{scale}
\]

The parameters of each micro-vertex are derived from a combination of the base triangle parameters extracted from the bottom-level acceleration structure, the barycentrics of that micro-vertex, and the displacement value fetched from the displacement micromap corresponding to that micro-vertex.

\[
\text{microVertexBasePosition} = \text{lerp(basePositions, microVertexBarycentrics)}
\]

\[
\text{microVertexDisplacementVector} = \text{lerp(displacementVectors, microVertexBarycentrics)}
\]

\[
\text{microVertexDisplacedPosition} = \text{microVertexBasePosition} + \text{microVertexDisplacementVector} \times \text{micromapDisplacementValue}
\]
Displacement micromap encoding

Displacement amounts are stored in displacement blocks, each covering a triangular region of microvertices. Depending on the subdivision level and encoding format, one or more displacement blocks combine to store all displacement values for a given displacement micromap.

Displacement blocks are organized along a space filling curve within a displacement micromap if more than one block is required, then micro-vertices are organized along the same space filling curve within a displacement micromap.

The space-filling curve is purely hierarchical with recursive splitting, similar to that for opacity micromaps but operating on vertices instead of triangles. To maintain that the hierarchical ordering is contiguous while keeping continuous winding, some triangles are flipped and wound differently.

The VK_DISPLACEMENT_MICROMAP_FORMAT_64_TRIANGLES_64_BYTES_NV format is an uncompressed, packed format which covers 64 microtriangles (subdivision level 3) in a block. The block contains 45 displacement values encoded as 11 bit unorm values and stored tightly packed in the vertex order described above, occupying 495 bits. This is followed by 15 unused bits then 2 reserved bits which must be 0. If this block is used to store displacement for a subdivision level below 3 the later unused values are ignored.

<table>
<thead>
<tr>
<th>Section</th>
<th>Field</th>
<th>Entries</th>
<th>Bits per entry</th>
<th>Starting bit offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>Vertex 0 - 44</td>
<td>45</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Unused</td>
<td></td>
<td>1</td>
<td>15</td>
<td>495</td>
</tr>
<tr>
<td>Reserved</td>
<td>Must be 0</td>
<td>1</td>
<td>2</td>
<td>510</td>
</tr>
</tbody>
</table>

The VK_DISPLACEMENT_MICROMAP_FORMAT_256_TRIANGLES_128_BYTES_NV and VK_DISPLACEMENT_MICROMAP_FORMAT_1024_TRIANGLES_128_BYTES_NV formats store displacements in a compressed form to save space. Both formats use the same compression algorithm, differing in the number of bits used in the different fields.

The compression algorithm works by starting with fully specified anchor vertices, then for each level, predicting the value for the displacement and encoding the correction for that value, using fewer bits for each level of subdivision.

When adding a vertex in the recursive subdivision process between two adjacent displacement values, the predicted value is given by the rounded average of the two adjacent values as integers:

\[
\text{prediction} = \frac{A + B + 1}{2}
\]

The decoded value after applying the correction is given by:

\[
\text{decoded} = \text{prediction} + (\text{SignExtend(correction)} \ll \text{shift})
\]

where correction is given by the corrections field for a given level and micro vertex and shift is given by the shifts field indexed from the level then by 4 values, selected from interior or the 3 edges in vertex order in that order.
The bit encoding for `VK_DISPLACEMENT_MICROMAP_FORMAT_256_TRIANGLES_128_BYTES_NV`

<table>
<thead>
<tr>
<th>Section</th>
<th>Field</th>
<th>Entries</th>
<th>Bits per entry</th>
<th>Starting bit offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchors</td>
<td>Vertex 0 - 2</td>
<td>3</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Corrections</td>
<td>Level 1</td>
<td>3</td>
<td>11</td>
<td>33</td>
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<tr>
<td></td>
<td>Level 2</td>
<td>9</td>
<td>11</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>Level 3</td>
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<td>10</td>
<td>165</td>
</tr>
<tr>
<td></td>
<td>Level 4</td>
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<td>5</td>
<td>465</td>
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<tr>
<td>Unused</td>
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<td>1</td>
<td>1005</td>
</tr>
<tr>
<td>Shifts</td>
<td>Level 4</td>
<td>4</td>
<td>3</td>
<td>1006</td>
</tr>
<tr>
<td></td>
<td>Level 3</td>
<td>4</td>
<td>1</td>
<td>1018</td>
</tr>
<tr>
<td>Reserved</td>
<td>Must be 0</td>
<td>1</td>
<td>2</td>
<td>1022</td>
</tr>
</tbody>
</table>

The bit encoding for `VK_DISPLACEMENT_MICROMAP_FORMAT_1024_TRIANGLES_128_BYTES_NV`

<table>
<thead>
<tr>
<th>Section</th>
<th>Field</th>
<th>Entries</th>
<th>Bits per entry</th>
<th>Starting bit offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchors</td>
<td>Vertex 0 - 2</td>
<td>3</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Corrections</td>
<td>Level 1</td>
<td>3</td>
<td>11</td>
<td>33</td>
</tr>
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<td></td>
<td>Level 2</td>
<td>9</td>
<td>8</td>
<td>66</td>
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<td></td>
<td>Level 3</td>
<td>30</td>
<td>4</td>
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<td></td>
<td>Level 4</td>
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</tr>
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<td>Level 5</td>
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<td>Unused</td>
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<td>1</td>
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<td>882</td>
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<tr>
<td>Shifts</td>
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<td>4</td>
<td>970</td>
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<tr>
<td></td>
<td>Level 4</td>
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<td>986</td>
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<tr>
<td></td>
<td>Level 3</td>
<td>4</td>
<td>3</td>
<td>1002</td>
</tr>
<tr>
<td></td>
<td>Level 2</td>
<td>4</td>
<td>2</td>
<td>1014</td>
</tr>
<tr>
<td>Reserved</td>
<td>Must be 0</td>
<td>1</td>
<td>2</td>
<td>1022</td>
</tr>
</tbody>
</table>
Chapter 39. Ray Traversal

The ray traversal process identifies and handles intersections between a ray and geometries in an acceleration structure.

Ray traversal cannot be started by a Vulkan API command directly - a shader must execute OpRayQueryProceedKHR or OpTraceRayKHR. When the rayTracingPipeline feature is enabled, OpTraceRayKHR can be used for ray tracing in a ray tracing pipeline. When the rayQuery feature is enabled, OpRayQueryProceedKHR can be used in any shader stage.

39.1. Ray Intersection Candidate Determination

Once tracing begins, rays are first tested against instances in a top-level acceleration structure. A ray that intersects an instance will be transformed into the space of the instance to continue traversal within that instance; therefore the transform matrix stored in the instance must be invertible.

In case multiple instances are intersected by a ray, the ray transformation into the space of the instance is invariant under the order in which these instances are encountered in the top-level acceleration structure.

Note
Applying multiple forward and reverse transforms to a ray to transition from one instance to another could result in accumulated errors. Thus an implementation should behave as if the ray is transformed from the origin for each instance independently.

Next, rays are tested against geometries in an bottom-level acceleration structure to determine if a hit occurred between them, initially based only on their geometric properties (i.e. their vertices). The implementation performs similar operations to that of rasterization, but with the effective viewport determined by the parameters of the ray, and the geometry transformed into a space determined by that viewport.

The vertices of each primitive are transformed from acceleration structure space to ray space according to the ray origin and direction as follows:

\[
\begin{pmatrix}
  x_r \\
  y_r \\
  z_r
\end{pmatrix} = \begin{pmatrix}
  a_x^2(1 - c) + c & a_x a_y (1 - c) - sa_z & a_x a_z (1 - c) + sa_y \\
  a_x a_y (1 - c) + sa_z & a_y^2(1 - c) + c & a_y a_z (1 - c) - sa_x \\
  a_x a_z (1 - c) - sa_y & a_y a_z (1 - c) + sa_x & a_z^2(1 - c) + c
\end{pmatrix} \begin{pmatrix}
  x_{as} - o_x \\
  y_{as} - o_y \\
  z_{as} - o_z
\end{pmatrix}
\]

\(a\) is the axis of rotation from the unnormalized ray direction vector \(d\) to the axis vector \(k\):
\[
\mathbf{a} = \begin{cases} 
\frac{\mathbf{d} \times \mathbf{k}}{\| \mathbf{d} \times \mathbf{k} \|} & \text{if } \| \mathbf{d} \times \mathbf{k} \| \neq 0 \\
(0, 1, 0) & \text{if } \| \mathbf{d} \times \mathbf{k} \| = 0
\end{cases}
\]

$s$ and $c$ are the sine and cosine of the angle of rotation about $\mathbf{a}$ from $\mathbf{d}$ to $\mathbf{k}$:

\[
c = \frac{\mathbf{d} \cdot \mathbf{k}}{\| \mathbf{d} \|} \\
s = \sqrt{1 - c^2}
\]

$k$ is the unit vector:

\[
k = \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix}
\]

$o$ and $d$ are the ray origin and unnormalized direction, respectively; the vector described by $x_{as}$, $y_{as}$, and $z_{as}$ is any position in acceleration structure space; and the vector described by $x_r$, $y_r$, and $z_r$ is the same position in ray space.

An intersection candidate is a unique point of intersection between a ray and a geometric primitive. For any primitive that has within its bounds a position $\mathbf{x y z}_{as}$ such that

\[
x_r = 0 \\
y_r = 0 \\
t_{min} \leq -\frac{z_r}{\| \mathbf{d} \|} < t_{max} \quad \text{if the primitive is a triangle,}
\]

\[
t_{min} \leq -\frac{z_r}{\| \mathbf{d} \|} \leq t_{max} \quad \text{otherwise}
\]

(where $t = -\frac{z_r}{\| \mathbf{d} \|}$), an intersection candidate exists.

Triangle primitive bounds consist of all points on the plane formed by the three vertices and within the bounds of the edges between the vertices, subject to the watertightness constraints below. AABB primitive bounds consist of all points within an implementation-defined bound which includes the specified box.

\[\text{Note}\]

The bounds of the AABB including all points internal to the bound implies that a ray started within the AABB will hit that AABB.
The determination of this condition is performed in an implementation specific manner, and may be performed with floating point operations. Due to the complexity and number of operations involved, inaccuracies are expected, particularly as the scale of values involved begins to diverge. Implementations should take efforts to maintain as much precision as possible.

Note

One very common case is when geometries are close to each other at some distance from the origin in acceleration structure space, where an effect similar to “z-fighting” is likely to be observed. Applications can mitigate this by ensuring their detailed geometries remain close to the origin.

Another likely case is when the origin of a ray is set to a position on a previously intersected surface, and its $t_{\text{min}}$ is zero or near zero; an intersection may be detected on the emitting surface. This case can usually be mitigated by offsetting $t_{\text{min}}$ slightly.

For a motion primitive or a motion instance, the positions for intersection are evaluated at the time specified in the `time` parameter to `OpTraceRayMotionNV` by interpolating between the two endpoints as specified for the given motion type. If a motion acceleration structure is traced with `OpTraceRayKHR`, it behaves as a `OpTraceRayMotionNV` with `time` of 0.0.

In the case of AABB geometries, implementations may increase their size in an acceleration structure in order to mitigate precision issues. This may result in false positive intersections being reported to the application.

For triangle intersection candidates, the $b$ and $c$ barycentric coordinates on the triangle where the above condition is met are made available to future shading. If the ray was traced with `OpTraceRayKHR`, these values are available as a vector of 2 32-bit floating point values in the `HitAttributeKHR` storage class.

Once an intersection candidate is determined, it proceeds through the following operations, in order:

1. Ray Intersection Culling
2. Ray Intersection Confirmation
3. Ray Closest Hit Determination
4. Ray Result Determination

The sections below describe the exact details of these tests. There is no ordering guarantee between
operations performed on different intersection candidates.

### 39.1.1. Watertightness

For a set of triangles with identical transforms, within a single instance:

- Any set of two or more triangles where all triangles have one vertex with an identical position value, that vertex is a *shared vertex*.
- Any set of two triangles with two shared vertices that were specified in the same *winding order* in each triangle have a *shared edge* defined by those vertices.

A *closed fan* is a set of three or more triangles where:

- All triangles in the set have the same shared vertex as one of their vertices.
- All edges that include the above vertex are shared edges.
- All above shared edges are shared by exactly two triangles from the set.
- No two triangles in the set intersect, except at shared edges.
- Every triangle in the set is joined to every other triangle in the set by a series of the above shared edges.

Implementations should not double-hit or miss when a ray intersects a shared edge, or a shared vertex of a closed fan.

### 39.2. Ray Intersection Culling

Candidate intersections go through several phases of culling before confirmation as an actual hit. There is no particular ordering dependency between the different culling operations.

#### 39.2.1. Ray Primitive Culling

If the *rayTraversalPrimitiveCulling* or *rayQuery* features are enabled, the *SkipTrianglesKHR* and *SkipAABBsKHR* ray flags can be specified when tracing a ray. *SkipTrianglesKHR* and *SkipAABBsKHR* are mutually exclusive. *SkipTrianglesKHR* is also mutually exclusive with *CullBackFacingTrianglesKHR* and *CullFrontFacingTrianglesKHR*.

If *SkipTrianglesKHR* was included in the Ray Flags operand of the ray trace instruction, and the intersection is with a triangle primitive, the intersection is dropped, and no further processing of this intersection occurs. If *VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR* was included in the pipeline, traversal with *OpTraceRayKHR* calls will all behave as if *SkipTrianglesKHR* was included in its Ray Flags operand.

If *SkipAABBsKHR* was included in the Ray Flags operand of the ray trace instruction, and the intersection is with an AABB primitive, the intersection is dropped, and no further processing of this intersection occurs. If *VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR* was included in the pipeline, traversal with *OpTraceRayKHR* calls will all behave as if *SkipAABBsKHR* was included in its Ray Flags operand.
39.2.2. Ray Mask Culling

Instances can be made invisible to particular rays based on the value of `VkAccelerationStructureInstanceKHR::mask` used to add that instance to a top-level acceleration structure, and the Cull Mask parameter used to trace the ray.

For the instance which is intersected, if `mask & Cull Mask == 0`, the intersection is dropped, and no further processing occurs.

39.2.3. Ray Face Culling

As in polygon rasterization, one of the stages of ray traversal is to determine if a triangle primitive is back- or front-facing, and primitives can be culled based on that facing.

If the intersection candidate is with an AABB primitive, this operation is skipped.

**Determination**

When a ray intersects a triangle primitive, the order that vertices are specified for the polygon affects whether the ray intersects the front or back face. Front or back facing is determined in the same way as they are for rasterization, based on the sign of the polygon's area but using the ray space coordinates instead of framebuffer coordinates. One way to compute this area is:

\[ a = -\frac{1}{2} \sum_{i=0}^{n-1} x_i y_{i+1} - x_{i+1} y_i \]

where \(x_i\) and \(y_i\) are the x and y ray space coordinates of the ith vertex of the n-vertex polygon (vertices are numbered starting at zero for the purposes of this computation) and \(i \oplus 1\) is \((i + 1) \text{ mod n}\).

By default, if \(a\) is negative then the intersection is with the front face of the triangle, otherwise it is with the back face. If `VK_GEOMETRY_INSTANCE_TRIANGLE_FLIP_FACING_BIT_KHR` is included in `VkAccelerationStructureInstanceKHR::flags` for the instance containing the intersected triangle, this determination is reversed. Additionally, if \(a\) is 0, the intersection candidate is treated as not intersecting with any face, irrespective of the sign.

**Note**

In a left-handed coordinate system, an intersection will be with the front face of a triangle if the vertices of the triangle, as defined in index order, appear from the ray’s perspective in a clockwise rotation order. `VK_GEOMETRY_INSTANCE_TRIANGLE_FLIP_FACING_BIT_KHR` was previously annotated as `VK_GEOMETRY_INSTANCE_TRIANGLE_FRONT_COUNTERCLOCKWISE_BIT_KHR` because of this.

If the ray was traced with `OpTraceRayKHR`, the `HitKindKHR` built-in is set to `HitKindFrontFacingTriangleKHR` if the intersection is with front-facing geometry, and `HitKindBackFacingTriangleKHR` if the intersection is with back-facing geometry, for shader stages considering this intersection.

If the ray was traced with `OpRayQueryProceedKHR`, `OpRayQueryGetIntersectionFrontFaceKHR` will return true for intersection candidates with front faces, or false for back faces.
**Culling**

If `CullBackFacingTrianglesKHR` was included in the Ray Flags parameter of the ray trace instruction, and the intersection is determined as with the back face of a triangle primitive, the intersection is dropped, and no further processing of this intersection occurs.

If `CullFrontFacingTrianglesKHR` was included in the Ray Flags parameter of the ray trace instruction, and the intersection is determined as with the front face of a triangle primitive, the intersection is dropped, and no further processing of this intersection occurs.

This culling is disabled if `VK_GEOMETRY_INSTANCE_TRIANGLE_FACING_CULL_DISABLE_BIT_KHR` was included in `VkAccelerationStructureInstanceKHR::flags` for the instance which the intersected geometry belongs to.

Intersection candidates that have not intersected with any face (a == 0) are unconditionally culled, irrespective of ray flags and geometry instance flags.

The `CullBackFacingTrianglesKHR` and `CullFrontFacingTrianglesKHR` Ray Flags are mutually exclusive.

### 39.2.4. Ray Opacity Culling

Each geometry in the acceleration structure may be considered either opaque or not. Opaque geometries continue through traversal as normal, whereas non-opaque geometries need to be either confirmed or discarded by shader code. Intersection candidates can also be culled based on their opacity.

**Determination**

Each individual intersection candidate is initially determined as opaque if `VK_GEOMETRY_OPAQUE_BIT_KHR` was included in the `VkAccelerationStructureGeometryKHR::flags` when the geometry it intersected with was built, otherwise it is considered non-opaque.

If the geometry includes an opacity micromap, the opacity of the intersection at this point is instead derived as described in Ray Opacity Micromap.

If the intersection candidate was generated by an intersection shader, the intersection is initially considered to have opacity matching the AABB candidate that it was generated from.

However, this opacity can be overridden when it is built into an instance. Setting `VK_GEOMETRY_INSTANCE_FORCE_OPAQUE_BIT_KHR` in `VkAccelerationStructureInstanceKHR::flags` will force all geometries in the instance to be considered opaque. Similarly, setting `VK_GEOMETRY_INSTANCE_FORCE_NO_OPAQUE_BIT_KHR` will force all geometries in the instance to be considered non-opaque.

This can again be overridden by including `OpaqueKHR` or `NoOpaqueKHR` in the Ray Flags parameter when tracing a ray. `OpaqueKHR` forces all geometries to behave as if they are opaque, regardless of their build parameters. Similarly, `NoOpaqueKHR` forces all geometries to behave as if they are non-opaque.

If the ray was traced with `OpRayQueryProceedKHR`, to determine the opacity of AABB intersection candidates, `OpRayQueryGetIntersectionCandidateAABBOpaqueKHR` can be used. This instruction will return `true` for opaque intersection candidates, and `false` for non-opaque intersection candidates.
Culling

If `CullOpaqueKHR` is included in the Ray Flags parameter when tracing a ray, an intersection with a geometry that is considered opaque is dropped, and no further processing occurs.

If `CullNoOpaqueKHR` is included in the Ray Flags parameter when tracing a ray, an intersection with a geometry that is considered non-opaque is dropped, and no further processing occurs.

The `OpaqueKHR`, `NoOpaqueKHR`, `CullOpaqueKHR`, and `CullNoOpaqueKHR` Ray Flags are mutually exclusive.

39.2.5. Ray Opacity Micromap

A `VK_GEOMETRY_TYPE_TRIANGLES_KHR` geometry in the acceleration structure may have an opacity micromap associated with it to give finer-grained opacity information.

If the intersection candidate is with a geometry with an associated opacity micromap and `VK_GEOMETRY_INSTANCE_DISABLE_OPACITY_MICROMAPS_EXT` is not set in its instance then the micromap is used to determine geometry opacity instead of the `VK_GEOMETRY_OPAQUE_BIT_KHR` flag in the geometry.

The opacity information in the micromap object is accessed using the candidate intersection u and v coordinates. The integer u and v are computed from $\lfloor u \rfloor + \lfloor v \rfloor$, clamping $\lfloor u \rfloor$ as needed to keep the sum less than or equal to $1 << \text{subdivision level}$. These values are mapped into a linear index with a space filling curve which is defined recursively by traversing into the sub-triangle nearest vertex 0, then the middle triangle with ordering flipped, then nearest vertex 1 then nearest vertex 2.

![Figure 29. Example ordering for micromap data](image)

**Note**

This encoding is spatially coherent, purely hierarchical, and allows a bit-parallel conversion between barycentric address and index values.

See the appendix for reference code implementing this mapping.

The result of the opacity micromap lookup and operations is to treat the intersection as opaque, non-opaque, or ignored. The interpretation of the values depends on
**39.3. Ray Intersection Confirmation**

Depending on the opacity of intersected geometry and whether it is a triangle or an AABB, candidate intersections are further processed to determine the eventual hit result. Candidates generated from AABB intersections run through the same confirmation process as triangle hits.
39.3.1. AABB Intersection Candidates

For an intersection candidate with an AABB geometry generated by Ray Intersection Candidate Determination, shader code is executed to determine whether any hits should be reported to the traversal infrastructure; no further processing of this intersection candidate occurs. The occurrence of an AABB intersection candidate does not guarantee the ray intersects the primitive bounds. To avoid propagating false intersections the application should verify the intersection candidate before reporting any hits.

If the ray was traced with OpTraceRayKHR, an intersection shader is invoked from the Shader Binding Table according to the specified indexing for the intersected geometry. If this shader calls OpReportIntersectionKHR, a new intersection candidate is generated as described below. If the intersection shader is VK_SHADER_UNUSED_KHR (which is only allowed for a zero shader group) then no further processing of the intersection candidate occurs.

Each new candidate generated as a result of this processing is a generated intersection candidate that intersects the AABB geometry, with a t value equal to the Hit parameter of the OpReportIntersectionKHR instruction. The new generated candidate is then independently run through Ray Intersection Confirmation as a generated intersection.

If the ray was traced with OpRayQueryProceedKHR, control is returned to the shader which executed OpRayQueryProceedKHR, returning true. The resulting ray query has a candidate intersection type of RayQueryCandidateIntersectionAABBKHR. OpRayQueryGenerateIntersectionKHR can be called to commit a new intersection candidate with committed intersection type of RayQueryCommittedIntersectionGeneratedKHR. Further ray query processing can be continued by executing OpRayQueryProceedKHR with the same ray query, or intersection can be terminated with OpRayQueryTerminateKHR. Unlike rays traced with OpTraceRayKHR, candidates generated in this way skip generated intersection candidate confirmation; applications should make this determination before generating the intersection.

This operation may be executed multiple times for the same intersection candidate.

39.3.2. Triangle and Generated Intersection Candidates

For triangle and generated intersection candidates, additional shader code may be executed based on the intersection’s opacity.

If the intersection is opaque, the candidate is immediately confirmed as a valid hit and passes to the next stage of processing.

For non-opaque intersection candidates, shader code is executed to determine whether a hit occurred or not.

If the ray was traced with OpTraceRayKHR, an any-hit shader is invoked from the Shader Binding Table according to the specified indexing. If this shader calls OpIgnoreIntersectionKHR, the candidate is dropped and no further processing of the candidate occurs. If the any-hit shader identified is VK_SHADER_UNUSED_KHR, the candidate is immediately confirmed as a valid hit and passes to the next stage of processing.

If the ray was traced with OpRayQueryProceedKHR, control is returned to the shader which executed
OpRayQueryProceedKHR, returning true. As only triangle candidates participate in this operation with ray queries, the resulting candidate intersection type is always RayQueryCandidateIntersectionTriangleKHR. OpRayQueryConfirmIntersectionKHR can be called on the ray query to confirm the candidate as a hit with committed intersection type of RayQueryCommittedIntersectionTriangleKHR. Further ray query processing can be continued by executing OpRayQueryProceedKHR with the same ray query, or intersection can be terminated with OpRayQueryTerminateKHR. If OpRayQueryConfirmIntersectionKHR has not been executed, the candidate is dropped and no further processing of the candidate occurs.

This operation may be executed multiple times for the same intersection candidate unless VK_GEOMETRY_NO_DUPLICATE_ANY_HIT_INVOCATION_BIT_KHR was specified for the intersected geometry.

### 39.4. Ray Closest Hit Determination

Unless the ray was traced with the TerminateOnFirstHitKHR ray flag, the implementation must track the closest confirmed hit until all geometries have been tested and either confirmed or dropped.

After an intersection candidate is confirmed, its t value is compared to \( t_{\text{max}} \) to determine which intersection is closer, where \( t \) is the parametric distance along the ray at which the intersection occurred.

- If \( t < t_{\text{max}} \), \( t_{\text{max}} \) is set to \( t \) and the candidate is set as the current closest hit.
- If \( t > t_{\text{max}} \), the candidate is dropped and no further processing of that candidate occurs.
- If \( t = t_{\text{max}} \), the candidate may be set as the current closest hit or dropped.

If TerminateOnFirstHitKHR was included in the Ray Flags used to trace the ray, once the first hit is confirmed, the ray trace is terminated.

### 39.5. Ray Result Determination

Once all candidates have finished processing the prior stages, or if the ray is forcibly terminated, the final result of the ray trace is determined.

If a closest hit result was identified by Ray Closest Hit Determination, a closest hit has occurred, otherwise the final result is a miss.

For rays traced with OpTraceRayKHR, if a closest hit result was identified, a closest hit shader is invoked from the Shader Binding Table according to the specified indexing for the intersected geometry. Control returns to the shader that executed OpTraceRayKHR once this shader returns. This shader is skipped if either the ray flags included SkipClosestHitShaderKHR, or if the closest hit shader identified is VK_SHADER_UNUSED_KHR.

For rays traced with OpTraceRayKHR where no hit result was identified, the miss shader identified by the Miss Index parameter of OpTraceRayKHR is invoked. Control returns to the shader that executed OpTraceRayKHR once this shader returns. This shader is skipped if the miss shader identified is VK_SHADER_UNUSED_KHR.

If the ray was traced with OpRayQueryProceedKHR, control is returned to the shader which executed
OpRayQueryProceedKHR, returning false. If a closest hit was identified by Ray Closest Hit Determination, the ray query will now have a committed intersection type of RayQueryCommittedIntersectionGeneratedKHR or RayQueryCommittedIntersectionTriangleKHR. If no closest hit was identified, the committed intersection type will be RayQueryCommittedIntersectionNoneKHR.

No further processing of a ray query occurs after this result is determined.
Chapter 40. Ray Tracing

Ray tracing uses a separate rendering pipeline from both the graphics and compute pipelines (see Ray Tracing Pipeline).

![Ray tracing pipeline execution](image)

**Caption**

Interaction between the different shader stages in the ray tracing pipeline

Within the ray tracing pipeline, `OpTraceRayKHR` or `OpTraceRayMotionNV` can be called to perform a ray traversal that invokes the various ray tracing shader stages during its execution. The relationship between the ray tracing pipeline object and the geometries present in the acceleration structure traversed is passed into the ray tracing command in a `VkBuffer` object known as a shader binding table. `OpExecuteCallableKHR` can also be used in ray tracing pipelines to invoke a callable shader.

During execution, control alternates between scheduling and other operations. The scheduling functionality is implementation-specific and is responsible for workload execution. The shader stages are programmable. *Traversal*, which refers to the process of traversing acceleration structures to find potential intersections of rays with geometry, is fixed function.

The programmable portions of the pipeline are exposed in a single-ray programming model, with each invocation handling one ray at a time. Memory operations can be synchronized using standard memory barriers. The Workgroup scope and variables with a storage class of Workgroup must not be used in the ray tracing pipeline.

### 40.1. Shader Call Instructions

A *shader call* is an instruction which may cause execution to continue elsewhere by creating one or more invocations that execute a different shader stage.

The shader call instructions are:

- `OpTraceRayKHR` which may invoke intersection, any-hit, closest hit, or miss shaders,
• OpTraceRayMotionNV which may invoke intersection, any-hit, closest hit, or miss shaders,
• OpReportIntersectionKHR which may invoke any-hit shaders, and
• OpExecuteCallableKHR which will invoke a callable shader.
• OpHitObjectTraceRayNV, OpHitObjectTraceRayMotionNV, and OpHitObjectExecuteShaderNV which may invoke intersection, any-hit, closest hit, miss, or callable shaders.

The invocations created by shader call instructions are grouped into subgroups by the implementation. Those subgroups may be unrelated to the subgroup of the parent invocation.

*Pipeline trace ray instructions can* be used recursively; invoked shaders can themselves execute pipeline trace ray instructions, to a maximum depth defined by the maxRecursionDepth or maxRayRecursionDepth limit.

Shaders directly invoked from the API always have a recursion depth of 0; each shader executed by a pipeline trace ray instruction has a recursion depth one higher than the recursion depth of the shader which invoked it. Applications must not invoke a shader with a recursion depth greater than the value of maxRecursionDepth or maxPipelineRayRecursionDepth specified in the pipeline.

There is no explicit recursion limit for other shader call instructions which may recurse (e.g. OpExecuteCallableKHR) but there is an upper bound determined by the stack size.

An *invocation repack instruction* is a ray tracing shader call instruction where the implementation may change the set of invocations that are executing. When a repack instruction is encountered, the invocation is suspended and a new invocation begins and executes the instruction. After executing the repack instruction (which may result in other ray tracing shader stages executing) the new invocation ends and the original invocation is resumed, but it may be resumed in a different subgroup or at a different SubgroupLocalInvocationId within the same subgroup. When a subset of invocations in a subgroup execute the invocation repack instruction, those that do not execute it remain in the same subgroup at the same SubgroupLocalInvocationId.


The invocations that are executing before an invocation repack instruction, after the instruction, or are created by the instruction, are shader-call-related.

If the implementation changes the composition of subgroups, the values of SubgroupSize, SubgroupLocalInvocationId, SMIDNV, WarpIDNV, and builtin variables that are derived from them (SubgroupEqMask, SubgroupGeMask, SubgroupGtMask, SubgroupLeMask, SubgroupLtMask) must be changed accordingly by the invocation repack instruction. The application must use Volatile semantics on these BuiltIn variables when used in the ray generation, closest hit, miss, intersection, and callable shaders. Similarly, the application must use Volatile semantics on any RayTmaxKHR decorated BuiltIn used in an intersection shader.

*Note*

Subgroup operations are permitted in the programmable ray tracing shader stages. However, shader call instructions place a bound on where results of subgroup instructions or subgroup-scoped instructions that execute the dynamic
instance of that instruction are potentially valid. For example, care **must** be taken when using the result of a ballot operation that was computed before an invocation repack instruction, after that repack instruction. The ballot **may** be incorrect as the set of invocations could have changed.

While the `SubgroupSize` built-in is required to be declared `Volatile`, its value will never change unless `VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT` is set on pipeline creation, as without that bit set, its value is required to match that of `VkPhysicalDeviceSubgroupProperties::subgroupSize`.

For clock operations, the value of a `Subgroup` scoped `OpReadClockKHR` read before the dynamic instance of a repack instruction **should** not be compared to the result of that clock instruction after the repack instruction.

When a ray tracing shader executes a dynamic instance of an invocation repack instruction which results in another ray tracing shader being invoked, their instructions are related by `shader-call-order`.

For ray tracing invocations that are `shader-call-related`:

- **memory operations** on `StorageBuffer`, `Image`, and `ShaderRecordBufferKHR` storage classes **can** be synchronized using the `ShaderCallKHR` scope.
- the `CallableDataKHR`, `IncomingCallableDataKHR`, `RayPayloadKHR`, `HitAttributeKHR`, and `IncomingRayPayloadKHR` storage classes are **system-synchronized** and no application availability and visibility operations are required.
- **memory operations** within a single invocation before and after the invocation repack instruction are ordered by `program-order` and do not require explicit synchronization.

### 40.2. Ray Tracing Commands

`Ray tracing commands` provoke work in the ray tracing pipeline. Ray tracing commands are recorded into a command buffer and when executed by a queue will produce work that executes according to the currently bound ray tracing pipeline. A ray tracing pipeline **must** be bound to a command buffer before any ray tracing commands are recorded in that command buffer.

To dispatch ray tracing use:

```c
// Provided by VK_NV_ray_tracing
void vkCmdTraceRaysNV(
    VkCommandBuffer commandBuffer,
    VkBuffer raygenShaderBindingTableBuffer,
    VkDeviceSize raygenShaderBindingOffset,
    VkBuffer missShaderBindingTableBuffer,
    VkDeviceSize missShaderBindingOffset,
    VkDeviceSize missShaderBindingStride,
    VkBuffer hitShaderBindingTableBuffer,
    VkDeviceSize hitShaderBindingOffset,
);
```
VkDeviceSize hitShaderBindingStride,
VkBuffer callableShaderBindingTableBuffer,
VkDeviceSize callableShaderBindingOffset,
callableShaderBindingStride,
uint32_t width,
uint32_t height,
uint32_t depth);

- commandBuffer is the command buffer into which the command will be recorded.
- raygenShaderBindingTableBuffer is the buffer object that holds the shader binding table data for the ray generation shader stage.
- raygenShaderBindingOffset is the offset in bytes (relative to raygenShaderBindingTableBuffer) of the ray generation shader being used for the trace.
- missShaderBindingTableBuffer is the buffer object that holds the shader binding table data for the miss shader stage.
- missShaderBindingOffset is the offset in bytes (relative to missShaderBindingTableBuffer) of the miss shader being used for the trace.
- missShaderBindingStride is the size in bytes of each shader binding table record in missShaderBindingTableBuffer.
- hitShaderBindingTableBuffer is the buffer object that holds the shader binding table data for the hit shader stages.
- hitShaderBindingOffset is the offset in bytes (relative to hitShaderBindingTableBuffer) of the hit shader group being used for the trace.
- hitShaderBindingStride is the size in bytes of each shader binding table record in hitShaderBindingTableBuffer.
- callableShaderBindingTableBuffer is the buffer object that holds the shader binding table data for the callable shader stage.
- callableShaderBindingOffset is the offset in bytes (relative to callableShaderBindingTableBuffer) of the callable shader being used for the trace.
- callableShaderBindingStride is the size in bytes of each shader binding table record in callableShaderBindingTableBuffer.
- width is the width of the ray trace query dimensions.
- height is height of the ray trace query dimensions.
- depth is depth of the ray trace query dimensions.

When the command is executed, a ray generation group of \( \text{width} \times \text{height} \times \text{depth} \) rays is assembled.

**Valid Usage**

- VUID-vkCmdTraceRaysNV-magFilter-04553

  If a VkSampler created with magFilter or minFilter equal to VK_FILTER_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this
command, then the image view’s format features must contain
VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

• VUID-vkCmdTraceRaysNV-mipmapMode-04770
If a VkSampler created with mipmapMode equal to VK_SAMPLER_MIPMAP_MODE_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

• VUID-vkCmdTraceRaysNV-None-06479
If a VkImageView is sampled with depth comparison, the image view’s format features must contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT

• VUID-vkCmdTraceRaysNV-None-02691
If a VkImageView is accessed using atomic operations as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

• VUID-vkCmdTraceRaysNV-None-07888
If a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer’s format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

• VUID-vkCmdTraceRaysNV-None-02692
If a VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT

• VUID-vkCmdTraceRaysNV-None-02693
If the VK_EXT_filter_cubic extension is not enabled and any VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, it must not have a VkImageViewType of VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

• VUID-vkCmdTraceRaysNV-filterCubic-02694
Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2

• VUID-vkCmdTraceRaysNV-filterCubicMinmax-02695
Any VkImageView being sampled with VK_FILTER_CUBIC_EXT with a reduction mode of either VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX as a result of this command must have a VkImageViewType and format that supports cubic filtering together with minmax filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax returned by vkGetPhysicalDeviceImageFormatProperties2

• VUID-vkCmdTraceRaysNV-cubicRangeClamp-09212
If the cubicRangeClamp feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must not have a VkSamplerReductionModeCreateInfo reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM
Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo`::`reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have `VkSamplerCubicWeightsCreateInfoQCOM`:cubicWeights equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`.

Any `VkImage` created with a `VkImageCreateInfo`::`flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

For any `VkImageView` being written as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view's format features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

For any `VkImageView` being read as a storage image where the image format field of the `OpTypeImage` is `Unknown`, the view's format features must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`.

For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, the view's buffer features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

For any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is `Unknown`, then the view's buffer features must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`.

For each set `n` that is statically used by a bound shader, a descriptor set must have been bound to `n` at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set `n`, with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the `VkPipelineLayout` or `VkDescriptorSetLayout` and `VkPushConstantRange` arrays used to create the current `VkPipeline` or `VkShaderEXT`, as described in Pipeline Layout Compatibility.

If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a `VkPipelineLayout` that is compatible for push constants, with the
VkPipelineLayout or VkDescriptorsetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdTraceRaysNV-None-08114
  Descriptors in each bound descriptor set, specified via vkCmdBindDescriptorSets, must be valid if they are statically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was not created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdTraceRaysNV-None-08115
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdBindDescriptorSets, the bound VkPipeline must have been created without VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdTraceRaysNV-None-08116
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdTraceRaysNV-None-08604
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdTraceRaysNV-None-08117
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdSetDescriptorBufferOffsetsEXT, the bound VkPipeline must have been created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdTraceRaysNV-None-08119
  If a descriptor is dynamically used with a VkPipeline created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdTraceRaysNV-None-08605
  If a descriptor is dynamically used with a VkShaderEXT created with a VkDescriptorsetLayout that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdTraceRaysNV-None-08606
  If the shaderObject feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command

- VUID-vkCmdTraceRaysNV-None-08607
  If the shaderObject is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and VK_NULL_HANDLE shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdTraceRaysNV-None-08608
  If a pipeline is bound to the pipeline bind point used by this command, there must not
have been any calls to dynamic state setting commands for any state not specified as dynamic in the \texttt{VkPipeline} object bound to the pipeline bind point used by this command, since that pipeline was bound

- \textbf{VUID-vkCmdTraceRaysNV-None-08609}

  If the \texttt{VkPipeline} object bound to the pipeline bind point used by this command or any \texttt{VkShaderEXT} bound to a stage corresponding to the pipeline bind point used by this command accesses a \texttt{VkSampler} object that uses unnormalized coordinates, that sampler \textbf{must} not be used to sample from any \texttt{VkImage} with a \texttt{VkImageView} of the type \texttt{VK_IMAGE_VIEW_TYPE_3D}, \texttt{VK_IMAGE_VIEW_TYPE_CUBE}, \texttt{VK_IMAGE_VIEW_TYPE_1D_ARRAY}, \texttt{VK_IMAGE_VIEW_TYPE_2D_ARRAY} or \texttt{VK_IMAGE_VIEW_TYPE_CUBE_ARRAY}, in any shader stage

- \textbf{VUID-vkCmdTraceRaysNV-None-08610}

  If the \texttt{VkPipeline} object bound to the pipeline bind point used by this command or any \texttt{VkShaderEXT} bound to a stage corresponding to the pipeline bind point used by this command accesses a \texttt{VkSampler} object that uses unnormalized coordinates, that sampler \textbf{must} not be used with any of the SPIR-V \texttt{OpImageSample*} or \texttt{OpImageSparseSample*} instructions with \texttt{ImplicitLod}, \texttt{Dref} or \texttt{Proj} in their name, in any shader stage

- \textbf{VUID-vkCmdTraceRaysNV-None-08611}

  If the \texttt{VkPipeline} object bound to the pipeline bind point used by this command or any \texttt{VkShaderEXT} bound to a stage corresponding to the pipeline bind point used by this command accesses a \texttt{VkSampler} object that uses unnormalized coordinates, that sampler \textbf{must} not be used with any of the SPIR-V \texttt{OpImageSample*} or \texttt{OpImageSparseSample*} instructions that includes a LOD bias or any offset values, in any shader stage

- \textbf{VUID-vkCmdTraceRaysNV-uniformBuffers-06935}

  If any stage of the \texttt{VkPipeline} object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either \texttt{VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT} or \texttt{VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT} for \texttt{uniformBuffers}, and the \texttt{robustBufferAccess} feature is not enabled, that stage \textbf{must} not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- \textbf{VUID-vkCmdTraceRaysNV-None-08612}

  If the \texttt{robustBufferAccess} feature is not enabled, and any \texttt{VkShaderEXT} bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it \textbf{must} not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- \textbf{VUID-vkCmdTraceRaysNV-storageBuffers-06936}

  If any stage of the \texttt{VkPipeline} object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either \texttt{VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT} or \texttt{VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT} for \texttt{storageBuffers}, and the \texttt{robustBufferAccess} feature is not enabled, that stage \textbf{must} not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- \textbf{VUID-vkCmdTraceRaysNV-None-08613}

  If the \texttt{robustBufferAccess} feature is not enabled, and any \texttt{VkShaderEXT} bound to a stage
corresponding to the pipeline bind point used by this command accesses a storage buffer, it **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdTraceRaysNV-commandBuffer-02707**
  If `commandBuffer` is an unprotected command buffer and `protectedNoFault` is not supported, any resource accessed by bound shaders **must** not be a protected resource.

- **VUID-vkCmdTraceRaysNV-None-06550**
  If a bound shader accesses a `VkSampler` or `VkImageView` object that enables `sampler Y'CbCr conversion`, that object **must** only be used with `OpImageSample*` or `OpImageSparseSample*` instructions.

- **VUID-vkCmdTraceRaysNV-ConstOffset-06551**
  If a bound shader accesses a `VkSampler` or `VkImageView` object that enables `sampler Y'CbCr conversion`, that object **must** not use the `ConstOffset` and `Offset` operands.

- **VUID-vkCmdTraceRaysNV-viewType-07752**
  If a `VkImageView` is accessed as a result of this command, then the image view’s `viewType` **must** match the `Dim` operand of the `OpTypeImage` as described in Instruction/Sampler/Image View Validation.

- **VUID-vkCmdTraceRaysNV-format-07753**
  If a `VkImageView` is accessed as a result of this command, then the numeric type of the image view’s `format` and the `Sampled Type` operand of the `OpTypeImage` **must** match.

- **VUID-vkCmdTraceRaysNV-OpImageWrite-08795**
  If a `VkImageView` created with a format other than `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the image view’s `format`.

- **VUID-vkCmdTraceRaysNV-OpImageWrite-08796**
  If a `VkImageView` created with the format `VK_FORMAT_A8_UNORM_KHR` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have four components.

- **VUID-vkCmdTraceRaysNV-OpImageWrite-04469**
  If a `VkBufferView` is accessed using `OpImageWrite` as a result of this command, then the `Type` of the `Texel` operand of that instruction **must** have at least as many components as the buffer view’s `format`.

- **VUID-vkCmdTraceRaysNV-SampledType-04470**
  If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 64.

- **VUID-vkCmdTraceRaysNV-SampledType-04471**
  If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 32.

- **VUID-vkCmdTraceRaysNV-SampledType-04472**
  If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction **must** have a `Width` of 64.
must have a Width of 64

- VUID-vkCmdTraceRaysNV-SampledType-04473
  If a VkBufferView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

- VUID-vkCmdTraceRaysNV-sparseImageInt64Atomics-04474
  If the sparseImageInt64Atomics feature is not enabled, VkImage objects created with the VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- VUID-vkCmdTraceRaysNV-sparseImageInt64Atomics-04475
  If the sparseImageInt64Atomics feature is not enabled, VkBuffer objects created with the VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- VUID-vkCmdTraceRaysNV-OpImageWeightedSampleQCOM-06971
  If OpImageWeightedSampleQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM

- VUID-vkCmdTraceRaysNV-OpImageWeightedSampleSampleQCOM-06972
  If OpImageWeightedSampleSampleQCOM uses a VkImageView as a sample weight image as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM

- VUID-vkCmdTraceRaysNV-OpImageBoxFilterQCOM-06973
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM

- VUID-vkCmdTraceRaysNV-OpImageBlockMatchWindowSSDQCOM-06974
  If OpImageBlockMatchWindowSSDQCOM is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_WINDOW_BIT_QCOM

- VUID-vkCmdTraceRaysNV-OpImageBlockMatchWindowSADQCOM-06975
  If OpImageBlockMatchWindowSADQCOM is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- VUID-vkCmdTraceRaysNV-OpImageWeightedSampleQCOM-06977
  If OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, or OpImageBlockMatchGatherSADQCOM uses a VkSampler as a result of this command, then the sampler must have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM
• VUID-vkCmdTraceRaysNV-OpImageWeightedSampleQCOM-06978
  If any command other than OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, or OpImageBlockMatchGatherSADQCOM uses a VkSampler as a result of this command, then the sampler must not have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM

• VUID-vkCmdTraceRaysNV-OpImageBlockMatchWindow-09215
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

• VUID-vkCmdTraceRaysNV-OpImageBlockMatchWindow-09216
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view's format must be a single-component format.

• VUID-vkCmdTraceRaysNV-OpImageBlockMatchWindow-09217
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

• VUID-vkCmdTraceRaysNV-None-07288
  Any shader invocation executed by this command must terminate

• VUID-vkCmdTraceRaysNV-None-03429
  Any shader group handle referenced by this call must have been queried from the currently bound ray tracing pipeline

• VUID-vkCmdTraceRaysNV-commandBuffer-04624
  commandBuffer must not be a protected command buffer

• VUID-vkCmdTraceRaysNV-maxRecursionDepth-03625
  This command must not cause a pipeline trace ray instruction to be executed from a shader invocation with a recursion depth greater than the value of maxRecursionDepth used to create the bound ray tracing pipeline

• VUID-vkCmdTraceRaysNV-raygenShaderBindingTableBuffer-04042
  If raygenShaderBindingTableBuffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

• VUID-vkCmdTraceRaysNV-raygenShaderBindingOffset-02455
  raygenShaderBindingOffset must be less than the size of raygenShaderBindingTableBuffer

• VUID-vkCmdTraceRaysNV-raygenShaderBindingOffset-02456
  raygenShaderBindingOffset must be a multiple of VkPhysicalDeviceRayTracingPropertiesNV::shaderGroupBaseAlignment

• VUID-vkCmdTraceRaysNV-missShaderBindingTableBuffer-04043
  If missShaderBindingTableBuffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

• VUID-vkCmdTraceRaysNV-missShaderBindingOffset-02457
  missShaderBindingOffset must be less than the size of missShaderBindingTableBuffer
- VUID-vkCmdTraceRaysNV-missShaderBindingOffset-02458
  missShaderBindingOffset must be a multiple of VkPhysicalDeviceRayTracingPropertiesNV::shaderGroupBaseAlignment

- VUID-vkCmdTraceRaysNV-hitShaderBindingTableBuffer-04044
  If hitShaderBindingTableBuffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdTraceRaysNV-hitShaderBindingOffset-02459
  hitShaderBindingOffset must be less than the size of hitShaderBindingTableBuffer

- VUID-vkCmdTraceRaysNV-hitShaderBindingOffset-02460
  hitShaderBindingOffset must be a multiple of VkPhysicalDeviceRayTracingPropertiesNV::shaderGroupBaseAlignment

- VUID-vkCmdTraceRaysNV-callableShaderBindingTableBuffer-04045
  If callableShaderBindingTableBuffer is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdTraceRaysNV-callableShaderBindingOffset-02461
  callableShaderBindingOffset must be less than the size of callableShaderBindingTableBuffer

- VUID-vkCmdTraceRaysNV-callableShaderBindingOffset-02462
  callableShaderBindingOffset must be a multiple of VkPhysicalDeviceRayTracingPropertiesNV::shaderGroupBaseAlignment

- VUID-vkCmdTraceRaysNV-missShaderBindingStride-02463
  missShaderBindingStride must be a multiple of VkPhysicalDeviceRayTracingPropertiesNV::shaderGroupHandleSize

- VUID-vkCmdTraceRaysNV-hitShaderBindingStride-02464
  hitShaderBindingStride must be a multiple of VkPhysicalDeviceRayTracingPropertiesNV::shaderGroupHandleSize

- VUID-vkCmdTraceRaysNV-callableShaderBindingStride-02465
  callableShaderBindingStride must be a multiple of VkPhysicalDeviceRayTracingPropertiesNV::shaderGroupHandleSize

- VUID-vkCmdTraceRaysNV-missShaderBindingStride-02466
  missShaderBindingStride must be less than or equal to VkPhysicalDeviceRayTracingPropertiesNV::maxShaderGroupStride

- VUID-vkCmdTraceRaysNV-hitShaderBindingStride-02467
  hitShaderBindingStride must be less than or equal to VkPhysicalDeviceRayTracingPropertiesNV::maxShaderGroupStride

- VUID-vkCmdTraceRaysNV-callableShaderBindingStride-02468
  callableShaderBindingStride must be less than or equal to VkPhysicalDeviceRayTracingPropertiesNV::maxShaderGroupStride

- VUID-vkCmdTraceRaysNV-width-02469
  width must be less than or equal to VkPhysicalDeviceLimits::maxComputeWorkGroupCount[0]

- VUID-vkCmdTraceRaysNV-height-02470
  height must be less than or equal to VkPhysicalDeviceLimits::maxComputeWorkGroupCount[1]
• VUID-vkCmdTraceRaysNV-depth-02471
  depth must be less than or equal to VkPhysicalDeviceLimits::maxComputeWorkGroupCount[2]

Valid Usage (Implicit)

• VUID-vkCmdTraceRaysNV-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

• VUID-vkCmdTraceRaysNV-raygenShaderBindingTableBuffer-parameter
  raygenShaderBindingTableBuffer must be a valid VkBuffer handle

• VUID-vkCmdTraceRaysNV-missShaderBindingTableBuffer-parameter
  If missShaderBindingTableBuffer is not VK_NULL_HANDLE, missShaderBindingTableBuffer must be a valid VkBuffer handle

• VUID-vkCmdTraceRaysNV-hitShaderBindingTableBuffer-parameter
  If hitShaderBindingTableBuffer is not VK_NULL_HANDLE, hitShaderBindingTableBuffer must be a valid VkBuffer handle

• VUID-vkCmdTraceRaysNV-callableShaderBindingTableBuffer-parameter
  If callableShaderBindingTableBuffer is not VK_NULL_HANDLE, callableShaderBindingTableBuffer must be a valid VkBuffer handle

• VUID-vkCmdTraceRaysNV-commandBuffer-recording
  commandBuffer must be in the recording state

• VUID-vkCmdTraceRaysNV-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support compute operations

• VUID-vkCmdTraceRaysNV-renderpass
  This command must only be called outside of a render pass instance

• VUID-vkCmdTraceRaysNV-videocoding
  This command must only be called outside of a video coding scope

• VUID-vkCmdTraceRaysNV-commonparent
  Each of callableShaderBindingTableBuffer, commandBuffer, hitShaderBindingTableBuffer, missShaderBindingTableBuffer, and raygenShaderBindingTableBuffer that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice

Host Synchronization

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
To dispatch ray tracing use:

```c
void vkCmdTraceRaysKHR(
    VkCommandBuffer commandBuffer,
    const VkStridedDeviceAddressRegionKHR* pRaygenShaderBindingTable,
    const VkStridedDeviceAddressRegionKHR* pMissShaderBindingTable,
    const VkStridedDeviceAddressRegionKHR* pHitShaderBindingTable,
    const VkStridedDeviceAddressRegionKHR* pCallableShaderBindingTable,
    uint32_t width,
    uint32_t height,
    uint32_t depth);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `pRaygenShaderBindingTable` is a `VkStridedDeviceAddressRegionKHR` that holds the shader binding table data for the ray generation shader stage.
- `pMissShaderBindingTable` is a `VkStridedDeviceAddressRegionKHR` that holds the shader binding table data for the miss shader stage.
- `pHitShaderBindingTable` is a `VkStridedDeviceAddressRegionKHR` that holds the shader binding table data for the hit shader stage.
- `pCallableShaderBindingTable` is a `VkStridedDeviceAddressRegionKHR` that holds the shader binding table data for the callable shader stage.
- `width` is the width of the ray trace query dimensions.
- `height` is height of the ray trace query dimensions.
- `depth` is depth of the ray trace query dimensions.

When the command is executed, a ray generation group of `width × height × depth` rays is assembled.

**Valid Usage**

- **VUID-vkCmdTraceRaysKHR-magFilter-04553**

  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`
If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`.

If a `VkImageView` is sampled with depth comparison, the image view's format features must contain `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT`.

If a `VkImageView` is accessed using atomic operations as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT`.

If a `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`.

Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo` as a result of this command must have a `VkImageFormatProperties2::filterCubicMinmax` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

If the `cubicRangeClamp` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must not have a `VkSamplerReductionModeCreateInfo::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGE_CLAMP_QCOM`.

Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo` as a result of this command must not have a `VkImageFormatProperties2::filterCubicMinmax` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

Any `VkImageView` being sampled with `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`. 
::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM as a result of this command must sample with VK_FILTER_CUBIC_EXT

- VUID-vkCmdTraceRaysKHR-selectableCubicWeights-09214
  If the selectableCubicWeights feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights equal to VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM

- VUID-vkCmdTraceRaysKHR-flags-02696
  Any VkImage created with a VkImageCreateInfo::flags containing VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV sampled as a result of this command must only be sampled using a VkSamplerAddressMode of VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE

- VUID-vkCmdTraceRaysKHR-OpTypeImage-07027
  For any VkImageView being written as a storage image where the image format field of the OpTypeImage is Unknown, the view's format features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

- VUID-vkCmdTraceRaysKHR-OpTypeImage-07028
  For any VkImageView being read as a storage image where the image format field of the OpTypeImage is Unknown, the view's format features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

- VUID-vkCmdTraceRaysKHR-OpTypeImage-07029
  For any VkBufferView being written as a storage texel buffer where the image format field of the OpTypeImage is Unknown, the view's buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

- VUID-vkCmdTraceRaysKHR-OpTypeImage-07030
  Any VkBufferView being read as a storage texel buffer where the image format field of the OpTypeImage is Unknown then the view's buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

- VUID-vkCmdTraceRaysKHR-None-08600
  For each set n that is statically used by a bound shader, a descriptor set must have been bound to n at the same pipeline bind point, with a VkPipelineLayout that is compatible for set n, with the VkPipelineLayout or VkDescriptorSetLayout array that was used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdTraceRaysKHR-None-08601
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdTraceRaysKHR-maintenance4-08602
  If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility
Compatibility

• VUID-vkCmdTraceRaysKHR-None-08114
  Descriptors in each bound descriptor set, specified via `vkCmdBindDescriptorSets`, **must be** valid if they are statically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was not created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

• VUID-vkCmdTraceRaysKHR-None-08115
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdBindDescriptorSets`, the bound `VkPipeline` **must have** been created without `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

• VUID-vkCmdTraceRaysKHR-None-08116
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, **must be** valid if they are dynamically used by the `VkPipeline` bound to the pipeline bind point used by this command and the bound `VkPipeline` was created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

• VUID-vkCmdTraceRaysKHR-None-08604
  Descriptors in bound descriptor buffers, specified via `vkCmdSetDescriptorBufferOffsetsEXT`, **must be** valid if they are dynamically used by any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command

• VUID-vkCmdTraceRaysKHR-None-08117
  If the descriptors used by the `VkPipeline` bound to the pipeline bind point were specified via `vkCmdSetDescriptorBufferOffsetsEXT`, the bound `VkPipeline` **must have** been created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

• VUID-vkCmdTraceRaysKHR-None-08119
  If a descriptor is dynamically used with a `VkPipeline` created with `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory **must be** resident

• VUID-vkCmdTraceRaysKHR-None-08605
  If a descriptor is dynamically used with a `VkShaderEXT` created with a `VkDescriptorSetLayout` that was created with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`, the descriptor memory **must be** resident

• VUID-vkCmdTraceRaysKHR-None-08606
  If the `shaderObject` feature is not enabled, a valid pipeline **must be** bound to the pipeline bind point used by this command

• VUID-vkCmdTraceRaysKHR-None-08607
  If the `shaderObject` is enabled, either a valid pipeline **must be** bound to the pipeline bind point used by this command, or a valid combination of valid and `VK_NULL_HANDLE` shader objects **must be** bound to every supported shader stage corresponding to the pipeline bind point used by this command

• VUID-vkCmdTraceRaysKHR-None-08608
  If a pipeline is bound to the pipeline bind point used by this command, there **must not** have been any calls to dynamic state setting commands for any state not specified as dynamic in the `VkPipeline` object bound to the pipeline bind point used by this command,
since that pipeline was bound

- **VUID-vkCmdTraceRaysKHR-None-08609**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler **must** not be used to sample from any `VkImage` with a `VkImageView` of the type `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, `VK_IMAGE_VIEW_TYPE_1D_ARRAY`, `VK_IMAGE_VIEW_TYPE_2D_ARRAY` or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`, in any shader stage.

- **VUID-vkCmdTraceRaysKHR-None-08610**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler **must** not be used with any of the SPIR-V `OpImageSample*` or `OpImageSparseSample*` instructions with `ImplicitLod`, `Dref` or `Proj` in their name, in any shader stage.

- **VUID-vkCmdTraceRaysKHR-None-08611**
  If the `VkPipeline` object bound to the pipeline bind point used by this command or any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a `VkSampler` object that uses unnormalized coordinates, that sampler **must** not be used with any of the SPIR-V `OpImageSample*` or `OpImageSparseSample*` instructions that includes a LOD bias or any offset values, in any shader stage.

- **VUID-vkCmdTraceRaysKHR-uniformBuffers-06935**
  If any stage of the `VkPipeline` object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT` or `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT` for `uniformBuffers`, and the `robustBufferAccess` feature is not enabled, that stage **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdTraceRaysKHR-None-08612**
  If the `robustBufferAccess` feature is not enabled, and any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdTraceRaysKHR-storageBuffers-06936**
  If any stage of the `VkPipeline` object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT` or `VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT` for `storageBuffers`, and the `robustBufferAccess` feature is not enabled, that stage **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdTraceRaysKHR-None-08613**
  If the `robustBufferAccess` feature is not enabled, and any `VkShaderEXT` bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it **must** not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.
set bound to the same pipeline bind point

• VUID-vkCmdTraceRaysKHR-commandBuffer-02707
If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource

• VUID-vkCmdTraceRaysKHR-None-06550
If a bound shader accesses a VkSampler or VkImageView object that enables sampler YC_aC conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions

• VUID-vkCmdTraceRaysKHR-ConstOffset-06551
If a bound shader accesses a VkSampler or VkImageView object that enables sampler YC_aC conversion, that object must not use the ConstOffset and Offset operands

• VUID-vkCmdTraceRaysKHR-viewType-07752
If a VkImageView is accessed as a result of this command, then the image view’s viewType must match the Dim operand of the OpTypeImage as described in Instruction/Sampler/Image View Validation

• VUID-vkCmdTraceRaysKHR-format-07753
If a VkImageView is accessed as a result of this command, then the numeric type of the image view’s format and the Sampled Type operand of the OpTypeImage must match

• VUID-vkCmdTraceRaysKHR-OpImageWrite-08795
If a VkImageView created with a format other than VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the image view’s format

• VUID-vkCmdTraceRaysKHR-OpImageWrite-08796
If a VkImageView created with the format VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have four components

• VUID-vkCmdTraceRaysKHR-SampledType-04470
If a VkImageView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64

• VUID-vkCmdTraceRaysKHR-SampledType-04471
If a VkImageView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

• VUID-vkCmdTraceRaysKHR-SampledType-04472
If a VkBufferView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64

• VUID-vkCmdTraceRaysKHR-SampledType-04473
If a `VkBufferView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a Width of 32.

- VUID-vkCmdTraceRaysKHR-sparseImageInt64Atomics-04474
  If the `sparseImageInt64Atomics` feature is not enabled, `VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a Width of 64 by this command.

- VUID-vkCmdTraceRaysKHR-sparseImageInt64Atomics-04475
  If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a Width of 64 by this command.

- VUID-vkCmdTraceRaysKHR-OpImageWeightedSampleQCOM-06971
  If `OpImageWeightedSampleQCOM` is used to sample a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`.

- VUID-vkCmdTraceRaysKHR-OpImageWeightedSampleQCOM-06972
  If `OpImageWeightedSampleQCOM` uses a `VkImageView` as a sample weight image as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`.

- VUID-vkCmdTraceRaysKHR-OpImageBoxFilterQCOM-06973
  If `OpImageBoxFilterQCOM` is used to sample a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM`.

- VUID-vkCmdTraceRaysKHR-OpImageBlockMatchSSDQCOM-06974
  If `OpImageBlockMatchSSDQCOM` is used to read from an `VkImageView` as a result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.

- VUID-vkCmdTraceRaysKHR-OpImageBlockMatchSADQCOM-06975
  If `OpImageBlockMatchSSDQCOM` or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

- VUID-vkCmdTraceRaysKHR-OpImageBlockMatchSADQCOM-06976
  If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, or `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the specified reference coordinates must not fail integer texel coordinate validation.
OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, OpImageBlockMatchSSDQCOM, or OpImageBlockMatchSADQCOM uses a VkSampler as a result of this command, then the sampler must not have been created with

\begin{verbatim}
VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM
\end{verbatim}

- VUID-vkCmdTraceRaysKHR-OpImageBlockMatchWindow-09215
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view's format features must contain \code{VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM}

- VUID-vkCmdTraceRaysKHR-OpImageBlockMatchWindow-09216
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view's format must be a single-component format.

- VUID-vkCmdTraceRaysKHR-OpImageBlockMatchWindow-09217
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- VUID-vkCmdTraceRaysKHR-None-07288
  Any shader invocation executed by this command must terminate

- VUID-vkCmdTraceRaysKHR-None-03429
  Any shader group handle referenced by this call must have been queried from the currently bound ray tracing pipeline

- VUID-vkCmdTraceRaysKHR-maxPipelineRayRecursionDepth-03679
  This command must not cause a shader call instruction to be executed from a shader invocation with a recursion depth greater than the value of \code{maxPipelineRayRecursionDepth} used to create the bound ray tracing pipeline

- VUID-vkCmdTraceRaysKHR-commandBuffer-03635
  commandBuffer must not be a protected command buffer

- VUID-vkCmdTraceRaysKHR-size-04023
  The size member of \code{pRayGenShaderBindingTable} must be equal to its stride member

- VUID-vkCmdTraceRaysKHR-pRayGenShaderBindingTable-03680
  If the buffer from which \code{pRayGenShaderBindingTable->deviceAddress} was queried is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdTraceRaysKHR-pRayGenShaderBindingTable-03681
  The buffer from which the \code{pRayGenShaderBindingTable->deviceAddress} is queried must have been created with the \code{VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR} usage flag

- VUID-vkCmdTraceRaysKHR-pRayGenShaderBindingTable-03682
  \code{pRayGenShaderBindingTable->deviceAddress} must be a multiple of \code{VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupBaseAlignment}

- VUID-vkCmdTraceRaysKHR-pMissShaderBindingTable-03683
  If the buffer from which \code{pMissShaderBindingTable->deviceAddress} was queried is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object
object

- VUID-vkCmdTraceRaysKHR-pMissShaderBindingTable-03684
  The buffer from which the pMissShaderBindingTable->deviceAddress is queried must have been created with the VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR usage flag

- VUID-vkCmdTraceRaysKHR-pMissShaderBindingTable-03685
  pMissShaderBindingTable->deviceAddress must be a multiple of VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupBaseAlignment

- VUID-vkCmdTraceRaysKHR-stride-03686
  pMissShaderBindingTable->stride must be a multiple of VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupHandleAlignment

- VUID-vkCmdTraceRaysKHR-stride-03687
  If the buffer from which pMissShaderBindingTable->deviceAddress was queried is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdTraceRaysKHR-pHitShaderBindingTable-03688
  The buffer from which the pHitShaderBindingTable->deviceAddress is queried must have been created with the VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR usage flag

- VUID-vkCmdTraceRaysKHR-pHitShaderBindingTable-03689
  pHitShaderBindingTable->deviceAddress must be a multiple of VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupBaseAlignment

- VUID-vkCmdTraceRaysKHR-stride-03690
  pHitShaderBindingTable->stride must be a multiple of VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupHandleAlignment

- VUID-vkCmdTraceRaysKHR-stride-03691
  If the buffer from which pHitShaderBindingTable->deviceAddress was queried is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdTraceRaysKHR-pCallableShaderBindingTable-03692
  The buffer from which the pCallableShaderBindingTable->deviceAddress is queried must have been created with the VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR usage flag

- VUID-vkCmdTraceRaysKHR-pCallableShaderBindingTable-03693
  pCallableShaderBindingTable->deviceAddress must be a multiple of VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupBaseAlignment

- VUID-vkCmdTraceRaysKHR-stride-03694
  pCallableShaderBindingTable->stride must be a multiple of VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupHandleAlignment
- **VUID-vkCmdTraceRaysKHR-stride-04041**
  pCallableShaderBindingTable->stride must be less than or equal to VkPhysicalDeviceRayTracingPipelinePropertiesKHR::maxShaderGroupStride

- **VUID-vkCmdTraceRaysKHR-flags-03696**
  If the currently bound ray tracing pipeline was created with flags that included VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR, pHitShaderBindingTable->deviceAddress must not be zero

- **VUID-vkCmdTraceRaysKHR-flags-03697**
  If the currently bound ray tracing pipeline was created with flags that included VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR, pHitShaderBindingTable->deviceAddress must not be zero

- **VUID-vkCmdTraceRaysKHR-flags-03511**
  If the currently bound ray tracing pipeline was created with flags that included VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR, the shader group handle identified by pMissShaderBindingTable->deviceAddress must not be set to zero

- **VUID-vkCmdTraceRaysKHR-flags-03512**
  If the currently bound ray tracing pipeline was created with flags that included VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR, entries in the table identified by pHitShaderBindingTable->deviceAddress accessed as a result of this command in order to execute an any-hit shader must not be set to zero

- **VUID-vkCmdTraceRaysKHR-flags-03513**
  If the currently bound ray tracing pipeline was created with flags that included VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR, entries in the table identified by pHitShaderBindingTable->deviceAddress accessed as a result of this command in order to execute a closest hit shader must not be set to zero

- **VUID-vkCmdTraceRaysKHR-flags-03514**
  If the currently bound ray tracing pipeline was created with flags that included VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR, entries in the table identified by pHitShaderBindingTable->deviceAddress accessed as a result of this command in order to execute an intersection shader must not be set to zero

- **VUID-vkCmdTraceRaysKHR-pHitShaderBindingTable-04735**
  Any non-zero hit shader group entries in the table identified by pHitShaderBindingTable->deviceAddress accessed by this call from a geometry with a geometryType of VK_GEOMETRY_TYPE_TRIANGLES_KHR must have been created with VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_KHR

- **VUID-vkCmdTraceRaysKHR-pHitShaderBindingTable-04736**
  Any non-zero hit shader group entries in the table identified by pHitShaderBindingTable->deviceAddress accessed by this call from a geometry with a geometryType of VK_GEOMETRY_TYPE_AABBS_KHR must have been created with VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_KHR

- **VUID-vkCmdTraceRaysKHR-width-03638**
  width must be less than or equal to VkPhysicalDeviceLimits::maxComputeWorkGroupCount[0] × VkPhysicalDeviceLimits::maxComputeWorkGroupSize[0]
- VUID-vkCmdTraceRaysKHR-height-03639
  height must be less than or equal to VkPhysicalDeviceLimits::maxComputeWorkGroupCount[1] × VkPhysicalDeviceLimits::maxComputeWorkGroupSize[1]

- VUID-vkCmdTraceRaysKHR-depth-03640
  depth must be less than or equal to VkPhysicalDeviceLimits::maxComputeWorkGroupCount[2] × VkPhysicalDeviceLimits::maxComputeWorkGroupSize[2]

- VUID-vkCmdTraceRaysKHR-width-03641
  width × height × depth must be less than or equal to VkPhysicalDeviceRayTracingPipelinePropertiesKHR::maxRayDispatchInvocationCount

Valid Usage (Implicit)

- VUID-vkCmdTraceRaysKHR-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdTraceRaysKHR-pRaygenShaderBindingTable-parameter
  pRaygenShaderBindingTable must be a valid pointer to a valid VkStridedDeviceAddressRegionKHR structure

- VUID-vkCmdTraceRaysKHR-pMissShaderBindingTable-parameter
  pMissShaderBindingTable must be a valid pointer to a valid VkStridedDeviceAddressRegionKHR structure

- VUID-vkCmdTraceRaysKHR-pHitShaderBindingTable-parameter
  pHitShaderBindingTable must be a valid pointer to a valid VkStridedDeviceAddressRegionKHR structure

- VUID-vkCmdTraceRaysKHR-pCallableShaderBindingTable-parameter
  pCallableShaderBindingTable must be a valid pointer to a valid VkStridedDeviceAddressRegionKHR structure

- VUID-vkCmdTraceRaysKHR-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdTraceRaysKHR-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support compute operations

- VUID-vkCmdTraceRaysKHR-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdTraceRaysKHR-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
The `VkStridedDeviceAddressRegionKHR` structure is defined as:

```c
typedef struct VkStridedDeviceAddressRegionKHR {
    VkDeviceAddress deviceAddress;
    VkDeviceSize stride;
    VkDeviceSize size;
} VkStridedDeviceAddressRegionKHR;
```

- `deviceAddress` is the device address (as returned by the `vkGetBufferDeviceAddress` command) at which the region starts, or zero if the region is unused.
- `stride` is the byte stride between consecutive elements.
- `size` is the size in bytes of the region starting at `deviceAddress`.

### Valid Usage

- **VUID-VkStridedDeviceAddressRegionKHR-size-04631**
  If `size` is not zero, all addresses between `deviceAddress` and `deviceAddress + size - 1` must be in the buffer device address range of the same buffer.

- **VUID-VkStridedDeviceAddressRegionKHR-size-04632**
  If `size` is not zero, `stride` must be less than or equal to the size of the buffer from which `deviceAddress` was queried.

When invocation mask image usage is enabled in the bound ray tracing pipeline, the pipeline uses an invocation mask image specified by the command:

```c
// Provided by VK_HUAWEI_invocation_mask
void vkCmdBindInvocationMaskHUAWEI(
    VkCommandBuffer commandBuffer,  
    VkImageView imageView,        
    VkImageLayout imageLayout);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `imageView` is an image view handle specifying the invocation mask image. `imageView` may be set to `VK_NULL_HANDLE`, which is equivalent to specifying a view of an image filled with ones value.
• **imageLayout** is the layout that the image subresources accessible from **imageView** will be in when the invocation mask image is accessed

### Valid Usage

- VUID-vkCmdBindInvocationMaskHUAWEI-None-04976
  The **invocationMask** feature must be enabled
- VUID-vkCmdBindInvocationMaskHUAWEI-imageView-04977
  If **imageView** is not **VK_NULL_HANDLE**, it must be a valid **VkImageView** handle of type **VK_IMAGE_VIEW_TYPE_2D**
- VUID-vkCmdBindInvocationMaskHUAWEI-imageView-04978
  If **imageView** is not **VK_NULL_HANDLE**, it must have a format of **VK_FORMAT_R8_UINT**
- VUID-vkCmdBindInvocationMaskHUAWEI-imageView-04979
  If **imageView** is not **VK_NULL_HANDLE**, it must have been created with **VK_IMAGE_USAGE_INVOCATION_MASK_BIT_HUAWEI** set
- VUID-vkCmdBindInvocationMaskHUAWEI-imageView-04980
  If **imageView** is not **VK_NULL_HANDLE**, **imageLayout** must be **VK_IMAGE_LAYOUT_GENERAL**
- VUID-vkCmdBindInvocationMaskHUAWEI-width-04981
  Thread mask image resolution must match the width and height in **vkCmdTraceRaysKHR**
- VUID-vkCmdBindInvocationMaskHUAWEI-None-04982
  Each element in the invocation mask image must have the value 0 or 1. The value 1 means the invocation is active
- VUID-vkCmdBindInvocationMaskHUAWEI-depth-04983
  **depth** in **vkCmdTraceRaysKHR** must be 1

### Valid Usage (Implicit)

- VUID-vkCmdBindInvocationMaskHUAWEI-commandBuffer-parameter
  commandBuffer must be a valid **VkCommandBuffer** handle
- VUID-vkCmdBindInvocationMaskHUAWEI-imageView-parameter
  If **imageView** is not **VK_NULL_HANDLE**, **imageView** must be a valid **VkImageView** handle
- VUID-vkCmdBindInvocationMaskHUAWEI-imageLayout-parameter
  **imageLayout** must be a valid **VkImageLayout** value
- VUID-vkCmdBindInvocationMaskHUAWEI-commandBuffer-recording
  commandBuffer must be in the recording state
- VUID-vkCmdBindInvocationMaskHUAWEI-commandBuffer-cmdpool
  The **VkCommandPool** that commandBuffer was allocated from must support compute operations
- VUID-vkCmdBindInvocationMaskHUAWEI-renderpass
  This command must only be called outside of a render pass instance
- VUID-vkCmdBindInvocationMaskHUAWEI-videocoding
This command **must** only be called outside of a video coding scope

- VUID-vkCmdBindInvocationMaskHUAWEI-commonparent
  Both of `commandBuffer`, and `imageView` that are valid handles of non-ignored parameters **must** have been created, allocated, or retrieved from the same `VkDevice`

### Host Synchronization

- Host access to `commandBuffer` **must** be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from **must** be externally synchronized

### Command Properties

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</tbody>
</table>

To dispatch ray tracing, with some parameters sourced on the device, use:

```c
// Provided by VK_KHR_ray_tracing_pipeline
void vkCmdTraceRaysIndirectKHR(
    VkCommandBuffer commandBuffer,
    const VkStridedDeviceAddressRegionKHR* pRaygenShaderBindingTable,
    const VkStridedDeviceAddressRegionKHR* pMissShaderBindingTable,
    const VkStridedDeviceAddressRegionKHR* pHitShaderBindingTable,
    const VkStridedDeviceAddressRegionKHR* pCallableShaderBindingTable,
    VkDeviceAddress indirectDeviceAddress);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `pRaygenShaderBindingTable` is a `VkStridedDeviceAddressRegionKHR` that holds the shader binding table data for the ray generation shader stage.
- `pMissShaderBindingTable` is a `VkStridedDeviceAddressRegionKHR` that holds the shader binding table data for the miss shader stage.
- `pHitShaderBindingTable` is a `VkStridedDeviceAddressRegionKHR` that holds the shader binding table data for the hit shader stage.
- `pCallableShaderBindingTable` is a `VkStridedDeviceAddressRegionKHR` that holds the shader binding table data for the callable shader stage.
- `indirectDeviceAddress` is a buffer device address which is a pointer to a `VkTraceRaysIndirectCommandKHR` structure containing the trace ray parameters.
vkCmdTraceRaysIndirectKHR behaves similarly to vkCmdTraceRaysKHR except that the ray trace query dimensions are read by the device from indirectDeviceAddress during execution.

Valid Usage

- **VUID-vkCmdTraceRaysIndirectKHR-magFilter-04553**
  If a VkSampler created with magFilter or minFilter equal to VK_FILTER_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- **VUID-vkCmdTraceRaysIndirectKHR-mipmapMode-04770**
  If a VkSampler created with mipmapMode equal to VK_SAMPLER_MIPMAP_MODE_LINEAR and compareEnable equal to VK_FALSE is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

- **VUID-vkCmdTraceRaysIndirectKHR-None-06479**
  If a VkImageView is sampled with depth comparison, the image view's format features must contain VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT

- **VUID-vkCmdTraceRaysIndirectKHR-None-02691**
  If a VkImageView is accessed using atomic operations as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

- **VUID-vkCmdTraceRaysIndirectKHR-None-02692**
  If a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

- **VUID-vkCmdTraceRaysIndirectKHR-None-02693**
  If the VK_EXT_filter_cubic extension is not enabled and any VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, it must not have a VkImageViewType of VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

- **VUID-vkCmdTraceRaysIndirectKHR-filterCubic-02694**
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2

- **VUID-vkCmdTraceRaysIndirectKHR-filterCubicMinmax-02695**
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT with a reduction mode of either VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX as a result of this command must have a VkImageViewType and format that supports cubic filtering together with minmax filtering, as specified by...
VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax returned by vkGetPhysicalDeviceImageFormatProperties2

- **VUID-vkCmdTraceRaysIndirectKHR-cubicRangeClamp-09212**
  If the cubicRangeClamp feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command **must not have a** VkSamplerReductionModeCreateInfo
  
  reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM

- **VUID-vkCmdTraceRaysIndirectKHR-reductionMode-09213**
  Any VkImageView being sampled with a VkSamplerReductionModeCreateInfo
  
  ::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM as a result of this command **must** sample with VK_FILTER_CUBIC_EXT

- **VUID-vkCmdTraceRaysIndirectKHR-selectableCubicWeights-09214**
  If the selectableCubicWeights feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command **must** have VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights equal to VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM

- **VUID-vkCmdTraceRaysIndirectKHR-flags-02696**
  Any VkImage created with a VkImageCreateInfo
  
  ::flags containing VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV sampled as a result of this command **must** only be sampled using a VkSamplerAddressMode of VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE

- **VUID-vkCmdTraceRaysIndirectKHR-OpTypeImage-07027**
  For any VkImageView being written as a storage image where the image format field of the OpTypeImage is Unknown, the view’s format features **must** contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

- **VUID-vkCmdTraceRaysIndirectKHR-OpTypeImage-07028**
  For any VkImageView being read as a storage image where the image format field of the OpTypeImage is Unknown, the view’s format features **must** contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

- **VUID-vkCmdTraceRaysIndirectKHR-OpTypeImage-07029**
  For any VkBufferView being written as a storage texel buffer where the image format field of the OpTypeImage is Unknown, the view’s buffer features **must** contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

- **VUID-vkCmdTraceRaysIndirectKHR-OpTypeImage-07030**
  Any VkBufferView being read as a storage texel buffer where the image format field of the OpTypeImage is Unknown then the view’s buffer features **must** contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

- **VUID-vkCmdTraceRaysIndirectKHR-None-08600**
  For each set n that is statically used by a bound shader, a descriptor set **must** have been bound to n at the same pipeline bind point, with a VkPipelineLayout that is compatible for set n, with the VkPipelineLayout or VkDescriptorsetLayout array that was used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- **VUID-vkCmdTraceRaysIndirectKHR-None-08601**
For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdTraceRaysIndirectKHR-maintenance4-08602
  If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout EXT

- VUID-vkCmdTraceRaysIndirectKHR-None-08114
  Descriptors in each bound descriptor set, specified via vkCmdBindDescriptorSets, must be valid if they are statically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was not created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdTraceRaysIndirectKHR-None-08115
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdBindDescriptorSets, the bound VkPipeline must have been created without VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdTraceRaysIndirectKHR-None-08116
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdTraceRaysIndirectKHR-None-08604
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdTraceRaysIndirectKHR-None-08117
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdSetDescriptorBufferOffsetsEXT, the bound VkPipeline must have been created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdTraceRaysIndirectKHR-None-08119
  If a descriptor is dynamically used with a VkPipeline created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdTraceRaysIndirectKHR-None-08605
  If a descriptor is dynamically used with a VkShaderEXT created with a VkDescriptorSetLayout that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdTraceRaysIndirectKHR-None-08606
If the shaderObject feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command

- **VUID-vkCmdTraceRaysIndirectKHR-None-08607**
  If the shaderObject is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and VK_NULL_HANDLE shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command.

- **VUID-vkCmdTraceRaysIndirectKHR-None-08608**
  If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the VkPipeline object bound to the pipeline bind point used by this command, since that pipeline was bound.

- **VUID-vkCmdTraceRaysIndirectKHR-None-08609**
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used to sample from any VkImage with a VkImageView of the type VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY, VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage.

- **VUID-vkCmdTraceRaysIndirectKHR-None-08610**
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage.

- **VUID-vkCmdTraceRaysIndirectKHR-None-08611**
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage.

- **VUID-vkCmdTraceRaysIndirectKHR-uniformBuffers-06935**
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdTraceRaysIndirectKHR-None-08612**
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- **VUID-vkCmdTraceRaysIndirectKHR-storageBuffers-06936**
If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdTraceRaysIndirectKHR-None-08613
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdTraceRaysIndirectKHR-commandBuffer-02707
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource

- VUID-vkCmdTraceRaysIndirectKHR-None-06550
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y’C_bC_r conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions

- VUID-vkCmdTraceRaysIndirectKHR-ConstOffset-06551
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y’C_bC_r conversion, that object must not use the ConstOffset and Offset operands

- VUID-vkCmdTraceRaysIndirectKHR-viewType-07752
  If a VkImageView is accessed as a result of this command, then the image view’s viewType must match the Dim operand of the OpTypeImage as described in Instruction/Sampler/Image View Validation

- VUID-vkCmdTraceRaysIndirectKHR-format-07753
  If a VkImageView is accessed as a result of this command, then the numeric type of the image view’s format and the Sampled Type operand of the OpTypeImage must match

- VUID-vkCmdTraceRaysIndirectKHR-OpImageWrite-08795
  If a VkImageView created with a format other than VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the image view’s format

- VUID-vkCmdTraceRaysIndirectKHR-OpImageWrite-08796
  If a VkImageView created with the format VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have four components

- VUID-vkCmdTraceRaysIndirectKHR-OpImageWrite-04469
  If a VkBufferView is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the buffer view’s format

- VUID-vkCmdTraceRaysIndirectKHR-SampledType-04470
  If a VkImageView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction...
must have a Width of 64

- VUID-vkCmdTraceRaysIndirectKHR-SampledType-04471
  If a VkImageView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

- VUID-vkCmdTraceRaysIndirectKHR-SampledType-04472
  If a VkBufferView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64

- VUID-vkCmdTraceRaysIndirectKHR-SampledType-04473
  If a VkBufferView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

- VUID-vkCmdTraceRaysIndirectKHR-sparseImageInt64Atomics-04474
  If the sparseImageInt64Atomics feature is not enabled, VkImage objects created with the VK_IMAGE_CREATE_SPARSE_Residency_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- VUID-vkCmdTraceRaysIndirectKHR-sparseImageInt64Atomics-04475
  If the sparseImageInt64Atomics feature is not enabled, VkBuffer objects created with the VK_BUFFER_CREATE_SPARSE_Residency_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- VUID-vkCmdTraceRaysIndirectKHR-OpImageWeightedSampleQCOM-06971
  If OpImageWeightedSampleQCOM is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM

- VUID-vkCmdTraceRaysIndirectKHR-OpImageWeightedSampleQCOM-06972
  If OpImageWeightedSampleQCOM uses a VkImageView as a sample weight image as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM

- VUID-vkCmdTraceRaysIndirectKHR-OpImageBoxFilterQCOM-06973
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM

- VUID-vkCmdTraceRaysIndirectKHR-OpImageBlockMatchSSDQCOM-06974
  If OpImageBlockMatchSSDQCOM is used to read from an VkImageView as a result of this command, then the image view’s format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- VUID-vkCmdTraceRaysIndirectKHR-OpImageBlockMatchSADQCOM-06975
  If OpImageBlockMatchSADQCOM or OpImageBlockMatchSSDQCOM is used to read from a
reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- **VUID-vkCmdTraceRaysIndirectKHR-OpImageWeightedSampleQCOM-06977**
  If `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, or `OpImageBlockMatchSSDQCOM` or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`

- **VUID-vkCmdTraceRaysIndirectKHR-OpImageWeightedSampleQCOM-06978**
  If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must not have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`

- **VUID-vkCmdTraceRaysIndirectKHR-OpImageBlockMatchWindow-09215**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`

- **VUID-vkCmdTraceRaysIndirectKHR-OpImageBlockMatchWindow-09216**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format must be a single-component format.

- **VUID-vkCmdTraceRaysIndirectKHR-OpImageBlockMatchWindow-09217**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- **VUID-vkCmdTraceRaysIndirectKHR-None-07288**
  Any shader invocation executed by this command must terminate

- **VUID-vkCmdTraceRaysIndirectKHR-None-03429**
  Any shader group handle referenced by this call must have been queried from the currently bound ray tracing pipeline

- **VUID-vkCmdTraceRaysIndirectKHR-maxPipelineRayRecursionDepth-03679**
  This command must not cause a shader call instruction to be executed from a shader invocation with a recursion depth greater than the value of `maxPipelineRayRecursionDepth` used to create the bound ray tracing pipeline

- **VUID-vkCmdTraceRaysIndirectKHR-commandBuffer-03635**
  `commandBuffer` must not be a protected command buffer

- **VUID-vkCmdTraceRaysIndirectKHR-size-04023**
  The size member of `pRayGenShaderBindingTable` must be equal to its stride member

- **VUID-vkCmdTraceRaysIndirectKHR-pRayGenShaderBindingTable-03680**
  If the buffer from which `pRayGenShaderBindingTable->deviceAddress` was queried is non-
sparse then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdTraceRaysIndirectKHR-pRayGenShaderBindingTable-03681**
  The buffer from which the `pRayGenShaderBindingTable->deviceAddress` is queried **must** have been created with the `VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR` usage flag

- **VUID-vkCmdTraceRaysIndirectKHR-pRayGenShaderBindingTable-03682**
  `pRayGenShaderBindingTable->deviceAddress` **must** be a multiple of `VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupBaseAlignment`

- **VUID-vkCmdTraceRaysIndirectKHR-pMissShaderBindingTable-03683**
  If the buffer from which `pMissShaderBindingTable->deviceAddress` was queried is non-sparse then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdTraceRaysIndirectKHR-pMissShaderBindingTable-03684**
  The buffer from which the `pMissShaderBindingTable->deviceAddress` is queried **must** have been created with the `VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR` usage flag

- **VUID-vkCmdTraceRaysIndirectKHR-pMissShaderBindingTable-03685**
  `pMissShaderBindingTable->deviceAddress` **must** be a multiple of `VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupBaseAlignment`

- **VUID-vkCmdTraceRaysIndirectKHR-stride-03686**
  `pMissShaderBindingTable->stride` **must** be a multiple of `VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupHandleAlignment`

- **VUID-vkCmdTraceRaysIndirectKHR-stride-04029**
  `pMissShaderBindingTable->stride` **must** be less than or equal to `VkPhysicalDeviceRayTracingPipelinePropertiesKHR::maxShaderGroupStride`

- **VUID-vkCmdTraceRaysIndirectKHR-pHitShaderBindingTable-03687**
  If the buffer from which `pHitShaderBindingTable->deviceAddress` was queried is non-sparse then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object

- **VUID-vkCmdTraceRaysIndirectKHR-pHitShaderBindingTable-03688**
  The buffer from which the `pHitShaderBindingTable->deviceAddress` is queried **must** have been created with the `VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR` usage flag

- **VUID-vkCmdTraceRaysIndirectKHR-pHitShaderBindingTable-03689**
  `pHitShaderBindingTable->deviceAddress` **must** be a multiple of `VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupBaseAlignment`

- **VUID-vkCmdTraceRaysIndirectKHR-stride-03690**
  `pHitShaderBindingTable->stride` **must** be a multiple of `VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupHandleAlignment`

- **VUID-vkCmdTraceRaysIndirectKHR-stride-04035**
  `pHitShaderBindingTable->stride` **must** be less than or equal to `VkPhysicalDeviceRayTracingPipelinePropertiesKHR::maxShaderGroupStride`

- **VUID-vkCmdTraceRaysIndirectKHR-pCallableShaderBindingTable-03691**
  If the buffer from which `pCallableShaderBindingTable->deviceAddress` was queried is non-sparse then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object
The buffer from which the `pCallableShaderBindingTable->deviceAddress` is queried must have been created with the `VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR` usage flag.

`pCallableShaderBindingTable->deviceAddress` must be a multiple of `VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupBaseAlignment`.

`pCallableShaderBindingTable->stride` must be a multiple of `VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupHandleAlignment`.

`pCallableShaderBindingTable->stride` must be less than or equal to `VkPhysicalDeviceRayTracingPipelinePropertiesKHR::maxShaderGroupStride`.

If the currently bound ray tracing pipeline was created with flags that included `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR`, `pHitShaderBindingTable->deviceAddress` must not be zero.

If the currently bound ray tracing pipeline was created with flags that included `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR`, `pHitShaderBindingTable->deviceAddress` must not be zero.

If the currently bound ray tracing pipeline was created with flags that included `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR`, the shader group handle identified by `pMissShaderBindingTable->deviceAddress` must not be set to zero.

If the currently bound ray tracing pipeline was created with flags that included `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR`, entries in the table identified by `pHitShaderBindingTable->deviceAddress` accessed as a result of this command in order to execute an any-hit shader must not be set to zero.

If the currently bound ray tracing pipeline was created with flags that included `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR`, entries in the table identified by `pHitShaderBindingTable->deviceAddress` accessed as a result of this command in order to execute a closest hit shader must not be set to zero.

If the currently bound ray tracing pipeline was created with flags that included `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR`, entries in the table identified by `pHitShaderBindingTable->deviceAddress` accessed as a result of this command in order to execute an intersection shader must not be set to zero.

Any non-zero hit shader group entries in the table identified by `pHitShaderBindingTable->deviceAddress` accessed by this call from a geometry with a `geometryType` of
VK_GEOMETRY_TYPE_TRIANGLES_KHR must have been created with VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_KHR

- VUID-vkCmdTraceRaysIndirectKHR-pHitShaderBindingTable-04736
  Any non-zero hit shader group entries in the table identified by pHitShaderBindingTable->deviceAddress accessed by this call from a geometry with a geometryType of VK_GEOMETRY_TYPE_AABBS_KHR must have been created with VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_KHR

- VUID-vkCmdTraceRaysIndirectKHR-indirectDeviceAddress-03632
  If the buffer from which indirectDeviceAddress was queried is non-sparse then it must be bound completely and contiguously to a single VkDeviceMemory object

- VUID-vkCmdTraceRaysIndirectKHR-indirectDeviceAddress-03633
  The buffer from which indirectDeviceAddress was queried must have been created with the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT bit set

- VUID-vkCmdTraceRaysIndirectKHR-indirectDeviceAddress-03634
  indirectDeviceAddress must be a multiple of 4

- VUID-vkCmdTraceRaysIndirectKHR-indirectDeviceAddress-03636
  All device addresses between indirectDeviceAddress and indirectDeviceAddress + sizeof (VkTraceRaysIndirectCommandKHR) - 1 must be in the buffer device address range of the same buffer

- VUID-vkCmdTraceRaysIndirectKHR-rayTracingPipelineTraceRaysIndirect-03637
  The rayTracingPipelineTraceRaysIndirect feature must be enabled

- VUID-vkCmdTraceRaysIndirectKHR-rayTracingMotionBlurPipelineTraceRaysIndirect-04951
  If the bound ray tracing pipeline was created with VK_PIPELINE_CREATE_RAY_TRACING_ALLOW_MOTION_BIT_NV VkPhysicalDeviceRayTracingMotionBlurFeaturesNV::rayTracingMotionBlurPipelineTraceRaysIndirect feature must be enabled

**Valid Usage (Implicit)**

- VUID-vkCmdTraceRaysIndirectKHR-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdTraceRaysIndirectKHR-pRaygenShaderBindingTable-parameter
  pRaygenShaderBindingTable must be a valid pointer to a valid VkStridedDeviceAddressRegionKHR structure

- VUID-vkCmdTraceRaysIndirectKHR-pMissShaderBindingTable-parameter
  pMissShaderBindingTable must be a valid pointer to a valid VkStridedDeviceAddressRegionKHR structure

- VUID-vkCmdTraceRaysIndirectKHR-pHitShaderBindingTable-parameter
  pHitShaderBindingTable must be a valid pointer to a valid VkStridedDeviceAddressRegionKHR structure

- VUID-vkCmdTraceRaysIndirectKHR-pCallableShaderBindingTable-parameter
pCallableShaderBindingTable must be a valid pointer to a valid VkStridedDeviceAddressRegionKHR structure

- VUID-vkCmdTraceRaysIndirectKHR-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdTraceRaysIndirectKHR-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support compute operations

- VUID-vkCmdTraceRaysIndirectKHR-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdTraceRaysIndirectKHR-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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The VkTraceRaysIndirectCommandKHR structure is defined as:

```c
// Provided by VK_KHR_ray_tracing_pipeline
typedef struct VkTraceRaysIndirectCommandKHR {
    uint32_t width;
    uint32_t height;
    uint32_t depth;
} VkTraceRaysIndirectCommandKHR;
```

- width is the width of the ray trace query dimensions.
- height is height of the ray trace query dimensions.
- depth is depth of the ray trace query dimensions.

The members of VkTraceRaysIndirectCommandKHR have the same meaning as the similarly named parameters of vkCmdTraceRaysKHR.
Valid Usage

- VUID-VkTraceRaysIndirectCommandKHR-width-03638
  
  width must be less than or equal to \( \text{VkPhysicalDeviceLimits::maxComputeWorkGroupCount}[0] \times \text{VkPhysicalDeviceLimits::maxComputeWorkGroupSize}[0] \)

- VUID-VkTraceRaysIndirectCommandKHR-height-03639
  
  height must be less than or equal to \( \text{VkPhysicalDeviceLimits::maxComputeWorkGroupCount}[1] \times \text{VkPhysicalDeviceLimits::maxComputeWorkGroupSize}[1] \)

- VUID-VkTraceRaysIndirectCommandKHR-depth-03640
  
  depth must be less than or equal to \( \text{VkPhysicalDeviceLimits::maxComputeWorkGroupCount}[2] \times \text{VkPhysicalDeviceLimits::maxComputeWorkGroupSize}[2] \)

- VUID-VkTraceRaysIndirectCommandKHR-width-03641
  
  \( \text{width} \times \text{height} \times \text{depth} \) must be less than or equal to \( \text{VkPhysicalDeviceRayTracingPipelinePropertiesKHR::maxRayDispatchInvocationCount} \)

To dispatch ray tracing, with some parameters sourced on the device, use:

```c
// Provided by VK_KHR_ray_tracing_maintenance1 with VK_KHR_ray_tracing_pipeline
void vkCmdTraceRaysIndirect2KHR(
    VkCommandBuffer commandBuffer,
    VkDeviceAddress indirectDeviceAddress);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `indirectDeviceAddress` is a buffer device address which is a pointer to a `VkTraceRaysIndirectCommand2KHR` structure containing the trace ray parameters.

`vkCmdTraceRaysIndirect2KHR` behaves similarly to `vkCmdTraceRaysIndirectKHR` except that shader binding table parameters as well as dispatch dimensions are read by the device from `indirectDeviceAddress` during execution.

Valid Usage

- VUID-vkCmdTraceRaysIndirect2KHR-magFilter-04553
  
  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- VUID-vkCmdTraceRaysIndirect2KHR-mipmapMode-04770
  
  If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- VUID-vkCmdTraceRaysIndirect2KHR-None-06479
If a `VkImageView` is sampled with depth comparison, the image view's format features must contain `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT`.

- VUID-vkCmdTraceRaysIndirect2KHR-None-02691
  If a `VkImageView` is accessed using atomic operations as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT`.

- VUID-vkCmdTraceRaysIndirect2KHR-None-07888
  If a `VkImageView` is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain `VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT`.

- VUID-vkCmdTraceRaysIndirect2KHR-None-02692
  If a `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`.

- VUID-vkCmdTraceRaysIndirect2KHR-None-02693
  If the `VK_EXT_filter_cubic` extension is not enabled and any `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, it must not have a `VkImageViewType` of `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`.

- VUID-vkCmdTraceRaysIndirect2KHR-filterCubic-02694
  Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

- VUID-vkCmdTraceRaysIndirect2KHR-filterCubicMinmax-02695
  Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` with a reduction mode of either `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering together with minmax filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

- VUID-vkCmdTraceRaysIndirect2KHR-cubicRangeClamp-09212
  If the cubicRangeClamp feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must not have a `VkSamplerReductionModeCreateInfo::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`.

- VUID-vkCmdTraceRaysIndirect2KHR-reductionMode-09213
  Any `VkImageView` being sampled with `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

- VUID-vkCmdTraceRaysIndirect2KHR-selectableCubicWeights-09214
  If the selectableCubicWeights feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to
• VUID-vkCmdTraceRaysIndirect2KHR-flags-02696
  Any VkImage created with a VkImageCreateInfo::flags containing VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV sampled as a result of this command must only be sampled using a VkSamplerAddressMode of VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE

• VUID-vkCmdTraceRaysIndirect2KHR-OpTypeImage-07027
  For any VkImageView being written as a storage image where the image format field of the OpTypeImage is Unknown, the view’s format features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

• VUID-vkCmdTraceRaysIndirect2KHR-OpTypeImage-07028
  For any VkImageView being read as a storage image where the image format field of the OpTypeImage is Unknown, the view’s format features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

• VUID-vkCmdTraceRaysIndirect2KHR-OpTypeImage-07029
  For any VkBufferView being written as a storage texel buffer where the image format field of the OpTypeImage is Unknown, the view’s buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

• VUID-vkCmdTraceRaysIndirect2KHR-OpTypeImage-07030
  Any VkBufferView being read as a storage texel buffer where the image format field of the OpTypeImage is Unknown then the view’s buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

• VUID-vkCmdTraceRaysIndirect2KHR-None-08600
  For each set n that is statically used by a bound shader, a descriptor set must have been bound to n at the same pipeline bind point, with a VkPipelineLayout that is compatible for set n, with the VkPipelineLayout or VkDescriptorSetLayout array that was used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

• VUID-vkCmdTraceRaysIndirect2KHR-None-08601
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

• VUID-vkCmdTraceRaysIndirect2KHR-maintenance4-08602
  If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

• VUID-vkCmdTraceRaysIndirect2KHR-None-08114
  Descriptors in each bound descriptor set, specified via vkCmdBindDescriptorSets, must be valid if they are statically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was not created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT
If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdBindDescriptorSets, the bound VkPipeline must have been created without VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT.

Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT.

Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command.

If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdSetDescriptorBufferOffsetsEXT, the bound VkPipeline must have been created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT.

If a descriptor is dynamically used with a VkPipeline created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident.

If a descriptor is dynamically used with a VkShaderEXT created with a VkDescriptorSetLayout that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident.

If the shaderObject feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command.

If the shaderObject is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and VK_NULL_HANDLE shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command.

If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the VkPipeline object bound to the pipeline bind point used by this command, since that pipeline was bound.

If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used to sample from any VkImage with a VkImageView of the type.
VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY, VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage

- VUID-vkCmdTraceRaysIndirect2KHR-None-08610
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage

- VUID-vkCmdTraceRaysIndirect2KHR-None-08611
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage

- VUID-vkCmdTraceRaysIndirect2KHR-uniformBuffers-06935
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdTraceRaysIndirect2KHR-None-08612
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdTraceRaysIndirect2KHR-storageBuffers-06936
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdTraceRaysIndirect2KHR-None-08613
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdTraceRaysIndirect2KHR-commandBuffer-02707
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource

- VUID-vkCmdTraceRaysIndirect2KHR-None-06550
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y'C
That object must only be used with \texttt{OpImageSample*} or \texttt{OpImageSparseSample*} instructions.

- **VUID-vkCmdTraceRaysIndirect2KHR-ConstOffset-06551**
  If a bound shader accesses a \texttt{VkSampler} or \texttt{VkImageView} object that enables sampler \texttt{Y'CbCr conversion}, that object must not use the \texttt{ConstOffset} and \texttt{Offset} operands.

- **VUID-vkCmdTraceRaysIndirect2KHR-viewType-07752**
  If a \texttt{VkImageView} is accessed as a result of this command, then the image view's \texttt{viewType} must match the \texttt{Dim} operand of the \texttt{OpTypeImage} as described in Instruction/Sampler/Image View Validation.

- **VUID-vkCmdTraceRaysIndirect2KHR-format-07753**
  If a \texttt{VkImageView} is accessed as a result of this command, then the numeric type of the image view's \texttt{format} and the \texttt{Sampled Type} operand of the \texttt{OpTypeImage} must match.

- **VUID-vkCmdTraceRaysIndirect2KHR-OpImageWrite-08795**
  If a \texttt{VkImageView} created with a format other than \texttt{VK_FORMAT_A8_UNORM_KHR} is accessed using \texttt{OpImageWrite} as a result of this command, then the \texttt{Type} of the \texttt{Texel} operand of that instruction must have at least as many components as the image view's \texttt{format}.

- **VUID-vkCmdTraceRaysIndirect2KHR-OpImageWrite-08796**
  If a \texttt{VkImageView} created with the format \texttt{VK_FORMAT_A8_UNORM_KHR} is accessed using \texttt{OpImageWrite} as a result of this command, then the \texttt{Type} of the \texttt{Texel} operand of that instruction must have four components.

- **VUID-vkCmdTraceRaysIndirect2KHR-SampledType-04470**
  If a \texttt{VkImageView} with a \texttt{VkFormat} that has a 64-bit component width is accessed as a result of this command, the \texttt{SampledType} of the \texttt{OpTypeImage} operand of that instruction must have a \texttt{Width} of 64.

- **VUID-vkCmdTraceRaysIndirect2KHR-SampledType-04471**
  If a \texttt{VkImageView} with a \texttt{VkFormat} that has a component width less than 64-bit is accessed as a result of this command, the \texttt{SampledType} of the \texttt{OpTypeImage} operand of that instruction must have a \texttt{Width} of 32.

- **VUID-vkCmdTraceRaysIndirect2KHR-SampledType-04472**
  If a \texttt{VkBufferView} with a \texttt{VkFormat} that has a 64-bit component width is accessed as a result of this command, the \texttt{SampledType} of the \texttt{OpTypeImage} operand of that instruction must have a \texttt{Width} of 64.

- **VUID-vkCmdTraceRaysIndirect2KHR-SampledType-04473**
  If a \texttt{VkBufferView} with a \texttt{VkFormat} that has a component width less than 64-bit is accessed as a result of this command, the \texttt{SampledType} of the \texttt{OpTypeImage} operand of that instruction must have a \texttt{Width} of 32.

- **VUID-vkCmdTraceRaysIndirect2KHR-sparseImageInt64Atomics-04474**
  If the \texttt{sparseImageInt64Atomics} feature is not enabled, \texttt{VkImage} objects created with the \texttt{VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT} flag must not be accessed by atomic instructions.
through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command

- **VUID-vkCmdTraceRaysIndirect2KHR-sparseImageInt64Atomics-04475**
  If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command

- **VUID-vkCmdTraceRaysIndirect2KHR-OpImageWeightedSampleQCOM-06971**
  If `OpImageWeightedSampleQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`

- **VUID-vkCmdTraceRaysIndirect2KHR-OpImageWeightedSampleQCOM-06972**
  If `OpImageWeightedSampleQCOM` uses a `VkImageView` as a sample weight image as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`

- **VUID-vkCmdTraceRaysIndirect2KHR-OpImageBoxFilterQCOM-06973**
  If `OpImageBoxFilterQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM`

- **VUID-vkCmdTraceRaysIndirect2KHR-OpImageBlockMatchSSDQCOM-06974**
  If `OpImageBlockMatchSSDQCOM` is used to read from a `VkImageView` as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`

- **VUID-vkCmdTraceRaysIndirect2KHR-OpImageBlockMatchSADQCOM-06975**
  If `OpImageBlockMatchSADQCOM` is used to read from a `reference image` as result of this command, then the specified reference coordinates must not fail `integer texel coordinate validation`

- **VUID-vkCmdTraceRaysIndirect2KHR-OpImageWeightedSampleQCOM-06977**
  If `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`

- **VUID-vkCmdTraceRaysIndirect2KHR-OpImageWeightedSampleQCOM-06978**
  If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler must not have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`

- **VUID-vkCmdTraceRaysIndirect2KHR-OpImageBlockMatchWindow-09215**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to
read from an VkImageView as a result of this command, then the image view's format features **must** contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

- **VUID-vkCmdTraceRaysIndirect2KHR-OpImageBlockMatchWindow-09216**
  If a *OpImageBlockMatchWindow*QCOM or *OpImageBlockMatchGather*QCOM instruction is used to read from an VkImageView as a result of this command, then the image view's format **must** be a single-component format.

- **VUID-vkCmdTraceRaysIndirect2KHR-OpImageBlockMatchWindow-09217**
  If a *OpImageBlockMatchWindow*QCOM or *OpImageBlockMatchGather*QCOM read from a reference image as result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation

- **VUID-vkCmdTraceRaysIndirect2KHR-None-07288**
  Any shader invocation executed by this command **must** terminate

- **VUID-vkCmdTraceRaysIndirect2KHR-None-03429**
  Any shader group handle referenced by this call **must** have been queried from the currently bound ray tracing pipeline

- **VUID-vkCmdTraceRaysIndirect2KHR-maxPipelineRayRecursionDepth-03679**
  This command **must** not cause a shader call instruction to be executed from a shader invocation with a recursion depth greater than the value of maxPipelineRayRecursionDepth used to create the bound ray tracing pipeline

- **VUID-vkCmdTraceRaysIndirect2KHR-commandBuffer-03635**
  commandBuffer **must** not be a protected command buffer

- **VUID-vkCmdTraceRaysIndirect2KHR-indirectDeviceAddress-03632**
  If the buffer from which indirectDeviceAddress was queried is non-sparse then it **must** be bound completely and contiguously to a single VkDeviceMemory object

- **VUID-vkCmdTraceRaysIndirect2KHR-indirectDeviceAddress-03633**
  The buffer from which indirectDeviceAddress was queried **must** have been created with the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT bit set

- **VUID-vkCmdTraceRaysIndirect2KHR-indirectDeviceAddress-03634**
  indirectDeviceAddress **must** be a multiple of 4

- **VUID-vkCmdTraceRaysIndirect2KHR-indirectDeviceAddress-03636**
  All device addresses between indirectDeviceAddress and indirectDeviceAddress + sizeof (VkTraceRaysIndirectCommand2KHR) - 1 **must** be in the buffer device address range of the same buffer

- **VUID-vkCmdTraceRaysIndirect2KHR-rayTracingPipelineTraceRaysIndirect2-03637**
  The rayTracingPipelineTraceRaysIndirect2 feature **must** be enabled

- **VUID-vkCmdTraceRaysIndirect2KHR-rayTracingMotionBlurPipelineTraceRaysIndirect-04951**
  If the bound ray tracing pipeline was created with VK_PIPELINE_CREATE_RAY_TRACING_ALLOW_MOTION_BIT_NV VkPhysicalDeviceRayTracingMotionBlurFeaturesNV::rayTracingMotionBlurPipelineTraceRaysIndirect feature **must** be enabled
Valid Usage (Implicit)

- VUID-vkCmdTraceRaysIndirect2KHR-commandBuffer-parameter
  
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdTraceRaysIndirect2KHR-commandBuffer-recording
  
  commandBuffer must be in the recording state

- VUID-vkCmdTraceRaysIndirect2KHR-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support compute operations

- VUID-vkCmdTraceRaysIndirect2KHR-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdTraceRaysIndirect2KHR-videocoding
  This command must only be called outside of a video coding scope

Host Synchronization

- Host access to commandBuffer must be externally synchronized

- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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The VkTraceRaysIndirectCommand2KHR structure is defined as:

```c
// Provided by VK_KHR_ray_tracing_maintenance1 with VK_KHR_ray_tracing_pipeline
typedef struct VkTraceRaysIndirectCommand2KHR {
    VkDeviceAddress raygenShaderRecordAddress;
    VkDeviceSize raygenShaderRecordSize;
    VkDeviceAddress missShaderBindingTableAddress;
    VkDeviceSize missShaderBindingTableSize;
    VkDeviceSize missShaderBindingTableStride;
    VkDeviceAddress callableShaderBindingTableAddress;
    VkDeviceSize callableShaderBindingTableSize;
    VkDeviceSize callableShaderBindingTableStride;
} VkTraceRaysIndirectCommand2KHR;
```
• `raygenShaderRecordAddress` is a `VkDeviceAddress` of the ray generation shader binding table record used by this command.

• `raygenShaderRecordSize` is a `VkDeviceSize` number of bytes corresponding to the ray generation shader binding table record at base address `raygenShaderRecordAddress`.

• `missShaderBindingTableAddress` is a `VkDeviceAddress` of the first record in the miss shader binding table used by this command.

• `missShaderBindingTableSize` is a `VkDeviceSize` number of bytes corresponding to the total size of the miss shader binding table at `missShaderBindingTableAddress` that may be accessed by this command.

• `missShaderBindingTableStride` is a `VkDeviceSize` number of bytes between records of the miss shader binding table.

• `hitShaderBindingTableAddress` is a `VkDeviceAddress` of the first record in the hit shader binding table used by this command.

• `hitShaderBindingTableSize` is a `VkDeviceSize` number of bytes corresponding to the total size of the hit shader binding table at `hitShaderBindingTableAddress` that may be accessed by this command.

• `hitShaderBindingTableStride` is a `VkDeviceSize` number of bytes between records of the hit shader binding table.

• `callableShaderBindingTableAddress` is a `VkDeviceAddress` of the first record in the callable shader binding table used by this command.

• `callableShaderBindingTableSize` is a `VkDeviceSize` number of bytes corresponding to the total size of the callable shader binding table at `callableShaderBindingTableAddress` that may be accessed by this command.

• `callableShaderBindingTableStride` is a `VkDeviceSize` number of bytes between records of the callable shader binding table.

• `width` is the width of the ray trace query dimensions.

• `height` is height of the ray trace query dimensions.

• `depth` is depth of the ray trace query dimensions.

The members of `VkTraceRaysIndirectCommand2KHR` have the same meaning as the similarly named parameters of `vkCmdTraceRaysKHR`.

Indirect shader binding table buffer parameters must satisfy the same memory alignment and binding requirements as their counterparts in `vkCmdTraceRaysIndirectKHR` and `vkCmdTraceRaysKHR`.
Valid Usage

- VUID-VkTraceRaysIndirectCommand2KHR-pRayGenShaderBindingTable-03680
  If the buffer from which raygenShaderRecordAddress was queried is non-sparse then it **must** be bound completely and contiguously to a single VkDeviceMemory object

- VUID-VkTraceRaysIndirectCommand2KHR-pRayGenShaderBindingTable-03681
  The buffer from which the raygenShaderRecordAddress is queried **must** have been created with the VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR usage flag

- VUID-VkTraceRaysIndirectCommand2KHR-pRayGenShaderBindingTable-03682
  raygenShaderRecordAddress **must** be a multiple of VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupBaseAlignment

- VUID-VkTraceRaysIndirectCommand2KHR-pMissShaderBindingTable-03683
  If the buffer from which missShaderBindingTableAddress was queried is non-sparse then it **must** be bound completely and contiguously to a single VkDeviceMemory object

- VUID-VkTraceRaysIndirectCommand2KHR-pMissShaderBindingTable-03684
  The buffer from which the missShaderBindingTableAddress is queried **must** have been created with the VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR usage flag

- VUID-VkTraceRaysIndirectCommand2KHR-pMissShaderBindingTable-03685
  missShaderBindingTableAddress **must** be a multiple of VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupBaseAlignment

- VUID-VkTraceRaysIndirectCommand2KHR-stride-03686
  missShaderBindingTableStride **must** be a multiple of VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupHandleAlignment

- VUID-VkTraceRaysIndirectCommand2KHR-stride-04029
  missShaderBindingTableStride **must** be less than or equal to VkPhysicalDeviceRayTracingPipelinePropertiesKHR::maxShaderGroupStride

- VUID-VkTraceRaysIndirectCommand2KHR-pHitShaderBindingTable-03687
  If the buffer from which hitShaderBindingTableAddress was queried is non-sparse then it **must** be bound completely and contiguously to a single VkDeviceMemory object

- VUID-VkTraceRaysIndirectCommand2KHR-pHitShaderBindingTable-03688
  The buffer from which the hitShaderBindingTableAddress is queried **must** have been created with the VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR usage flag

- VUID-VkTraceRaysIndirectCommand2KHR-pHitShaderBindingTable-03689
  hitShaderBindingTableAddress **must** be a multiple of VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupBaseAlignment

- VUID-VkTraceRaysIndirectCommand2KHR-stride-03690
  hitShaderBindingTableStride **must** be a multiple of VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupHandleAlignment

- VUID-VkTraceRaysIndirectCommand2KHR-stride-04035
  hitShaderBindingTableStride **must** be less than or equal to VkPhysicalDeviceRayTracingPipelinePropertiesKHR::maxShaderGroupStride

- VUID-VkTraceRaysIndirectCommand2KHR-pCallableShaderBindingTable-03691
If the buffer from which `callableShaderBindingTableAddress` was queried is non-sparse then it **must** be bound completely and contiguously to a single `VkDeviceMemory` object.

- **VUID-VkTraceRaysIndirectCommand2KHR-pCallableShaderBindingTable-03692**
  The buffer from which the `callableShaderBindingTableAddress` is queried **must** have been created with the `VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR` usage flag.

- **VUID-VkTraceRaysIndirectCommand2KHR-pCallableShaderBindingTable-03693**
  `callableShaderBindingTableAddress` **must** be a multiple of `VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupBaseAlignment`.

- **VUID-VkTraceRaysIndirectCommand2KHR-stride-03694**
  `callableShaderBindingTableStride` **must** be a multiple of `VkPhysicalDeviceRayTracingPipelinePropertiesKHR::shaderGroupHandleAlignment`.

- **VUID-VkTraceRaysIndirectCommand2KHR-stride-04041**
  `callableShaderBindingTableStride` **must** be less than or equal to `VkPhysicalDeviceRayTracingPipelinePropertiesKHR::maxShaderGroupStride`.

- **VUID-VkTraceRaysIndirectCommand2KHR-flags-03696**
  If the currently bound ray tracing pipeline was created with flags that included `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR`, `hitShaderBindingTableAddress` **must** not be zero.

- **VUID-VkTraceRaysIndirectCommand2KHR-flags-03697**
  If the currently bound ray tracing pipeline was created with flags that included `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR`, `hitShaderBindingTableAddress` **must** not be zero.

- **VUID-VkTraceRaysIndirectCommand2KHR-flags-03511**
  If the currently bound ray tracing pipeline was created with flags that included `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR`, the shader group handle identified by `missShaderBindingTableAddress` **must** not be set to zero.

- **VUID-VkTraceRaysIndirectCommand2KHR-flags-03512**
  If the currently bound ray tracing pipeline was created with flags that included `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR`, entries in the table identified by `hitShaderBindingTableAddress` accessed as a result of this command in order to execute an any-hit shader **must** not be set to zero.

- **VUID-VkTraceRaysIndirectCommand2KHR-flags-03513**
  If the currently bound ray tracing pipeline was created with flags that included `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR`, entries in the table identified by `hitShaderBindingTableAddress` accessed as a result of this command in order to execute a closest hit shader **must** not be set to zero.

- **VUID-VkTraceRaysIndirectCommand2KHR-flags-03514**
  If the currently bound ray tracing pipeline was created with flags that included `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR`, entries in the table identified by `hitShaderBindingTableAddress` accessed as a result of this command in order to execute an intersection shader **must** not be set to zero.

- **VUID-VkTraceRaysIndirectCommand2KHR-pHitShaderBindingTable-04735**
  Any non-zero hit shader group entries in the table identified by...
40.3. Shader Binding Table

A shader binding table is a resource which establishes the relationship between the ray tracing pipeline and the acceleration structures that were built for the ray tracing pipeline. It indicates the shaders that operate on each geometry in an acceleration structure. In addition, it contains the resources accessed by each shader, including indices of textures, buffer device addresses, and constants. The application allocates and manages shader binding tables as VkBuffer objects.

Each entry in the shader binding table consists of shaderGroupHandleSize bytes of data, either as queried by vkGetRayTracingShaderGroupHandlesKHR to refer to those specified shaders, or all zeros to refer to a zero shader group. A zero shader group behaves as though it is a shader group consisting entirely of VK_SHADER_UNUSED_KHR. The remainder of the data specified by the stride is application-visible data that can be referenced by a ShaderRecordBufferKHR block in the shader.

The shader binding tables to use in a ray tracing pipeline are passed to the vkCmdTraceRaysNV, vkCmdTraceRaysKHR, or vkCmdTraceRaysIndirectKHR commands. Shader binding tables are readonly in shaders that are executing on the ray tracing pipeline.

Shader variables identified with the ShaderRecordBufferKHR storage class are used to access the provided shader binding table. Such variables must be:

- typed as OpTypeStruct, or an array of this type,
- identified with a Block decoration, and

hitShaderBindingTableAddress accessed by this call from a geometry with a geometryType of VK_GEOMETRY_TYPE_TRIANGLES_KHR must have been created with VK_RAY_TRACING_SHADER_GROUP_TYPE_TRIANGLES_HIT_GROUP_KHR

- VUID-VkTraceRaysIndirectCommand2KHR-pHitShaderBindingTable-04736
  Any non-zero hit shader group entries in the table identified by hitShaderBindingTableAddress accessed by this call from a geometry with a geometryType of VK_GEOMETRY_TYPE_AABBS_KHR must have been created with VK_RAY_TRACING_SHADER_GROUP_TYPE_PROCEDURAL_HIT_GROUP_KHR

- VUID-VkTraceRaysIndirectCommand2KHR-width-03638
  width must be less than or equal to VkPhysicalDeviceLimits::maxComputeWorkGroupCount[0] × VkPhysicalDeviceLimits::maxComputeWorkGroupSize[0]

- VUID-VkTraceRaysIndirectCommand2KHR-height-03639
  height must be less than or equal to VkPhysicalDeviceLimits::maxComputeWorkGroupCount[1] × VkPhysicalDeviceLimits::maxComputeWorkGroupSize[1]

- VUID-VkTraceRaysIndirectCommand2KHR-depth-03640
  depth must be less than or equal to VkPhysicalDeviceLimits::maxComputeWorkGroupCount[2] × VkPhysicalDeviceLimits::maxComputeWorkGroupSize[2]

- VUID-VkTraceRaysIndirectCommand2KHR-width-03641
  width × height × depth must be less than or equal to VkPhysicalDeviceRayTracingPipelinePropertiesKHR::maxRayDispatchInvocationCount
• laid out explicitly using the Offset, ArrayStride, and MatrixStride decorations as specified in Offset and Stride Assignment.

The Offset decoration for any member of a Block-decorated variable in the ShaderRecordBufferKHR storage class must not cause the space required for that variable to extend outside the range [0, maxStorageBufferRange).

Accesses to the shader binding table from ray tracing pipelines must be synchronized with the VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR pipeline stage and an access type of VK_ACCESS_SHADER_READ_BIT.

Note
Because different shader record buffers can be associated with the same shader, a shader variable with ShaderRecordBufferKHR storage class will not be dynamically uniform if different invocations of the same shader can reference different data in the shader record buffer, such as if the same shader occurs twice in the shader binding table with a different shader record buffer. In this case, indexing resources based on values in the ShaderRecordBufferKHR storage class, the index should be decorated as NonUniform.

40.3.1. Indexing Rules

In order to execute the correct shaders and access the correct resources during a ray tracing dispatch, the implementation must be able to locate shader binding table entries at various stages of execution. This is accomplished by defining a set of indexing rules that compute shader binding table record positions relative to the buffer's base address in memory. The application must organize the contents of the shader binding table's memory in a way that application of the indexing rules will lead to correct records.

Ray Generation Shaders

Only one ray generation shader is executed per ray tracing dispatch.

For vkCmdTraceRaysKHR, the location of the ray generation shader is specified by the pRaygenShaderBindingTable->deviceAddress parameter—there is no indexing. All data accessed must be less than pRaygenShaderBindingTable->size bytes from deviceAddress. pRaygenShaderBindingTable->stride is unused, and must be equal to pRaygenShaderBindingTable->size.

For vkCmdTraceRaysNV, the location of the ray generation shader is specified by the raygenShaderBindingTableBuffer and raygenShaderBindingOffset parameters—there is no indexing.

Hit Shaders

The base for the computation of intersection, any-hit, and closest hit shader locations is the instanceShaderBindingTableRecordOffset value stored with each instance of a top-level acceleration structure (VkAccelerationStructureInstanceKHR). This value determines the beginning of the shader binding table records for a given instance.
In the following rule, `geometryIndex` refers to the `geometry index` of the intersected geometry within the instance.

The `sbtRecordOffset` and `sbtRecordStride` values are passed in as parameters to `traceNV()` or `traceRayEXT()` calls made in the shaders. See Section 8.19 (Ray Tracing Functions) of the OpenGL Shading Language Specification for more details. In SPIR-V, these correspond to the `SBTOffset` and `SBTStride` parameters to the `OpTraceRayNV` or `OpTraceRayKHR` or `OpTraceRayMotionNV` instruction.

The result of this computation is then added to `pHitShaderBindingTable->deviceAddress`, a device address passed to `vkCmdTraceRaysKHR`, or `hitShaderBindingOffset`, a base offset passed to `vkCmdTraceRaysNV`.

For `vkCmdTraceRaysKHR`, the complete rule to compute a hit shader binding table record address in the `pHitShaderBindingTable` is:

\[
\text{pHitShaderBindingTable->deviceAddress} + \text{pHitShaderBindingTable->stride} \times (\text{instanceShaderBindingTableRecordOffset} + \text{geometryIndex} \times \text{sbtRecordStride} + \text{sbtRecordOffset})
\]

All data accessed must be less than `pHitShaderBindingTable->size` bytes from the base address.

For `vkCmdTraceRaysNV`, the offset and stride come from direct parameters, so the full rule to compute a hit shader binding table record address in the `hitShaderBindingTableBuffer` is:

\[
\text{hitShaderBindingOffset} + \text{hitShaderBindingStride} \times (\text{instanceShaderBindingTableRecordOffset} + \text{geometryIndex} \times \text{sbtRecordStride} + \text{sbtRecordOffset})
\]

**Miss Shaders**

A miss shader is executed whenever a ray query fails to find an intersection for the given scene geometry. Multiple miss shaders may be executed throughout a ray tracing dispatch.

The base for the computation of miss shader locations is `pMissShaderBindingTable->deviceAddress`, a device address passed into `vkCmdTraceRaysKHR`, or `missShaderBindingOffset`, a base offset passed into `vkCmdTraceRaysNV`.

The `missIndex` value is passed in as a parameter to `traceNV()` or `traceRayEXT()` calls made in the shaders. See Section 8.19 (Ray Tracing Functions) of the OpenGL Shading Language Specification for more details. In SPIR-V, this corresponds to the `MissIndex` parameter to the `OpTraceRayNV` or `OpTraceRayKHR` or `OpTraceRayMotionNV` instruction.

For `vkCmdTraceRaysKHR`, the complete rule to compute a miss shader binding table record address in the `pMissShaderBindingTable` is:

\[
\text{pMissShaderBindingTable->deviceAddress} + \text{pMissShaderBindingTable->stride} \times \text{missIndex}
\]

All data accessed must be less than `pMissShaderBindingTable->size` bytes from the base address.
For \texttt{vkCmdTraceRaysNV}, the offset and stride come from direct parameters, so the full rule to compute a miss shader binding table record address in the \texttt{missShaderBindingTableBuffer} is:

\[
\text{missShaderBindingOffset} + \text{missShaderBindingStride} \times \text{missIndex}
\]

Callable Shaders

A callable shader is executed when requested by a ray tracing shader. Multiple callable shaders may be executed throughout a ray tracing dispatch.

The base for the computation of callable shader locations is \texttt{pCallableShaderBindingTable->deviceAddress}, a device address passed into \texttt{vkCmdTraceRaysKHR}, or \texttt{callableShaderBindingOffset}, a base offset passed into \texttt{vkCmdTraceRaysNV}.

The \texttt{sbtRecordIndex} value is passed in as a parameter to \texttt{executeCallableNV()} or \texttt{executeCallableEXT()} calls made in the shaders. See Section 8.19 (Ray Tracing Functions) of the OpenGL Shading Language Specification for more details. In SPIR-V, this corresponds to the \texttt{SBTIndex} parameter to the \texttt{OpExecuteCallableNV} or \texttt{OpExecuteCallableKHR} instruction.

For \texttt{vkCmdTraceRaysKHR}, the complete rule to compute a callable shader binding table record address in the \texttt{pCallableShaderBindingTable} is:

\[
\text{pCallableShaderBindingTable->deviceAddress} + \text{pCallableShaderBindingTable->stride} \times \text{sbtRecordIndex}
\]

All data accessed must be less than \texttt{pCallableShaderBindingTable->size} bytes from the base address.

For \texttt{vkCmdTraceRaysNV}, the offset and stride come from direct parameters, so the full rule to compute a callable shader binding table record address in the \texttt{callableShaderBindingTableBuffer} is:

\[
\text{callableShaderBindingOffset} + \text{callableShaderBindingStride} \times \text{sbtRecordIndex}
\]

40.4. Ray Tracing Pipeline Stack

Ray tracing pipelines have a potentially large set of shaders which may be invoked in various call chain combinations to perform ray tracing. To store parameters for a given shader execution, an implementation may use a stack of data in memory. This stack must be sized to the sum of the stack sizes of all shaders in any call chain executed by the application.

If the stack size is not set explicitly, the stack size for a pipeline is:

\[
\text{rayGenStackMax} + \min(1, \text{maxPipelineRayRecursionDepth}) \times \max(\text{closestHitStackMax}, \text{missStackMax}, \text{intersectionStackMax} + \text{anyHitStackMax}) + \max(0, \text{maxPipelineRayRecursionDepth} - 1) \times \max(\text{closestHitStackMax}, \text{missStackMax}) + 2 \times \text{callableStackMax}
\]
where `rayGenStackMax`, `closestHitStackMax`, `missStackMax`, `anyHitStackMax`, `intersectionStackMax`, and `callableStackMax` are the maximum stack values queried by the respective shader stages for any shaders in any shader groups defined by the pipeline.

This stack size is potentially significant, so an application may want to provide a more accurate stack size after pipeline compilation. The value that the application provides is the maximum value of the sum of all shaders in a call chain across all possible call chains, taking into account any application specific knowledge about the properties of the call chains.

**Note**

For example, if an application has two types of closest hit and miss shaders that it can use but the first level of rays will only use the first kind (possibly reflection) and the second level will only use the second kind (occlusion or shadow ray, for example) then the application can compute the stack size by something similar to:

\[
\text{rayGenStack} + \max(\text{closestHit1Stack, miss1Stack}) + \max(\text{closestHit2Stack, miss2Stack})
\]

This is guaranteed to be no larger than the default stack size computation which assumes that both call levels may be the larger of the two.

### 40.5. Ray Tracing Capture Replay

In a similar way to `bufferDeviceAddressCaptureReplay`, the `rayTracingPipelineShaderGroupHandleCaptureReplay` feature allows the querying of opaque data which can be used in a future replay.

During the capture phase, capture/replay tools are expected to query opaque data for shader group handle replay using `vkGetRayTracingCaptureReplayShaderGroupHandlesKHR`.

Providing the opaque data during replay, using `VkRayTracingShaderGroupCreateInfoKHR.pShaderGroupCaptureReplayHandle` at pipeline creation time, causes the implementation to generate identical shader group handles to those in the capture phase, allowing capture/replay tools to reuse previously recorded shader binding table buffer contents or to obtain the same handles by calling `vkGetRayTracingCaptureReplayShaderGroupHandlesKHR` again.
Chapter 41. Memory Decompression

To decompress data between one or more memory regions call:

```c
// Provided by VK_NV_memory_decompression
void vkCmdDecompressMemoryNV(
    VkCommandBuffer commandBuffer,
    uint32_t decompressRegionCount,
    const VkDecompressMemoryRegionNV* pDecompressMemoryRegions);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `decompressRegionCount` is the number of memory regions to decompress.
- `pDecompressMemoryRegions` is a pointer to an array of `decompressRegionCount` `VkDecompressMemoryRegionNV` structures specifying decompression parameters.

Each region specified in `pDecompressMemoryRegions` is decompressed from the source to destination region based on the specified decompression method.

Valid Usage

- VUID-vkCmdDecompressMemoryNV-None-07684
  The `memoryDecompression` feature must be enabled

Valid Usage (Implicit)

- VUID-vkCmdDecompressMemoryNV-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdDecompressMemoryNV-pDecompressMemoryRegions-parameter
  `pDecompressMemoryRegions` must be a valid pointer to an array of `decompressRegionCount` valid `VkDecompressMemoryRegionNV` structures

- VUID-vkCmdDecompressMemoryNV-commandBuffer-recording
  `commandBuffer` must be in the recording state

- VUID-vkCmdDecompressMemoryNV-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, or compute operations

- VUID-vkCmdDecompressMemoryNV-renderpass
  This command must only be called outside of a render pass instance

- VUID-vkCmdDecompressMemoryNV-videocoding
  This command must only be called outside of a video coding scope

- VUID-vkCmdDecompressMemoryNV-decompressRegionCount-arraylength
  `decompressRegionCount` must be greater than 0
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

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The `VkDecompressMemoryRegionNV` structure is defined as:

```c
// Provided by VK_NV_memory_decompression
typedef struct VkDecompressMemoryRegionNV {
    VkDeviceAddress srcAddress;
    VkDeviceAddress dstAddress;
    VkDeviceSize compressedSize;
    VkDeviceSize decompressedSize;
    VkMemoryDecompressionMethodFlagsNV decompressionMethod;
} VkDecompressMemoryRegionNV;
```

- `srcAddress` is the address where compressed data is stored.
- `dstAddress` is the destination address where decompressed data will be written.
- `compressedSize` is the size of compressed data in bytes.
- `decompressedSize` is the size of decompressed data in bytes.
- `decompressionMethod` is a bitmask of `VkMemoryDecompressionMethodFlagBitsNV` with a single bit set specifying the method used to decompress data.

Valid Usage

- VUID-VkDecompressMemoryRegionNV-srcAddress-07685
  The `srcAddress` must be 4 byte aligned.
- VUID-VkDecompressMemoryRegionNV-srcAddress-07686
  The memory in range `srcAddress` and `srcAddress + compressedSize` must be valid and bound to a `VkDeviceMemory` object.
- VUID-VkDecompressMemoryRegionNV-dstAddress-07687
  The `dstAddress` must be 4 byte aligned.
- VUID-VkDecompressMemoryRegionNV-dstAddress-07688
The memory in range `dstAddress` and `dstAddress + decompressedSize` must be valid and bound to a `VkDeviceMemory` object.

- VUID-VkDecompressMemoryRegionNV-decompressedSize-07689
  The `decompressedSize` must be large enough to hold the decompressed data based on the `decompressionMethod`.

- VUID-VkDecompressMemoryRegionNV-decompressionMethod-07690
  The `decompressionMethod` must have a single bit set.

- VUID-VkDecompressMemoryRegionNV-srcAddress-07691
  The `srcAddress` to `srcAddress + compressedSize` region must not overlap with the `dstAddress` and `dstAddress + decompressedSize` region.

**Valid Usage (Implicit)**

- VUID-VkDecompressMemoryRegionNV-decompressionMethod-parameter
  `decompressionMethod` must be a valid combination of `VkMemoryDecompressionMethodFlagBitsNV` values.

- VUID-VkDecompressMemoryRegionNV-decompressionMethod-requiredbitmask
  `decompressionMethod` must not be 0.

To decompress data between one or more memory regions by specifying decompression parameters indirectly in a buffer, call:

```c
// Provided by VK_NV_memory_decompression
void vkCmdDecompressMemoryIndirectCountNV(
    VkCommandBuffer commandBuffer,
    VkDeviceAddress indirectCommandsAddress,
    VkDeviceAddress indirectCommandsCountAddress,
    uint32_t stride);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `indirectCommandsAddress` is the device address containing decompression parameters laid out as an array of `VkDecompressMemoryRegionNV` structures.
- `indirectCommandsCountAddress` is the device address containing the decompression count.
- `stride` is the byte stride between successive sets of decompression parameters located starting from `indirectCommandsAddress`.

Each region specified in `indirectCommandsAddress` is decompressed from the source to destination region based on the specified decompression method.

**Valid Usage**

- VUID-vkCmdDecompressMemoryIndirectCountNV-None-07692
  The `memoryDecompression` feature must be enabled.
If \textit{indirectCommandsAddress} comes from a non-sparse buffer then it \textbf{must} be bound completely and contiguously to a single \texttt{VkDeviceMemory} object.

The \texttt{VkBuffer} that \textit{indirect CommandsAddress} comes from \textbf{must} have been created with the \texttt{VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT} bit set.

\textit{offset} \textbf{must} be a multiple of 4.

If \textit{indirectCommandsCountAddress} comes from a non-sparse buffer then it \textbf{must} be bound completely and contiguously to a single \texttt{VkDeviceMemory} object.

The \texttt{VkBuffer} that \textit{indirectCommandsCountAddress} comes from \textbf{must} have been created with the \texttt{VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT} bit set.

\textit{indirectCommandsCountAddress} \textbf{must} be a multiple of 4.

\textit{indirectCommandsCountAddress} \textbf{must} be a multiple of 4 and \textbf{must} be greater than or equal to \texttt{sizeof(VkDecompressMemoryRegionNV)}.

\textbf{must} be less than or equal to \texttt{sizeof(VkDecompressMemoryRegionNV)}.

\textbf{must} be less than or equal to the size of the \texttt{VkBuffer} that \textit{indirectCommandsAddress} comes from.

\textbf{must} be less than or equal to the last valid address in the \texttt{VkBuffer} that \textit{indirectCommandsAddress} was created from.

\textbf{Valid Usage (Implicit)}

\textbf{commandBuffer} \textbf{must} be a valid \texttt{VkCommandBuffer} handle.

\textbf{commandBuffer-recording}
**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

### Command Properties

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Bits which can be set in `VkDecompressMemoryRegionNV::decompressionMethod` specifying the decompression method to select, or returned in `VkPhysicalDeviceMemoryDecompressionPropertiesNV::decompressionMethods` specifying the available decompression methods are:

```cpp
// Provided by VK_NV_memory_decompression
// Flag bits for VkMemoryDecompressionMethodFlagBitsNV
typedef VkFlags64 VkMemoryDecompressionMethodFlagBitsNV;
static const VkMemoryDecompressionMethodFlagBitsNV VK_MEMORY_DECOMPRESSION_METHOD_GDEFLATE_1_0_BIT_NV = 0x00000001ULL;
```

- `VK_MEMORY_DECOMPRESSION_METHOD_GDEFLATE_1_0_BIT_NV` specifies that the GDeflate 1.0 algorithm is used to decompress data.

```cpp
// Provided by VK_NV_memory_decompression
typedef VkFlags64 VkMemoryDecompressionMethodFlagsNV;
```

`VkMemoryDecompressionMethodFlagsNV` is a bitmask type for specifying a mask of one or more `VkMemoryDecompressionMethodFlagBitsNV`.
Chapter 42. Video Coding

Vulkan implementations may expose one or more queue families supporting video coding operations. These operations are performed by recording them into a command buffer within a video coding scope, and submitting them to queues with compatible video coding capabilities.

The Vulkan video functionalities are designed to be made available through a set of APIs built on top of each other, consisting of:

- A core API providing common video coding functionalities,
- APIs providing codec-independent video decode and video encode related functionalities, respectively,
- Additional codec-specific APIs built on top of those.

This chapter details the fundamental components and operations of these.

42.1. Video Picture Resources

In the context of video coding, multidimensional arrays of image data that can be used as the source or target of video coding operations are referred to as video picture resources. They may store additional metadata that includes implementation-private information used during the execution of video coding operations, as discussed later.

Video picture resources are backed by VkImage objects. Individual subregions of VkImageView objects created from such resources can be used as decode output pictures, encode input pictures, reconstructed pictures, and/or reference pictures.

The parameters of a video picture resource are specified using a VkVideoPictureResourceInfoKHR structure.

The VkVideoPictureResourceInfoKHR structure is defined as:

```c
typedef struct VkVideoPictureResourceInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkOffset2D codedOffset;
    VkExtent2D codedExtent;
    uint32_t baseArrayLayer;
    VkImageView imageViewBinding;
} VkVideoPictureResourceInfoKHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- codedOffset is the offset in texels of the image subregion to use.
- codedExtent is the size in pixels of the coded image data.
• **baseArrayLayer** is the array layer of the image view specified in **imageViewBinding** to use as the video picture resource.

• **imageViewBinding** is an image view representing the video picture resource.

The image subresource referred to by such a structure is defined as the image array layer index specified in **baseArrayLayer** relative to the image subresource range the image view specified in **imageViewBinding** was created with.

The meaning of the **codedOffset** and **codedExtent** depends on the command and context the video picture resource is used in, as well as on the used video profile and corresponding codec-specific semantics, as described later.

A video picture resource is uniquely defined by the image subresource referred to by an instance of this structure, together with the **codedOffset** and **codedExtent** members that identify the image subregion within the image subresource referenced corresponding to the video picture resource according to the particular codec-specific semantics.

Accesses to image data within a video picture resource happen at the granularity indicated by **VkVideoCapabilitiesKHR::pictureAccessGranularity**, as returned by **vkGetPhysicalDeviceVideoCapabilitiesKHR** for the used video profile. As a result, given an effective image subregion corresponding to a video picture resource, the actual image subregion accessed may be larger than that as it may include additional padding texels due to the picture access granularity. Any writes performed by video coding operations to such padding texels will result in undefined texel values.

Two video picture resources match if they refer to the same image subresource and they specify identical **codedOffset** and **codedExtent** values.

---

**Valid Usage**

- VUID-VkVideoPictureResourceInfoKHR-baseArrayLayer-07175
  - **baseArrayLayer** must be less than the **VkImageViewCreateInfo::subresourceRange.layerCount** specified when the image view **imageViewBinding** was created

---

**Valid Usage (Implicit)**

- VUID-VkVideoPictureResourceInfoKHR-sType-sType
  - **sType** must be **VK_STRUCTURE_TYPE_VIDEO_PICTURE_RESOURCE_INFO_KHR**

- VUID-VkVideoPictureResourceInfoKHR-pNext-pNext
  - **pNext** must be **NULL**

- VUID-VkVideoPictureResourceInfoKHR-imageViewBinding-parameter
  - **imageViewBinding** must be a valid **VkImageView** handle
42.2. Decoded Picture Buffer

An integral part of video coding pipelines is the reconstruction of pictures from a compressed video bitstream. A reconstructed picture is a video picture resource resulting from this process.

Such reconstructed pictures can be used as reference pictures in subsequent video coding operations to provide predictions of the values of samples of subsequently decoded or encoded pictures. The correct use of such reconstructed pictures as reference pictures is driven by the video compression standard, the implementation, and the application-specific use cases.

The list of reference pictures used to provide such predictions within a single video coding operation is referred to as the list of active reference pictures.

The decoded picture buffer (DPB) is an indexed data structure that maintains the set of reference pictures available to be used in video coding operations. Individual indexed entries of the DPB are referred to as the decoded picture buffer (DPB) slots. The range of valid DPB slot indices is between zero and $N-1$, where $N$ is the capacity of the DPB. Each DPB slot can refer to a reference picture containing a video frame or can refer to up to two reference pictures containing the top and/or bottom fields that, when both present, together represent a full video frame.

In Vulkan, the state and the backing store of the DPB is separated as follows:

- The state of individual DPB slots is maintained by video session objects.
- The backing store of DPB slots is provided by subregions of VkImage objects used as video picture resources.

In addition, the implementation may also maintain opaque metadata associated with DPB slots, including:

- Reference picture metadata corresponding to the video picture resource associated with the DPB slot.

Such metadata may be stored by the implementation as part of the DPB slot state maintained by the video session, or as part of the video picture resource backing the DPB slot.

Any metadata stored in the video picture resources backing DPB slots are independent of the video session used to store it, hence such video picture resources can be shared with other video sessions. Correspondingly, any metadata that is dependent on the video session will always be stored as part of the DPB slot state maintained by that video session.

The responsibility of managing the DPB is split between the application and the implementation as follows:

- The application maintains the association between DPB slot indices and corresponding video picture resources.
- The implementation maintains global and per-slot opaque reference picture metadata.

In addition, the application is also responsible for managing the mapping between the codec-specific picture IDs and DPB slots, and any other codec-specific states unless otherwise specified.
42.2.1. DPB Slot States

At a given time, each DPB slot is either in active or inactive state. Initially, all DPB slots managed by a video session are in inactive state.

A DPB slot can be activated by using it as the target of picture reconstruction within a video coding operation, changing its state to active.

As part of the picture reconstruction, the implementation may also generate reference picture metadata.

If such a video coding operation completes successfully, the activated DPB slot will have a valid picture reference and the reconstructed picture is associated with the DPB slot. This is true even if the DPB slot is used as the target of a picture reconstruction that only sets up a top field or bottom field reference picture and thus does not yet refer to a complete frame. However, if any data provided as input to such a video coding operation is not compliant to the video compression standard used, that video coding operation may complete unsuccessfully, in which case the activated DPB slot will have an invalid picture reference. This is true even if the DPB slot previously had a valid picture reference to a top field or bottom field reference picture, but the reconstruction of the other field corresponding to the DPB slot failed.

The application can use queries to get feedback about the outcome of video coding operations and use the resulting VkQueryResultStatusKHR value to determine whether the video coding operation completed successfully (result status is positive) or unsuccessfully (result status is negative).

Using a reference picture associated with a DPB slot that has an invalid picture reference as an active reference picture in subsequent video coding operations is legal, however, the contents of the outputs of such operations are undefined, and any DPB slots activated by such video coding operations will also have an invalid picture reference. This is true even if such video coding operations may otherwise complete successfully.

A DPB slot can also be deactivated by the application, changing its state to inactive and invalidating any picture references and reference picture metadata associated with the DPB slot.

A DPB slot can be activated with a new frame even if it is already active. In this case all previous associations of the DPB slots with reference pictures are replaced with an association with the reconstructed picture used to activate it. If an already active DPB slot is activated with a reconstructed field picture, then the behavior is as follows:

- If the DPB slot is currently associated with a frame, then that association is replaced with an association with the reconstructed field picture used to activate it.
- If the DPB slot is not currently associated with a top field picture and the DPB slot is activated with a top field picture, or if the DPB slot is not currently associated with a bottom field picture and the DPB slot is activated with a bottom field picture, then the DPB slot is associated with the reconstructed field picture used to activate it, without disturbing the other field picture association, if any.
- If the DPB slot is currently associated with a top field picture and the DPB slot is activated with a new top field picture, or if the DPB slot is currently associated with a bottom field picture and the DPB slot is activated with a new bottom field picture, then that association is replaced with
an association with the reconstructed field picture used to activate it, without disturbing the other field picture association, if any.

42.3. Video Profiles

The VkVideoProfileInfoKHR structure is defined as follows:

```c
// Provided by VK_KHR_video_queue
typedef struct VkVideoProfileInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkVideoCodecOperationFlagBitsKHR videoCodecOperation;
    VkVideoChromaSubsamplingFlagsKHR chromaSubsampling;
    VkVideoComponentBitDepthFlagsKHR lumaBitDepth;
    VkVideoComponentBitDepthFlagsKHR chromaBitDepth;
} VkVideoProfileInfoKHR;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `videoCodecOperation` is a VkVideoCodecOperationFlagBitsKHR value specifying a video codec operation.
- `chromaSubsampling` is a bitmask of VkVideoChromaSubsamplingFlagBitsKHR specifying video chroma subsampling information.
- `lumaBitDepth` is a bitmask of VkVideoComponentBitDepthFlagBitsKHR specifying video luma bit depth information.
- `chromaBitDepth` is a bitmask of VkVideoComponentBitDepthFlagBitsKHR specifying video chroma bit depth information.

Video profiles are provided as input to video capability queries such as vkGetPhysicalDeviceVideoCapabilitiesKHR or vkGetPhysicalDeviceVideoFormatPropertiesKHR, as well as when creating resources to be used by video coding operations such as images, buffers, query pools, and video sessions.

The full description of a video profile is specified by an instance of this structure, and the codec-specific and auxiliary structures provided in its `pNext` chain.

When this structure is specified as an input parameter to vkGetPhysicalDeviceVideoCapabilitiesKHR, or through the `pProfiles` member of an VkVideoProfileListInfoKHR structure in the `pNext` chain of the input parameter of a query command such as vkGetPhysicalDeviceVideoFormatPropertiesKHR or vkGetPhysicalDeviceImageFormatProperties2, the following error codes indicate specific causes of the failure of the query operation:

- VK_ERROR_VIDEO_PICTURE_LAYOUT_NOT_SUPPORTED_KHR indicates that the requested video picture layout (e.g. through the `pictureLayout` member of a VkVideoDecodeH264ProfileInfoKHR structure included in the `pNext` chain of VkVideoProfileInfoKHR) is not supported.
• **VK_ERROR_VIDEO_PROFILE_OPERATION_NOT_SUPPORTED_KHR** indicates that a video profile operation specified by `videoCodecOperation` is not supported.

• **VK_ERROR_VIDEO_PROFILE_FORMAT_NOT_SUPPORTED_KHR** indicates that video format parameters specified by `chromaSubsampling`, `lumaBitDepth`, or `chromaBitDepth` are not supported.

• **VK_ERROR_VIDEO_PROFILE_CODEC_NOT_SUPPORTED_KHR** indicates that the codec-specific parameters corresponding to the video codec operation are not supported.

### Valid Usage

- **VUID-VkVideoProfileInfoKHR-chromaSubsampling-07013**
  
  `chromaSubsampling` must have a single bit set

- **VUID-VkVideoProfileInfoKHR-lumaBitDepth-07014**
  
  `lumaBitDepth` must have a single bit set

- **VUID-VkVideoProfileInfoKHR-chromaSubsampling-07015**
  
  If `chromaSubsampling` is not **VK_VIDEO_CHROMA_SUBSAMPLING_MONOCHROME_BIT_KHR**, then `chromaBitDepth` must have a single bit set

- **VUID-VkVideoProfileInfoKHR-videoCodecOperation-07179**
  
  If `videoCodecOperation` is **VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR**, then the `pNext` chain must include a `VkVideoDecodeH264ProfileInfoKHR` structure

- **VUID-VkVideoProfileInfoKHR-videoCodecOperation-07180**
  
  If `videoCodecOperation` is **VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR**, then the `pNext` chain must include a `VkVideoDecodeH265ProfileInfoKHR` structure

- **VUID-VkVideoProfileInfoKHR-videoCodecOperation-07181**
  
  If `videoCodecOperation` is **VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT**, then the `pNext` chain must include a `VkVideoEncodeH264ProfileInfoEXT` structure

- **VUID-VkVideoProfileInfoKHR-videoCodecOperation-07182**
  
  If `videoCodecOperation` is **VK_VIDEO_CODEC_OPERATION_ENCODE_H265_BIT_EXT**, then the `pNext` chain must include a `VkVideoEncodeH265ProfileInfoEXT` structure

### Valid Usage (Implicit)

- **VUID-VkVideoProfileInfoKHR-sType-sType**
  
  `sType` must be **VK_STRUCTURE_TYPE_VIDEO_PROFILE_INFO_KHR**

- **VUID-VkVideoProfileInfoKHR-videoCodecOperation-parameter**
  
  `videoCodecOperation` must be a valid `VkVideoCodecOperationFlagBitsKHR` value

- **VUID-VkVideoProfileInfoKHR-chromaSubsampling-parameter**
  
  `chromaSubsampling` must be a valid combination of `VkVideoChromaSubsamplingFlagBitsKHR` values

- **VUID-VkVideoProfileInfoKHR-chromaSubsampling-required bitmask**
  
  `chromaSubsampling` must not be 0

- **VUID-VkVideoProfileInfoKHR-lumaBitDepth-parameter**
  
  `lumaBitDepth` must be a valid combination of `VkVideoComponentBitDepthFlagBitsKHR` values
values

• VUID-VkVideoProfileInfoKHR-lumaBitDepth-required bitmask
  lumaBitDepth must not be 0

• VUID-VkVideoProfileInfoKHR-chromaBitDepth-parameter
  chromaBitDepth must be a valid combination of VkVideoComponentBitDepthFlagBitsKHR values

Possible values of VkVideoProfileInfoKHR::videoCodecOperation, specifying the type of video coding operation and video compression standard used by a video profile, are:

```c
// Provided by VK_KHR_video_queue
typedef enum VkVideoCodecOperationFlagBitsKHR {
    VK_VIDEO_CODEC_OPERATION_NONE_KHR = 0,
    #ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h264
    VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT = 0x00010000,
    #endif
    #ifdef VK_ENABLE_BETA_EXTENSIONS
    // Provided by VK_EXT_video_encode_h265
    VK_VIDEO_CODEC_OPERATION_ENCODE_H265_BIT_EXT = 0x00020000,
    #endif
    // Provided by VK_KHR_video_decode_h264
    VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR = 0x00000001,
    // Provided by VK_KHR_video_decode_h265
    VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR = 0x00000002,
} VkVideoCodecOperationFlagBitsKHR;
```

• VK_VIDEO_CODEC_OPERATION_NONE_KHR indicates no support for any video codec operations.
• VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR specifies support for H.264 video decode operations.
• VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR specifies support for H.265 video decode operations.
• VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT specifies support for H.264 video encode operations.
• VK_VIDEO_CODEC_OPERATION_ENCODE_H265_BIT_EXT specifies support for H.265 video encode operations.

```c
// Provided by VK_KHR_video_queue
typedef VkFlags VkVideoCodecOperationFlagsKHR;
```

VkVideoCodecOperationFlagsKHR is a bitmask type for setting a mask of zero or more VkVideoCodecOperationFlagBitsKHR.

The video format chroma subsampling is defined with the following enums:
**Provided by VK_KHR_video_queue**

```c
typedef enum VkVideoChromaSubsamplingFlagBitsKHR {
    VK_VIDEO_CHROMA_SUBSAMPLING_INVALID_KHR = 0,
    VK_VIDEO_CHROMA_SUBSAMPLING_MONOCHROME_BIT_KHR = 0x00000001,
    VK_VIDEO_CHROMA_SUBSAMPLING_420_BIT_KHR = 0x00000002,
    VK_VIDEO_CHROMA_SUBSAMPLING_422_BIT_KHR = 0x00000004,
    VK_VIDEO_CHROMA_SUBSAMPLING_444_BIT_KHR = 0x00000008,
} VkVideoChromaSubsamplingFlagBitsKHR;
```

- **VK_VIDEO_CHROMA_SUBSAMPLING_MONOCHROME_BIT_KHR** specifies that the format is monochrome.
- **VK_VIDEO_CHROMA_SUBSAMPLING_420_BIT_KHR** specifies that the format is 4:2:0 chroma subsampled, i.e. the two chroma components are sampled horizontally and vertically at half the sample rate of the luma component.
- **VK_VIDEO_CHROMA_SUBSAMPLING_422_BIT_KHR** - the format is 4:2:2 chroma subsampled, i.e. the two chroma components are sampled horizontally at half the sample rate of the luma component.
- **VK_VIDEO_CHROMA_SUBSAMPLING_444_BIT_KHR** - the format is 4:4:4 chroma sampled, i.e. all three components of the \( Y'C_bC_r \) format are sampled at the same rate, thus there is no chroma subsampling.

Chroma subsampling is described in more detail in the Chroma Reconstruction section.

**Provided by VK_KHR_video_queue**

```c
typedef VkFlags VkVideoChromaSubsamplingFlagsKHR;
```

**VkVideoChromaSubsamplingFlagsKHR** is a bitmask type for setting a mask of zero or more **VkVideoChromaSubsamplingFlagBitsKHR**.

Possible values for the video format component bit depth are:

**Provided by VK_KHR_video_queue**

```c
typedef enum VkVideoComponentBitDepthFlagBitsKHR {
    VK_VIDEO_COMPONENT_BIT_DEPTH_INVALID_KHR = 0,
    VK_VIDEO_COMPONENT_BIT_DEPTH_8_BIT_KHR = 0x00000001,
    VK_VIDEO_COMPONENT_BIT_DEPTH_10_BIT_KHR = 0x00000004,
    VK_VIDEO_COMPONENT_BIT_DEPTH_12_BIT_KHR = 0x00000010,
} VkVideoComponentBitDepthFlagBitsKHR;
```

- **VK_VIDEO_COMPONENT_BIT_DEPTH_8_BIT_KHR** specifies a component bit depth of 8 bits.
- **VK_VIDEO_COMPONENT_BIT_DEPTH_10_BIT_KHR** specifies a component bit depth of 10 bits.
- **VK_VIDEO_COMPONENT_BIT_DEPTH_12_BIT_KHR** specifies a component bit depth of 12 bits.

**Provided by VK_KHR_video_queue**

```c
typedef VkFlags VkVideoComponentBitDepthFlagsKHR;
```
VkVideoComponentBitDepthFlagsKHR is a bitmask type for setting a mask of zero or more VkVideoComponentBitDepthFlagBitsKHR.

Additional information about the video decode use case can be provided by adding a VkVideoDecodeUsageInfoKHR structure to the pNext chain of VkVideoProfileInfoKHR.

The VkVideoDecodeUsageInfoKHR structure is defined as:

```c
typedef struct VkVideoDecodeUsageInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkVideoDecodeUsageFlagsKHR videoUsageHints;
} VkVideoDecodeUsageInfoKHR;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `videoUsageHints` is a bitmask of VkVideoDecodeUsageFlagBitsKHR specifying hints about the intended use of the video decode profile.

**Valid Usage (Implicit)**

- VUID-VkVideoDecodeUsageInfoKHR-sType-sType
  - `sType` must be VK_STRUCTURE_TYPE_VIDEO_DECODE_USAGE_INFO_KHR
- VUID-VkVideoDecodeUsageInfoKHR-videoUsageHints-parameter
  - `videoUsageHints` must be a valid combination of VkVideoDecodeUsageFlagBitsKHR values

The following bits can be specified in VkVideoDecodeUsageInfoKHR::videoUsageHints as a hint about the video decode use case:

```c
typedef enum VkVideoDecodeUsageFlagBitsKHR {
    Vk_VIDEO_DECODE_USAGE_DEFAULT_KHR = 0,
    VK_VIDEO_DECODE_USAGE_TRANSCODING_BIT_KHR = 0x00000001,
    VK_VIDEO_DECODE_USAGE_OFFLINE_BIT_KHR = 0x00000002,
    VK_VIDEO_DECODE_USAGE_STREAMING_BIT_KHR = 0x00000004,
} VkVideoDecodeUsageFlagBitsKHR;
```

- `VK_VIDEO_DECODE_USAGE_TRANSCODING_BIT_KHR` specifies that video decoding is intended to be used in conjunction with video encoding to transcode a video bitstream with the same and/or different codecs.
- `VK_VIDEO_DECODE_USAGE_OFFLINE_BIT_KHR` specifies that video decoding is intended to be used to consume a local video bitstream.
- `VK_VIDEO_DECODE_USAGE_STREAMING_BIT_KHR` specifies that video decoding is intended to be used to
consume a video bitstream received as a continuous flow over network.

**Note**

There are no restrictions on the combination of bits that **can** be specified by the application. However, applications **should** use reasonable combinations in order for the implementation to be able to select the most appropriate mode of operation for the particular use case.

```c
// Provided by VK_KHR_video_decode_queue
typedef VkFlags VkVideoDecodeUsageFlagsKHR;
```

**VkVideoDecodeUsageFlagsKHR** is a bitmask type for setting a mask of zero or more **VkVideoDecodeUsageFlagBitsKHR**.

Additional information about the video encode use case **can** be provided by adding a **VkVideoEncodeUsageInfoKHR** structure to the **pNext** chain of **VkVideoProfileInfoKHR**.

The **VkVideoEncodeUsageInfoKHR** structure is defined as:

```c
// Provided by VK_KHR_video_encode_queue
typedef struct VkVideoEncodeUsageInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkVideoEncodeUsageFlagsKHR videoUsageHints;
    VkVideoEncodeContentFlagsKHR videoContentHints;
    VkVideoEncodeTuningModeKHR tuningMode;
} VkVideoEncodeUsageInfoKHR;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **videoUsageHints** is a bitmask of **VkVideoEncodeUsageFlagBitsKHR** specifying hints about the intended use of the video encode profile.
- **videoContentHints** is a bitmask of **VkVideoEncodeContentFlagBitsKHR** specifying hints about the content to be encoded using the video encode profile.
- **tuningMode** is a **VkVideoEncodeTuningModeKHR** value specifying the tuning mode to use when encoding with the video profile.

**Valid Usage (Implicit)**

- **VUID-VkVideoEncodeUsageInfoKHR-sType-sType**
  - **sType** must be **VK_STRUCTURE_TYPE_VIDEO_ENCODE_USAGE_INFO_KHR**

- **VUID-VkVideoEncodeUsageInfoKHR-videoUsageHints-parameter**
  - **videoUsageHints** must be a valid combination of **VkVideoEncodeUsageFlagBitsKHR** values

- **VUID-VkVideoEncodeUsageInfoKHR-videoContentHints-parameter**
videoContentHints must be a valid combination of VkVideoEncodeContentFlagBitsKHR values

• VUID-VkVideoEncodeUsageInfoKHR-tuningMode-parameter
  If tuningMode is not 0, tuningMode must be a valid VkVideoEncodeTuningModeKHR value

The following bits can be specified in VkVideoEncodeUsageInfoKHR::videoUsageHints as a hint about the video encode use case:

```c
// Provided by VK_KHR_video_encode_queue
typedef enum VkVideoEncodeUsageFlagBitsKHR {
    VK_VIDEO_ENCODE_USAGE_DEFAULT_KHR = 0,
    VK_VIDEO_ENCODE_USAGE_TRANSCODING_BIT_KHR = 0x00000001,
    VK_VIDEO_ENCODE_USAGE_STREAMING_BIT_KHR = 0x00000002,
    VK_VIDEO_ENCODE_USAGE_RECORDING_BIT_KHR = 0x00000004,
    VK_VIDEO_ENCODE_USAGE_CONFERENCING_BIT_KHR = 0x00000008,
} VkVideoEncodeUsageFlagBitsKHR;
```

• VK_VIDEO_ENCODE_USAGE_TRANSCODING_BIT_KHR specifies that video encoding is intended to be used in conjunction with video decoding to transcode a video bitstream with the same and/or different codecs.

• VK_VIDEO_ENCODE_USAGE_STREAMING_BIT_KHR specifies that video encoding is intended to be used to produce a video bitstream that is expected to be sent as a continuous flow over network.

• VK_VIDEO_ENCODE_USAGE_RECORDING_BIT_KHR specifies that video encoding is intended to be used for real-time recording for offline consumption.

• VK_VIDEO_ENCODE_USAGE_CONFERENCING_BIT_KHR specifies that video encoding is intended to be used in a video conferencing scenario.

\[\text{Note}\]

There are no restrictions on the combination of bits that can be specified by the application. However, applications should use reasonable combinations in order for the implementation to be able to select the most appropriate mode of operation for the particular use case.

```c
// Provided by VK_KHR_video_encode_queue
typedef VkFlags VkVideoEncodeUsageFlagsKHR;
```

VkVideoEncodeUsageFlagsKHR is a bitmask type for setting a mask of zero or more VkVideoEncodeUsageFlagBitsKHR.

The following bits can be specified in VkVideoEncodeUsageInfoKHR::videoContentHints as a hint about the encoded video content:

```c
// Provided by VK_KHR_video_encode_queue
typedef enum VkVideoEncodeContentFlagBitsKHR {
```
VK_VIDEO_ENCODE_CONTENT_DEFAULT_KHR = 0,
VK_VIDEO_ENCODE_CONTENT_CAMERA_BIT_KHR = 0x00000001,
VK_VIDEO_ENCODE_CONTENT_DESKTOP_BIT_KHR = 0x00000002,
VK_VIDEO_ENCODE_CONTENT_RENDERED_BIT_KHR = 0x00000004,
} VkVideoEncodeContentFlagBitsKHR;

- **VK_VIDEO_ENCODE_CONTENT_CAMERA_BIT_KHR** specifies that video encoding is intended to be used to encode camera content.
- **VK_VIDEO_ENCODE_CONTENT_DESKTOP_BIT_KHR** specifies that video encoding is intended to be used to encode desktop content.
- **VK_VIDEO_ENCODE_CONTENT_RENDERED_BIT_KHR** specified that video encoding is intended to be used to encode rendered (e.g. game) content.

Note

There are no restrictions on the combination of bits that can be specified by the application. However, applications should use reasonable combinations in order for the implementation to be able to select the most appropriate mode of operation for the particular content type.

// Provided by VK_KHR_video_encode_queue
typedef VkFlags VkVideoEncodeContentFlagsKHR;

VkVideoEncodeContentFlagsKHR is a bitmask type for setting a mask of zero or more VkVideoEncodeContentFlagBitsKHR.

Possible video encode tuning mode values are as follows:

// Provided by VK_KHR_video_encode_queue
typedef enum VkVideoEncodeTuningModeKHR {
    VK_VIDEO_ENCODE_TUNING_MODE_DEFAULT_KHR = 0,
    VK_VIDEO_ENCODE_TUNING_MODE_HIGH_QUALITY_KHR = 1,
    VK_VIDEO_ENCODE_TUNING_MODE_LOW_LATENCY_KHR = 2,
    VK_VIDEO_ENCODE_TUNING_MODE_ULTRA_LOW_LATENCY_KHR = 3,
    VK_VIDEO_ENCODE_TUNING_MODE_LOSSLESS_KHR = 4,
} VkVideoEncodeTuningModeKHR;

- **VK_VIDEO_ENCODE_TUNING_MODE_DEFAULT_KHR** specifies the default tuning mode.
- **VK_VIDEO_ENCODE_TUNING_MODE_HIGH_QUALITY_KHR** specifies that video encoding is tuned for high quality. When using this tuning mode, the implementation may compromise the latency of video encoding operations to improve quality.
- **VK_VIDEO_ENCODE_TUNING_MODE_LOW_LATENCY_KHR** specifies that video encoding is tuned for low latency. When using this tuning mode, the implementation may compromise quality to increase the performance and lower the latency of video encode operations.
- **VK_VIDEO_ENCODE_TUNING_MODE_ULTRA_LOW_LATENCY_KHR** specifies that video encoding is tuned for
ultra-low latency. When using this tuning mode, the implementation may compromise quality to maximize the performance and minimize the latency of video encoding operations.

- **VK_VIDEO_ENCODE_TUNING_MODE_LOSSLESS_KHR** specifies that video encoding is tuned for lossless encoding. When using this tuning mode, video encode operations produce lossless output.

The **VkVideoProfileListInfoKHR** structure is defined as:

```c
// Provided by VK_KHR_video_queue
typedef struct VkVideoProfileListInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t profileCount;
    const VkVideoProfileInfoKHR* pProfiles;
} VkVideoProfileListInfoKHR;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **profileCount** is the number of elements in the **pProfiles** array.
- **pProfiles** is a pointer to an array of **VkVideoProfileInfoKHR** structures.

**Note:**
Video transcoding is an example of a use case that necessitates the specification of multiple profiles in various contexts.

When the application provides a video decode profile and one or more video encode profiles in the profile list, the implementation ensures that any capabilities returned or resources created are suitable for the video transcoding use cases without the need for manual data transformations.

**Valid Usage**

- **VUID-VkVideoProfileListInfoKHR-pProfiles-06813**
  pProfiles must not contain more than one element whose **videoCodecOperation** member specifies a decode operation

**Valid Usage (Implicit)**

- **VUID-VkVideoProfileListInfoKHR-sType-sType**
  sType must be **VK_STRUCTURE_TYPE_VIDEO_PROFILE_LIST_INFO_KHR**

- **VUID-VkVideoProfileListInfoKHR-pProfiles-parameter**
  If **profileCount** is not 0, pProfiles must be a valid pointer to an array of **profileCount** valid **VkVideoProfileInfoKHR** structures
42.4. Video Capabilities

42.4.1. Video Coding Capabilities

To query video coding capabilities for a specific video profile, call:

```c
// Provided by VK_KHR_video_queue
VkResult vkGetPhysicalDeviceVideoCapabilitiesKHR(
    VkPhysicalDevice physicalDevice,
    const VkVideoProfileInfoKHR* pVideoProfile,
    VkVideoCapabilitiesKHR* pCapabilities);
```

- `physicalDevice` is the physical device from which to query the video decode or encode capabilities.
- `pVideoProfile` is a pointer to a `VkVideoProfileInfoKHR` structure.
- `pCapabilities` is a pointer to a `VkVideoCapabilitiesKHR` structure in which the capabilities are returned.

If the video profile described by `pVideoProfile` is supported by the implementation, then this command returns `VK_SUCCESS` and `pCapabilities` is filled with the capabilities supported with the specified video profile. Otherwise, one of the video-profile-specific error codes are returned.

**Valid Usage**

- VUID-vkGetPhysicalDeviceVideoCapabilitiesKHR-pVideoProfile-07183
  If `pVideoProfile->videoCodecOperation` specifies a decode operation, then the `pNext` chain of `pCapabilities` must include a `VkVideoDecodeCapabilitiesKHR` structure

- VUID-vkGetPhysicalDeviceVideoCapabilitiesKHR-pVideoProfile-07184
  If `pVideoProfile->videoCodecOperation` is `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR`, then the `pNext` chain of `pCapabilities` must include a `VkVideoDecodeH264CapabilitiesKHR` structure

- VUID-vkGetPhysicalDeviceVideoCapabilitiesKHR-pVideoProfile-07185
  If `pVideoProfile->videoCodecOperation` is `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, then the `pNext` chain of `pCapabilities` must include a `VkVideoDecodeH265CapabilitiesKHR` structure

- VUID-vkGetPhysicalDeviceVideoCapabilitiesKHR-pVideoProfile-07186
  If `pVideoProfile->videoCodecOperation` specifies an encode operation, then the `pNext` chain of `pCapabilities` must include a `VkVideoEncodeCapabilitiesKHR` structure

- VUID-vkGetPhysicalDeviceVideoCapabilitiesKHR-pVideoProfile-07187
  If `pVideoProfile->videoCodecOperation` is `VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT`, then the `pNext` chain of `pCapabilities` must include a `VkVideoEncodeH264CapabilitiesEXT` structure

- VUID-vkGetPhysicalDeviceVideoCapabilitiesKHR-pVideoProfile-07188
  If `pVideoProfile->videoCodecOperation` is `VK_VIDEO_CODEC_OPERATION_ENCODE_H265_BIT_EXT`,
then the `pNext` chain of `pCapabilities` must include a `VkVideoEncodeH265CapabilitiesEXT` structure

### Valid Usage (Implicit)

- `VUID-vkGetPhysicalDeviceVideoCapabilitiesKHR-physicalDevice-parameter` physicalDevice must be a valid `VkPhysicalDevice` handle
- `VUID-vkGetPhysicalDeviceVideoCapabilitiesKHR-pVideoProfile-parameter` pVideoProfile must be a valid pointer to a valid `VkVideoProfileInfoKHR` structure
- `VUID-vkGetPhysicalDeviceVideoCapabilitiesKHR-pCapabilities-parameter` pCapabilities must be a valid pointer to a `VkVideoCapabilitiesKHR` structure

### Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_VIDEO_PROFILE_OPERATION_NOT_SUPPORTED_KHR`
- `VK_ERROR_VIDEO_PROFILE_FORMAT_NOT_SUPPORTED_KHR`
- `VK_ERROR_VIDEO_PICTURE_LAYOUT_NOT_SUPPORTED_KHR`
- `VK_ERROR_VIDEO_PROFILE_CODEC_NOT_SUPPORTED_KHR`

The `VkVideoCapabilitiesKHR` structure is defined as:

```c
// Provided by VK_KHR_video_queue
typedef struct VkVideoCapabilitiesKHR {
    VkStructureType sType;
    void* pNext;
    VkVideoCapabilityFlagsKHR flags;
    VkDeviceSize minBitstreamBufferOffsetAlignment;
    VkDeviceSize minBitstreamBufferSizeAlignment;
    VkExtent2D pictureAccessGranularity;
    VkExtent2D minCodedExtent;
    VkExtent2D maxCodedExtent;
    uint32_t maxDpbSlots;
    uint32_t maxActiveReferencePictures;
    VkExtensionProperties stdHeaderVersion;
} VkVideoCapabilitiesKHR;
```
- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is a bitmask of `VkVideoCapabilityFlagBitsKHR` specifying capability flags.
- **minBitstreamBufferOffsetAlignment** is the minimum alignment for bitstream buffer offsets.
- **minBitstreamBufferSizeAlignment** is the minimum alignment for bitstream buffer range sizes.
- **pictureAccessGranularity** is the granularity at which image access to video picture resources happen.
- **minCodedExtent** is the minimum width and height of the coded frames.
- **maxCodedExtent** is the maximum width and height of the coded frames.
- **maxDpbSlots** is the maximum number of DPB slots supported by a single video session.
- **maxActiveReferencePictures** is the maximum number of active reference pictures a single video coding operation can use.
- **stdHeaderVersion** is a `VkExtensionProperties` structure reporting the Video Std header name and version supported for the video profile.

**Note:**
It is common for video compression standards to allow using all reference pictures associated with active DPB slots as active reference pictures, hence for video decode profiles the values returned in `maxDpbSlots` and `maxActiveReferencePictures` are often equal. Similarly, in case of video decode profiles supporting field pictures the value of `maxActiveReferencePictures` often equals `maxDpbSlots × 2`.

**Valid Usage (Implicit)**

- **VUID-VkVideoCapabilitiesKHR-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_VIDEO_CAPABILITIES_KHR`

- **VUID-VkVideoCapabilitiesKHR-pNext-pNext**
  
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkVideoDecodeCapabilitiesKHR`, `VkVideoDecodeH264CapabilitiesKHR`, `VkVideoDecodeH265CapabilitiesKHR`, `VkVideoEncodeCapabilitiesKHR`, `VkVideoEncodeH264CapabilitiesEXT`, or `VkVideoEncodeH265CapabilitiesEXT`

- **VUID-VkVideoCapabilitiesKHR-sType-unique**
  
  The `sType` value of each struct in the `pNext` chain must be unique

Bits which can be set in `VkVideoCapabilitiesKHR::flags` are:

```cpp
// Provided by VK_KHR_video_queue
typedef enum VkVideoCapabilityFlagBitsKHR {
  VK_VIDEO_CAPABILITY_PROTECTED_CONTENT_BIT_KHR = 0x00000001,
  VK_VIDEO_CAPABILITY_SEPARATE_REFERENCE_IMAGES_BIT_KHR = 0x00000002,
};
```
• **VK_VIDEO_CAPABILITY_PROTECTED_CONTENT_BIT_KHR** specifies that video sessions support producing and consuming protected content.

• **VK_VIDEO_CAPABILITY_SEPARATE_REFERENCE_IMAGES_BIT_KHR** specifies that the video picture resources associated with the DPB slots of a video session **can** be backed by separate VkImage objects. If this capability flag is not present, then all DPB slots of a video session **must** be associated with video picture resources backed by the same VkImage object (e.g. using different layers of the same image).

```cpp
// Provided by VK_KHR_video_queue
typedef VkFlags VkVideoCapabilityFlagsKHR;
```

**VkVideoCapabilityFlagsKHR** is a bitmask type for setting a mask of zero or more VkVideoCapabilityFlagBitsKHR.

### 42.4.2. Video Format Capabilities

To enumerate the supported output, input and DPB image formats and corresponding capabilities for a specific video profile, call:

```cpp
// Provided by VK_KHR_video_queue
VkResult vkGetPhysicalDeviceVideoFormatPropertiesKHR(
    VkPhysicalDevice physicalDevice,
    const VkPhysicalDeviceVideoFormatInfoKHR* pVideoFormatInfo,
    uint32_t* pVideoFormatPropertyCount,
    VkVideoFormatPropertiesKHR* pVideoFormatProperties);
```

• **physicalDevice** is the physical device from which to query the video format properties.

• **pVideoFormatInfo** is a pointer to a VkPhysicalDeviceVideoFormatInfoKHR structure specifying the usage and video profiles for which supported image formats and capabilities are returned.

• **pVideoFormatPropertyCount** is a pointer to an integer related to the number of video format properties available or queried, as described below.

• **pVideoFormatProperties** is a pointer to an array of VkVideoFormatPropertiesKHR structures in which supported image formats and capabilities are returned.

If **pVideoFormatProperties** is NULL, then the number of video format properties supported for the given **physicalDevice** is returned in **pVideoFormatPropertyCount**. Otherwise, **pVideoFormatPropertyCount** must point to a variable set by the user to the number of elements in the **pVideoFormatProperties** array, and on return the variable is overwritten with the number of values actually written to **pVideoFormatProperties**. If the value of **pVideoFormatPropertyCount** is less than the number of video format properties supported, at most **pVideoFormatPropertyCount** values will be written to **pVideoFormatProperties**, and **VK_INCOMPLETE** will be returned instead of **VK_SUCCESS**, to indicate that not all the available values were returned.
Video format properties are always queried with respect to a specific set of video profiles. These are specified by chaining the 
\texttt{VkVideoProfileListInfoKHR} structure to \texttt{pVideoFormatInfo}.

For most use cases, the images are used by a single video session and a single video profile is provided. For a use case such as video transcoding, where a decode session output image \textit{can} be used as encode input in one or more encode sessions, multiple video profiles corresponding to the video sessions that will share the image \textbf{must} be provided.

If any of the \textit{video profiles} specified via \texttt{VkVideoProfileListInfoKHR::pProfiles} are not supported, then this command returns one of the \textit{video-profile-specific error codes}. Furthermore, if \texttt{VkPhysicalDeviceVideoFormatInfoKHR::imageUsage} includes any image usage flags not supported by the specified video profiles, then this command returns \texttt{VK_ERROR_IMAGE_USAGE_NOT_SUPPORTED_KHR}.

This command also returns \texttt{VK_ERROR_IMAGE_USAGE_NOT_SUPPORTED_KHR} if \texttt{VkPhysicalDeviceVideoFormatInfoKHR::imageUsage} does not include the appropriate flags as dictated by the decode capability flags returned in \texttt{VkVideoDecodeCapabilitiesKHR::flags} for any of the profiles specified in the \texttt{VkVideoProfileListInfoKHR} structure provided in the \texttt{pNext} chain of \texttt{pVideoFormatInfo}.

If the decode capability flags include \texttt{VK_VIDEO_DECODE_CAPABILITY_DPB_AND_OUTPUT_COINCIDE_BIT_KHR} but not \texttt{VK_VIDEO_DECODE_CAPABILITY_DPB_AND_OUTPUT_DISTINCT_BIT_KHR}, then in order to query video format properties for decode DPB and output usage, \texttt{VkPhysicalDeviceVideoFormatInfoKHR::imageUsage} \textbf{must} include both \texttt{VK_IMAGE_USAGE_VIDEO_DECODE_DPB_BIT_KHR} and \texttt{VK_IMAGE_USAGE_VIDEO_DECODE_DST_BIT_KHR}. Otherwise, the call will fail with \texttt{VK_ERROR_IMAGE_USAGE_NOT_SUPPORTED_KHR}.

If the decode capability flags include \texttt{VK_VIDEO_DECODE_CAPABILITY_DPB_AND_OUTPUT_DISTINCT_BIT_KHR} but not \texttt{VK_VIDEO_DECODE_CAPABILITY_DPB_AND_OUTPUT_COINCIDE_BIT_KHR}, then in order to query video format properties for decode DPB usage, \texttt{VkPhysicalDeviceVideoFormatInfoKHR::imageUsage} \textbf{must} include \texttt{VK_IMAGE_USAGE_VIDEO_DECODE_DPB_BIT_KHR}, but not \texttt{VK_IMAGE_USAGE_VIDEO_DECODE_DST_BIT_KHR}. Otherwise, the call will fail with \texttt{VK_ERROR_IMAGE_USAGE_NOT_SUPPORTED_KHR}. Similarly, to query video format properties for decode output usage, \texttt{VkPhysicalDeviceVideoFormatInfoKHR::imageUsage} \textbf{must} include \texttt{VK_IMAGE_USAGE_VIDEO_DECODE_DST_BIT_KHR}, but not \texttt{VK_IMAGE_USAGE_VIDEO_DECODE_DPB_BIT_KHR}. Otherwise, the call will fail with \texttt{VK_ERROR_IMAGE_USAGE_NOT_SUPPORTED_KHR}.

The \textit{imageUsage} member of the \texttt{VkPhysicalDeviceVideoFormatInfoKHR} structure specifies the expected video usage flags that the returned video formats \textbf{must} support. Correspondingly, the \textit{imageUsageFlags} member of each \texttt{VkVideoFormatPropertiesKHR} structure returned will contain at least the same set of image usage flags.

If the implementation supports using video input, output, or DPB images of a particular format in operations other than video decode/encode then the \textit{imageUsageFlags} member of the corresponding \texttt{VkVideoFormatPropertiesKHR} structure returned will include additional image usage flags indicating that.

\begin{itemize}
  \item \textbf{Note:}\n  
  For most use cases, only decode or encode related usage flags are going to be specified. For a use case such as transcoding, if the image were to be shared between
decode and encode session(s), then both decode and encode related usage flags can be set.

Multiple VkVideoFormatPropertiesKHR entries may be returned with the same format member with different componentMapping, imageType, or imageTiling values, as described later.

In addition, a different set of VkVideoFormatPropertiesKHR entries may be returned depending on the imageUsage member of the VkPhysicalDeviceVideoFormatInfoKHR structure, even for the same set of video profiles, for example, based on whether encode input, encode DPB, decode output, and/or decode DPB usage is requested.

The application can select the parameters returned in the VkVideoFormatPropertiesKHR entries and use compatible parameters when creating the input, output, and DPB images. The implementation will report all image creation and usage flags that are valid for images used with the requested video profiles but applications should create images only with those that are necessary for the particular use case.

Before creating an image, the application can obtain the complete set of supported image format features by calling vkGetPhysicalDeviceImageFormatProperties2 using parameters derived from the members of one of the reported VkVideoFormatPropertiesKHR entries and adding the same VkVideoProfileListInfoKHR structure to the pNext chain of VkPhysicalDeviceImageFormatInfo2.

The following applies to all VkVideoFormatPropertiesKHR entries returned by vkGetPhysicalDeviceVideoFormatPropertiesKHR:

- vkGetPhysicalDeviceFormatProperties2 must succeed when called with VkVideoFormatPropertiesKHR::format.
- If VkVideoFormatPropertiesKHR::imageTiling is VK_IMAGE_TILING_OPTIMAL, then the optimalTilingFeatures returned by vkGetPhysicalDeviceFormatProperties2 must include all format features required by the image usage flags reported in VkVideoFormatPropertiesKHR::imageUsageFlags for the format, as indicated in the Format Feature Dependent Usage Flags section.
- If VkVideoFormatPropertiesKHR::imageTiling is VK_IMAGE_TILING_LINEAR, then the linearTilingFeatures returned by vkGetPhysicalDeviceFormatProperties2 must include all format features required by the image usage flags reported in VkVideoFormatPropertiesKHR::imageUsageFlags for the format, as indicated in the Format Feature Dependent Usage Flags section.
- vkGetPhysicalDeviceImageFormatProperties2 must succeed when called with a VkPhysicalDeviceImageFormatInfo2 structure containing the following information:
  - The pNext chain including the same VkVideoProfileListInfoKHR structure used to call vkGetPhysicalDeviceVideoFormatPropertiesKHR.
  - format set to the value of VkVideoFormatPropertiesKHR::format.
  - type set to the value of VkVideoFormatPropertiesKHR::imageType.
  - tiling set to the value of VkVideoFormatPropertiesKHR::imageTiling.
  - usage set to the value of VkVideoFormatPropertiesKHR::imageUsageFlags.
flags set to the value of VkVideoFormatPropertiesKHR::imageCreateFlags.

The componentMapping member of VkVideoFormatPropertiesKHR defines the ordering of the Y′CbCr color channels from the perspective of the video codec operations specified in VkVideoProfileListInfoKHR. For example, if the implementation produces video decode output with the format VK_FORMAT_G8_B8R8_2PLANE_420_UNORM where the blue and red chrominance channels are swapped then the componentMapping member of the corresponding VkVideoFormatPropertiesKHR structure will have the following member values:

```
components.r = VK_COMPONENT_SWIZZLE_B;  // Cb component
components.g = VK_COMPONENT_SWIZZLE_IDENTITY;  // Y component
components.b = VK_COMPONENT_SWIZZLE_R;  // Cr component
components.a = VK_COMPONENT_SWIZZLE_IDENTITY;  // unused, defaults to 1.0
```

Valid Usage

- VUID-vkGetPhysicalDeviceVideoFormatPropertiesKHR-pNext-06812
  The pNext chain of pVideoFormatInfo must include a VkVideoProfileListInfoKHR structure with profileCount greater than 0

Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceVideoFormatPropertiesKHR-physicalDevice-parameter
  physicalDevice must be a valid VkPhysicalDevice handle

- VUID-vkGetPhysicalDeviceVideoFormatPropertiesKHR-pVideoFormatInfo-parameter
  pVideoFormatInfo must be a valid pointer to a valid VkPhysicalDeviceVideoFormatInfoKHR structure

- VUID-vkGetPhysicalDeviceVideoFormatPropertiesKHR-pVideoFormatPropertyCount-parameter
  pVideoFormatPropertyCount must be a valid pointer to a uint32_t value

- VUID-vkGetPhysicalDeviceVideoFormatPropertiesKHR-pVideoFormatProperties-parameter
  If the value referenced by pVideoFormatPropertyCount is not 0, and pVideoFormatProperties is not NULL, pVideoFormatProperties must be a valid pointer to an array of pVideoFormatPropertyCount VkVideoFormatPropertiesKHR structures

Return Codes

Success

- VK_SUCCESS
- VK_INCOMPLETE
The `VkPhysicalDeviceVideoFormatInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_video_queue
typedef struct VkPhysicalDeviceVideoFormatInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkImageUsageFlags imageUsage;
} VkPhysicalDeviceVideoFormatInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `imageUsage` is a bitmask of `VkImageUsageFlagBits` specifying the intended usage of the video images.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceVideoFormatInfoKHR-sType-sType `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VIDEO_FORMAT_INFO_KHR`
- VUID-VkPhysicalDeviceVideoFormatInfoKHR-pNext-pNext `pNext` must be `NULL` or a pointer to a valid instance of `VkVideoProfileListInfoKHR`
- VUID-VkPhysicalDeviceVideoFormatInfoKHR-sType-unique The `sType` value of each struct in the `pNext` chain must be unique
- VUID-VkPhysicalDeviceVideoFormatInfoKHR-imageUsage-parameter `imageUsage` must be a valid combination of `VkImageUsageFlagBits` values
- VUID-VkPhysicalDeviceVideoFormatInfoKHR-imageUsage-requiredbitmask `imageUsage` must not be 0

The `VkVideoFormatPropertiesKHR` structure is defined as:

```c
// Provided by VK_KHR_video_queue
typedef struct VkVideoFormatPropertiesKHR {
    VkStructureType sType;
    VkVideoQueueFlags queueFlags;
} VkVideoFormatPropertiesKHR;
```
`void*` *pNext;
VkFormat format;
VkComponentMapping componentMapping;
VkImageCreateFlags imageCreateFlags;
VkImageType imageType;
VkImageTiling imageTiling;
VkImageUsageFlags imageUsageFlags;
} VkVideoFormatPropertiesKHR;

• `sType` is a `VkStructureType` value identifying this structure.
• `pNext` is NULL or a pointer to a structure extending this structure.
• `format` is a `VkFormat` that specifies the format that can be used with the specified video profiles and image usages.
• `componentMapping` defines the color channel order used for the format. `format` along with `componentMapping` describe how the color channels are ordered when producing video decoder output or are expected to be ordered in video encoder input, when applicable. If the `format` reported does not require component swizzling then all members of `componentMapping` will be set to `VK_COMPONENT_SWIZZLE_IDENTITY`.
• `imageCreateFlags` is a bitmask of `VkImageCreateFlagBits` specifying the supported image creation flags for the format.
• `imageType` is a `VkImageType` that specifies the image type the format can be used with.
• `imageTiling` is a `VkImageTiling` that specifies the image tiling the format can be used with.
• `imageUsageFlags` is a bitmask of `VkImageUsageFlagBits` specifying the supported image usage flags for the format.

### Valid Usage (Implicit)

- VUID-VkVideoFormatPropertiesKHR-sType-sType `sType` must be `VK_STRUCTURE_TYPE_VIDEO_FORMAT_PROPERTIES_KHR`  
- VUID-VkVideoFormatPropertiesKHR-pNext-pNext `pNext` must be NULL

### 42.5. Video Sessions

Video sessions are objects that represent and maintain the state needed to perform video decode or encode operations using a specific video profile.

Video sessions are represented by `VkVideoSessionKHR` handles:

```c
// Provided by VK_KHR_video_queue
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkVideoSessionKHR)
```
42.5.1. Creating a Video Session

To create a video session object, call:

```c
// Provided by VK_KHR_video_queue
VkResult vkCreateVideoSessionKHR(
    VkDevice device,
    const VkVideoSessionCreateInfoKHR* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkVideoSessionKHR* pVideoSession);
```

- **device** is the logical device that creates the video session.
- **pCreateInfo** is a pointer to a `VkVideoSessionCreateInfoKHR` structure containing parameters to be used to create the video session.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
- **pVideoSession** is a pointer to a `VkVideoSessionKHR` handle in which the resulting video session object is returned.

The resulting video session object is said to be created with the video codec operation specified in `pCreateInfo->pVideoProfile->videoCodecOperation`.

The name and version of the codec-specific Video Std header to be used with the video session is specified by the `VkExtensionProperties` structure pointed to by `pCreateInfo->pStdHeaderVersion`. If a non-existent or unsupported Video Std header version is specified in `pCreateInfo->pStdHeaderVersion->specVersion`, then this command returns `VK_ERROR_VIDEO_STD_VERSION_NOT_SUPPORTED_KHR`.

Video session objects are created in uninitialized state. In order to transition the video session into initial state, the application must issue a `vkCmdControlVideoCodingKHR` command with `VkVideoCodingControlInfoKHR::flags` including `VK_VIDEO_CODING_CONTROL_RESET_BIT_KHR`.

Video session objects also maintain the state of the DPB. The number of DPB slots usable with the created video session is specified in `pCreateInfo->maxDpbSlots`, and each slot is initially in the inactive state.

Each DPB slot maintained by the created video session can refer to a reference picture representing a video frame.

In addition, if the `videoCodecOperation` member of the `VkVideoProfileInfoKHR` structure pointed to by `pCreateInfo->pVideoProfile` is `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR` and the `pictureLayout` member of the `VkVideoDecodeH264ProfileInfoKHR` structure provided in the `VkVideoProfileInfoKHR::pNext` chain is not `VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_PROGRESSIVE_KHR`, then the created video session supports interlaced frames and each DPB slot maintained by the created video session can instead refer to separate top field and bottom field reference pictures that together can represent a full video frame. In this case, it is up to the application, driven by the video content, whether it associates any individual DPB slot with separate top and/or bottom field pictures or a single picture representing a full frame.
The created video session can be used to perform video coding operations using video frames up to the maximum size specified in `pCreateInfo->maxCodedExtent`. The minimum frame size allowed is implicitly derived from `VkVideoCapabilitiesKHR::minCodedExtent`, as returned by `vkGetPhysicalDeviceVideoCapabilitiesKHR` for the video profile specified by `pCreateInfo->pVideoProfile`. Accordingly, the created video session is said to be created with a `minCodedExtent` equal to that.

In case of video session objects created with a video encode operation, implementations may return the `VK_ERROR_INVALID_VIDEO_STD_PARAMETERS_KHR` error if any of the specified Video Std parameters do not adhere to the syntactic or semantic requirements of the used video compression standard, or if values derived from parameters according to the rules defined by the used video compression standard do not adhere to the capabilities of the video compression standard or the implementation.

**Note**

Applications should not rely on the `VK_ERROR_INVALID_VIDEO_STD_PARAMETERS_KHR` error being returned by any command as a means to verify Video Std parameters, as implementations are not required to report the error in any specific set of cases.

### Valid Usage (Implicit)

- VUID-vkCreateVideoSessionKHR-device-parameter
  - `device` must be a valid `VkDevice` handle
- VUID-vkCreateVideoSessionKHR-pCreateInfo-parameter
  - `pCreateInfo` must be a valid pointer to a valid `VkVideoSessionCreateInfoKHR` structure
- VUID-vkCreateVideoSessionKHR-pAllocator-parameter
  - If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure
- VUID-vkCreateVideoSessionKHR-pVideoSession-parameter
  - `pVideoSession` must be a valid pointer to a `VkVideoSessionKHR` handle

### Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_INITIALIZATION_FAILED`
- `VK_ERROR_VIDEO_STD_VERSION_NOT_SUPPORTED_KHR`
- `VK_ERROR_INVALID_VIDEO_STD_PARAMETERS_KHR`
The `VkVideoSessionCreateInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_video_queue
typedef struct VkVideoSessionCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkVideoSessionCreateFlagsKHR queueFamilyIndex;
    const VkVideoProfileInfoKHR* pVideoProfile;
    VkFormat pictureFormat;
    VkFormat referencePictureFormat;
    uint32_t maxDpbSlots;
    uint32_t maxActiveReferencePictures;
    const VkExtensionProperties* pStdHeaderVersion;
} VkVideoSessionCreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `queueFamilyIndex` is the index of the queue family the created video session will be used with.
- `flags` is a bitmask of `VkVideoSessionCreateFlagBitsKHR` specifying creation flags.
- `pVideoProfile` is a pointer to a `VkVideoProfileInfoKHR` structure specifying the video profile the created video session will be used with.
- `pictureFormat` is the image format the created video session will be used with. If `pVideoProfile->videoCodecOperation` specifies a decode operation, then `pictureFormat` is the image format of decode output pictures usable with the created video session. If `pVideoProfile->videoCodecOperation` specifies an encode operation, then `pictureFormat` is the image format of encode input pictures usable with the created video session.
- `maxCodedExtent` is the maximum width and height of the coded frames the created video session will be used with.
- `referencePictureFormat` is the image format of reference pictures stored in the DPB the created video session will be used with.
- `maxDpbSlots` is the maximum number of DPB Slots that can be used with the created video session.
- `maxActiveReferencePictures` is the maximum number of active reference pictures that can be used in a single video coding operation using the created video session.
- `pStdHeaderVersion` is a pointer to a `VkExtensionProperties` structure requesting the Video Std header version to use for the `videoCodecOperation` specified in `pVideoProfile`.

**Valid Usage**

- `VUID-VkVideoSessionCreateInfoKHR-protectedMemory-07189
If the protectedMemory feature is not enabled or if `VkVideoCapabilitiesKHR::flags` does not
include VK_VIDEO_CAPABILITY_PROTECTED_CONTENT_BIT_KHR, as returned by vkGetPhysicalDeviceVideoCapabilitiesKHR for the video profile specified by pVideoProfile, then flags must not include VK_VIDEO_SESSION_CREATE_PROTECTED_CONTENT_BIT_KHR

- VUID-VkVideoSessionCreateInfoKHR-pVideoProfile-04845
  pVideoProfile must be a supported video profile

- VUID-VkVideoSessionCreateInfoKHR-maxDpbSlots-04847
  maxDpbSlots must be less than or equal to VkVideoCapabilitiesKHR::maxDpbSlots, as returned by vkGetPhysicalDeviceVideoCapabilitiesKHR for the video profile specified by pVideoProfile

- VUID-VkVideoSessionCreateInfoKHR-maxActiveReferencePictures-04849
  maxActiveReferencePictures must be less than or equal to VkVideoCapabilitiesKHR::maxActiveReferencePictures, as returned by vkGetPhysicalDeviceVideoCapabilitiesKHR for the video profile specified by pVideoProfile

- VUID-VkVideoSessionCreateInfoKHR-maxDpbSlots-04850
  If either maxDpbSlots or maxActiveReferencePictures is 0, then both must be 0

- VUID-VkVideoSessionCreateInfoKHR-maxCodedExtent-04851
  maxCodedExtent must be between VkVideoCapabilitiesKHR::minCodedExtent and VkVideoCapabilitiesKHR::maxCodedExtent, inclusive, as returned by vkGetPhysicalDeviceVideoCapabilitiesKHR for the video profile specified by pVideoProfile

- VUID-VkVideoSessionCreateInfoKHR-referencePictureFormat-04852
  If pVideoProfile->videoCodecOperation specifies a decode operation and maxActiveReferencePictures is greater than 0, then referencePictureFormat must be one of the supported decode DPB formats, as returned by vkGetPhysicalDeviceVideoFormatPropertiesKHR in VkVideoFormatPropertiesKHR::format when called with the imageUsage member of its pVideoFormatInfo parameter containing VK_IMAGE_USAGE_VIDEO_DECODE_DPB_BIT_KHR, and with a VkVideoProfileListInfoKHR structure specified in the pNext chain of its pVideoFormatInfo parameter whose pProfiles member contains an element matching pVideoProfile

- VUID-VkVideoSessionCreateInfoKHR-referencePictureFormat-06814
  If pVideoProfile->videoCodecOperation specifies an encode operation and maxActiveReferencePictures is greater than 0, then referencePictureFormat must be one of the supported encode DPB formats, as returned by vkGetPhysicalDeviceVideoFormatPropertiesKHR in VkVideoFormatPropertiesKHR::format when called with the imageUsage member of its pVideoFormatInfo parameter containing VK_IMAGE_USAGE_VIDEO_ENCODE_DPB_BIT_KHR, and with a VkVideoProfileListInfoKHR structure specified in the pNext chain of its pVideoFormatInfo parameter whose pProfiles member contains an element matching pVideoProfile

- VUID-VkVideoSessionCreateInfoKHR-pictureFormat-04853
  If pVideoProfile->videoCodecOperation specifies a decode operation, then pictureFormat must be one of the supported decode output formats, as returned by vkGetPhysicalDeviceVideoFormatPropertiesKHR in VkVideoFormatPropertiesKHR::format when called with the imageUsage member of its pVideoFormatInfo parameter containing VK_IMAGE_USAGE_VIDEO_DECODE_DST_BIT_KHR, and with a VkVideoProfileListInfoKHR
structure specified in the pNext chain of its pVideoFormatInfo parameter whose pProfiles member contains an element matching pVideoProfile

- VUID-VkVideoSessionCreateInfoKHR-pictureFormat-04854
  If pVideoProfile->videoCodecOperation specifies an encode operation, then pictureFormat must be one of the supported encode input formats, as returned by vkGetPhysicalDeviceVideoFormatPropertiesKHR in VkVideoFormatPropertiesKHR::format when called with the imageUsage member of its pVideoFormatInfo parameter containing VK_IMAGE_USAGE_VIDEO_ENCODE_SRC_BIT_KHR, and with a VkVideoProfileListInfoKHR structure specified in the pNext chain of its pVideoFormatInfo parameter whose pProfiles member contains an element matching pVideoProfile

- VUID-VkVideoSessionCreateInfoKHR-pStdHeaderVersion-07190
  pStdHeaderVersion->extensionName must match VkVideoCapabilitiesKHR::stdHeaderVersion.extensionName, as returned by vkGetPhysicalDeviceVideoCapabilitiesKHR for the video profile specified by pVideoProfile

- VUID-VkVideoSessionCreateInfoKHR-pStdHeaderVersion-07191
  pStdHeaderVersion->specVersion must be less than or equal to VkVideoCapabilitiesKHR::stdHeaderVersion.specVersion, as returned by vkGetPhysicalDeviceVideoCapabilitiesKHR for the video profile specified by pVideoProfile

Valid Usage (Implicit)

- VUID-VkVideoSessionCreateInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_VIDEO_SESSION_CREATE_INFO_KHR

- VUID-VkVideoSessionCreateInfoKHR-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkVideoEncodeH264SessionCreateInfoEXT or VkVideoEncodeH265SessionCreateInfoEXT

- VUID-VkVideoSessionCreateInfoKHR-sType-unique
  The sType value of each struct in the pNext chain must be unique

- VUID-VkVideoSessionCreateInfoKHR-flags-parameter
  flags must be a valid combination of VkVideoSessionCreateFlagBitsKHR values

- VUID-VkVideoSessionCreateInfoKHR-pVideoProfile-parameter
  pVideoProfile must be a valid pointer to a valid VkVideoProfileInfoKHR structure

- VUID-VkVideoSessionCreateInfoKHR-pictureFormat-parameter
  pictureFormat must be a valid VkFormat value

- VUID-VkVideoSessionCreateInfoKHR-referencePictureFormat-parameter
  referencePictureFormat must be a valid VkFormat value

- VUID-VkVideoSessionCreateInfoKHR-pStdHeaderVersion-parameter
  pStdHeaderVersion must be a valid pointer to a valid VkExtensionProperties structure

Bits which can be set in VkVideoSessionCreateInfoKHR::flags are:
• **VK_VIDEO_SESSION_CREATE_PROTECTED_CONTENT_BIT_KHR** specifies that the video session uses protected video content.

• **VK_VIDEO_SESSION_CREATE_ALLOW_ENCODE_PARAMETER_OPTIMIZATIONS_BIT_KHR** specifies that the implementation is allowed to override video session parameters and other codec-specific encoding parameters to optimize video encode operations based on the specific use case defined by the video profile and the used video encode quality level.

42.5.2. Destroying a Video Session

To destroy a video session, call:

```c
void vkDestroyVideoSessionKHR(
    VkDevice device,
    VkVideoSessionKHR videoSession,
    const VkAllocationCallbacks* pAllocator);
```

• **device** is the logical device that destroys the video session.

• **videoSession** is the video session to destroy.

• **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.

**Valid Usage**

• VUID-vkDestroyVideoSessionKHR-videoSession-07192
  All submitted commands that refer to **videoSession** must have completed execution

• VUID-vkDestroyVideoSessionKHR-videoSession-07193
  If **VkAllocationCallbacks** were provided when **videoSession** was created, a compatible set of callbacks **must** be provided here
42.5.3. Video Session Memory Association

After creating a video session object, and before the object can be used to record video coding operations into command buffers using it, the application must allocate and bind device memory to the video session. Device memory is allocated separately (see Device Memory) and then associated with the video session.

Video sessions may have multiple memory bindings identified by unique unsigned integer values. Appropriate device memory must be bound to each such memory binding before using the video session to record command buffer commands with it.

To determine the memory requirements for a video session object, call:

```c
// Provided by VK_KHR_video_queue
VkResult vkGetVideoSessionMemoryRequirementsKHR(
    VkDevice device,  // Logical device that owns the video session.
    VkVideoSessionKHR videoSession,  // Video session handle.
    uint32_t* pMemoryRequirementsCount,  // Output: Count of memory requirements.
    VkVideoSessionMemoryRequirementsKHR* pMemoryRequirements) {  // Memory requirements for the video session.
```

- `device` is the logical device that owns the video session.
• `videoSession` is the video session to query.

• `pMemoryRequirementsCount` is a pointer to an integer related to the number of memory binding requirements available or queried, as described below.

• `pMemoryRequirements` is `NULL` or a pointer to an array of `VkVideoSessionMemoryRequirementsKHR` structures in which the memory binding requirements of the video session are returned.

If `pMemoryRequirements` is `NULL`, then the number of memory bindings required for the video session is returned in `pMemoryRequirementsCount`. Otherwise, `pMemoryRequirementsCount` must point to a variable set by the user with the number of elements in the `pMemoryRequirements` array, and on return the variable is overwritten with the number of memory binding requirements actually written to `pMemoryRequirements`. If `pMemoryRequirementsCount` is less than the number of memory bindings required for the video session, then at most `pMemoryRequirementsCount` elements will be written to `pMemoryRequirements`, and `VK_INCOMPLETE` will be returned, instead of `VK_SUCCESS`, to indicate that not all required memory binding requirements were returned.

Valid Usage (Implicit)

- VUID-vkGetVideoSessionMemoryRequirementsKHR-device-parameter
  `device` must be a valid `VkDevice` handle

- VUID-vkGetVideoSessionMemoryRequirementsKHR-videoSession-parameter
  `videoSession` must be a valid `VkVideoSessionKHR` handle

- VUID-vkGetVideoSessionMemoryRequirementsKHR-pMemoryRequirementsCount-parameter
  `pMemoryRequirementsCount` must be a valid pointer to a `uint32_t` value

- VUID-vkGetVideoSessionMemoryRequirementsKHR-pMemoryRequirements-parameter
  If the value referenced by `pMemoryRequirementsCount` is not 0, and `pMemoryRequirements` is not `NULL`, `pMemoryRequirements` must be a valid pointer to an array of `pMemoryRequirementsCount` `VkVideoSessionMemoryRequirementsKHR` structures

- VUID-vkGetVideoSessionMemoryRequirementsKHR-videoSession-parent
  `videoSession` must have been created, allocated, or retrieved from `device`

Return Codes

Success

- `VK_SUCCESS`
- `VK_INCOMPLETE`

The `VkVideoSessionMemoryRequirementsKHR` structure is defined as:

```c
// Provided by VK_KHR_video_queue
typedef struct VkVideoSessionMemoryRequirementsKHR {
    VkStructureType sType;
    // Other fields...}
```
```c
void* pNext;
uint32_t memoryBindIndex;
VkMemoryRequirements memoryRequirements;
} VkVideoSessionMemoryRequirementsKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **memoryBindIndex** is the index of the memory binding.
- **memoryRequirements** is a `VkMemoryRequirements` structure in which the requested memory binding requirements for the binding index specified by `memoryBindIndex` are returned.

### Valid Usage (Implicit)

- **VUID-VkVideoSessionMemoryRequirementsKHR-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_VIDEO_SESSION_MEMORY_REQUIREMENTS_KHR`

- **VUID-VkVideoSessionMemoryRequirementsKHR-pNext-pNext**
  
  `pNext` must be `NULL`

To attach memory to a video session object, call:

```c
// Provided by VK_KHR_video_queue
VkResult vkBindVideoSessionMemoryKHR(
    VkDevice device,
    VkVideoSessionKHR videoSession,
    uint32_t bindSessionMemoryInfoCount,
    const VkBindVideoSessionMemoryInfoKHR* pBindSessionMemoryInfos);
```

- **device** is the logical device that owns the video session.
- **videoSession** is the video session to be bound with device memory.
- **bindSessionMemoryInfoCount** is the number of elements in `pBindSessionMemoryInfos`.
- **pBindSessionMemoryInfos** is a pointer to an array of `bindSessionMemoryInfoCount` `VkBindVideoSessionMemoryInfoKHR` structures specifying memory regions to be bound to specific memory bindings of the video session.

The valid usage statements below refer to the `VkMemoryRequirements` structure corresponding to a specific element of `pBindSessionMemoryInfos`, which is defined as follows:

- If the `memoryBindIndex` member of the element of `pBindSessionMemoryInfos` in question matches the `memoryBindIndex` member of one of the elements returned in `pMemoryRequirements` when `vkGetVideoSessionMemoryRequirementsKHR` is called with the same `videoSession` and with `pMemoryRequirementsCount` equal to `bindSessionMemoryInfoCount`, then the `memoryRequirements` member of that element of `pMemoryRequirements` is the `VkMemoryRequirements` structure corresponding to the element of `pBindSessionMemoryInfos` in question.
Otherwise the element of `pBindSessionMemoryInfos` in question is said to not have a corresponding `VkMemoryRequirements` structure.

**Valid Usage**

- **VUID-vkBindVideoSessionMemoryKHR-videoSession-07195**
  The memory binding of `videoSession` identified by the `memoryBindIndex` member of any element of `pBindSessionMemoryInfos` must not already be backed by a memory object.

- **VUID-vkBindVideoSessionMemoryKHR-memoryBindIndex-07196**
  The `memoryBindIndex` member of each element of `pBindSessionMemoryInfos` must be unique within `pBindSessionMemoryInfos`.

- **VUID-vkBindVideoSessionMemoryKHR-pBindSessionMemoryInfos-07197**
  Each element of `pBindSessionMemoryInfos` must have a corresponding `VkMemoryRequirements` structure.

- **VUID-vkBindVideoSessionMemoryKHR-pBindSessionMemoryInfos-07198**
  If an element of `pBindSessionMemoryInfos` has a corresponding `VkMemoryRequirements` structure, then the `memory` member of that element of `pBindSessionMemoryInfos` must have been allocated using one of the memory types allowed in the `memoryTypeBits` member of the corresponding `VkMemoryRequirements` structure.

- **VUID-vkBindVideoSessionMemoryKHR-pBindSessionMemoryInfos-07199**
  If an element of `pBindSessionMemoryInfos` has a corresponding `VkMemoryRequirements` structure, then the `memoryOffset` member of that element of `pBindSessionMemoryInfos` must be an integer multiple of the `alignment` member of the corresponding `VkMemoryRequirements` structure.

- **VUID-vkBindVideoSessionMemoryKHR-pBindSessionMemoryInfos-07200**
  If an element of `pBindSessionMemoryInfos` has a corresponding `VkMemoryRequirements` structure, then the `memorySize` member of that element of `pBindSessionMemoryInfos` must equal the `size` member of the corresponding `VkMemoryRequirements` structure.

**Valid Usage (Implicit)**

- **VUID-vkBindVideoSessionMemoryKHR-device-parameter**
  `device` must be a valid `VkDevice` handle.

- **VUID-vkBindVideoSessionMemoryKHR-videoSession-parameter**
  `videoSession` must be a valid `VkVideoSessionKHR` handle.

- **VUID-vkBindVideoSessionMemoryKHR-pBindSessionMemoryInfos-parameter**
  `pBindSessionMemoryInfos` must be a valid pointer to an array of `bindSessionMemoryInfoCount` valid `VkBindVideoSessionMemoryInfoKHR` structures.

- **VUID-vkBindVideoSessionMemoryKHR-bindSessionMemoryInfoCount-arraylength**
  `bindSessionMemoryInfoCount` must be greater than 0.

- **VUID-vkBindVideoSessionMemoryKHR-videoSession-parent**
  `videoSession` must have been created, allocated, or retrieved from `device`. 
Host Synchronization

- Host access to videoSession must be externally synchronized

Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkBindVideoSessionMemoryInfoKHR structure is defined as:

```c
// Provided by VK_KHR_video_queue
typedef struct VkBindVideoSessionMemoryInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t memoryBindIndex;
    VkDeviceMemory memory;
    VkDeviceSize memoryOffset;
    VkDeviceSize memorySize;
} VkBindVideoSessionMemoryInfoKHR;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `memoryBindIndex` is the memory binding index to bind memory to.
- `memory` is the allocated device memory to be bound to the video session's memory binding with index `memoryBindIndex`.
- `memoryOffset` is the start offset of the region of `memory` which is to be bound.
- `memorySize` is the size in bytes of the region of `memory`, starting from `memoryOffset` bytes, to be bound.

Valid Usage

- VUID-VkBindVideoSessionMemoryInfoKHR-memoryOffset-07201
  memoryOffset must be less than the size of `memory`

- VUID-VkBindVideoSessionMemoryInfoKHR-memorySize-07202
  memorySize must be less than or equal to the size of `memory` minus `memoryOffset`
42.6. Video Profile Compatibility

Resources and query pools used with a particular video session must be compatible with the video profile the video session was created with.

A VkBuffer is compatible with a video profile if it was created with the VkBufferCreateInfo::pNext chain including a VkVideoProfileListInfoKHR structure with its pProfiles member containing an element matching the VkVideoProfileInfoKHR structure chain describing the video profile, and VkBufferCreateInfo::usage including at least one bit specific to video coding usage.

- VK_BUFFER_USAGE_VIDEO_DECODE_SRC_BIT_KHR
- VK_BUFFER_USAGE_VIDEO_DECODE_DST_BIT_KHR
- VK_BUFFER_USAGE_VIDEO_ENCODE_SRC_BIT_KHR
- VK_BUFFER_USAGE_VIDEO_ENCODE_DST_BIT_KHR

A VkImage is compatible with a video profile if it was created with the VkImageCreateInfo::pNext chain including a VkVideoProfileListInfoKHR structure with its pProfiles member containing an element matching the VkVideoProfileInfoKHR structure chain describing the video profile, and VkImageCreateInfo::usage including at least one bit specific to video coding usage.

- VK_IMAGE_USAGE_VIDEO_DECODE_SRC_BIT_KHR
- VK_IMAGE_USAGE_VIDEO_DECODE_DST_BIT_KHR
- VK_IMAGE_USAGE_VIDEO_ENCODE_SRC_BIT_KHR
- VK_IMAGE_USAGE_VIDEO_ENCODE_DPB_BIT_KHR

A VkImageView is compatible with a video profile if the VkImage it was created from is also compatible with that video profile.

A VkQueryPool is compatible with a video profile if it was created with the VkQueryPoolCreateInfo::pNext chain including a VkVideoProfileInfoKHR structure chain describing the same video profile, and VkQueryPoolCreateInfo::queryType having one of the following values:

- VK_QUERY_TYPE_RESULT_STATUS_ONLY_KHR
42.7. Video Session Parameters

Video session parameters objects can store preprocessed codec-specific parameters used with a compatible video session, and enable reducing the number of parameters needed to be provided and processed by the implementation while recording video coding operations into command buffers.

Parameters stored in such objects are immutable to facilitate the concurrent use of the stored parameters in multiple threads. At the same time, new parameters can be added to existing objects using the `vkUpdateVideoSessionParametersKHR` command.

In order to support concurrent use of the stored immutable parameters while also allowing the video session parameters object to be extended with new parameters, each video session parameters object maintains an update sequence counter that is set to 0 at object creation time and must be incremented by each subsequent update operation.

Certain video sequences that adhere to particular video compression standards permit updating previously supplied parameters. If a parameter update is necessary, the application has the following options:

- Cache the set of parameters on the application side and create a new video session parameters object adding all the parameters with appropriate changes, as necessary; or
- Create a new video session parameters object providing only the updated parameters and the previously used object as the template, which ensures that parameters not specified at creation time will be copied unmodified from the template object.

The actual types of parameters that can be stored and the capacity for individual parameter types, and the methods of initializing, updating, and referring to individual parameters are specific to the video codec operation the video session parameters object was created with.

- For `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR` these are defined in the H.264 Decode Parameter Sets section.
- For `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR` these are defined in the H.265 Decode Parameter Sets section.

Video session parameters are represented by `VkVideoSessionParametersKHR` handles:

```c
// Provided by VK_KHR_video_queue
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkVideoSessionParametersKHR)
```

42.7.1. Creating Video Session Parameters

To create a video session parameters object, call:

```c
// Provided by VK_KHR_video_queue
```
VkResult vkCreateVideoSessionParametersKHR(VkDevice device, const VkVideoSessionParametersCreateInfoKHR* pCreateInfo, const VkAllocationCallbacks* pAllocator, VkVideoSessionParametersKHR* pVideoSessionParameters);

- **device** is the logical device that creates the video session parameters object.
- **pCreateInfo** is a pointer to `VkVideoSessionParametersCreateInfoKHR` structure containing parameters to be used to create the video session parameters object.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
- **pVideoSessionParameters** is a pointer to a `VkVideoSessionParametersKHR` handle in which the resulting video session parameters object is returned.

The resulting video session parameters object is said to be created with the video codec operation `pCreateInfo->videoSession` was created with.

If `pCreateInfo->videoSessionParametersTemplate` is not `VK_NULL_HANDLE`, then it will be used as a template for constructing the new video session parameters object. This happens by first adding any parameters according to the additional creation parameters provided in the `pCreateInfo->pNext` chain, followed by adding any parameters from the template object that have a key that does not match the key of any of the already added parameters.

If `pCreateInfo->videoSession` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODER_H264_BIT_KHR`, then the created video session parameters object will initially contain the following sets of parameter entries:

- **StdVideoH264SequenceParameterSet** structures representing H.264 SPS entries, as follows:
  - If the `pParametersAddInfo` member of the `VkVideoDecodeH264SessionParametersCreateInfoKHR` structure provided in the `pCreateInfo->pNext` chain is not `NULL`, then the set of `StdVideoH264SequenceParameterSet` entries specified in `pParametersAddInfo->pStdSPSs` are added first;
  - If `pCreateInfo->videoSessionParametersTemplate` is not `VK_NULL_HANDLE`, then each `StdVideoH264SequenceParameterSet` entry stored in it is copied to the created video session parameters object if the created object does not already contain such an entry with the same `seq_parameter_set_id`.

- **StdVideoH264PictureParameterSet** structures representing H.264 PPS entries, as follows:
  - If the `pParametersAddInfo` member of the `VkVideoDecodeH264SessionParametersCreateInfoKHR` structure provided in the `pCreateInfo->pNext` chain is not `NULL`, then the set of `StdVideoH264PictureParameterSet` entries specified in `pParametersAddInfo->pStdPPSs` are added first;
  - If `pCreateInfo->videoSessionParametersTemplate` is not `VK_NULL_HANDLE`, then each `StdVideoH264PictureParameterSet` entry stored in it is copied to the created video session parameters object if the created object does not already contain such an entry with the same `seq_parameter_set_id` and `pic_parameter_set_id`.

If `pCreateInfo->videoSession` was created with the video codec operation
VK_VIDEO_CODEC_OPERATION_DECOD_H265_BIT_KHR, then the created video session parameters object will initially contain the following sets of parameter entries:

- **StdVideoH265VideoParameterSet** structures representing **H.265 VPS** entries, as follows:
  - If the `pParametersAddInfo` member of the `VkVideoDecodeH265SessionParametersCreateInfoKHR` structure provided in the `pCreateInfo->pNext` chain is not NULL, then the set of `StdVideoH265VideoParameterSet` entries specified in `pParametersAddInfo->pStdVPSs` are added first;
  - If `pCreateInfo->videoSessionParametersTemplate` is not `VK_NULL_HANDLE`, then each `StdVideoH265VideoParameterSet` entry stored in it is copied to the created video session parameters object if the created object does not already contain such an entry with the same `vps_video_parameter_set_id`.

- **StdVideoH265SequenceParameterSet** structures representing **H.265 SPS** entries, as follows:
  - If the `pParametersAddInfo` member of the `VkVideoDecodeH265SessionParametersCreateInfoKHR` structure provided in the `pCreateInfo->pNext` chain is not NULL, then the set of `StdVideoH265SequenceParameterSet` entries specified in `pParametersAddInfo->pStdSPSs` are added first;
  - If `pCreateInfo->videoSessionParametersTemplate` is not `VK_NULL_HANDLE`, then each `StdVideoH265SequenceParameterSet` entry stored in it is copied to the created video session parameters object if the created object does not already contain such an entry with the same `sps_video_parameter_set_id` and `sps_seq_parameter_set_id`.

- **StdVideoH265PictureParameterSet** structures representing **H.265 PPS** entries, as follows:
  - If the `pParametersAddInfo` member of the `VkVideoDecodeH265SessionParametersCreateInfoKHR` structure provided in the `pCreateInfo->pNext` chain is not NULL, then the set of `StdVideoH265PictureParameterSet` entries specified in `pParametersAddInfo->pStdPPSs` are added first;
  - If `pCreateInfo->videoSessionParametersTemplate` is not `VK_NULL_HANDLE`, then each `StdVideoH265PictureParameterSet` entry stored in it is copied to the created video session parameters object if the created object does not already contain such an entry with the same `sps_video_parameter_set_id`, `pps_seq_parameter_set_id`, and `pps_pic_parameter_set_id`.

In case of video session parameters objects created with a video encode operation, implementations **may** return the `VK_ERROR_INVALID_VIDEO_STD_PARAMETERS_KHR` error if any of the specified Video Std parameters do not adhere to the syntactic or semantic requirements of the used video compression standard, or if values derived from parameters according to the rules defined by the used video compression standard do not adhere to the capabilities of the video compression standard or the implementation.

**Note**

Applications **should** not rely on the `VK_ERROR_INVALID_VIDEO_STD_PARAMETERS_KHR` error being returned by any command as a means to verify Video Std parameters, as implementations are not required to report the error in any specific set of cases.
### Valid Usage (Implicit)

- **VUID-vkCreateVideoSessionParametersKHR-device-parameter**
  
  `device` must be a valid `VkDevice` handle

- **VUID-vkCreateVideoSessionParametersKHR-pCreateInfo-parameter**
  
  `pCreateInfo` must be a valid pointer to a valid `VkVideoSessionParametersCreateInfoKHR` structure

- **VUID-vkCreateVideoSessionParametersKHR-pAllocator-parameter**
  
  If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

- **VUID-vkCreateVideoSessionParametersKHR-pVideoSessionParameters-parameter**
  
  `pVideoSessionParameters` must be a valid pointer to a `VkVideoSessionParametersKHR` handle

### Return Codes

**Success**

- `VK_SUCCESS`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_INITIALIZATION_FAILED`
- `VK_ERROR_INVALID_VIDEO_STD_PARAMETERS_KHR`

The `VkVideoSessionParametersCreateInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_video_queue
typedef struct VkVideoSessionParametersCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkVideoSessionParametersCreateFlagsKHR flags;
    VkVideoSessionParametersKHR videoSessionParametersTemplate;
    VkVideoSessionKHR videoSession;
} VkVideoSessionParametersCreateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is reserved for future use.
- `videoSessionParametersTemplate` is `VK_NULL_HANDLE` or a valid handle to a `VkVideoSessionParametersKHR` object used as a template for constructing the new video session parameters object.
- **videoSession** is the video session object against which the video session parameters object is going to be created.

Limiting values are defined below that are referenced by the relevant valid usage statements of this structure.

- If `videoSession` was created with the codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR`, then let `StdVideoH264SequenceParameterSet spsAddList[]` be the list of H.264 SPS entries to add to the created video session parameters object, defined as follows:
  - If the `pParametersAddInfo` member of the `VkVideoDecodeH264SessionParametersCreateInfoKHR` structure provided in the `pNext` chain is not `NULL`, then the set of `StdVideoH264SequenceParameterSet` entries specified in `pParametersAddInfo->pStdSPSs` are added to `spsAddList`;
  - If `videoSessionParametersTemplate` is not `VK_NULL_HANDLE`, then each `StdVideoH264SequenceParameterSet` entry stored in it with `seq_parameter_set_id` not matching any of the entries already in `spsAddList` is added to `spsAddList`.

- If `videoSession` was created with the codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR`, then let `StdVideoH264PictureParameterSet ppsAddList[]` be the list of H.264 PPS entries to add to the created video session parameters object, defined as follows:
  - If the `pParametersAddInfo` member of the `VkVideoDecodeH264SessionParametersCreateInfoKHR` structure provided in the `pNext` chain is not `NULL`, then the set of `StdVideoH264PictureParameterSet` entries specified in `pParametersAddInfo->pStdPPSs` are added to `ppsAddList`;
  - If `videoSessionParametersTemplate` is not `VK_NULL_HANDLE`, then each `StdVideoH264PictureParameterSet` entry stored in it with `seq_parameter_set_id` or `pic_parameter_set_id` not matching any of the entries already in `ppsAddList` is added to `ppsAddList`.

- If `videoSession` was created with the codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, then let `StdVideoH265VideoParameterSet vpsAddList[]` be the list of H.265 VPS entries to add to the created video session parameters object, defined as follows:
  - If the `pParametersAddInfo` member of the `VkVideoDecodeH265SessionParametersCreateInfoKHR` structure provided in the `pNext` chain is not `NULL`, then the set of `StdVideoH265VideoParameterSet` entries specified in `pParametersAddInfo->pStdVPSs` are added to `vpsAddList`;
  - If `videoSessionParametersTemplate` is not `VK_NULL_HANDLE`, then each `StdVideoH265VideoParameterSet` entry stored in it with `vps_video_parameter_set_id` not matching any of the entries already in `vpsAddList` is added to `vpsAddList`.

- If `videoSession` was created with the codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, then let `StdVideoH265SequenceParameterSet spsAddList[]` be the list of H.265 SPS entries to add to the created video session parameters object, defined as follows:
If the `pParametersAddInfo` member of the `VkVideoDecodeH265SessionParametersCreateInfoKHR` structure provided in the `pNext` chain is not `NULL`, then the set of `StdVideoH265SequenceParameterSet` entries specified in `pParametersAddInfo->pStdSPSs` are added to `spsAddList`;

If `videoSessionParametersTemplate` is not `VK_NULL_HANDLE`, then each `StdVideoH265SequenceParameterSet` entry stored in it with `sps_video_parameter_set_id` or `sps_seq_parameter_set_id` not matching any of the entries already in `spsAddList` is added to `spsAddList`.

If `videoSession` was created with the codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, then let `StdVideoH265PictureParameterSet` `ppsAddList[]` be the list of H.265 PPS entries to add to the created video session parameters object, defined as follows:

- If the `pParametersAddInfo` member of the `VkVideoDecodeH265SessionParametersCreateInfoKHR` structure provided in the `pNext` chain is not `NULL`, then the set of `StdVideoH265PictureParameterSet` entries specified in `pParametersAddInfo->pStdPPSs` are added to `ppsAddList`;
- If `videoSessionParametersTemplate` is not `VK_NULL_HANDLE`, then each `StdVideoH265PictureParameterSet` entry stored in it with `sps_video_parameter_set_id`, `pps_seq_parameter_set_id`, or `pps_pic_parameter_set_id` not matching any of the entries already in `ppsAddList` is added to `ppsAddList`.

### Valid Usage

- **VUID-VkVideoSessionParametersCreateInfoKHR-videoSessionParametersTemplate-04855**
  If `videoSessionParametersTemplate` represents a valid handle, it must have been created against `videoSession`.

- **VUID-VkVideoSessionParametersCreateInfoKHR-videoSession-07203**
  If `videoSession` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR`, then the `pNext` chain must include a `VkVideoDecodeH264SessionParametersCreateInfoKHR` structure.

- **VUID-VkVideoSessionParametersCreateInfoKHR-videoSession-07204**
  If `videoSession` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR`, then the number of elements of `spsAddList` must be less than or equal to the `maxStdSPSCount` specified in the `VkVideoDecodeH264SessionParametersCreateInfoKHR` structure included in the `pNext` chain.

- **VUID-VkVideoSessionParametersCreateInfoKHR-videoSession-07205**
  If `videoSession` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR`, then the number of elements of `ppsAddList` must be less than or equal to the `maxStdPPSCount` specified in the `VkVideoDecodeH264SessionParametersCreateInfoKHR` structure included in the `pNext` chain.

- **VUID-VkVideoSessionParametersCreateInfoKHR-videoSession-07206**
  If `videoSession` was created with the video codec operation
VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR, then the pNext chain must include a
VkVideoDecodeH265SessionParametersCreateInfoKHR structure

- VUID-VkVideoSessionParametersCreateInfoKHR-videoSession-07207
  If videoSession was created with the video codec operation
  VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR, then the number of elements of vpsAddList
  must be less than or equal to the maxStdVPSCount specified in the
  VkVideoDecodeH265SessionParametersCreateInfoKHR structure included in the pNext
  chain

- VUID-VkVideoSessionParametersCreateInfoKHR-videoSession-07208
  If videoSession was created with the video codec operation
  VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR, then the number of elements of spsAddList
  must be less than or equal to the maxStdSPSCount specified in the
  VkVideoDecodeH265SessionParametersCreateInfoKHR structure included in the pNext
  chain

- VUID-VkVideoSessionParametersCreateInfoKHR-videoSession-07209
  If videoSession was created with the video codec operation
  VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR, then the number of elements of ppsAddList
  must be less than or equal to the maxStdPPSCount specified in the
  VkVideoDecodeH265SessionParametersCreateInfoKHR structure included in the pNext
  chain

- VUID-VkVideoSessionParametersCreateInfoKHR-videoSession-07210
  If videoSession was created with the video codec operation
  VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT, then the pNext chain must include a
  VkVideoEncodeH264SessionParametersCreateInfoEXT structure

- VUID-VkVideoSessionParametersCreateInfoKHR-videoSession-07211
  If videoSession was created with the video codec operation
  VK_VIDEO_CODEC_OPERATION_ENCODE_H265_BIT_EXT, then the pNext chain must include a
  VkVideoEncodeH265SessionParametersCreateInfoEXT structure

Valid Usage (Implicit)

- VUID-VkVideoSessionParametersCreateInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_VIDEO_SESSION_PARAMETERS_CREATE_INFO_KHR

- VUID-VkVideoSessionParametersCreateInfoKHR-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either
  NULL or a pointer to a valid instance of
  VkVideoDecodeH264SessionParametersCreateInfoKHR,
  VkVideoDecodeH265SessionParametersCreateInfoKHR,
  VkVideoEncodeH264SessionParametersCreateInfoEXT,
  VkVideoEncodeH265SessionParametersCreateInfoEXT,
  or
  VkVideoEncodeQualityLevelInfoKHR

- VUID-VkVideoSessionParametersCreateInfoKHR-sType-unique
  The sType value of each struct in the pNext chain must be unique
• VUID-VkVideoSessionParametersCreateInfoKHR-flags-zerobitmask
  flags must be 0

• VUID-VkVideoSessionParametersCreateInfoKHR-videoSessionParametersTemplate-parameter
  If videoSessionParametersTemplate is not VK_NULL_HANDLE, videoSessionParametersTemplate must be a valid VkVideoSessionParametersKHR handle

• VUID-VkVideoSessionParametersCreateInfoKHR-videoSession-parameter
  videoSession must be a valid VkVideoSessionKHR handle

• VUID-VkVideoSessionParametersCreateInfoKHR-videoSessionParametersTemplate-parent
  If videoSessionParametersTemplate is a valid handle, it must have been created, allocated, or retrieved from videoSession

• VUID-VkVideoSessionParametersCreateInfoKHR-commonparent
  Both of videoSession, and videoSessionParametersTemplate that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice

// Provided by VK_KHR_video_queue
typedef VkFlags VkVideoSessionParametersCreateFlagsKHR;

VkVideoSessionParametersCreateFlagsKHR is a bitmask type for setting a mask, but is currently reserved for future use.

42.7.2. Destroying Video Session Parameters

To destroy a video session parameters object, call:

// Provided by VK_KHR_video_queue
void vkDestroyVideoSessionParametersKHR(
    VkDevice device,
    VkVideoSessionParametersKHR videoSessionParameters,
    const VkAllocationCallbacks* pAllocator);

• device is the logical device that destroys the video session parameters object.
• videoSessionParameters is the video session parameters object to destroy.
• pAllocator controls host memory allocation as described in the Memory Allocation chapter.

Valid Usage

• VUID-vkDestroyVideoSessionParametersKHR-videoSessionParameters-07212
  All submitted commands that refer to videoSessionParameters must have completed execution

• VUID-vkDestroyVideoSessionParametersKHR-videoSessionParameters-07213
  If VkAllocationCallbacks were provided when videoSessionParameters was created, a
compatible set of callbacks must be provided here

- VUID-vkDestroyVideoSessionParametersKHR-videoSessionParameters-07214
  If no VkAllocationCallbacks were provided when videoSessionParameters was created, pAllocator must be NULL

Valid Usage (Implicit)

- VUID-vkDestroyVideoSessionParametersKHR-device-parameter
device must be a valid VkDevice handle

- VUID-vkDestroyVideoSessionParametersKHR-videoSessionParameters-parameter
If videoSessionParameters is not VK_NULL_HANDLE, videoSessionParameters must be a valid VkVideoSessionParametersKHR handle

- VUID-vkDestroyVideoSessionParametersKHR-pAllocator-parameter
If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- VUID-vkDestroyVideoSessionParametersKHR-videoSessionParameters-parent
If videoSessionParameters is a valid handle, it must have been created, allocated, or retrieved from device

Host Synchronization

- Host access to videoSessionParameters must be externally synchronized

42.7.3. Updating Video Session Parameters

To update video session parameters object with new parameters, call:

```c
// Provided by VK_KHR_video_queue
VkResult vkUpdateVideoSessionParametersKHR(
    VkDevice device,       // Provided by VK_KHR_video_queue
    VkVideoSessionParametersKHR videoSessionParameters, // Provided by VK_KHR_video_queue
    const VkVideoSessionParametersUpdateInfoKHR* pUpdateInfo);
```

- device is the logical device that updates the video session parameters.
- videoSessionParameters is the video session parameters object to update.
- pUpdateInfo is a pointer to a VkVideoSessionParametersUpdateInfoKHR structure specifying the parameter update information.

After a successful call to this command, the update sequence counter of videoSessionParameters is changed to the value specified in pUpdateInfo->updateSequenceCount.

Note:
As each update issued to a video session parameters object needs to specify the next available update sequence count value, concurrent updates of the same video session parameters object are inherently disallowed. However, recording video coding operations to command buffers referring to parameters previously added to the video session parameters object is allowed, even if there is a concurrent update in progress adding some new entries to the object.

If \texttt{videoSessionParameters} was created with the video codec operation \texttt{VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR} and the \texttt{pUpdateInfo->pNext} chain includes a \texttt{VkVideoDecodeH264SessionParametersAddInfoKHR} structure, then this command adds the following parameter entries to \texttt{videoSessionParameters}:

- The \texttt{H.264 SPS} entries specified in \texttt{VkVideoDecodeH264SessionParametersAddInfoKHR::pStdSPSs}.
- The \texttt{H.264 PPS} entries specified in \texttt{VkVideoDecodeH264SessionParametersAddInfoKHR::pStdPPSs}.

If \texttt{videoSessionParameters} was created with the video codec operation \texttt{VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR} and the \texttt{pUpdateInfo->pNext} chain includes a \texttt{VkVideoDecodeH265SessionParametersAddInfoKHR} structure, then this command adds the following parameter entries to \texttt{videoSessionParameters}:

- The \texttt{H.265 VPS} entries specified in \texttt{VkVideoDecodeH265SessionParametersAddInfoKHR::pStdVPSs}.
- The \texttt{H.265 SPS} entries specified in \texttt{VkVideoDecodeH265SessionParametersAddInfoKHR::pStdSPSs}.
- The \texttt{H.265 PPS} entries specified in \texttt{VkVideoDecodeH265SessionParametersAddInfoKHR::pStdPPSs}.

In case of video session parameters objects created with a video encode operation, implementations \textbf{may} return the \texttt{VK_ERROR_INVALID_VIDEO_STD_PARAMETERS_KHR} error if any of the specified Video Std parameters do not adhere to the syntactic or semantic requirements of the used video compression standard, or if values derived from parameters according to the rules defined by the used video compression standard do not adhere to the capabilities of the video compression standard or the implementation.

\textbf{Note}

Applications \textbf{should} not rely on the \texttt{VK_ERROR_INVALID_VIDEO_STD_PARAMETERS_KHR} error being returned by any command as a means to verify Video Std parameters, as implementations are not required to report the error in any specific set of cases.

\textbf{Valid Usage}

- \texttt{VUID-vkUpdateVideoSessionParametersKHR-pUpdateInfo-07215}
  \texttt{pUpdateInfo->updateSequenceCount} \textbf{must} equal the current \texttt{update sequence counter} of \texttt{videoSessionParameters} plus one
If `videoSessionParameters` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR` and the `pNext` chain of `pUpdateInfo` includes a `VkVideoDecodeH264SessionParametersAddInfoKHR` structure, then `videoSessionParameters` must not already contain a `StdVideoH264SequenceParameterSet` entry with `seq_parameter_set_id` matching any of the elements of `VkVideoDecodeH264SessionParametersAddInfoKHR::pStdSPSs`.

If `videoSessionParameters` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR`, then the number of `StdVideoH264SequenceParameterSet` entries already stored in it plus the value of the `stdSPSCount` member of the `VkVideoDecodeH264SessionParametersAddInfoKHR` structure included in the `pUpdateInfo->pNext` chain must be less than or equal to the `VkVideoDecodeH264SessionParametersCreateInfoKHR::maxStdSPSCount`.

If `videoSessionParameters` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR` and the `pNext` chain of `pUpdateInfo` includes a `VkVideoDecodeH265SessionParametersAddInfoKHR` structure, then `videoSessionParameters` must not already contain a `StdVideoH265VideoParameterSet` entry with `vps_video_parameter_set_id` matching any of the elements of `VkVideoDecodeH265SessionParametersAddInfoKHR::pStdVPSs`.

If `videoSessionParameters` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, then the number of `StdVideoH265VideoParameterSet` entries already stored in it plus the value of the `stdVPSCount` member of the `VkVideoDecodeH265SessionParametersAddInfoKHR` structure included in the `pUpdateInfo->pNext` chain must be less than or equal to the `VkVideoDecodeH265SessionParametersCreateInfoKHR::maxStdVPSCount`.

If `videoSessionParameters` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR` and the `pNext` chain of `pUpdateInfo` includes a `VkVideoDecodeH265SessionParametersAddInfoKHR` structure, then `videoSessionParameters` must not already contain a `StdVideoH265PictureParameterSet` entry with `seq_parameter_set_id` and `pic_parameter_set_id` matching any of the elements of `VkVideoDecodeH265SessionParametersAddInfoKHR::pStdPPSs`.

If `videoSessionParameters` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, then the number of `StdVideoH265PictureParameterSet` entries already stored in it plus the value of the `stdPPSCount` member of the `VkVideoDecodeH265SessionParametersAddInfoKHR` structure included in the `pUpdateInfo->pNext` chain must be less than or equal to the `VkVideoDecodeH265SessionParametersCreateInfoKHR::maxStdPPSCount`. 
If `videoSessionParameters` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR` and the `pNext` chain of `pUpdateInfo` includes a `VkVideoDecodeH265SessionParametersAddInfoKHR` structure, then `videoSessionParameters` must not already contain a `StdVideoH265SequenceParameterSet` entry with both `sps_video_parameter_set_id` and `sps_seq_parameter_set_id` matching any of the elements of `VkVideoDecodeH265SessionParametersAddInfoKHR::pStdSPSs`.

If `videoSessionParameters` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, then the number of `StdVideoH265SequenceParameterSet` entries already stored in it plus the value of the `stdSPSCount` member of the `VkVideoDecodeH265SessionParametersAddInfoKHR` structure included in the `pUpdateInfo->pNext` chain must be less than or equal to the `VkVideoDecodeH265SessionParametersCreateInfoKHR::maxStdSPSCount`.

If `videoSessionParameters` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT` and the `pNext` chain of `pUpdateInfo` includes a `VkVideoEncodeH264SessionParametersAddInfoEXT` structure, then `videoSessionParameters` must not already contain a `StdVideoH264SequenceParameterSet` entry with `seq_parameter_set_id` matching any of the elements of `VkVideoEncodeH264SessionParametersAddInfoEXT::pStdSPSs`.

If `videoSessionParameters` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT` and the `pNext` chain of `pUpdateInfo` includes a `VkVideoEncodeH264SessionParametersAddInfoEXT` structure, then `videoSessionParameters` must not already contain a `StdVideoH264PictureParameterSet` entry with both `seq_parameter_set_id` and `pic_parameter_set_id` matching any of the elements of `VkVideoEncodeH264SessionParametersAddInfoEXT::pStdPPSs`.

If `videoSessionParameters` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT`, then the number of `StdVideoH264PictureParameterSet` entries already stored in it plus the value of the `stdPPSCount` member of the `VkVideoEncodeH264SessionParametersAddInfoEXT` structure included in the `pUpdateInfo->pNext` chain must be less than or equal to the `VkVideoEncodeH264SessionParametersCreateInfoEXT::maxStdPPSCount`.

If `videoSessionParameters` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT`, then the number of `StdVideoH264PictureParameterSet` entries already stored in it plus the value of the `stdPPSCount` member of the `VkVideoEncodeH264SessionParametersAddInfoEXT` structure included in the `pUpdateInfo->pNext` chain must be less than or equal to the `VkVideoEncodeH264SessionParametersCreateInfoEXT::maxStdPPSCount`.

If `videoSessionParameters` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT` and the `pNext` chain of `pUpdateInfo` includes a `VkVideoEncodeH264SessionParametersAddInfoEXT` structure, then `videoSessionParameters` must not already contain a `StdVideoH264SequenceParameterSet` entry with `seq_parameter_set_id` matching any of the elements of `VkVideoEncodeH264SessionParametersAddInfoEXT::pStdSPSs`.

If `videoSessionParameters` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT` and the `pNext` chain of `pUpdateInfo` includes a `VkVideoEncodeH264SessionParametersAddInfoEXT` structure, then `videoSessionParameters` must not already contain a `StdVideoH264PictureParameterSet` entry with both `seq_parameter_set_id` and `pic_parameter_set_id` matching any of the elements of `VkVideoEncodeH264SessionParametersAddInfoEXT::pStdPPSs`.
If videoSessionParameters was created with the video codec operation VK_VIDEO_CODEC_OPERATION_ENCODE_H265_BIT_EXT and the pNext chain of pUpdateInfo includes a VkVideoEncodeH265SessionParametersAddInfoEXT structure, then videoSessionParameters must not already contain a StdVideoH265VideoParameterSet entry with vps_video_parameter_set_id matching any of the elements of VkVideoEncodeH265SessionParametersAddInfoEXT::pStdVPSs.

If videoSessionParameters was created with the video codec operation VK_VIDEO_CODEC_OPERATION_ENCODE_H265_BIT_EXT and the pNext chain of pUpdateInfo includes a VkVideoEncodeH265SessionParametersAddInfoEXT structure, then videoSessionParameters must not already contain a StdVideoH265SequenceParameterSet entry with both sps_video_parameter_set_id and sps_seq_parameter_set_id matching any of the elements of VkVideoEncodeH265SessionParametersAddInfoEXT::pStdSPSs.

If videoSessionParameters was created with the video codec operation VK_VIDEO_CODEC_OPERATION_ENCODE_H265_BIT_EXT and the pNext chain of pUpdateInfo includes a VkVideoEncodeH265SessionParametersAddInfoEXT structure, then videoSessionParameters must not already contain a StdVideoH265PictureParameterSet entry with sps_video_parameter_set_id, pps_seq_parameter_set_id, and pps_pic_parameter_set_id all matching any of the elements of VkVideoEncodeH265SessionParametersAddInfoEXT::pStdPPSs.

Valid Usage (Implicit)

- VUID-vkUpdateVideoSessionParametersKHR-device-parameter: device must be a valid VkDevice handle
- VUID-vkUpdateVideoSessionParametersKHR-videoSessionParameters-parameter: videoSessionParameters must be a valid VkVideoSessionParametersKHR handle
- VUID-vkUpdateVideoSessionParametersKHR-pUpdateInfo-parameter: pUpdateInfo must be a valid pointer to a valid VkVideoSessionParametersUpdateInfoKHR structure
- VUID-vkUpdateVideoSessionParametersKHR-videoSessionParameters-parent: videoSessionParameters must have been created, allocated, or retrieved from device

Return Codes

Success
- VK_SUCCESS

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
The `VkVideoSessionParametersUpdateInfoKHR` structure is defined as:

```c
typedef struct VkVideoSessionParametersUpdateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t updateSequenceCount;
} VkVideoSessionParametersUpdateInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `updateSequenceCount` is the new update sequence count to set for the video session parameters object.

### Valid Usage (Implicit)

- VUID-VkVideoSessionParametersUpdateInfoKHR-sType-sType
  * `sType` must be `VK_STRUCTURE_TYPE_VIDEO_SESSION_PARAMETERS_UPDATE_INFO_KHR`

- VUID-VkVideoSessionParametersUpdateInfoKHR-pNext-pNext
  * Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkVideoDecodeH264SessionParametersAddInfoKHR`, `VkVideoDecodeH265SessionParametersAddInfoKHR`, `VkVideoEncodeH264SessionParametersAddInfoEXT`, or `VkVideoEncodeH265SessionParametersAddInfoEXT`

- VUID-VkVideoSessionParametersUpdateInfoKHR-sType-unique
  * The `sType` value of each struct in the `pNext` chain must be unique

### 42.8. Video Coding Scope

Applications can record video coding commands for a video session only within a video coding scope.

To begin a video coding scope, call:

```c
void vkCmdBeginVideoCodingKHR(
    VkCommandBuffer commandBuffer,
    const VkVideoBeginCodingInfoKHR* pBeginInfo);
```

- `commandBuffer` is the command buffer in which to record the command.
• `pBeginInfo` is a pointer to a `VkVideoBeginCodingInfoKHR` structure specifying the parameters of the video coding scope, including the video session and video session parameters object to use.

After beginning a video coding scope, the video session object specified in `pBeginInfo->videoSession` is `bound` to the command buffer, and the command buffer is ready to record video coding operations. Similarly, if `pBeginInfo->videoSessionParameters` is not `VK_NULL_HANDLE`, it is also `bound` to the command buffer, and video coding operations can refer to the codec-specific parameters stored in it.

This command also establishes the set of `bound reference picture resources` that can be used as `reconstructed pictures` or `reference pictures` within the video coding scope. Each element of this set consists of a `video picture resource` and the DPB slot index associated with it, if there is one.

The set of bound reference picture resources is immutable within a video coding scope, however, the DPB slot index associated with any of the bound reference picture resources can change during the video coding scope in response to video coding operations.

The `VkVideoReferenceSlotInfoKHR` structures provided as the elements of `pBeginInfo->pReferenceSlots` are interpreted by this command as follows:

- If `slotIndex` is non-negative and `pPictureResource` is not `NULL`, then the `video picture resource` defined by the `VkVideoPictureResourceInfoKHR` structure pointed to by `pPictureResource` is added to the set of bound reference picture resources and is associated with the DPB slot index specified in `slotIndex`.
- If `slotIndex` is non-negative and `pPictureResource` is `NULL`, then the DPB slot with index `slotIndex` is `deactivated` by this command.
- If `slotIndex` is negative and `pPictureResource` is not `NULL`, then the `video picture resource` defined by the `VkVideoPictureResourceInfoKHR` structure pointed to by `pPictureResource` is added to the set of bound reference picture resources without an associated DPB slot. Such a picture resource can be subsequently used as a `reconstructed picture` to associate it with a DPB slot.
- If `slotIndex` is negative and `pPictureResource` is `NULL`, then the element is ignored.

**Note:**

It is possible for multiple bound reference picture resources to be associated with the same DPB slot index, or for a single bound reference picture to refer to multiple separate reference pictures. For example, in case of an H.264 decode profile with interlaced frame support a single DPB slot can refer to two separate pictures for the top and bottom fields. Depending on the picture layout used by the H.264 decode profile, the following special cases may arise:

- If the picture layout is `VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_INTERLEAVED_LINES_BIT_KHR`, then the top and bottom field pictures are physically co-located in the same video picture resource with even scanlines corresponding to the top field and odd scanlines corresponding to the bottom field, respectively.
- If the picture layout is `VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_SEPARATE_PLANES_BIT_KHR`, then...
the top and bottom field pictures are stored in separate video picture resources (in separate subregions of the same image layer, in separate layers of the same image, or in entirely separate images), hence two elements of 

\texttt{VkVideoBeginCodingInfoKHR::pReferenceSlots} can contain the same \texttt{slotIndex} but specify different video picture resources in their \texttt{pPictureResource} members.

All non-negative \texttt{slotIndex} values specified in the elements of \texttt{pBeginInfo->pReferenceSlots} must identify DPB slots of the video session that are in the \textit{active state} at the time this command is executed on the device.

\textit{Note:}

The application does not have to specify an entry in \texttt{pBeginInfo->pReferenceSlots} corresponding to all active DPB slots of the video session, but only for those which are intended to be used in the video coding scope. This way the application can avoid any potential runtime cost associated with binding the corresponding picture resources to the command buffer.

\textbf{Valid Usage}

- **VUID-vkCmdBeginVideoCodingKHR-commandBuffer-07231**
  The \texttt{VkCommandPool} that \texttt{commandBuffer} was allocated from must support the video codec operation \texttt{pBeginInfo->videoSession} was created with, as returned by \texttt{vkGetPhysicalDeviceQueueFamilyProperties2} in \texttt{VkQueueFamilyVideoPropertiesKHR::videoCodecOperations}

- **VUID-vkCmdBeginVideoCodingKHR-None-07232**
  There must be no active queries.

- **VUID-vkCmdBeginVideoCodingKHR-commandBuffer-07233**
  If \texttt{commandBuffer} is an unprotected command buffer and \texttt{protectedNoFault} is not supported, then \texttt{pBeginInfo->videoSession} must not have been created with \texttt{VK_VIDEO_SESSION_CREATE_PROTECTED_CONTENT_BIT_KHR}

- **VUID-vkCmdBeginVideoCodingKHR-commandBuffer-07234**
  If \texttt{commandBuffer} is a protected command buffer and \texttt{protectedNoFault} is not supported, then \texttt{pBeginInfo->videoSession} must have been created with \texttt{VK_VIDEO_SESSION_CREATE_PROTECTED_CONTENT_BIT_KHR}

- **VUID-vkCmdBeginVideoCodingKHR-commandBuffer-07235**
  If \texttt{commandBuffer} is an unprotected command buffer, \texttt{protectedNoFault} is not supported, and the \texttt{pPictureResource} member of any element of \texttt{pBeginInfo->pReferenceSlots} is not NULL, then \texttt{pPictureResource->imageViewBinding} for that element must not specify an image view created from a protected image.

- **VUID-vkCmdBeginVideoCodingKHR-commandBuffer-07236**
  If \texttt{commandBuffer} is a protected command buffer \texttt{protectedNoFault} is not supported, and the \texttt{pPictureResource} member of any element of \texttt{pBeginInfo->pReferenceSlots} is not NULL, then \texttt{pPictureResource->imageViewBinding} for that element must specify an image view created from a protected image.
• VUID-vkCmdBeginVideoCodingKHR-slotIndex-07239
  If the slotIndex member of any element of pBeginInfo->pReferenceSlots is not negative, then it must specify the index of a DPB slot that is in the active state in pBeginInfo->videoSession at the time the command is executed on the device.

• VUID-vkCmdBeginVideoCodingKHR-pPictureResource-07265
  Each video picture resource specified by any non-NULL pPictureResource member specified in the elements of pBeginInfo->pReferenceSlots for which slotIndex is not negative must match one of the video picture resources currently associated with the DPB slot index of pBeginInfo->videoSession specified by slotIndex at the time the command is executed on the device.

---

**Valid Usage (Implicit)**

• VUID-vkCmdBeginVideoCodingKHR-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

• VUID-vkCmdBeginVideoCodingKHR-pBeginInfo-parameter
  pBeginInfo must be a valid pointer to a valid VkVideoBeginCodingInfoKHR structure

• VUID-vkCmdBeginVideoCodingKHR-commandBuffer-recording
  commandBuffer must be in the recording state

• VUID-vkCmdBeginVideoCodingKHR-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support decode, or encode operations

• VUID-vkCmdBeginVideoCodingKHR-renderpass
  This command must only be called outside of a render pass instance

• VUID-vkCmdBeginVideoCodingKHR-videocoding
  This command must only be called outside of a video coding scope

• VUID-vkCmdBeginVideoCodingKHR-bufferlevel
  commandBuffer must be a primary VkCommandBuffer

---

**Host Synchronization**

• Host access to commandBuffer must be externally synchronized

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
The `VkVideoBeginCodingInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_video_queue
typedef struct VkVideoBeginCodingInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkVideoBeginCodingFlagsKHR flags;
    VkVideoSessionKHR videoSession;
    VkVideoSessionParametersKHR videoSessionParameters;
    uint32_t referenceSlotCount;
    const VkVideoReferenceSlotInfoKHR* pReferenceSlots;
} VkVideoBeginCodingInfoKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **videoSession** is the video session object to be bound for the processing of the video commands.
- **videoSessionParameters** is `VK_NULL_HANDLE` or a handle of a `VkVideoSessionParametersKHR` object to be used for the processing of the video commands. If `VK_NULL_HANDLE`, then no video session parameters object is bound for the duration of the video coding scope.
- **referenceSlotCount** is the number of elements in the `pReferenceSlots` array.
- **pReferenceSlots** is a pointer to an array of `VkVideoReferenceSlotInfoKHR` structures specifying the information used to determine the set of bound reference picture resources for the video coding scope and their initial association with DPB slot indices.

Limiting values are defined below that are referenced by the relevant valid usage statements of this structure.

- Let `VkOffset2D codedOffsetGranularity` be the minimum alignment requirement for the coded offset of video picture resources. Unless otherwise defined, the value of the `x` and `y` members of `codedOffsetGranularity` are 0.
  - If `videoSession` was created with an H.264 decode profile with a `VkVideoDecodeH264ProfileInfoKHR::pictureLayout` of `VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_SEPARATE_PLANES_BIT_KHR`, then `codedOffsetGranularity` is equal to `VkVideoDecodeH264CapabilitiesKHR::fieldOffsetGranularity`, as returned by `vkGetPhysicalDeviceVideoCapabilitiesKHR` for that
Valid Usage

- VUID-VkVideoBeginCodingInfoKHR-videoSession-07237
  
  `videoSession` must have memory bound to all of its memory bindings returned by `vkGetVideoSessionMemoryRequirementsKHR` for `videoSession`.

- VUID-VkVideoBeginCodingInfoKHR-slotIndex-04856
  
  Each non-negative `VkVideoReferenceSlotInfoKHR::slotIndex` specified in the elements of `pReferenceSlots` must be less than the `VkVideoSessionCreateInfoKHR::maxDpbSlots` specified when `videoSession` was created.

- VUID-VkVideoBeginCodingInfoKHR-pPictureResource-07238
  
  Each video picture resource corresponding to any non-NULL `pPictureResource` member specified in the elements of `pReferenceSlots` must be unique within `pReferenceSlots`.

- VUID-VkVideoBeginCodingInfoKHR-pPictureResource-07240
  
  If the `pPictureResource` member of any element of `pReferenceSlots` is not NULL, then the image view specified in `pPictureResource->imageViewBinding` for that element must be compatible with the video profile `videoSession` was created with.

- VUID-VkVideoBeginCodingInfoKHR-pPictureResource-07241
  
  If the `pPictureResource` member of any element of `pReferenceSlots` is not NULL, then the format of the image view specified in `pPictureResource->imageViewBinding` for that element must match the `VkVideoSessionCreateInfoKHR::referencePictureFormat` `videoSession` was created with.

- VUID-VkVideoBeginCodingInfoKHR-pPictureResource-07242
  
  If the `pPictureResource` member of any element of `pReferenceSlots` is not NULL, then its `codedOffset` member must be an integer multiple of `codedOffsetGranularity`.

- VUID-VkVideoBeginCodingInfoKHR-pPictureResource-07243
  
  If the `pPictureResource` member of any element of `pReferenceSlots` is not NULL, then its `codedExtent` member must be between `minCodedExtent` and `maxCodedExtent`, inclusive, `videoSession` was created with.

- VUID-VkVideoBeginCodingInfoKHR-flags-07244
  
  If `VkVideoCapabilitiesKHR::flags` does not include `VK_VIDEO_CAPABILITY_SEPARATE_REFERENCE_IMAGES_BIT_KHR`, as returned by `vkGetPhysicalDeviceVideoCapabilitiesKHR` for the video profile `videoSession` was created with, then `pPictureResource->imageViewBinding` of all elements of `pReferenceSlots` with a non-NULL `pPictureResource` member must specify image views created from the same image.

- VUID-VkVideoBeginCodingInfoKHR-slotIndex-07245
  
  If `videoSession` was created with a decode operation and the `slotIndex` member of any element of `pReferenceSlots` is not negative, then the image view specified in `pPictureResource->imageViewBinding` for that element must have been created with `VK_IMAGE_USAGE_VIDEO_DECODE_DPB_BIT_KHR`.

- VUID-VkVideoBeginCodingInfoKHR-slotIndex-07246
  
  If `videoSession` was created with an encode operation and the `slotIndex` member of any
element of `pReferenceSlots` is not negative, then the image view specified in `pPictureResource->imageViewBinding` for that element must have been created with `VK_IMAGE_USAGE_VIDEO_ENCODE_DPB_BIT_KHR`.

- **VUID-VkVideoBeginCodingInfoKHR-videoSession-07247**
  If `videoSession` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR`, then `videoSessionParameters` must not be `VK_NULL_HANDLE`.

- **VUID-VkVideoBeginCodingInfoKHR-videoSession-07248**
  If `videoSession` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, then `videoSessionParameters` must not be `VK_NULL_HANDLE`.

- **VUID-VkVideoBeginCodingInfoKHR-videoSession-07249**
  If `videoSession` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT`, then `videoSessionParameters` must not be `VK_NULL_HANDLE`.

- **VUID-VkVideoBeginCodingInfoKHR-videoSession-07250**
  If `videoSession` was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_ENCODE_H265_BIT_EXT`, then `videoSessionParameters` must not be `VK_NULL_HANDLE`.

- **VUID-VkVideoBeginCodingInfoKHR-videoSessionParameters-04857**
  If `videoSessionParameters` is not `VK_NULL_HANDLE`, it must have been created with `videoSession` specified in `VkVideoSessionParametersCreateInfoKHR::videoSession`.

### Valid Usage (Implicit)

- **VUID-VkVideoBeginCodingInfoKHR-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_VIDEO_BEGIN_CODING_INFO_KHR`.

- **VUID-VkVideoBeginCodingInfoKHR-pNext-pNext**
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkVideoEncodeH264GopRemainingFrameInfoEXT`, `VkVideoEncodeH264RateControlInfoEXT`, `VkVideoEncodeH265GopRemainingFrameInfoEXT`, `VkVideoEncodeH265RateControlInfoEXT`, or `VkVideoEncodeRateControlInfoKHR`.

- **VUID-VkVideoBeginCodingInfoKHR-sType-unique**
  The `sType` value of each struct in the `pNext` chain must be unique.

- **VUID-VkVideoBeginCodingInfoKHR-flags-zerobitmask**
  `flags` must be 0.

- **VUID-VkVideoBeginCodingInfoKHR-videoSession-parameter**
  `videoSession` must be a valid `VkVideoSessionKHR` handle.

- **VUID-VkVideoBeginCodingInfoKHR-videoSessionParameters-parameter**
  If `videoSessionParameters` is not `VK_NULL_HANDLE`, `videoSessionParameters` must be a valid `VkVideoSessionParametersKHR` handle.
If `referenceSlotCount` is not 0, `pReferenceSlots` must be a valid pointer to an array of `referenceSlotCount` valid `VkVideoReferenceSlotInfoKHR` structures.

If `videoSessionParameters` is a valid handle, it must have been created, allocated, or retrieved from `videoSession`.

Both of `videoSession`, and `videoSessionParameters` that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same `VkDevice`.

---

```c
// Provided by VK_KHR_video_queue
typedef VkFlags VkVideoBeginCodingFlagsKHR;
```

`VkVideoBeginCodingFlagsKHR` is a bitmask type for setting a mask, but is currently reserved for future use.

The `VkVideoReferenceSlotInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_video_queue
typedef struct VkVideoReferenceSlotInfoKHR {
    VkStructureType sType;
    const void* pNext;
    int32_t slotIndex;
    const VkVideoPictureResourceInfoKHR* pPictureResource;
} VkVideoReferenceSlotInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `slotIndex` is the index of the DPB slot or a negative integer value.
- `pPictureResource` is `NULL` or a pointer to a `VkVideoPictureResourceInfoKHR` structure describing the video picture resource associated with the DPB slot index specified by `slotIndex`.

---

**Valid Usage (Implicit)**

- VUID-VkVideoReferenceSlotInfoKHR-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_VIDEO_REFERENCE_SLOT_INFO_KHR`

- VUID-VkVideoReferenceSlotInfoKHR-pNext-pNext
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkVideoDecodeH264DpbSlotInfoKHR`, `VkVideoDecodeH265DpbSlotInfoKHR`, `VkVideoEncodeH264DpbSlotInfoEXT`, or `VkVideoEncodeH265DpbSlotInfoEXT`

- VUID-VkVideoReferenceSlotInfoKHR-sType-unique
  The `sType` value of each struct in the `pNext` chain must be unique
To end a video coding scope, call:

```c
// Provided by VK_KHR_video_queue
void vkCmdEndVideoCodingKHR(
    VkCommandBuffer commandBuffer,      // Provided by VK_KHR_video_queue
    const VkVideoEndCodingInfoKHR* pEndCodingInfo);
```

- `commandBuffer` is the command buffer in which to record the command.
- `pEndCodingInfo` is a pointer to a `VkVideoEndCodingInfoKHR` structure specifying the parameters for ending the video coding scope.

After ending a video coding scope, the video session object, the optional video session parameters object, and all reference picture resources previously bound by the corresponding `vkCmdBeginVideoCodingKHR` command are unbound.

**Valid Usage**

- VUID-vkCmdEndVideoCodingKHR-None-07251
  There must be no active queries

**Valid Usage (Implicit)**

- VUID-vkCmdEndVideoCodingKHR-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdEndVideoCodingKHR-pEndCodingInfo-parameter
  `pEndCodingInfo` must be a valid pointer to a valid `VkVideoEndCodingInfoKHR` structure
- VUID-vkCmdEndVideoCodingKHR-commandBuffer-recording
  `commandBuffer` must be in the recording state
- VUID-vkCmdEndVideoCodingKHR-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support decode, or encode operations
- VUID-vkCmdEndVideoCodingKHR-renderpass
  This command must only be called outside of a render pass instance
- VUID-vkCmdEndVideoCodingKHR-videocoding
  This command must only be called inside of a video coding scope
- VUID-vkCmdEndVideoCodingKHR-bufferlevel
  `commandBuffer` must be a primary `VkCommandBuffer`
Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

Command Properties

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<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
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<tr>
<td>Primary</td>
<td>Outside</td>
<td>Inside</td>
<td>Decode Encode</td>
<td>Action State</td>
</tr>
</tbody>
</table>

The `VkVideoEndCodingInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_video_queue
typedef struct VkVideoEndCodingInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkVideoEndCodingFlagsKHR flags;
} VkVideoEndCodingInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is reserved for future use.

Valid Usage (Implicit)

- VUID-VkVideoEndCodingInfoKHR-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_VIDEO_END_CODING_INFO_KHR`
- VUID-VkVideoEndCodingInfoKHR-pNext-pNext
  `pNext` must be `NULL`
- VUID-VkVideoEndCodingInfoKHR-flags-zerobitmask
  `flags` must be `0`

```c
// Provided by VK_KHR_video_queue
typedef VkFlags VkVideoEndCodingFlagsKHR;
```

`VkVideoEndCodingFlagsKHR` is a bitmask type for setting a mask, but is currently reserved for future use.
42.9. Video Coding Control

To apply dynamic controls to the currently bound video session object, call:

```
// Provided by VK_KHR_video_queue
void vkCmdControlVideoCodingKHR(
    VkCommandBuffer commandBuffer,
    const VkVideoCodingControlInfoKHR* pCodingControlInfo);
```

- `commandBuffer` is the command buffer in which to record the command.
- `pCodingControlInfo` is a pointer to a `VkVideoCodingControlInfoKHR` structure specifying the control parameters.

The control parameters provided in this call are applied to the video session at the time the command executes on the device and are in effect until a subsequent call to this command with the same video session bound changes the corresponding control parameters.

A newly created video session **must** be reset before performing video coding operations using it by including `VK_VIDEO_CODING_CONTROL_RESET_BIT_KHR` in `pCodingControlInfo->flags`. The reset operation also returns all DPB slots of the video session to the inactive state. Correspondingly, any DPB slot index associated with the bound reference picture resources is removed.

For encode sessions, the reset operation returns rate control configuration to implementation default settings and sets the video encode quality level to zero.

After video coding operations are performed using a video session, the reset operation **can** be used to return the video session to the same initial state as after the reset of a newly created video session. This **can** be used, for example, when different video sequences are needed to be processed with the same video session object.

### Valid Usage

- **VUID-vkCmdControlVideoCodingKHR-flags-07017**
  If `pCodingControlInfo->flags` does not include `VK_VIDEO_CODING_CONTROL_RESET_BIT_KHR`, then the bound video session **must** not be in uninitialized state at the time the command is executed on the device

### Valid Usage (Implicit)

- **VUID-vkCmdControlVideoCodingKHR-commandBuffer-parameter**
  `commandBuffer` **must** be a valid `VkCommandBuffer` handle

- **VUID-vkCmdControlVideoCodingKHR-pCodingControlInfo-parameter**
  `pCodingControlInfo` **must** be a valid pointer to a valid `VkVideoCodingControlInfoKHR` structure

- **VUID-vkCmdControlVideoCodingKHR-commandBuffer-recording**
**commandBuffer** must be in the recording state

- VUID-vkCmdControlVideoCodingKHR-commandBuffer-cmdpool
  The **VkCommandPool** that **commandBuffer** was allocated from **must** support decode, or encode operations

- VUID-vkCmdControlVideoCodingKHR-renderpass
  This command **must** only be called outside of a render pass instance

- VUID-vkCmdControlVideoCodingKHR-videocoding
  This command **must** only be called inside of a video coding scope

- VUID-vkCmdControlVideoCodingKHR-bufferlevel
  **commandBuffer** must be a primary **VkCommandBuffer**

**Host Synchronization**

- Host access to **commandBuffer** **must** be externally synchronized

- Host access to the **VkCommandPool** that **commandBuffer** was allocated from **must** be externally synchronized

**Command Properties**

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
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<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
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</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Outside</td>
<td>Inside</td>
<td>Decode</td>
<td>Action</td>
</tr>
</tbody>
</table>

The **VkVideoCodingControlInfoKHR** structure is defined as:

```c
// Provided by VK_KHR_video_queue
typedef struct VkVideoCodingControlInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkVideoCodingControlFlagsKHR flags;
} VkVideoCodingControlInfoKHR;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **flags** is a bitmask of **VkVideoCodingControlFlagsKHR** specifying control flags.

**Valid Usage**

- VUID-VkVideoCodingControlInfoKHR-flags-07018
  If **flags** includes **VK_VIDEO_CODING_CONTROL_ENCODE_RATE_CONTROL_BIT_KHR**, then the **pNext**
chain must include a VkVideoEncodeRateControlInfoKHR structure

- VUID-VkVideoCodingControlInfoKHR-flags-07021
  If flags includes VK_VIDEO_CODING_CONTROL_ENCODE_RATE_CONTROL_BIT_KHR, the rateControlMode member of VkVideoEncodeRateControlInfoKHR included in the pNext chain is not VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DEFAULT_KHR or VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DISABLED_BIT_KHR, and the bound video session was created with the video codec operation VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT, then the pNext chain must include a VkVideoEncodeH264RateControlInfoEXT structure

- VUID-VkVideoCodingControlInfoKHR-pNext-07022
  If the pNext chain includes a VkVideoEncodeRateControlInfoKHR, and VkVideoEncodeRateControlInfoKHR::layerCount is greater than 1, then VkVideoEncodeH264RateControlInfoEXT::temporalLayerCount must be equal to layerCount

- VUID-VkVideoCodingControlInfoKHR-flags-07024
  If flags includes VK_VIDEO_CODING_CONTROL_ENCODE_RATE_CONTROL_BIT_KHR, the rateControlMode member of VkVideoEncodeRateControlInfoKHR included in the pNext chain is not VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DEFAULT_KHR or VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DISABLED_BIT_KHR, and the bound video session was created with the video codec operation VK_VIDEO_CODEC_OPERATION_ENCODE_H265_BIT_EXT, then the pNext chain must include a VkVideoEncodeH265RateControlInfoEXT structure

- VUID-VkVideoCodingControlInfoKHR-pNext-07025
  If the pNext chain includes a VkVideoEncodeRateControlInfoKHR, and VkVideoEncodeRateControlInfoKHR::layerCount is greater than 1, then VkVideoEncodeH265RateControlInfoEXT::subLayerCount must be equal to layerCount

Valid Usage (Implicit)

- VUID-VkVideoCodingControlInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_VIDEO_CODING_CONTROL_INFO_KHR

- VUID-VkVideoCodingControlInfoKHR-pNext-pNext
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkVideoEncodeH264RateControlInfoEXT, VkVideoEncodeH265RateControlInfoEXT, VkVideoEncodeQualityLevelInfoKHR, or VkVideoEncodeRateControlInfoKHR

- VUID-VkVideoCodingControlInfoKHR-sType-unique
  The sType value of each struct in the pNext chain must be unique

- VUID-VkVideoCodingControlInfoKHR-flags-parameter
  flags must be a valid combination of VkVideoCodingControlFlagBitsKHR values

- VUID-VkVideoCodingControlInfoKHR-flags-requiredbitmask
  flags must not be 0

Bits which can be set in VkVideoCodingControlInfoKHR::flags, specifying the video coding control parameters to be modified, are:
typedef enum VkVideoCodingControlFlagBitsKHR {
    VK_VIDEO_CODING_CONTROL_RESET_BIT_KHR = 0x00000001,
} VkVideoCodingControlFlagBitsKHR;

• VK_VIDEO_CODING_CONTROL_RESET_BIT_KHR indicates a request for the bound video session to be reset before other coding control parameters are applied.

• VK_VIDEO_CODING_CONTROL_ENCODE_RATE_CONTROL_BIT_KHR indicates that the coding control parameters include video encode rate control parameters (see VkVideoEncodeRateControlInfoKHR).

• VK_VIDEO_CODING_CONTROL_ENCODE_QUALITY_LEVEL_BIT_KHR indicates that the coding control parameters include video encode quality level parameters (see VkVideoEncodeQualityLevelInfoKHR).

typedef VkFlags VkVideoCodingControlFlagsKHR;

VkVideoCodingControlFlagsKHR is a bitmask type for setting a mask of zero or more VkVideoCodingControlFlagBitsKHR.

42.10. Video Decode Operations

Video decode operations consume compressed video data from a video bitstream buffer and zero or more reference pictures, and produce a decode output picture and an optional reconstructed picture.

Note:

Such decode output pictures can be shared with the Decoded Picture Buffer, and can also be used as the input of video encode operations, with graphics or compute operations, or with Window System Integration APIs, depending on the capabilities of the implementation.

Video decode operations may access the following resources in the VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR stage:

• The source video bitstream buffer range and the image subregions corresponding to the list of active reference pictures with access VK_ACCESS_2_VIDEO_DECODE_READ_BIT_KHR.
• The image subregions corresponding to the target decode output picture and reconstructed picture with access VK_ACCESS_2_VIDEO_DECODE_WRITE_BIT_KHR.

The image subresource of each video picture resource accessed by the video coding operation is specified using a corresponding VkVideoPictureResourceInfoKHR structure. Each such image subresource must be in the appropriate image layout as follows:

• If the image subresource is used in the video decode operation only as decode output picture, then it must be in the VK_IMAGE_LAYOUT_VIDEO_DECODE_DST_KHR layout.

• If the image subresource is used in the video decode operation both as decode output picture and reconstructed picture, then it must be in the VK_IMAGE_LAYOUT_VIDEO_DECODE_DPB_KHR layout.

• If the image subresource is used in the video decode operation only as reconstructed picture, then it must be in the VK_IMAGE_LAYOUT_VIDEO_DECODE_DPB_KHR layout.

• If the image subresource is used in the video decode operation as a reference picture, then it must be in the VK_IMAGE_LAYOUT_VIDEO_DECODE_DPB_KHR layout.

A video decode operation may complete unsuccessfully. In this case the decode output picture will have undefined contents. Similarly, if a reconstructed picture is specified, it will also have undefined contents, and the activated DPB slot will have an invalid picture reference.

42.10.1. Codec-Specific Semantics

The following aspects of video decode operations are codec-specific:

• The interpretation of the contents of the source video bitstream buffer range.

• The construction and interpretation of the list of active reference pictures and the interpretation of the picture data referred to by the corresponding image subregions.

• The construction and interpretation of information related to the decode output picture and the generation of picture data to the corresponding image subregion.

• The construction and interpretation of information related to the optional reconstructed picture and the generation of picture data to the corresponding image subregion.

These codec-specific behaviors are defined for each video codec operation separately.

• If the used video codec operation is VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR, then the codec-specific aspects of the video decoding process are performed as defined in the H.264 Decode Operations section.

• If the used video codec operation is VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR, then the codec-specific aspects of the video decoding process are performed as defined in the H.265 Decode Operations section.

42.10.2. Video Decode Operation Steps

Each video decode operation performs the following steps in the VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR stage:

1. Reads the encoded video data from the source video bitstream buffer range.
2. Performs picture reconstruction of the encoded video data according to the **codec-specific semantics**, applying any prediction data read from the **active reference pictures** in the process;

3. Writes the decoded picture data to the **decode output picture**, and to the **reconstructed picture**, if one is specified and is different from the decode output picture, according to the **codec-specific semantics**;

4. When **reconstructed picture information** is provided, the requested **DPB slot** is **activated** with the specified picture and the DPB slot index is associated with the corresponding **bound reference picture resource**.

### 42.10.3. Capabilities

When calling `vkGetPhysicalDeviceVideoCapabilitiesKHR` with `pVideoProfile->videoCodecOperation` specifying a decode operation, the `VkVideoDecodeCapabilitiesKHR` structure **must** be included in the `pNext` chain of the `VkVideoCapabilitiesKHR` structure to retrieve capabilities specific to video decoding.

The `VkVideoDecodeCapabilitiesKHR` structure is defined as:

```c
// Provided by VK_KHR_video_decode_queue
typedef struct VkVideoDecodeCapabilitiesKHR {
    VkStructureType sType;
    void* pNext;
    VkVideoDecodeCapabilityFlagsKHR flags;
} VkVideoDecodeCapabilitiesKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is a bitmask of `VkVideoDecodeCapabilityFlagBitsKHR` describing the supported video decoding capabilities.

### Valid Usage (Implicit)

- VUID-VkVideoDecodeCapabilitiesKHR-sType-sType
  - **sType** must be `VK_STRUCTURE_TYPE_VIDEO_DECODE_CAPABILITIES_KHR`

Bits which **may** be set in `VkVideoDecodeCapabilitiesKHR::flags`, indicating the decoding capabilities supported, are:

```c
// Provided by VK_KHR_video_decode_queue
typedef enum VkVideoDecodeCapabilityFlagBitsKHR {
    VK_VIDEO_DECODE_CAPABILITY_DPB_AND_OUTPUT_COINCIDE_BIT_KHR = 0x00000001,
    VK_VIDEO_DECODE_CAPABILITY_DPB_AND_OUTPUT_DISTINCT_BIT_KHR = 0x00000002,
} VkVideoDecodeCapabilityFlagBitsKHR;
```
• **VK_VIDEO_DECODE_CAPABILITY_DPB_AND_OUTPUT_COINCIDE_BIT_KHR** indicates support for using the same video picture resource as the reconstructed picture and decode output picture in a video decode operation.

• **VK_VIDEO_DECODE_CAPABILITY_DPB_AND_OUTPUT_DISTINCT_BIT_KHR** indicates support for using distinct video picture resources as the reconstructed picture and decode output picture in a video decode operation.

Implementations are only required to support one of **VK_VIDEO_DECODE_CAPABILITY_DPB_AND_OUTPUT_COINCIDE_BIT_KHR** and **VK_VIDEO_DECODE_CAPABILITY_DPB_AND_OUTPUT_DISTINCT_BIT_KHR**. Accordingly, applications should handle both cases to maximize portability.

**Note:**

If both **VK_VIDEO_DECODE_CAPABILITY_DPB_AND_OUTPUT_COINCIDE_BIT_KHR** and **VK_VIDEO_DECODE_CAPABILITY_DPB_AND_OUTPUT_DISTINCT_BIT_KHR** are supported, an application can choose to create separate images for decode DPB and decode output. E.g. in cases when linear tiling is preferred (and supported) for the decode output picture and the DPB requires optimal tiling, this avoids the need for a separate copy at the expense of additional memory bandwidth requirements during decoding.

```c
// Provided by VK_KHR_video_decode_queue
typedef VkFlags VkVideoDecodeCapabilityFlagsKHR;
```

**VkVideoDecodeCapabilityFlagsKHR** is a bitmask type for setting a mask of zero or more **VkVideoDecodeCapabilityFlagBitsKHR**.

## 42.10.4. Video Decode Commands

To launch video decode operations, call:

```c
// Provided by VK_KHR_video_decode_queue
void vkCmdDecodeVideoKHR(
    VkCommandBuffer commandBuffer,
    const VkVideoDecodeInfoKHR* pDecodeInfo);
```

• **commandBuffer** is the command buffer in which to record the command.

• **pDecodeInfo** is a pointer to a **VkVideoDecodeInfoKHR** structure specifying the parameters of the video decode operations.

Each call issues one or more video decode operations. The implicit parameter **opCount** corresponds to the number of video decode operations issued by the command. After calling this command, the active query index of each active query is incremented by **opCount**.

Currently each call to this command results in the issue of a single video decode operation.
Active Reference Picture Information

The list of active reference pictures used by a video decode operation is a list of image subregions used as the source of reference picture data and related parameters, and is derived from the VkVideoReferenceSlotInfoKHR structures provided as the elements of the pDecodeInfo->pReferenceSlots array. For each element of pDecodeInfo->pReferenceSlots, one or more elements are added to the active reference picture list, as defined by the codec-specific semantics. Each element of this list contains the following information:

- The image subregion within the image subresource referred to by the video picture resource used as the reference picture.
- The DPB slot index the reference picture is associated with.
- The codec-specific reference information related to the reference picture.

Reconstructed Picture Information

Information related to the optional reconstructed picture used by a video decode operation is derived from the VkVideoReferenceSlotInfoKHR structure pointed to by pDecodeInfo->pSetupReferenceSlot, if not NULL, as defined by the codec-specific semantics, and consists of the following:

- The image subregion within the image subresource referred to by the video picture resource used as the reconstructed picture.
- The DPB slot index to activate with the reconstructed picture.
- The codec-specific reference information related to the reconstructed picture.

Decode Output Picture Information

Information related to the decode output picture used by a video decode operation is derived from pDecodeInfo->dstPictureResource and any codec-specific parameters provided in the pDecodeInfo->pNext chain, as defined by the codec-specific semantics, and consists of the following:

- The image subregion within the image subresource referred to by the video picture resource used as the decode output picture.
- The codec-specific picture information related to the decode output picture.

Several limiting values are defined below that are referenced by the relevant valid usage statements of this command.

- Let uint32_t activeReferencePictureCount be the size of the list of active reference pictures used by the video decode operation. Unless otherwise defined, activeReferencePictureCount is set to the value of pDecodeInfo->referenceSlotCount.

  - If the bound video session was created with an H.264 decode profile, then let activeReferencePictureCount be the value of pDecodeInfo->referenceSlotCount plus the number of elements of the pDecodeInfo->pReferenceSlots array that have a VkVideoDecodeH264DpbSlotInfoKHR structure included in their pNext chain with both pStdReferenceInfo->flags.top_field_flag and pStdReferenceInfo->flags.bottom_field_flag set.
Note

This means that the elements of pDecodeInfo->pReferenceSlots that include both a top and bottom field reference are counted as two separate active reference pictures, as described in the active reference picture list construction rules for H.264 decode operations.

• Let VkOffset2D codedOffsetGranularity be the minimum alignment requirement for the coded offset of video picture resources. Unless otherwise defined, the value of the x and y members of codedOffsetGranularity are 0.
  ◦ If the bound video session was created with an H.264 decode profile with a VkVideoDecodeH264ProfileInfoKHR::pictureLayout of VK_VIDEO_CODEC_H264_PICTURE_LAYOUT_INTERLACED_SEPARATE_PLANES_BIT_KHR, then codedOffsetGranularity is equal to VkVideoDecodeH264CapabilitiesKHR::fieldOffsetGranularity, as returned by vkGetPhysicalDeviceVideoCapabilitiesKHR for that video profile.

• Let uint32_t dpbFrameUseCount[] be an array of size maxDpbSlots, where maxDpbSlots is the VkVideoSessionCreateInfoKHR::maxDpbSlots the bound video session was created with, with each element indicating the number of times a frame associated with the corresponding DPB slot index is referred to by the video coding operation. Let the initial value of each element of the array be 0.
  ◦ If pDecodeInfo->pSetupReferenceSlot is not NULL, then dpbFrameUseCount[i] is incremented by one, where i equals pDecodeInfo->pSetupReferenceSlot->slotIndex. If the bound video session object was created with an H.264 decode profile, then dpbFrameUseCount[i] is decremented by one if either pStdReferenceInfo->flags.top_field_flag or pStdReferenceInfo->flags.bottom_field_flag is set in the VkVideoDecodeH264DpbSlotInfoKHR structure in the pDecodeInfo->pSetupReferenceSlot->pNext chain.
  ◦ For each element of pDecodeInfo->pReferenceSlots, dpbFrameUseCount[i] is incremented by one, where i equals the slotIndex member of the corresponding element. If the bound video session object was created with an H.264 decode profile, then dpbFrameUseCount[i] is decremented by one if either pStdReferenceInfo->flags.top_field_flag or pStdReferenceInfo->flags.bottom_field_flag is set in the VkVideoDecodeH264DpbSlotInfoKHR structure in the pNext chain of the corresponding element of pDecodeInfo->pReferenceSlots.

• Let uint32_t dpbTopFieldUseCount[] and uint32_t dpbBottomFieldUseCount[] be arrays of size maxDpbSlots, where maxDpbSlots is the VkVideoSessionCreateInfoKHR::maxDpbSlots the bound video session was created with, with each element indicating the number of times the top field or the bottom field, respectively, associated with the corresponding DPB slot index is referred to by the video coding operation. Let the initial value of each element of the arrays be 0.
  ◦ If the bound video session object was created with an H.264 decode profile and pDecodeInfo->pSetupReferenceSlot is not NULL, then perform the following:
    • If pStdReferenceInfo->flags.top_field_flag is set in the VkVideoDecodeH264DpbSlotInfoKHR structure in the pDecodeInfo->pSetupReferenceSlot->pNext chain, then dpbTopFieldUseCount[i] is incremented by one, where i equals
pDecodeInfo->pSetupReferenceSlot->slotIndex.

- If pStdReferenceInfo->flags.bottom_field_flag is set in the VkVideoDecodeH264DpbSlotInfoKHR structure in the pDecodeInfo->pSetupReferenceSlot->pNext chain, then dpbBottomFieldUseCount[i] is incremented by one, where i equals pDecodeInfo->pSetupReferenceSlot->slotIndex.

- If the bound video session object was created with an H.264 decode profile, then perform the following for each element of pDecodeInfo->pReferenceSlots:
  - If pStdReferenceInfo->flags.top_field_flag is set in the VkVideoDecodeH264DpbSlotInfoKHR structure in the pNext chain of the element, then dpbTopFieldUseCount[i] is incremented by one, where i equals the slotIndex member of the element.
  - If pStdReferenceInfo->flags.bottom_field_flag is set in the VkVideoDecodeH264DpbSlotInfoKHR structure in the pNext chain of the element, then dpbBottomFieldUseCount[i] is incremented by one, where i equals the slotIndex member of the element.

Valid Usage

- VUID-vkCmdDecodeVideoKHR-None-07011
  The bound video session must not be in uninitialized state at the time the command is executed on the device.

- VUID-vkCmdDecodeVideoKHR-opCount-07134
  For each active query, the active query index corresponding to the query type of that query plus opCount must be less than or equal to the last activatable query index corresponding to the query type of that query plus one.

- VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07135
  pDecodeInfo->srcBuffer must be compatible with the video profile the bound video session was created with.

- VUID-vkCmdDecodeVideoKHR-commandBuffer-07136
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, then pDecodeInfo->srcBuffer must not be a protected buffer.

- VUID-vkCmdDecodeVideoKHR-commandBuffer-07137
  If commandBuffer is a protected command buffer and protectedNoFault is not supported, then pDecodeInfo->srcBuffer must be a protected buffer.

- VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07138
  pDecodeInfo->srcBufferOffset must be an integer multiple of VkVideoCapabilitiesKHR::minBitstreamBufferOffsetAlignment, as returned by vkGetPhysicalDeviceVideoCapabilitiesKHR for the video profile the bound video session was created with.

- VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07139
  pDecodeInfo->srcBufferRange must be an integer multiple of VkVideoCapabilitiesKHR::minBitstreamBufferSizeAlignment, as returned by vkGetPhysicalDeviceVideoCapabilitiesKHR for the video profile the bound video session was created with.
If pDecodeInfo->pSetupReferenceSlot is not NULL and VkVideoDecodeCapabilitiesKHR::flags does not include VK_VIDEO_DECODER_CODEC_DHBCAND_OUTPUT_COINCIDE_BIT_KHR, as returned by vkGetPhysicalDeviceVideoCapabilitiesKHR for the video profile the bound video session was created with, then the video picture resources specified by pDecodeInfo->dstPictureResource and pDecodeInfo->pSetupReferenceSlot->pPictureResource must not match.

If pDecodeInfo->pSetupReferenceSlot is not NULL and VkVideoDecodeCapabilitiesKHR::flags does not include VK_VIDEO_DECODER_CODEC_DHBCAND_OUTPUT_DISTINCT_BIT_KHR, as returned by vkGetPhysicalDeviceVideoCapabilitiesKHR for the video profile the bound video session was created with, then the video picture resources specified by pDecodeInfo->dstPictureResource and pDecodeInfo->pSetupReferenceSlot->pPictureResource must match.

pDecodeInfo->dstPictureResource.imageViewBinding must be compatible with the video profile the bound video session was created with.

The format of pDecodeInfo->dstPictureResource.imageViewBinding must match the VkVideoSessionCreateInfoKHR::pictureFormat the bound video session was created with.

pDecodeInfo->dstPictureResource.codedOffset must be an integer multiple of codedOffsetGranularity.

pDecodeInfo->dstPictureResource.codedExtent must be between minCodedExtent and maxCodedExtent, inclusive, the bound video session was created with.

pDecodeInfo->dstPictureResource.imageViewBinding must have been created with VK_IMAGE_USAGE_VIDEO_DECODER_DST_BIT_KHR.

If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, then pDecodeInfo->dstPictureResource.imageViewBinding must not have been created from a protected image.

If commandBuffer is a protected command buffer and protectedNoFault is not supported, then pDecodeInfo->dstPictureResource.imageViewBinding must have been created from a protected image.

If pDecodeInfo->pSetupReferenceSlot is not NULL, then pDecodeInfo->pSetupReferenceSlot->slotIndex must be less than the VkVideoSessionCreateInfoKHR::maxDpbSlots specified when the bound video session was created.

If pDecodeInfo->pSetupReferenceSlot is not NULL, then pDecodeInfo->pSetupReferenceSlot-
>pPictureResource->codedOffset must be an integer multiple of codedOffsetGranularity

- **VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07149**
  If pDecodeInfo->pSetupReferenceSlot is not NULL, then pDecodeInfo->pSetupReferenceSlot->pPictureResource must match one of the bound reference picture resource

- **VUID-vkCmdDecodeVideoKHR-activeReferencePictureCount-07150**
  activeReferencePictureCount must be less than or equal to the VkVideoSessionCreateInfoKHR::maxActiveReferencePictures specified when the bound video session was created

- **VUID-vkCmdDecodeVideoKHR-slotIndex-07256**
  The slotIndex member of each element of pDecodeInfo->pReferenceSlots must be less than or equal to the VkVideoSessionCreateInfoKHR::maxDpbSlots specified when the bound video session was created

- **VUID-vkCmdDecodeVideoKHR-codedOffset-07257**
  The codedOffset member of the VkVideoPictureResourceInfoKHR structure pointed to by the pPictureResource member of each element of pDecodeInfo->pReferenceSlots must be an integer multiple of codedOffsetGranularity

- **VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07151**
  The pPictureResource member of each element of pDecodeInfo->pReferenceSlots must match one of the bound reference picture resource associated with the DPB slot index specified in the slotIndex member of that element

- **VUID-vkCmdDecodeVideoKHR-dpbFrameUseCount-07176**
  All elements of dpbFrameUseCount must be less than or equal to 1

- **VUID-vkCmdDecodeVideoKHR-dpbTopFieldUseCount-07177**
  All elements of dpbTopFieldUseCount must be less than or equal to 1

- **VUID-vkCmdDecodeVideoKHR-dpbBottomFieldUseCount-07178**
  All elements of dpbBottomFieldUseCount must be less than or equal to 1

- **VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07252**
  If pDecodeInfo->pSetupReferenceSlot is not NULL or pDecodeInfo->pSetupReferenceSlot->pPictureResource does not refer to the same image subresource as pDecodeInfo->dstPictureResource, then the image subresource referred to by pDecodeInfo->dstPictureResource must be in the VK_IMAGE_LAYOUT_VIDEO_DECODE_DST_KHR layout at the time the video decode operation is executed on the device

- **VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07253**
  If pDecodeInfo->pSetupReferenceSlot is not NULL and pDecodeInfo->pSetupReferenceSlot->pPictureResource refers to the same image subresource as pDecodeInfo->dstPictureResource, then the image subresource referred to by pDecodeInfo->dstPictureResource must be in the VK_IMAGE_LAYOUT_VIDEO_DECODE_DPB_KHR layout at the time the video decode operation is executed on the device

- **VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07254**
If `pDecodeInfo->pSetupReferenceSlot` is not `NULL`, then the image subresource referred to by `pDecodeInfo->pSetupReferenceSlot->pPictureResource` must be in the `VK_IMAGE_LAYOUT_VIDEO_DECODE_DPB_KHR` layout at the time the video decode operation is executed on the device.

- **VUID-vkCmdDecodeVideoKHR-pPictureResource-07255**  
The image subresource referred to by the `pPictureResource` member of each element of `pDecodeInfo->pReferenceSlots` must be in the `VK_IMAGE_LAYOUT_VIDEO_DECODE_DPB_KHR` layout at the time the video decode operation is executed on the device.

- **VUID-vkCmdDecodeVideoKHR-pNext-07152**  
If the bound video session was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR`, then the `pNext` chain of `pDecodeInfo` must include a `VkVideoDecodeH264PictureInfoKHR` structure.

- **VUID-vkCmdDecodeVideoKHR-None-07258**  
If the bound video session was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR` but was not created with interlaced frame support, then the decode output picture must represent a frame.

- **VUID-vkCmdDecodeVideoKHR-pSliceOffsets-07153**  
If the bound video session was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR`, then all elements of the `pSliceOffsets` member of the `VkVideoDecodeH264PictureInfoKHR` structure included in the `pNext` chain of `pDecodeInfo` must be less than `pDecodeInfo->srcBufferRange`.

- **VUID-vkCmdDecodeVideoKHR-StdVideoH264SequenceParameterSet-07154**  
If the bound video session was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR`, then the bound video session parameters object must contain a `StdVideoH264SequenceParameterSet` entry with `seq_parameter_set_id` matching `StdVideoDecodeH264PictureInfo::seq_parameter_set_id` that is provided in the `pStdPictureInfo` member of the `VkVideoDecodeH264PictureInfoKHR` structure included in the `pNext` chain of `pDecodeInfo`.

- **VUID-vkCmdDecodeVideoKHR-StdVideoH264PictureParameterSet-07155**  
If the bound video session was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR`, then the bound video session parameters object must contain a `StdVideoH264PictureParameterSet` entry with `seq_parameter_set_id` and `pic_parameter_set_id` matching `StdVideoDecodeH264PictureInfo::seq_parameter_set_id` and `StdVideoDecodeH264PictureInfo::pic_parameter_set_id`, respectively, that are provided in the `pStdPictureInfo` member of the `VkVideoDecodeH264PictureInfoKHR` structure included in the `pNext` chain of `pDecodeInfo`.

- **VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07156**  
If the bound video session was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR` and `pDecodeInfo->pSetupReferenceSlot` is not `NULL`, then the `pNext` chain of `pDecodeInfo->pSetupReferenceSlot` must include a `VkVideoDecodeH264DpbSlotInfoKHR` structure.

- **VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07259**  
If the bound video session was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR` but was not created with interlaced frame support, and `pDecodeInfo->pSetupReferenceSlot` is not `NULL`, then the reconstructed picture...
must represent a frame

• VUID-vkCmdDecodeVideoKHR-pNext-07157
If the bound video session was created with the video codec operation
VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR, then the pNext chain of each element of
pDecodeInfo->pReferenceSlots must include a VkVideoDecodeH264DpbSlotInfoKHR
structure

• VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07260
If the bound video session was created with the video codec operation
VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR but was not created with interlaced frame
support, then each active reference picture corresponding to the elements of pDecodeInfo-
> pReferenceSlots must represent a frame

• VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07261
If the bound video session was created with the video codec operation
VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR, pDecodeInfo->pSetupReferenceSlot is not
NULL, and the decode output picture represents a frame, then the reconstructed picture
must also represent a frame

• VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07262
If the bound video session was created with the video codec operation
VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR, pDecodeInfo->pSetupReferenceSlot is not
NULL, and the decode output picture represents a top field, then the reconstructed picture
must also represent a top field

• VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07263
If the bound video session was created with the video codec operation
VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR, pDecodeInfo->pSetupReferenceSlot is not
NULL, and the decode output picture represents a bottom field, then the reconstructed picture
must also represent a bottom field

• VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07266
If the bound video session was created with the video codec operation
VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR and an active reference picture
corresponding to any element of pDecodeInfo->pReferenceSlots represents a frame, then
the DPB slot index of the bound video session specified by the slotIndex member of that
element must be currently associated with a frame picture matching the video picture
resource specified by the pPictureResource member of the same element at the time the
command is executed on the device

• VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07267
If the bound video session was created with the video codec operation
VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR and an active reference picture
corresponding to any element of pDecodeInfo->pReferenceSlots represents a top field, then
the DPB slot index of the bound video session specified by the slotIndex member of that
element must be currently associated with a top field picture matching the video picture
resource specified by the pPictureResource member of the same element at the time the
command is executed on the device

• VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07268
If the bound video session was created with the video codec operation
VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR and an active reference picture
corresponding to any element of `pDecodeInfo->pReferenceSlots` represents a bottom field, then the DPB slot index of the bound video session specified by the `slotIndex` member of that element **must** be currently associated with a bottom field picture matching the video picture resource specified by the `pPictureResource` member of the same element at the time the command is executed on the device

- **VUID-vkCmdDecodeVideoKHR-pNext-07158**
  If the bound video session was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, then the `pNext` chain of `pDecodeInfo` **must** include a `VkVideoDecodeH265PictureInfoKHR` structure

- **VUID-vkCmdDecodeVideoKHR-pSliceSegmentOffsets-07159**
  If the bound video session was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, then all elements of the `pSliceSegmentOffsets` member of the `VkVideoDecodeH265PictureInfoKHR` structure included in the `pNext` chain of `pDecodeInfo` **must** be less than `pDecodeInfo->srcBufferRange`

- **VUID-vkCmdDecodeVideoKHR-StdVideoH265VideoParameterSet-07160**
  If the bound video session was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, then the bound video session parameters object **must** contain a `StdVideoH265VideoParameterSet` entry with `vps_video_parameter_set_id` matching `StdVideoDecodeH265PictureInfo::sps_video_parameter_set_id` that is provided in the `pStdPictureInfo` member of the `VkVideoDecodeH265PictureInfoKHR` structure included in the `pNext` chain of `pDecodeInfo`

- **VUID-vkCmdDecodeVideoKHR-StdVideoH265SequenceParameterSet-07161**
  If the bound video session was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, then the bound video session parameters object **must** contain a `StdVideoH265SequenceParameterSet` entry with `sps_video_parameter_set_id` and `sps_seq_parameter_set_id` matching `StdVideoDecodeH265PictureInfo::sps_video_parameter_set_id` and `StdVideoDecodeH265PictureInfo::pps_seq_parameter_set_id`, respectively, that are provided in the `pStdPictureInfo` member of the `VkVideoDecodeH265PictureInfoKHR` structure included in the `pNext` chain of `pDecodeInfo`

- **VUID-vkCmdDecodeVideoKHR-StdVideoH265PictureParameterSet-07162**
  If the bound video session was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, then the bound video session parameters object **must** contain a `StdVideoH265PictureParameterSet` entry with `sps_video_parameter_set_id`, `pps_seq_parameter_set_id`, and `pps_pic_parameter_set_id` matching `StdVideoDecodeH265PictureInfo::sps_video_parameter_set_id`, `StdVideoDecodeH265PictureInfo::pps_seq_parameter_set_id`, and `StdVideoDecodeH265PictureInfo::pps_pic_parameter_set_id`, respectively, that are provided in the `pStdPictureInfo` member of the `VkVideoDecodeH265PictureInfoKHR` structure included in the `pNext` chain of `pDecodeInfo`

- **VUID-vkCmdDecodeVideoKHR-pDecodeInfo-07163**
  If the bound video session was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR` and `pDecodeInfo->pSetupReferenceSlot` is not `NULL`, then the `pNext` chain of `pDecodeInfo->pSetupReferenceSlot` **must** include a `VkVideoDecodeH265DpbSlotInfoKHR` structure
If the bound video session was created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, then the `pNext` chain of each element of `pDecodeInfo->pReferenceSlots` must include a `VkVideoDecodeH265DpbSlotInfoKHR` structure.

---

**Valid Usage (Implicit)**

- VUID-vkCmdDecodeVideoKHR-pCommandBuffer-parameter
  
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- VUID-vkCmdDecodeVideoKHR-pDecodeInfo-parameter
  
  `pDecodeInfo` must be a valid pointer to a valid `VkVideoDecodeInfoKHR` structure.

- VUID-vkCmdDecodeVideoKHR-pCommandBuffer-recording
  
  `commandBuffer` must be in the recording state.

- VUID-vkCmdDecodeVideoKHR-pCommandBuffer-cmdpool
  
  The `VkCommandPool` that `commandBuffer` was allocated from must support decode operations.

- VUID-vkCmdDecodeVideoKHR-pRenderPass
  
  This command must only be called outside of a render pass instance.

- VUID-vkCmdDecodeVideoKHR-pVideoCoding
  
  This command must only be called inside of a video coding scope.

- VUID-vkCmdDecodeVideoKHR-pBufferLevel
  
  `commandBuffer` must be a primary `VkCommandBuffer`.

---

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized.

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

---

**Command Properties**

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The `VkVideoDecodeInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_video_decode_queue
typedef struct VkVideoDecodeInfoKHR {
    VkStructureType sType;
```
const void* pNext;
VkVideoDecodeFlagsKHR flags;
VkBuffer srcBuffer;
VkDeviceSize srcBufferOffset;
VkDeviceSize srcBufferRange;
VkVideoPictureResourceInfoKHR dstPictureResource;
const VkVideoReferenceSlotInfoKHR* pSetupReferenceSlot;
uint32_t referenceSlotCount;
const VkVideoReferenceSlotInfoKHR* pReferenceSlots;
}

VkVideoDecodeInfoKHR;

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **srcBuffer** is the source video bitstream buffer to read the encoded bitstream from.
- **srcBufferOffset** is the starting offset in bytes from the start of **srcBuffer** to read the encoded bitstream from.
- **srcBufferRange** is the size in bytes of the encoded bitstream to decode from **srcBuffer**, starting from **srcBufferOffset**.
- **dstPictureResource** is the video picture resource to use as the decode output picture.
- **pSetupReferenceSlot** is NULL or a pointer to a VkVideoReferenceSlotInfoKHR structure describing the DPB slot to activate and the video picture resource to use as the reconstructed picture to activate the DPB slot with.
- **referenceSlotCount** is the number of elements in the **pReferenceSlots** array.
- **pReferenceSlots** is NULL or a pointer to an array of VkVideoReferenceSlotInfoKHR structures describing the DPB slots and corresponding reference picture resources to use in this video decode operation (the set of active reference pictures).

### Valid Usage

- **VUID-VkVideoDecodeInfoKHR-srcBuffer-07165**
  
  **srcBuffer** must have been created with VK_BUFFER_USAGE_VIDEO_DECODE_SRC_BIT_KHR set

- **VUID-VkVideoDecodeInfoKHR-srcBufferOffset-07166**
  
  **srcBufferOffset** must be less than the size of **srcBuffer**

- **VUID-VkVideoDecodeInfoKHR-srcBufferRange-07167**
  
  **srcBufferRange** must be less than or equal to the size of **srcBuffer** minus **srcBufferOffset**

- **VUID-VkVideoDecodeInfoKHR-pSetupReferenceSlot-07168**
  
  If **pSetupReferenceSlot** is not NULL, then its **slotIndex** member must not be negative

- **VUID-VkVideoDecodeInfoKHR-pSetupReferenceSlot-07169**
  
  If **pSetupReferenceSlot** is not NULL, then its **pPictureResource** must not be NULL

- **VUID-VkVideoDecodeInfoKHR-slotIndex-07171**
  
  The **slotIndex** member of each element of **pReferenceSlots** must not be negative
Valid Usage (Implicit)

- **VUID-VkVideoDecodeInfoKHR-sType-sType**
  sType must be VK_STRUCTURE_TYPE_VIDEO_DECODE_INFO_KHR

- **VUID-VkVideoDecodeInfoKHR-pNext-pNext**
  Each pNext member of any structure (including this one) in the pNext chain must be either NULL or a pointer to a valid instance of VkVideoDecodeH264PictureInfoKHR or VkVideoDecodeH265PictureInfoKHR

- **VUID-VkVideoDecodeInfoKHR-sType-unique**
  The sType value of each struct in the pNext chain must be unique

- **VUID-VkVideoDecodeInfoKHR-flags-zerobitmask**
  flags must be 0

- **VUID-VkVideoDecodeInfoKHR-srcBuffer-parameter**
  srcBuffer must be a valid VkBuffer handle

- **VUID-VkVideoDecodeInfoKHR-dstPictureResource-parameter**
  dstPictureResource must be a valid VkVideoPictureResourceInfoKHR structure

- **VUID-VkVideoDecodeInfoKHR-pSetupReferenceSlot-parameter**
  If pSetupReferenceSlot is not NULL, pSetupReferenceSlot must be a valid pointer to a valid VkVideoReferenceSlotInfoKHR structure

- **VUID-VkVideoDecodeInfoKHR-pReferenceSlots-parameter**
  If referenceSlotCount is not 0, pReferenceSlots must be a valid pointer to an array of referenceSlotCount valid VkVideoReferenceSlotInfoKHR structures

---

```c
// Provided by VK_KHR_video_decode_queue
typedef VkFlags VkVideoDecodeFlagsKHR;
```

VkVideoDecodeFlagsKHR is a bitmask type for setting a mask, but is currently reserved for future use.

## 42.11. H.264 Decode Operations

Video decode operations using an H.264 decode profile can be used to decode elementary video stream sequences compliant to the ITU-T H.264 Specification.

**Note**
Refer to the Preamble for information on how the Khronos Intellectual Property Rights Policy relates to normative references to external materials not created by Khronos.

This process is performed according to the video decode operation steps with the codec-specific
semantics defined in section 8 of the ITU-T H.264 Specification as follows:

- Syntax elements, derived values, and other parameters are applied from the following structures:
  - The `StdVideoH264SequenceParameterSet` structure corresponding to the active SPS specifying the H.264 sequence parameter set.
  - The `StdVideoH264PictureParameterSet` structure corresponding to the active PPS specifying the H.264 picture parameter set.
  - The `StdVideoDecodeH264PictureInfo` structure specifying the H.264 picture information.
  - The `StdVideoDecodeH264ReferenceInfo` structures specifying the H.264 reference information corresponding to the optional reconstructed picture and any active reference pictures.
- The contents of the provided video bitstream buffer range are interpreted as defined in the H.264 Decode Bitstream Data Access section.
- Picture data in the video picture resources corresponding to the used active reference pictures, decode output picture, and optional reconstructed picture is accessed as defined in the H.264 Decode Picture Data Access section.

If the parameters and the bitstream adhere to the syntactic and semantic requirements defined in the corresponding sections of the ITU-T H.264 Specification, as described above, and the DPB slots associated with the active reference pictures all refer to valid picture references, then the video decode operation will complete successfully. Otherwise, the video decode operation may complete unsuccessfully.

### 42.11.1. H.264 Decode Bitstream Data Access

If the target decode output picture is a frame, then the video bitstream buffer range should contain a VCL NAL unit comprised of the slice headers and data of a picture representing an entire frame, as defined in sections 7.3.3 and 7.3.4, and this data is interpreted as defined in sections 7.4.3 and 7.4.4 of the ITU-T H.264 Specification, respectively.

If the target decode output picture is a field, then the video bitstream buffer range should contain a VCL NAL unit comprised of the slice headers and data of a picture representing a field, as defined in sections 7.3.3 and 7.3.4, and this data is interpreted as defined in sections 7.4.3 and 7.4.4 of the ITU-T H.264 Specification, respectively.

The offsets provided in VkVideoDecodeH264PictureInfoKHR::pSliceOffsets should specify the starting offsets corresponding to each slice header within the video bitstream buffer range.

### 42.11.2. H.264 Decode Picture Data Access

The effective imageOffset and imageExtent corresponding to a decode output picture, reference picture, or reconstructed picture used in video decode operations with an H.264 decode profile are defined as follows:

- imageOffset is `(codedOffset.x, codedOffset.y)` and imageExtent is `(codedExtent.width, codedExtent.height)`, if the picture represents a frame.
• imageOffset is \((\text{codedOffset.x}, \text{codedOffset.y})\) and imageExtent is \((\text{codedExtent.width}, \\text{codedExtent.height})\), if the picture represents a field and the picture layout of the used H.264 decode profile is \text{VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_INTERLEAVED_LINES_BIT_KHR}.

• imageOffset is \((\text{codedOffset.x}, \text{codedOffset.y})\) and imageExtent is \((\text{codedExtent.width}, \text{codedExtent.height} / 2)\), if the picture represents a field and the picture layout of the used H.264 decode profile is \text{VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_SEPARATE_PLANES_BIT_KHR}.

Where \text{codedOffset} and \text{codedExtent} are the members of the \text{VkVideoPictureResourceInfoKHR} structure corresponding to the picture.

However, accesses to image data within a video picture resource happen at the granularity indicated by \text{VkVideoCapabilitiesKHR::pictureAccessGranularity}, as returned by \text{vkGetPhysicalDeviceVideoCapabilitiesKHR} for the used video profile. This means that the complete image subregion accessed by video coding operations using an H.264 decode profile for the video picture resource is defined as the set of texels within the coordinate range:

\[
((\text{startX}, \text{endX}), (\text{startY}, \text{endY}))
\]

Where:

• startX equals \(\text{imageOffset.x}\) rounded down to the nearest integer multiple of \text{pictureAccessGranularity.width};

• endX equals \(\text{imageOffset.x} + \text{imageExtent.width}\) rounded up to the nearest integer multiple of \text{pictureAccessGranularity.width} and clamped to the width of the image subresource referred to by the corresponding \text{VkVideoPictureResourceInfoKHR} structure;

• startY equals \(\text{imageOffset.y}\) rounded down to the nearest integer multiple of \text{pictureAccessGranularity.height};

• endY equals \(\text{imageOffset.y} + \text{imageExtent.height}\) rounded up to the nearest integer multiple of \text{pictureAccessGranularity.height} and clamped to the height of the image subresource referred to by the corresponding \text{VkVideoPictureResourceInfoKHR} structure.

In case of video decode operations using an H.264 decode profile, any access to a picture at the coordinates \((x,y)\), as defined by the ITU-T H.264 Specification, is an access to the image subresource referred to by the corresponding \text{VkVideoPictureResourceInfoKHR} structure at the texel coordinates specified below:

• \((x,y)\), if the accessed picture represents a frame.

• \((x,y \times 2)\), if the accessed picture represents a top field and the picture layout of the used H.264 decode profile is \text{VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_INTERLEAVED_LINES_BIT_KHR}.

• \((x,y \times 2 + 1)\), if the accessed picture represents a bottom field and the picture layout of the used H.264 decode profile is \text{VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_INTERLEAVED_LINES_BIT_KHR}.

• \((x,y)\), if the accessed picture represents a top field and the picture layout of the used H.264 decode profile is \text{VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_SEPARATE_PLANES_BIT_KHR}.

• \((\text{codedOffset.x} + x, \text{codedOffset.y} + y)\), if the accessed picture represents a bottom field and the
picture layout of the used H.264 decode profile is VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_SEPARATE_PLANES_BIT_KHR.

Where codedOffset is the member of the corresponding VkVideoPictureResourceInfoKHR structure.

42.11.3. H.264 Decode Profile

A video profile supporting H.264 video decode operations is specified by setting VkVideoProfileInfoKHR::videoCodecOperation to VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR and adding a VkVideoDecodeH264ProfileInfoKHR structure to the VkVideoProfileInfoKHR::pNext chain.

The VkVideoDecodeH264ProfileInfoKHR structure is defined as:

```c
// Provided by VK_KHR_video_decode_h264
typedef struct VkVideoDecodeH264ProfileInfoKHR {
    VkStructureType sType;
    const void* pNext;
    StdVideoH264ProfileIdc stdProfileIdc;
    VkVideoDecodeH264PictureLayoutFlagBitsKHR pictureLayout;
} VkVideoDecodeH264ProfileInfoKHR;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **stdProfileIdc** is a StdVideoH264ProfileIdc value specifying the H.264 codec profile IDC, as defined in section A.2 of the ITU-T H.264 Specification.
- **pictureLayout** is a VkVideoDecodeH264PictureLayoutFlagBitsKHR value specifying the picture layout used by the H.264 video sequence to be decoded.

### Valid Usage (Implicit)

- VUID-VkVideoDecodeH264ProfileInfoKHR-sType-sType
  - **sType** must be VK_STRUCTURE_TYPE_VIDEO_DECODE_H264_PROFILE_INFO_KHR
- VUID-VkVideoDecodeH264ProfileInfoKHR-pictureLayout-parameter
  - If **pictureLayout** is not 0, **pictureLayout** must be a valid VkVideoDecodeH264PictureLayoutFlagBitsKHR value

The H.264 video decode picture layout flags are defined as follows:

```c
// Provided by VK_KHR_video_decode_h264
typedef enum VkVideoDecodeH264PictureLayoutFlagBitsKHR {
    VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_PROGRESSIVE_KHR = 0,
    VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_INTERLEAVED_LINES_BIT_KHR = 0x00000001,
    VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_SEPARATE_PLANES_BIT_KHR = 0x00000002,
};
```
- **VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_PROGRESSIVE_KHR** specifies support for progressive content. This flag has the value 0.

- **VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_INTERLEAVED_LINES_BIT_KHR** specifies support for or use of a picture layout for interlaced content where all lines belonging to the top field are decoded to the even-numbered lines within the picture resource, and all lines belonging to the bottom field are decoded to the odd-numbered lines within the picture resource.

- **VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_SEPARATE_PLANES_BIT_KHR** specifies support for or use of a picture layout for interlaced content where all lines belonging to a field are grouped together in a single image subregion, and the two fields comprising the frame can be stored in separate image subregions of the same image subresource or in separate image subresources.

```c
// Provided by VK_KHR_video_decode_h264
typedef VkFlags VkVideoDecodeH264PictureLayoutFlagsKHR;
```

**VkVideoDecodeH264PictureLayoutFlagsKHR** is a bitmask type for setting a mask of zero or more **VkVideoDecodeH264PictureLayoutFlagBitsKHR**.

### 42.11.4. H.264 Decode Capabilities

When calling **vkGetPhysicalDeviceVideoCapabilitiesKHR** to query the capabilities for an H.264 decode profile, the **VkVideoCapabilitiesKHR::pNext** chain must include a **VkVideoDecodeH264CapabilitiesKHR** structure that will be filled with the profile-specific capabilities.

The **VkVideoDecodeH264CapabilitiesKHR** structure is defined as:

```c
// Provided by VK_KHR_video_decode_h264
typedef struct VkVideoDecodeH264CapabilitiesKHR {
    VkStructureType sType;
    void* pNext;
    StdVideoH264LevelIdc maxLevelIdc;
    VkOffset2D fieldOffsetGranularity;
} VkVideoDecodeH264CapabilitiesKHR;
```

- **sType** is a **VkStructureType** value identifying this structure.

- **pNext** is NULL or a pointer to a structure extending this structure.

- **maxLevelIdc** is a **StdVideoH264LevelIdc** value specifying the maximum H.264 level supported by the profile, where enum constant **STD_VIDEO_H264_LEVEL_IDC_<major>_<minor>** identifies H.264 level <major>.<minor> as defined in section A.3 of the ITU-T H.264 Specification.

- **fieldOffsetGranularity** is the minimum alignment for **VkVideoPictureResourceInfoKHR::codedOffset** specified for a video picture resource when using the picture layout **VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_SEPARATE_PLANES_BIT_KHR**.
Valid Usage (Implicit)

- VUID-VkVideoDecodeH264CapabilitiesKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_VIDEO_DECODE_H264_CAPABILITIES_KHR

42.11.5. H.264 Decode Parameter Sets

Video session parameters objects created with the video codec operation VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR can contain the following types of parameters:

H.264 Sequence Parameter Sets (SPS)

Represented by StdVideoH264SequenceParameterSet structures and interpreted as follows:

- reserved1 and reserved2 are used only for padding purposes and are otherwise ignored;
- seq_parameter_set_id is used as the key of the SPS entry;
- level_idc is one of the enum constants STD_VIDEO_H264_LEVEL_IDC_<major>_<minor> identifying the H.264 level <major>.<minor> as defined in section A.3 of the ITU-T H.264 Specification;
- if flags.seq_scaling_matrix_present_flag is set, then the StdVideoH264ScalingLists structure pointed to by pScalingLists is interpreted as follows:
  - scaling_list_present_mask is a bitmask where bit index i corresponds to seq_scaling_list_present_flag[i] as defined in section 7.4.2.1 of the ITU-T H.264 Specification;
  - use_default_scaling_matrix_mask is a bitmask where bit index i corresponds to UseDefaultScalingMatrix4x4Flag[i], when i < 6, or corresponds to UseDefaultScalingMatrix8x8Flag[i-6], otherwise, as defined in section 7.3.2.1 of the ITU-T H.264 Specification;
  - ScalingList4x4 and ScalingList8x8 correspond to the identically named syntax elements defined in section 7.3.2.1 of the ITU-T H.264 Specification;
- if flags.vui_parameters_present_flag is set, then pSequenceParameterSetVui is a pointer to a StdVideoH264SequenceParameterSetVui structure that is interpreted as follows:
  - reserved1 is used only for padding purposes and is otherwise ignored;
  - if flags.nal_hrd_parameters_present_flag or flags.vcl_hrd_parameters_present_flag is set, then the StdVideoH264HrdParameters structure pointed to by pHrdParameters is interpreted as follows:
    - reserved1 is used only for padding purposes and is otherwise ignored;
    - all other members of StdVideoH264HrdParameters are interpreted as defined in section E.2.2 of the ITU-T H.264 Specification;
    - all other members of StdVideoH264SequenceParameterSetVui are interpreted as defined in section E.2.1 of the ITU-T H.264 Specification;
- all other members of StdVideoH264SequenceParameterSet are interpreted as defined in section 7.4.2.1 of the ITU-T H.264 Specification.
H.264 Picture Parameter Sets (PPS)

Represented by StdVideoH264PictureParameterSet structures and interpreted as follows:

- the pair constructed from seq_parameter_set_id and pic_parameter_set_id is used as the key of the PPS entry;
- if flags.pic_scaling_matrix_present_flag is set, then the StdVideoH264ScalingLists structure pointed to by pScalingLists is interpreted as follows:
  - scaling_list_present_mask is a bitmask where bit index i corresponds to pic_scaling_list_present_flag[i] as defined in section 7.4.2.2 of the ITU-T H.264 Specification;
  - use_default_scaling_matrix_mask is a bitmask where bit index i corresponds to UseDefaultScalingMatrix4x4Flag[i], when i < 6, or corresponds to UseDefaultScalingMatrix8x8Flag[i-6], otherwise, as defined in section 7.3.2.2 of the ITU-T H.264 Specification;
  - ScalingList4x4 and ScalingList8x8 correspond to the identically named syntax elements defined in section 7.3.2.2 of the ITU-T H.264 Specification;
- all other members of StdVideoH264PictureParameterSet are interpreted as defined in section 7.4.2.2 of the ITU-T H.264 Specification.

When a video session parameters object is created with the codec operation VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR, the VkVideoSessionParametersCreateInfoKHR::pNext chain must include a VkVideoDecodeH264SessionParametersCreateInfoKHR structure specifying the capacity and initial contents of the object.

The VkVideoDecodeH264SessionParametersCreateInfoKHR structure is defined as:

```c
// Provided by VK_KHR_video_decode_h264
typedef struct VkVideoDecodeH264SessionParametersCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t maxStdSPSCount;
    uint32_t maxStdPPSCount;
    const VkVideoDecodeH264SessionParametersAddInfoKHR* pParametersAddInfo;
} VkVideoDecodeH264SessionParametersCreateInfoKHR;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **maxStdSPSCount** is the maximum number of H.264 SPS entries the created VkVideoSessionParametersKHR can contain.
- **maxStdPPSCount** is the maximum number of H.264 PPS entries the created VkVideoSessionParametersKHR can contain.
- **pParametersAddInfo** is NULL or a pointer to a VkVideoDecodeH264SessionParametersAddInfoKHR structure specifying H.264 parameters to add upon object creation.
Valid Usage (Implicit)

- VUID-VkVideoDecodeH264SessionParametersCreateInfoKHR-sType-sType
  \textbf{sType must} be VK_STRUCTURE_TYPE_VIDEO_DECODE_H264_SESSION_PARAMETERS_CREATE_INFO_KHR

- VUID-VkVideoDecodeH264SessionParametersCreateInfoKHR-pParametersAddInfo-parameter
  If \texttt{pParametersAddInfo} is not \texttt{NULL}, \texttt{pParametersAddInfo} \textbf{must} be a valid pointer to a valid
  \texttt{VkVideoDecodeH264SessionParametersAddInfoKHR} structure

The \texttt{VkVideoDecodeH264SessionParametersAddInfoKHR} structure is defined as:

```c
// Provided by VK_KHR_video_decode_h264
typedef struct VkVideoDecodeH264SessionParametersAddInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t stdSPSCount;
    const StdVideoH264SequenceParameterSet* pStdSPSSs;
    uint32_t stdPPSCount;
    const StdVideoH264PictureParameterSet* pStdPPSSs;
} VkVideoDecodeH264SessionParametersAddInfoKHR;
```

- \texttt{sType} is a \texttt{VkStructureType} value identifying this structure.
- \texttt{pNext} is \texttt{NULL} or a pointer to a structure extending this structure.
- \texttt{stdSPSCount} is the number of elements in the \texttt{pStdSPSSs} array.
- \texttt{pStdSPSSs} is a pointer to an array of \texttt{StdVideoH264SequenceParameterSet} structures describing the
  H.264 \texttt{SPS} entries to add.
- \texttt{stdPPSCount} is the number of elements in the \texttt{pStdPPSSs} array.
- \texttt{pStdPPSSs} is a pointer to an array of \texttt{StdVideoH264PictureParameterSet} structures describing the
  H.264 \texttt{PPS} entries to add.

This structure \textbf{can} be specified in the following places:

- In the \texttt{pParametersAddInfo} member of the \texttt{VkVideoDecodeH264SessionParametersCreateInfoKHR}
  structure specified in the \texttt{pNext} chain of \texttt{VkVideoSessionParametersCreateInfoKHR} used to
  create a video session parameters object. In this case, if the video codec operation the video
  session parameters object is created with \texttt{VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR}, then
  it defines the set of initial parameters to add to the created object (see Creating Video Session
  Parameters).

- In the \texttt{pNext} chain of \texttt{VkVideoSessionParametersUpdateInfoKHR}. In this case, if the video codec
  operation the video session parameters object to be updated was created with is \texttt{VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR},
  then it defines the set of parameters to add to it (see Updating Video Session Parameters).
Valid Usage

• VUID-VkVideoDecodeH264SessionParametersAddInfoKHR-None-04825
  The seq_parameter_set_id member of each StdVideoH264SequenceParameterSet structure specified in the elements of pStdSPSs must be unique within pStdSPSs.

• VUID-VkVideoDecodeH264SessionParametersAddInfoKHR-None-04826
  The pair constructed from the seq_parameter_set_id and pic_parameter_set_id members of each StdVideoH264PictureParameterSet structure specified in the elements of pStdPPSs must be unique within pStdPPSs.

Valid Usage (Implicit)

• VUID-VkVideoDecodeH264SessionParametersAddInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_VIDEO_DECODE_H264_SESSION_PARAMETERS_ADD_INFO_KHR.

• VUID-VkVideoDecodeH264SessionParametersAddInfoKHR-pStdSPSs-parameter
  If stdSPSCount is not 0, pStdSPSs must be a valid pointer to an array of stdSPSCount StdVideoH264SequenceParameterSet values.

• VUID-VkVideoDecodeH264SessionParametersAddInfoKHR-pStdPPSs-parameter
  If stdPPSCount is not 0, pStdPPSs must be a valid pointer to an array of stdPPSCount StdVideoH264PictureParameterSet values.

42.11.6. H.264 Decoding Parameters

The VkVideoDecodeH264PictureInfoKHR structure is defined as:

```
// Provided by VK_KHR_video_decode_h264
typedef struct VkVideoDecodeH264PictureInfoKHR {
    VkStructureType sType;
    const void* pNext;
    const StdVideoDecodeH264PictureInfo* pStdPictureInfo;
    uint32_t sliceCount;
    pSliceOffsets;
} VkVideoDecodeH264PictureInfoKHR;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• pStdPictureInfo is a pointer to a StdVideoDecodeH264PictureInfo structure specifying H.264 picture information.
• sliceCount is the number of elements in pSliceOffsets.
• pSliceOffsets is a pointer to an array of sliceCount offsets specifying the start offset of the slices of the picture within the video bitstream buffer range specified in VkVideoDecodeInfoKHR.
This structure is specified in the `pNext` chain of the `VkVideoDecodeInfoKHR` structure passed to `vkCmdDecodeVideoKHR` to specify the codec-specific picture information for an H.264 decode operation.

**Decode Output Picture Information**

When this structure is specified in the `pNext` chain of the `VkVideoDecodeInfoKHR` structure passed to `vkCmdDecodeVideoKHR`, the information related to the decode output picture is defined as follows:

- If `pStdPictureInfo->flags.field_pic_flag` is not set, then the picture represents a frame.
- If `pStdPictureInfo->flags.field_pic_flag` is set, then the picture represents a field. Specifically:
  - If `pStdPictureInfo->flags.bottom_field_flag` is not set, then the picture represents the top field of the frame.
  - If `pStdPictureInfo->flags.bottom_field_flag` is set, then the picture represents the bottom field of the frame.
- The image subregion used is determined according to the H.264 Decode Picture Data Access section.
- The decode output picture is associated with the H.264 picture information provided in `pStdPictureInfo`.

**Std Picture Information**

The members of the `StdVideoDecodeH264PictureInfo` structure pointed to by `pStdPictureInfo` are interpreted as follows:

- `reserved1` and `reserved2` are used only for padding purposes and are otherwise ignored;
- `flags.is_intra` as defined in section 3.73 of the ITU-T H.264 Specification;
- `flags.is_reference` as defined in section 3.136 of the ITU-T H.264 Specification;
- `flags.complementary_field_pair` as defined in section 3.35 of the ITU-T H.264 Specification;
- `seq_parameter_set_id` and `pic_parameter_set_id` are used to identify the active parameter sets, as described below;
- all other members are interpreted as defined in section 7.4.3 of the ITU-T H.264 Specification.

**Active Parameter Sets**

The members of the `StdVideoDecodeH264PictureInfo` structure pointed to by `pStdPictureInfo` are used to select the active parameter sets to use from the bound video session parameters object, as follows:

- The active SPS is the SPS identified by the key specified in `StdVideoDecodeH264PictureInfo::seq_parameter_set_id`.
- The active PPS is the PPS identified by the key specified by the pair constructed from `StdVideoDecodeH264PictureInfo::seq_parameter_set_id` and `StdVideoDecodeH264PictureInfo::pic_parameter_set_id`.
Valid Usage (Implicit)

- **VUID-VkVideoDecodeH264PictureInfoKHR-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_VIDEO_DECODE_H264_PICTURE_INFO_KHR`

- **VUID-VkVideoDecodeH264PictureInfoKHR-pStdPictureInfo-parameter**
  - `pStdPictureInfo` must be a valid pointer to a valid `StdVideoDecodeH264PictureInfo` value

- **VUID-VkVideoDecodeH264PictureInfoKHR-pSliceOffsets-parameter**
  - `pSliceOffsets` must be a valid pointer to an array of `sliceCount` `uint32_t` values

- **VUID-VkVideoDecodeH264PictureInfoKHR-sliceCount-arraylength**
  - `sliceCount` must be greater than 0

The `VkVideoDecodeH264DpbSlotInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_video_decode_h264
typedef struct VkVideoDecodeH264DpbSlotInfoKHR {
    VkStructureType sType;
    const void* pNext;
    const StdVideoDecodeH264ReferenceInfo* pStdReferenceInfo;
} VkVideoDecodeH264DpbSlotInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `pStdReferenceInfo` is a pointer to a `StdVideoDecodeH264ReferenceInfo` structure specifying H.264 reference information.

This structure is specified in the `pNext` chain of `VkVideoDecodeInfoKHR::pSetupReferenceSlot`, if not `NULL`, and the `pNext` chain of the elements of `VkVideoDecodeInfoKHR::pReferenceSlots` to specify the codec-specific reference picture information for an H.264 decode operation.

Active Reference Picture Information

When this structure is specified in the `pNext` chain of the elements of `VkVideoDecodeInfoKHR::pReferenceSlots`, one or two elements are added to the list of active reference pictures used by the video decode operation for each element of `VkVideoDecodeInfoKHR::pReferenceSlots` as follows:

- If neither `pStdReferenceInfo->flags.top_field_flag` nor `pStdReferenceInfo->flags.bottom_field_flag` is set, then the picture is added as a frame reference to the list of active reference pictures.

- If `pStdReferenceInfo->flags.top_field_flag` is set, then the picture is added as a top field reference to the list of active reference pictures.

- If `pStdReferenceInfo->flags.bottom_field_flag` is set, then the picture is added as a bottom field reference to the list of active reference pictures.

- For each added reference picture, the corresponding image subregion used is determined
according to the H.264 Decode Picture Data Access section.

- Each added reference picture is associated with the DPB slot index specified in the slotIndex member of the corresponding element of VkVideoDecodeInfoKHR::pReferenceSlots.
- Each added reference picture is associated with the H.264 reference information provided in pStdReferenceInfo.

**Note**
When both the top and bottom field of an interlaced frame currently associated with a DPB slot is intended to be used as an active reference picture and both fields are stored in the same image subregion (which is the case when using VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_INTERLEAVED_LINES_BIT_KHR which stores the two fields at even and odd scanlines of the same image subregion), both references have to be provided through a single VkVideoReferenceSlotInfoKHR structure that has both flags.top_field_flag and flags.bottom_field_flag set in the StdVideoDecodeH264ReferenceInfo structure pointed to by the pStdReferenceInfo member of the VkVideoDecodeH264DpbSlotInfoKHR structure included in the corresponding VkVideoReferenceSlotInfoKHR structure's pNext chain. However, this approach can only be used when both fields are stored in the same image subregion. If that is not the case (e.g. when using VK_VIDEO_DECODE_H264_PICTURE_LAYOUT_INTERLACED_SEPARATE_PLANES_BIT_KHR which requires separate codedOffset values for the two fields and also allows storing the two fields of a frame in separate image layers or entirely separate images), then a separate VkVideoReferenceSlotInfoKHR structure needs to be provided for referencing the two fields, each only setting one of flags.top_field_flag or flags.bottom_field_flag, and providing the appropriate video picture resource information in VkVideoReferenceSlotInfoKHR::pPictureResource.

**Reconstructed Picture Information**
When this structure is specified in the pNext chain of VkVideoDecodeInfoKHR::pSetupReferenceSlot, the information related to the reconstructed picture is defined as follows:

- If neither pStdReferenceInfo->flags.top_field_flag nor pStdReferenceInfo->flags.bottom_field_flag is set, then the picture represents a frame.
- If pStdReferenceInfo->flags.top_field_flag is set, then the picture represents a field, specifically, the top field of the frame.
- If pStdReferenceInfo->flags.bottom_field_flag is set, then the picture represents a field, specifically, the bottom field of the frame.
- The image subregion used is determined according to the H.264 Decode Picture Data Access section.
- The reconstructed picture is used to activate the DPB slot with the index specified in VkVideoDecodeInfoKHR::pSetupReferenceSlot->slotIndex.
- The reconstructed picture is associated with the H.264 reference information provided in pStdReferenceInfo.
Std Reference Information

The members of the StdVideoDecodeH264ReferenceInfo structure pointed to by pStdReferenceInfo are interpreted as follows:

- **flags.top_field_flag** is used to indicate whether the reference is used as top field reference;
- **flags.bottom_field_flag** is used to indicate whether the reference is used as bottom field reference;
- **flags.used_for_long_term_reference** is used to indicate whether the picture is marked as “used for long-term reference” as defined in section 8.2.5.1 of the ITU-T H.264 Specification;
- **flags.is_non_existing** is used to indicate whether the picture is marked as “non-existing” as defined in section 8.2.5.2 of the ITU-T H.264 Specification;
- all other members are interpreted as defined in section 8.2 of the ITU-T H.264 Specification.

Valid Usage (Implicit)

- VUID-VkVideoDecodeH264DpbSlotInfoKHR-sType-sType
  sType **must** be VK_STRUCTURE_TYPE_VIDEO_DECODE_H264_DPB_SLOT_INFO_KHR
- VUID-VkVideoDecodeH264DpbSlotInfoKHR-pStdReferenceInfo-parameter
  pStdReferenceInfo **must** be a valid pointer to a valid StdVideoDecodeH264ReferenceInfo value

42.11.7. H.264 Decode Requirements

This section describes the **required** H.264 decoding capabilities for physical devices that have at least one queue family that supports the video codec operation **VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR**, as returned by **vkGetPhysicalDeviceQueueFamilyProperties2** in **VkQueueFamilyVideoPropertiesKHR::videoCodecOperations**.

<table>
<thead>
<tr>
<th>Table 51. Required Video Std Header Versions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Video Std Header Name</strong></td>
<td><strong>Version</strong></td>
</tr>
<tr>
<td>vulkan_video_codec_h264std_decode</td>
<td>1.0.0</td>
</tr>
</tbody>
</table>

42.12. H.265 Decode Operations

Video decode operations using an **H.265 decode profile can** be used to decode elementary video stream sequences compliant to the **ITU-T H.265 Specification**.

*Note*

Refer to the **Preamble** for information on how the Khronos Intellectual Property Rights Policy relates to normative references to external materials not created by Khronos.
This process is performed according to the video decode operation steps with the codec-specific semantics defined in section 8 of ITU-T H.265 Specification:

- Syntax elements, derived values, and other parameters are applied from the following structures:
  - The StdVideoH265VideoParameterSet structure corresponding to the active VPS specifying the H.265 video parameter set.
  - The StdVideoH265SequenceParameterSet structure corresponding to the active SPS specifying the H.265 sequence parameter set.
  - The StdVideoH265PictureParameterSet structure corresponding to the active PPS specifying the H.265 picture parameter set.
  - The StdVideoDecodeH265PictureInfo structure specifying the H.265 picture information.
  - The StdVideoDecodeH265ReferenceInfo structures specifying the H.265 reference information corresponding to the optional reconstructed picture and any active reference pictures.

- The contents of the provided video bitstream buffer range are interpreted as defined in the H.265 Decode Bitstream Data Access section.

- Picture data in the video picture resources corresponding to the used active reference pictures, decode output picture, and optional reconstructed picture is accessed as defined in the H.265 Decode Picture Data Access section.

If the parameters and the bitstream adhere to the syntactic and semantic requirements defined in the corresponding sections of the ITU-T H.265 Specification, as described above, and the DPB slots associated with the active reference pictures all refer to valid picture references, then the video decode operation will complete successfully. Otherwise, the video decode operation may complete unsuccessfully.

### 42.12.1. H.265 Decode Bitstream Data Access

The video bitstream buffer range should contain a VCL NAL unit comprised of the slice segment headers and data of a picture representing a frame, as defined in sections 7.3.6 and 7.3.8, and this data is interpreted as defined in sections 7.4.7 and 7.4.9 of the ITU-T H.265 Specification, respectively.

The offsets provided in VkVideoDecodeH265PictureInfoKHR::pSliceSegmentOffsets should specify the starting offsets corresponding to each slice segment header within the video bitstream buffer range.

### 42.12.2. H.265 Decode Picture Data Access

Accesses to image data within a video picture resource happen at the granularity indicated by VkVideoCapabilitiesKHR::pictureAccessGranularity, as returned by vkGetPhysicalDeviceVideoCapabilitiesKHR for the used video profile. Accordingly, the complete image subregion of a decode output picture, reference picture, or reconstructed picture accessed by video coding operations using an H.265 decode profile is defined as the set of texels within the coordinate range:
(0,endX),(0,endY))

Where:

- endX equals codedExtent.width rounded up to the nearest integer multiple of pictureAccessGranularity.width and clamped to the width of the image subresource referred to by the corresponding VkVideoPictureResourceInfoKHR structure;
- endY equals codedExtent.height rounded up to the nearest integer multiple of pictureAccessGranularity.height and clamped to the height of the image subresource referred to by the corresponding VkVideoPictureResourceInfoKHR structure;

Where codedExtent is the member of the VkVideoPictureResourceInfoKHR structure corresponding to the picture.

In case of video decode operations using an H.265 decode profile, any access to a picture at the coordinates (x,y), as defined by the ITU-T H.265 Specification, is an access to the image subresource referred to by the corresponding VkVideoPictureResourceInfoKHR structure at the texel coordinates (x,y).

42.12.3. H.265 Decode Profile

A video profile supporting H.265 video decode operations is specified by setting VkVideoProfileInfoKHR::videoCodecOperation to VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR and adding a VkVideoDecodeH265ProfileInfoKHR structure to the VkVideoProfileInfoKHR::pNext chain.

The VkVideoDecodeH265ProfileInfoKHR structure is defined as:

```
// Provided by VK_KHR_video_decode_h265
typedef struct VkVideoDecodeH265ProfileInfoKHR {
    VkStructureType sType;
    const void* pNext;
    StdVideoH265ProfileIdc stdProfileIdc;
} VkVideoDecodeH265ProfileInfoKHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- stdProfileIdc is a StdVideoH265ProfileIdc value specifying the H.265 codec profile IDC, as defined in section A3 of the ITU-T H.265 Specification.

Valid Usage (Implicit)

- VUID-VkVideoDecodeH265ProfileInfoKHR-sType-sType sType must be VK_STRUCTURE_TYPE_VIDEO_DECODE_H265_PROFILE_INFO_KHR
42.12.4. H.265 Decode Capabilities

When calling `vkGetPhysicalDeviceVideoCapabilitiesKHR` to query the capabilities for an H.265 decode profile, the `VkVideoCapabilitiesKHR::pNext` chain must include a `VkVideoDecodeH265CapabilitiesKHR` structure that will be filled with the profile-specific capabilities.

The `VkVideoDecodeH265CapabilitiesKHR` structure is defined as:

```
// Provided by VK_KHR_video_decode_h265
typedef struct VkVideoDecodeH265CapabilitiesKHR {
    VkStructureType sType;
    void* pNext;
    StdVideoH265LevelIdc maxLevelIdc;
} VkVideoDecodeH265CapabilitiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `maxLevelIdc` is a `StdVideoH265LevelIdc` value specifying the maximum H.265 level supported by the profile, where enum constant `STD_VIDEO_H265_LEVEL_IDC_<major>_<minor>` identifies H.265 level `<major>.<minor>` as defined in section A.4 of the ITU-T H.265 Specification.

Valid Usage ( Implicit )

- VUID-VkVideoDecodeH265CapabilitiesKHR-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_VIDEO_DECODE_H265_CAPABILITIES_KHR`

42.12.5. H.265 Decode Parameter Sets

Video session parameters objects created with the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR` can contain the following types of parameters:

H.265 Video Parameter Sets ( VPS )

Represented by `StdVideoH265VideoParameterSet` structures and interpreted as follows:

- `reserved1`, `reserved2`, and `reserved3` are used only for padding purposes and are otherwise ignored;
- `vps_video_parameter_set_id` is used as the key of the VPS entry;
- the `max_latency_increase_plus1`, `max_dec_pic_buffering_minus1`, and `max_num_reorder_pics` members of the `StdVideoH265DecPicBufMgr` structure pointed to by `pDecPicBufMgr` correspond to `vps_max_latency_increase_plus1`, `vps_max_dec_pic_buffering_minus1`, and `vps_max_num_reorder_pics`, respectively, as defined in section 7.4.3.1 of the ITU-T H.265 Specification;
- the `StdVideoH265HrdParameters` structure pointed to by `pHrdParameters` is interpreted as follows:
  - `reserved` is used only for padding purposes and is otherwise ignored;
• flags.fixed_pic_rate_general_flag is a bitmask where bit index i corresponds to fixed_pic_rate_general_flag[i] as defined in section E.3.2 of the ITU-T H.265 Specification;

• flags.fixed_pic_rate_within_cvs_flag is a bitmask where bit index i corresponds to fixed_pic_rate_within_cvs_flag[i] as defined in section E.3.2 of the ITU-T H.265 Specification;

• flags.low_delay_hrd_flag is a bitmask where bit index i corresponds to low_delay_hrd_flag[i] as defined in section E.3.2 of the ITU-T H.265 Specification;

• if flags.nal_hrd_parameters_present_flag is set, then pSubLayerHrdParametersNal is a pointer to an array of vps_max_sub_layers_minus1 + 1 number of StdVideoH265SubLayerHrdParameters structures where vps_max_sub_layers_minus1 is the corresponding member of the encompassing StdVideoH265VideoParameterSet structure and each element is interpreted as follows:
  ▪ cbr_flag is a bitmask where bit index i corresponds to cbr_flag[i] as defined in section E.3.3 of the ITU-T H.265 Specification;
  ▪ all other members of the StdVideoH265SubLayerHrdParameters structure are interpreted as defined in section E.3.3 of the ITU-T H.265 Specification;

• if flags.vcl_hrd_parameters_present_flag is set, then pSubLayerHrdParametersVcl is a pointer to an array of vps_max_sub_layers_minus1 + 1 number of StdVideoH265SubLayerHrdParameters structures where vps_max_sub_layers_minus1 is the corresponding member of the encompassing StdVideoH265VideoParameterSet structure and each element is interpreted as follows:
  ▪ cbr_flag is a bitmask where bit index i corresponds to cbr_flag[i] as defined in section E.3.3 of the ITU-T H.265 Specification;
  ▪ all other members of the StdVideoH265SubLayerHrdParameters structure are interpreted as defined in section E.3.3 of the ITU-T H.265 Specification;

• all other members of StdVideoH265HrdParameters are interpreted as defined in section E.3.2 of the ITU-T H.265 Specification;

• the StdVideoH265ProfileTierLevel structure pointed to by pProfileTierLevel are interpreted as follows:
  ▪ general_level_idc is one of the enum constants STD_VIDEO_H265_LEVEL_IDC_<major>_<minor> identifying the H.265 level <major>.<minor> as defined in section A.4 of the ITU-T H.265 Specification;
  ▪ all other members of StdVideoH265ProfileTierLevel are interpreted as defined in section 7.4.4 of the ITU-T H.265 Specification;

• all other members of StdVideoH265VideoParameterSet are interpreted as defined in section 7.4.3.1 of the ITU-T H.265 Specification.

H.265 Sequence Parameter Sets (SPS)

Represented by StdVideoH265SequenceParameterSet structures and interpreted as follows:

• reserved1 and reserved2 are used only for padding purposes and are otherwise ignored;
• the pair constructed from sps_video_parameter_set_id and sps_seq_parameter_set_id is used
as the key of the SPS entry;

• the StdVideoH265ProfileTierLevel structure pointed to by pProfileTierLevel are interpreted as follows:
  
  ◦ general_level_idc is one of the enum constants STD_VIDEO_H265_LEVEL_IDC_<major>_<minor> identifying the H.265 level <major>.<minor> as defined in section A.4 of the ITU-T H.265 Specification;
  
  ◦ all other members of StdVideoH265ProfileTierLevel are interpreted as defined in section 7.4.4 of the ITU-T H.265 Specification;

• the max_latency_increase_plus1, max_dec_pic_buffering_minus1, and max_num_reorder_pics members of the StdVideoH265DecPicBufMgr structure pointed to by pDecPicBufMgr correspond to sps_max_latency_increase_plus1, sps_max_dec_pic_buffering_minus1, and sps_max_num_reorder_pics, respectively, as defined in section 7.4.3.2 of the ITU-T H.265 Specification;

• if flags.sps_scaling_list_data_present_flag is set, then the StdVideoH265ScalingLists structure pointed to by pScalingLists is interpreted as follows:
  
  ◦ ScalingList4x4, ScalingList8x8, ScalingList16x16, and ScalingList32x32 correspond to ScalingList[0], ScalingList[1], ScalingList[2], and ScalingList[3], respectively, as defined in section 7.3.4 of the ITU-T H.265 Specification;
  
  ◦ ScalingListDCCoef16x16 and ScalingListDCCoef32x32 correspond to scaling_list_dc_coef_minus8[0] and scaling_list_dc_coef_minus8[1], respectively, as defined in section 7.3.4 of the ITU-T H.265 Specification;

• pShortTermRefPicSet is a pointer to an array of num_short_term_ref_pic_sets number of StdVideoH265ShortTermRefPicSet structures where each element is interpreted as follows:
  
  ◦ reserved1, reserved2, and reserved3 are used only for padding purposes and are otherwise ignored;
  
  ◦ used_by_curr_pic_flag is a bitmask where bit index i corresponds to used_by_curr_pic_flag[i] as defined in section 7.4.8 of the ITU-T H.265 Specification;
  
  ◦ use_delta_flag is a bitmask where bit index i corresponds to use_delta_flag[i] as defined in section 7.4.8 of the ITU-T H.265 Specification;
  
  ◦ used_by_curr_pic_s0_flag is a bitmask where bit index i corresponds to used_by_curr_pic_s0_flag[i] as defined in section 7.4.8 of the ITU-T H.265 Specification;
  
  ◦ used_by_curr_pic_s1_flag is a bitmask where bit index i corresponds to used_by_curr_pic_s1_flag[i] as defined in section 7.4.8 of the ITU-T H.265 Specification;
  
  ◦ all other members of StdVideoH265ShortTermRefPicSet are interpreted as defined in section 7.4.8 of the ITU-T H.265 Specification;

• if flags.long_term_ref_pics_present_flag is set then the StdVideoH265LongTermRefPicsSps structure pointed to by pLongTermRefPicsSps is interpreted as follows:
  
  ◦ used_by_curr_pic_lt_sps_flag is a bitmask where bit index i corresponds to used_by_curr_pic_lt_sps_flag[i] as defined in section 7.4.3.2 of the ITU-T H.265 Specification;
  
  ◦ all other members of StdVideoH265LongTermRefPicsSps are interpreted as defined in
if flags.vui_parameters_present_flag is set, then the StdVideoH265SequenceParameterSetVui structure pointed to by pSequenceParameterSetVui is interpreted as follows:

- reserved1, reserved2, and reserved3 are used only for padding purposes and are otherwise ignored;
- the StdVideoH265HrdParameters structure pointed to by pHrdParameters is interpreted as follows:
  - flags.fixed_pic_rate_general_flag is a bitmask where bit index i corresponds to fixed_pic_rate_general_flag[i] as defined in section E.3.2 of the ITU-T H.265 Specification;
  - flags.fixed_pic_rate_within_cvs_flag is a bitmask where bit index i corresponds to fixed_pic_rate_within_cvs_flag[i] as defined in section E.3.2 of the ITU-T H.265 Specification;
  - flags.low_delay_hrd_flag is a bitmask where bit index i corresponds to low_delay_hrd_flag[i] as defined in section E.3.2 of the ITU-T H.265 Specification;
  - if flags.nal_hrd_parameters_present_flag is set, then pSubLayerHrdParametersNal is a pointer to an array of sps_max_sub_layers_minus1 + 1 number of StdVideoH265SubLayerHrdParameters structures where sps_max_sub_layers_minus1 is the corresponding member of the encompassing StdVideoH265SequenceParameterSet structure and each element is interpreted as follows:
    - cbr_flag is a bitmask where bit index i corresponds to cbr_flag[i] as defined in section E.3.3 of the ITU-T H.265 Specification;
    - all other members of the StdVideoH265SubLayerHrdParameters structure are interpreted as defined in section E.3.3 of the ITU-T H.265 Specification;
  - if flags.vcl_hrd_parameters_present_flag is set, then pSubLayerHrdParametersVcl is a pointer to an array of sps_max_sub_layers_minus1 + 1 number of StdVideoH265SubLayerHrdParameters structures where sps_max_sub_layers_minus1 is the corresponding member of the encompassing StdVideoH265SequenceParameterSet structure and each element is interpreted as follows:
    - cbr_flag is a bitmask where bit index i corresponds to cbr_flag[i] as defined in section E.3.3 of the ITU-T H.265 Specification;
    - all other members of the StdVideoH265SubLayerHrdParameters structure are interpreted as defined in section E.3.3 of the ITU-T H.265 Specification;
    - all other members of StdVideoH265HrdParameters are interpreted as defined in section E.3.2 of the ITU-T H.265 Specification;
    - all other members of pSequenceParameterSetVui are interpreted as defined in section E.3.1 of the ITU-T H.265 Specification;
  - if flags.sps_palette_predictor_initializer_present_flag is set, then the PredictorPaletteEntries member of the StdVideoH265PredictorPaletteEntries structure pointed to by pPredictorPaletteEntries is interpreted as defined in section 7.4.9.13 of the ITU-T H.265 Specification;
• all other members of StdVideoH265SequenceParameterSet are interpreted as defined in section 7.4.3.1 of the ITU-T H.265 Specification.

H.265 Picture Parameter Sets (PPS)
Represented by StdVideoH265PictureParameterSet structures and interpreted as follows:

• reserved1, reserved2, and reserved3 are used only for padding purposes and are otherwise ignored;
• the triplet constructed from sps_video_parameter_set_id, pps_seq_parameter_set_id, and pps_pic_parameter_set_id is used as the key of the PPS entry;
• if flags.pps_scaling_list_data_present_flag is set, then the StdVideoH265ScalingLists structure pointed to by pScalingLists is interpreted as follows:
  ◦ ScalingList4x4, ScalingList8x8, ScalingList16x16, and ScalingList32x32 correspond to ScalingList[0], ScalingList[1], ScalingList[2], and ScalingList[3], respectively, as defined in section 7.3.4 of the ITU-T H.265 Specification;
  ◦ ScalingListDCCoeff16x16 and ScalingListDCCoeff32x32 correspond to scaling_list_dc_coef_minus8[0] and scaling_list_dc_coef_minus8[1], respectively, as defined in section 7.3.4 of the ITU-T H.265 Specification;
• if flags.pps_palette_predictor_initializer_present_flag is set, then the PredictorPaletteEntries member of the StdVideoH265PredictorPaletteEntries structure pointed to by pPredictorPaletteEntries is interpreted as defined in section 7.4.9.13 of the ITU-T H.265 Specification;
• all other members of StdVideoH265PictureParameterSet are interpreted as defined in section 7.4.3.3 of the ITU-T H.265 Specification.

When a video session parameters object is created with the codec operation VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR, the VkVideoSessionParametersCreateInfoKHR::pNext chain must include a VkVideoDecodeH265SessionParametersCreateInfoKHR structure specifying the capacity and initial contents of the object.

The VkVideoDecodeH265SessionParametersCreateInfoKHR structure is defined as:

```c
// Provided by VK_KHR_video_decode_h265
typedef struct VkVideoDecodeH265SessionParametersCreateInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t maxStdVPSCount;
    uint32_t maxStdSPSCount;
    uint32_t maxStdPPSCount;
    const VkVideoDecodeH265SessionParametersAddInfoKHR* pParametersAddInfo;
} VkVideoDecodeH265SessionParametersCreateInfoKHR;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• maxStdVPSCount is the maximum number of H.265 VPS entries the created
 VkVideoSessionParametersKHR can contain.

- maxStdSPSCount is the maximum number of H.265 SPS entries the created VkVideoSessionParametersKHR can contain.
- maxStdPPSCount is the maximum number of H.265 PPS entries the created VkVideoSessionParametersKHR can contain.
- pParametersAddInfo is NULL or a pointer to a VkVideoDecodeH265SessionParametersAddInfoKHR structure specifying H.265 parameters to add upon object creation.

**Valid Usage (Implicit)**

- VUID-VkVideoDecodeH265SessionParametersCreateInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_VIDEO_DECODE_H265_SESSION_PARAMETERS_CREATE_INFO_KHR
- VUID-VkVideoDecodeH265SessionParametersCreateInfoKHR-pParametersAddInfo-parameter
  If pParametersAddInfo is not NULL, pParametersAddInfo must be a valid pointer to a valid VkVideoDecodeH265SessionParametersAddInfoKHR structure

The VkVideoDecodeH265SessionParametersAddInfoKHR structure is defined as:

```c
// Provided by VK_KHR_video_decode_h265
typedef struct VkVideoDecodeH265SessionParametersAddInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t stdVPSCount;
    const StdVideoH265VideoParameterSet* pStdVPSs;
    uint32_t stdSPSCount;
    const StdVideoH265SequenceParameterSet* pStdSPSs;
    uint32_t stdPPSCount;
    const StdVideoH265PictureParameterSet* pStdPPSs;
} VkVideoDecodeH265SessionParametersAddInfoKHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- stdVPSCount is the number of elements in the pStdVPSs array.
- pStdVPSs is a pointer to an array of StdVideoH265VideoParameterSet structures describing the H.265 VPS entries to add.
- stdSPSCount is the number of elements in the pStdSPSs array.
- pStdSPSs is a pointer to an array of StdVideoH265SequenceParameterSet structures describing the H.265 SPS entries to add.
- stdPPSCount is the number of elements in the pStdPPSs array.
- pStdPPSs is a pointer to an array of StdVideoH265PictureParameterSet structures describing the H.265 PPS entries to add.
This structure can be specified in the following places:

- In the pParametersAddInfo member of the VkVideoDecodeH265SessionParametersCreateInfoKHR structure specified in the pNext chain of VkVideoSessionParametersCreateInfoKHR used to create a video session parameters object. In this case, if the video codec operation the video session parameters object is created with is VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR, then it defines the set of initial parameters to add to the created object (see Creating Video Session Parameters).

- In the pNext chain of VkVideoSessionParametersUpdateInfoKHR. In this case, if the video codec operation the video session parameters object to be updated was created with is VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR, then it defines the set of parameters to add to it (see Updating Video Session Parameters).

### Valid Usage

- VUID-VkVideoDecodeH265SessionParametersAddInfoKHR-None-04833
  The vps_video_parameter_set_id member of each StdVideoH265VideoParameterSet structure specified in the elements of pStdVPSs must be unique within pStdVPSs.

- VUID-VkVideoDecodeH265SessionParametersAddInfoKHR-None-04834
  The pair constructed from the sps_video_parameter_set_id and sps_seq_parameter_set_id members of each StdVideoH265SequenceParameterSet structure specified in the elements of pStdSPSs must be unique within pStdSPSs.

- VUID-VkVideoDecodeH265SessionParametersAddInfoKHR-None-04835
  The triplet constructed from the sps_video_parameter_set_id, pps_seq_parameter_set_id, and pps_pic_parameter_set_id members of each StdVideoH265PictureParameterSet structure specified in the elements of pStdPPSs must be unique within pStdPPSs.

### Valid Usage (Implicit)

- VUID-VkVideoDecodeH265SessionParametersAddInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_VIDEO_DECODER_H265_SESSION_PARAMETERS_ADD_INFO_KHR.

- VUID-VkVideoDecodeH265SessionParametersAddInfoKHR-pStdVPSs-parameter
  If stdVPCount is not 0, pStdVPSs must be a valid pointer to an array of stdVPCount StdVideoH265VideoParameterSet values.

- VUID-VkVideoDecodeH265SessionParametersAddInfoKHR-pStdSPSs-parameter
  If stdSPSCount is not 0, pStdSPSs must be a valid pointer to an array of stdSPSCount StdVideoH265SequenceParameterSet values.

- VUID-VkVideoDecodeH265SessionParametersAddInfoKHR-pStdPPSs-parameter
  If stdPPSCount is not 0, pStdPPSs must be a valid pointer to an array of stdPPSCount StdVideoH265PictureParameterSet values.
42.12.6. H.265 Decoding Parameters

The VkVideoDecodeH265PictureInfoKHR structure is defined as:

```c
// Provided by VK_KHR_video_decode_h265
typedef struct VkVideoDecodeH265PictureInfoKHR {
    VkStructureType sType;
    const void* pNext;
    const StdVideoDecodeH265PictureInfo* pStdPictureInfo;
    uint32_t sliceSegmentCount;
    const uint32_t* pSliceSegmentOffsets;
} VkVideoDecodeH265PictureInfoKHR;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `pStdPictureInfo` is a pointer to a StdVideoDecodeH265PictureInfo structure specifying H.265 picture information.
- `sliceSegmentCount` is the number of elements in `pSliceSegmentOffsets`.
- `pSliceSegmentOffsets` is a pointer to an array of `sliceSegmentCount` offsets specifying the start offset of the slice segments of the picture within the video bitstream buffer range specified in VkVideoDecodeInfoKHR.

This structure is specified in the `pNext` chain of the VkVideoDecodeInfoKHR structure passed to vkCmdDecodeVideoKHR to specify the codec-specific picture information for an H.265 decode operation.

**Decode Output Picture Information**

When this structure is specified in the `pNext` chain of the VkVideoDecodeInfoKHR structure passed to vkCmdDecodeVideoKHR, the information related to the decode output picture is defined as follows:

- The image subregion used is determined according to the H.265 Decode Picture Data Access section.
- The decode output picture is associated with the H.265 picture information provided in `pStdPictureInfo`.

**Std Picture Information**

The members of the StdVideoDecodeH265PictureInfo structure pointed to by `pStdPictureInfo` are interpreted as follows:

- `reserved` is used only for padding purposes and is otherwise ignored;
- `flags.IrapPicFlag` as defined in section 3.73 of the ITU-T H.265 Specification;
- `flags.IdrPicFlag` as defined in section 3.67 of the ITU-T H.265 Specification;
- `flags.IsReference` as defined in section 3.132 of the ITU-T H.265 Specification;
- `sps_video_parameter_set_id`, `pps_seq_parameter_set_id`, and `pps_pic_parameter_set_id` are
used to identify the active parameter sets, as described below;

- **PicOrderCntVal** as defined in section 8.3.1 of the [ITU-T H.265 Specification](https://www.itu.int/rec/T-REC-H.265-201304-I/en);
- **NumBitsForSTRefPicSetInSlice** is the number of bits used in `st_ref_pic_set` when `short_term_ref_pic_set_sps_flag` is 0, or 0 otherwise, as defined in sections 7.4.7 and 7.4.8 of the [ITU-T H.265 Specification](https://www.itu.int/rec/T-REC-H.265-201304-I/en);
- **NumDeltaPocsOfRefRpsIdx** is the value of `NumDeltaPocs[RefRpsIdx]` when `short_term_ref_pic_set_sps_flag` is 1, or 0 otherwise, as defined in sections 7.4.7 and 7.4.8 of the [ITU-T H.265 Specification](https://www.itu.int/rec/T-REC-H.265-201304-I/en);
- **RefPicSetStCurrBefore**, **RefPicSetStCurrAfter**, and **RefPicSetLtCurr** are interpreted as defined in section 8.3.2 of the [ITU-T H.265 Specification](https://www.itu.int/rec/T-REC-H.265-201304-I/en) where each element of these arrays either identifies an active reference picture using its DPB slot index or contains the value 0xFF to indicate "no reference picture";
- all other members are interpreted as defined in section 8.3.2 of the [ITU-T H.265 Specification](https://www.itu.int/rec/T-REC-H.265-201304-I/en).

**Active Parameter Sets**

The members of the `StdVideoDecodeH265PictureInfo` structure pointed to by `pStdPictureInfo` are used to select the active parameter sets to use from the bound video session parameters object, as follows:

- The **active VPS** is the VPS identified by the key specified in `StdVideoDecodeH265PictureInfo::sps_video_parameter_set_id`.
- The **active SPS** is the SPS identified by the key specified by the pair constructed from `StdVideoDecodeH265PictureInfo::sps_video_parameter_set_id` and `StdVideoDecodeH265PictureInfo::pps_seq_parameter_set_id`.
- The **active PPS** is the PPS identified by the key specified by the triplet constructed from `StdVideoDecodeH265PictureInfo::sps_video_parameter_set_id`, `StdVideoDecodeH265PictureInfo::pps_seq_parameter_set_id`, and `StdVideoDecodeH265PictureInfo::pps_pic_parameter_set_id`.

### Valid Usage (Implicit)

- **VUID-VkVideoDecodeH265PictureInfoKHR-sType-sType**
  - `sType` **must** be `VK_STRUCTURE_TYPE_VIDEO_DECODE_H265_PICTURE_INFO_KHR`
- **VUID-VkVideoDecodeH265PictureInfoKHR-pStdPictureInfo-parameter**
  - `pStdPictureInfo` **must** be a valid pointer to a valid `StdVideoDecodeH265PictureInfo` value
- **VUID-VkVideoDecodeH265PictureInfoKHR-pSliceSegmentOffsets-parameter**
  - `pSliceSegmentOffsets` **must** be a valid pointer to an array of `sliceSegmentCount` `uint32_t` values
- **VUID-VkVideoDecodeH265PictureInfoKHR-sliceSegmentCount-arraylength**
  - `sliceSegmentCount` **must** be greater than 0

The `VkVideoDecodeH265DpbSlotInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_video_decode_h265
```
typedef struct VkVideoDecodeH265DpbSlotInfoKHR {
    VkStructureType sType;
    const void* pNext;
    const StdVideoDecodeH265ReferenceInfo* pStdReferenceInfo;
} VkVideoDecodeH265DpbSlotInfoKHR;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `pStdReferenceInfo` is a pointer to a `StdVideoDecodeH265ReferenceInfo` structure specifying reference picture information described in section 8.3 of the ITU-T H.265 Specification.

This structure is specified in the `pNext` chain of `VkVideoDecodeInfoKHR::pSetupReferenceSlot`, if not `NULL`, and the `pNext` chain of the elements of `VkVideoDecodeInfoKHR::pReferenceSlots` to specify the codec-specific reference picture information for an H.265 decode operation.

**Active Reference Picture Information**

When this structure is specified in the `pNext` chain of the elements of `VkVideoDecodeInfoKHR::pReferenceSlots`, one element is added to the list of active reference pictures used by the video decode operation for each element of `VkVideoDecodeInfoKHR::pReferenceSlots` as follows:

- The image subregion used is determined according to the H.265 Decode Picture Data Access section.
- The reference picture is associated with the DPB slot index specified in the `slotIndex` member of the corresponding element of `VkVideoDecodeInfoKHR::pReferenceSlots`.
- The reference picture is associated with the H.265 reference information provided in `pStdReferenceInfo`.

**Reconstructed Picture Information**

When this structure is specified in the `pNext` chain of `VkVideoDecodeInfoKHR::pSetupReferenceSlot`, the information related to the reconstructed picture is defined as follows:

- The image subregion used is determined according to the H.265 Decode Picture Data Access section.
- The reconstructed picture is used to activate the DPB slot with the index specified in `VkVideoDecodeInfoKHR::pSetupReferenceSlot->slotIndex`.
- The reconstructed picture is associated with the H.265 reference information provided in `pStdReferenceInfo`.

**Std Reference Information**

The members of the `StdVideoDecodeH265ReferenceInfo` structure pointed to by `pStdReferenceInfo` are interpreted as follows:

- `flags.used_for_long_term_reference` is used to indicate whether the picture is marked as “used for long-term reference” as defined in section 8.3.2 of the ITU-T H.265 Specification;
- `flags.unused_for_reference` is used to indicate whether the picture is marked as “unused for reference” as defined in section 8.3.2 of the ITU-T H.265 Specification;
42.12.7. H.265 Decode Requirements

This section describes the **required** H.265 decoding capabilities for physical devices that have at least one queue family that supports the video codec operation `VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR`, as returned by `vkGetPhysicalDeviceQueueFamilyProperties2` in `VkQueueFamilyVideoPropertiesKHR::videoCodecOperations`.

<table>
<thead>
<tr>
<th>Video Std Header Name</th>
<th>Version</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>vulkan_video_codec_h265std_decode</code></td>
<td>1.0.0</td>
</tr>
</tbody>
</table>

42.13. Video Encode Operations

Before the application can start recording Vulkan command buffers for the Video Encode Operations, it **must** do the following, beforehand:

1. Ensure that the implementation can encode the Video Content by querying the supported codec operations and profiles using `vkGetPhysicalDeviceQueueFamilyProperties2`.

2. By using `vkGetPhysicalDeviceVideoFormatPropertiesKHR` and providing one or more video profiles, choose the Vulkan formats supported by the implementation. The formats for **input** and **reference** pictures **must** be queried and chosen separately. Refer to the section on Video Format Capabilities.

3. Before creating an image to be used as a video picture resource, obtain the supported image creation parameters by querying with `vkGetPhysicalDeviceFormatProperties2` and `vkGetPhysicalDeviceImageFormatProperties2` using one of the reported formats and adding `VkVideoProfileListInfoKHR` to the `pNext` chain of `VkFormatProperties2`. When querying the parameters with `vkGetPhysicalDeviceImageFormatProperties2` for images targeting **input** and **reference (DPB)** pictures, the `VkPhysicalDeviceImageFormatInfo2::usage` field should contain `VK_IMAGE_USAGE_VIDEO_ENCODE_SRC_BIT_KHR` and `VK_IMAGE_USAGE_VIDEO_ENCODE_DPB_BIT_KHR`, respectively.

4. Create none, some, or all of the required **images** for the **input** and **reference** pictures. More Video Picture Resources **can** be created at some later point if needed while processing the content to be encoded. Also, if the size of the picture to be encoded is expected to change, the
5. Create the **video session** to be used for video encode operations. Before creating the Encode Video Session, the encode capabilities **should** be queried with `vkGetPhysicalDeviceVideoCapabilitiesKHR` to obtain the limits of the parameters allowed by the implementation for a particular codec profile.

6. Bind memory resources with the encode video session by calling `vkBindVideoSessionMemoryKHR`. The video session **cannot** be used until memory resources are allocated and bound to it. In order to determine the required memory sizes and heap types of the device memory allocations, `vkGetVideoSessionMemoryRequirementsKHR` **should** be called.

7. Create one or more **Video Session Parameter objects** for use across command buffer recording operations, if required by the codec extension in use. These objects **must** be created against a video session with the parameters required by the codec. Each Video Session Parameter object created is a child object of the associated **Session object** and **cannot** be bound in the command buffer with any other Session Object.

The recording of Video Encode Commands against a Vulkan Command Buffer consists of the following sequence:

1. `vkCmdBeginVideoCodingKHR` starts the recording of one or more Video Encode operations in the command buffer. For each Video Encode Command operation, a Video Session **must** be bound to the command buffer within this command. This command establishes a Vulkan Video Encode Context that consists of the bound Video Session Object, Session Parameters Object, and the required Video Picture Resources. The established Video Encode Context is in effect until the `vkCmdEndVideoCodingKHR` command is recorded. If more Video Encode operations are to be required after the `vkCmdEndVideoCodingKHR` command, another Video Encode Context **can** be started with the `vkCmdBeginVideoCodingKHR` command.

2. `vkCmdEncodeVideoKHR` specifies one or more frames to be encoded. The `VkVideoEncodeInfoKHR` parameters, and the codec extension structures chained to this, specify the details of the encode operation.

3. `vkCmdControlVideoCodingKHR` records operations against the encoded data, encoding device, or the Video Session state.

4. `vkCmdEndVideoCodingKHR` signals the end of the recording of the Vulkan Video Encode Context, as established by `vkCmdBeginVideoCodingKHR`.

In addition to the above, the following commands **can** be recorded between `vkCmdBeginVideoCodingKHR` and `vkCmdEndVideoCodingKHR`:

- Query operations
- Global Memory Barriers
- Buffer Memory Barriers
- Image Memory Barriers (these **must** be used to transition the Video Picture Resources to the proper `VK_IMAGE_LAYOUT_VIDEO_ENCODE_SRC_KHR` and `VK_IMAGE_LAYOUT_VIDEO_ENCODE_DPB_KHR` layouts).
- Pipeline Barriers
• Events
• Timestamps
• Device Groups (device mask)

The following Video Encode related commands must be recorded outside the Vulkan Video Encode Context established with the `vkCmdBeginVideoCodingKHR` and `vkCmdEndVideoCodingKHR` commands:

• Sparse Memory Binding
• Copy Commands
• Clear Commands

42.13.1. Encode Input Picture

The primary source of input pixels for the video encoding process is the Encode Input Picture, represented by a `VkImageView`. It may also be a direct target of video decode, graphics, or compute operations, or with Window System Integration APIs.

42.13.2. Capabilities

When calling `vkGetPhysicalDeviceVideoCapabilitiesKHR` with `pVideoProfile->videoCodecOperation` specified as one of the encode operation bits, the `VkVideoEncodeCapabilitiesKHR` structure must be included in the `pNext` chain of the `VkVideoCapabilitiesKHR` structure to retrieve capabilities specific to video encoding.

The `VkVideoEncodeCapabilitiesKHR` structure is defined as:

```c
// Provided by VK_KHR_video_encode_queue
typedef struct VkVideoEncodeCapabilitiesKHR {
    VkStructureType sType;
    void* pNext;
    VkVideoEncodeCapabilityFlagsKHR flags;
    VkVideoEncodeRateControlModeFlagsKHR rateControlModes;
    uint32_t maxRateControlLayers;
    uint32_t maxBitrate;
    uint32_t maxQualityLevels;
    VkExtent2D encodeInputPictureGranularity;
    VkVideoEncodeFeedbackFlagsKHR supportedEncodeFeedbackFlags;
} VkVideoEncodeCapabilitiesKHR;
```

• `sType` is a `VkStructureType` value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.
• `flags` is a bitmask of `VkVideoEncodeCapabilityFlagBitsKHR` describing supported encoding features.
• `rateControlModes` is a bitmask of `VkVideoEncodeRateControlModeFlagBitsKHR` indicating supported rate control modes.
• `maxRateControlLayers` indicates the maximum number of rate control layers supported.

• `maxBitrate` indicates the maximum supported bitrate.

• `maxQualityLevels` indicates the number of discrete video encode quality levels supported. Implementations must report at least 1.

• `encodeInputPictureGranularity` indicates the granularity at which encode input picture data is encoded.

• `supportedEncodeFeedbackFlags` is a bitmask of `VkVideoEncodeFeedbackFlagBitsKHR` values specifying the supported flags for video encode feedback queries.

Implementations must include support for at least `VK_VIDEO_ENCODE_FEEDBACK_BITSTREAM_BUFFER_OFFSET_BIT_KHR` and `VK_VIDEO_ENCODE_FEEDBACK_BITSTREAM_BYTES_WRITTEN_BIT_KHR` in `supportedEncodeFeedbackFlags`.

The input content and encode resolution (specified in `VkVideoEncodeInfoKHR::codedExtent`) may not be aligned with the codec-specific coding block size. For example, the input content may be 1920x1080 and the coding block size may be 16x16 pixel blocks. In this example, the content is horizontally aligned with the coding block size, but not vertically aligned with the coding block size. Encoding of the last row of blocks may be impacted by contents of the input image in pixel rows 1081 to 1088 (the next vertical alignment with the coding block size). In general, to ensure efficient encoding for the last row/column of blocks, and/or to ensure consistent encoding results between repeated encoding of the same input content, these extra pixel rows/columns should be filled to known values up to the coding block size alignment before encoding operations are performed. Some implementations support performing auto-fill of unaligned pixels beyond a specific alignment for the purposes of encoding, which is reported in `encodeInputPictureGranularity`. For example, if an implementation reports 1x1 in `encodeInputPictureGranularity`, then the implementation will perform auto-fill for any unaligned pixels beyond the encode resolution up to the next coding block size. For a coding block size of 16x16, if the implementation reports 16x16 in `encodeInputPictureGranularity`, then it is the application's responsibility to fill any unaligned pixels, if desired. When the application does not fill these unaligned pixels, there may be an impact on the encoding efficiency but there will be no effect on the validity of the generated bitstream. If the implementation reports 8x8 in `encodeInputPictureGranularity`, then for the 1920x1080 example, since the content is aligned to 8 pixels vertically, the implementation will auto-fill pixel rows 1081 to 1088 (up to the 16x16 coding block size in the example). The auto-fill value(s) are implementation-specific. The auto-fill value(s) are not written to the input image memory, but are used as part of the encoding operation on the input image.

---

**Valid Usage (Implicit)**

- `VUID-VkVideoEncodeCapabilitiesKHR-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_CAPABILITIES_KHR`

---

```c
// Provided by VK_KHR_video_encode_queue
typedef VkFlags VkVideoEncodeCapabilityFlagsKHR;
```

`VkVideoEncodeCapabilityFlagsKHR` is a bitmask type for setting a mask of zero or more
Bits which may be set in `VkVideoEncodeCapabilitiesKHR::flags`, indicating the encoding tools supported, are:

```c
// Provided by VK_KHR_video_encode_queue
typedef enum VkVideoEncodeCapabilityFlagBitsKHR {
    VK_VIDEO_ENCODE_CAPABILITY_PRECEDING_EXTERNALLY_ENCODED_BYTES_BIT_KHR = 0x00000001,
    VK_VIDEO_ENCODE_CAPABILITY_INSUFFICIENT_BITSTREAM_BUFFER_RANGE_DETECTION_BIT_KHR = 0x00000002,
} VkVideoEncodeCapabilityFlagBitsKHR;
```

- `VK_VIDEO_ENCODE_CAPABILITY_PRECEDING_EXTERNALLY_ENCODED_BYTES_BIT_KHR` indicates that the implementation supports the use of `VkVideoEncodeInfoKHR::precedingExternallyEncodedBytes`.
- `VK_VIDEO_ENCODE_CAPABILITY_INSUFFICIENT_BITSTREAM_BUFFER_RANGE_DETECTION_BIT_KHR` indicates that the implementation is able to detect and report when the destination video bitstream buffer range provided by the application is not sufficiently large to fit the encoded bitstream data produced by a video encode operation by reporting the `VK_QUERY_RESULT_STATUS_INSUFFICIENT_BITSTREAM_BUFFER_RANGE_KHR` query result status code.

**Note**

Some implementations may not be able to reliably detect insufficient bitstream buffer range conditions in all situations. Such implementations will not report support for the `VK_VIDEO_ENCODE_CAPABILITY_INSUFFICIENT_BITSTREAM_BUFFER_RANGE_DETECTION_BIT_KHR` encode capability flag for the video profile, but may still report the `VK_QUERY_RESULT_STATUS_INSUFFICIENT_BITSTREAM_BUFFER_RANGE_KHR` query result status code in certain cases. Applications should always check for the specific query result status code even when this encode capability flag is not supported by the implementation for the video profile in question. However, applications must not assume that a different negative query result status code indicating an unsuccessful completion of a video encode operation is not the result of an insufficient bitstream buffer condition unless this encode capability flag is supported.

### 42.13.3. Video Encode Quality Levels

To query properties for a specific video encode quality level supported by a video encode profile, call:

```c
// Provided by VK_KHR_video_encode_queue
VkResult vkGetPhysicalDeviceVideoEncodeQualityLevelPropertiesKHR(
    VkPhysicalDevice physicalDevice,
    const VkPhysicalDeviceVideoEncodeQualityLevelInfoKHR* pQualityLevelInfo,
);```
• `physicalDevice` is the physical device to query the video encode quality level properties for.
• `pQualityLevelInfo` is a pointer to a `VkPhysicalDeviceVideoEncodeQualityLevelInfoKHR` structure specifying the video encode profile and quality level to query properties for.
• `pQualityLevelProperties` is a pointer to a `VkVideoEncodeQualityLevelPropertiesKHR` structure in which the properties are returned.

Valid Usage (Implicit)

• VUID-vkGetPhysicalDeviceVideoEncodeQualityLevelPropertiesKHR-physicalDevice-parameter
  `physicalDevice` must be a valid `VkPhysicalDevice` handle
• VUID-vkGetPhysicalDeviceVideoEncodeQualityLevelPropertiesKHR-pQualityLevelInfo-parameter
  `pQualityLevelInfo` must be a valid pointer to a valid `VkPhysicalDeviceVideoEncodeQualityLevelInfoKHR` structure
• VUID-vkGetPhysicalDeviceVideoEncodeQualityLevelPropertiesKHR-pQualityLevelProperties-parameter
  `pQualityLevelProperties` must be a valid pointer to a `VkVideoEncodeQualityLevelPropertiesKHR` structure

Return Codes

Success
  • `VK_SUCCESS`

Failure
  • `VK_ERROR_OUT_OF_HOST_MEMORY`
  • `VK_ERROR_OUT_OF_DEVICE_MEMORY`
  • `VK_ERROR_VIDEO_PROFILE_OPERATION_NOT_SUPPORTED_KHR`
  • `VK_ERROR_VIDEO_PROFILE_FORMAT_NOT_SUPPORTED_KHR`
  • `VK_ERROR_VIDEO_PICTURE_LAYOUT_NOT_SUPPORTED_KHR`
  • `VK_ERROR_VIDEO_PROFILE_CODEC_NOT_SUPPORTED_KHR`

The `VkPhysicalDeviceVideoEncodeQualityLevelInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_video_encode_queue
typedef struct VkPhysicalDeviceVideoEncodeQualityLevelInfoKHR {
    VkStructureType sType;
    const void* pNext;
    const VkVideoProfileInfoKHR* pVideoProfile;
} VkPhysicalDeviceVideoEncodeQualityLevelInfoKHR;
```
uint32_t qualityLevel;
} VkPhysicalDeviceVideoEncodeQualityLevelInfoKHR;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **pVideoProfile** is a pointer to a `VkVideoProfileInfoKHR` structure specifying the video profile to query the video encode quality level properties for.
- **qualityLevel** is the video encode quality level to query properties for.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceVideoEncodeQualityLevelInfoKHR-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VIDEO_ENCODE_QUALITY_LEVEL_INFO_KHR`

- VUID-VkPhysicalDeviceVideoEncodeQualityLevelInfoKHR-pNext-pNext
  
  `pNext` must be `NULL`

- VUID-VkPhysicalDeviceVideoEncodeQualityLevelInfoKHR-pVideoProfile-parameter
  
  `pVideoProfile` must be a valid pointer to a valid `VkVideoProfileInfoKHR` structure

The `VkVideoEncodeQualityLevelPropertiesKHR` structure is defined as:

```c
// Provided by VK_KHR_video_encode_queue
typedef struct VkVideoEncodeQualityLevelPropertiesKHR {
    VkStructureType sType;
    void* pNext;
    VkVideoEncodeRateControlModeFlagBitsKHR preferredRateControlMode;
    uint32_t preferredRateControlLayerCount;
} VkVideoEncodeQualityLevelPropertiesKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **preferredRateControlMode** is a `VkVideoEncodeRateControlModeFlagBitsKHR` value indicating the preferred rate control mode to use with the video encode quality level.
- **preferredRateControlLayerCount** indicates the preferred number of rate control layers to use with the quality level.

### Valid Usage (Implicit)

- VUID-VkVideoEncodeQualityLevelPropertiesKHR-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_QUALITY_LEVEL_PROPERTIES_KHR`

- VUID-VkVideoEncodeQualityLevelPropertiesKHR-pNext-pNext
  
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkVideoEncodeH264QualityLevelPropertiesEXT` or
The `VkVideoEncodeQualityLevelInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_video_encode_queue
typedef struct VkVideoEncodeQualityLevelInfoKHR {
    VkStructureType sType;
    const void* pNext;
    uint32_t qualityLevel;
} VkVideoEncodeQualityLevelInfoKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **qualityLevel** is the used video encode quality level.

This structure **can** be specified in the following places:

- In the **pNext** chain of `VkVideoSessionParametersCreateInfoKHR` to specify the video encode quality level to use for a video session parameters object created for a video encode session. If no instance of this structure is included in the **pNext** chain of `VkVideoSessionParametersCreateInfoKHR`, then the video session parameters object is created with a video encode quality level of zero.
- In the **pNext** chain of `VkVideoCodingControlInfoKHR` to change the video encode quality level state of the bound video session.

**Valid Usage (Implicit)**

- VUID-VkVideoEncodeQualityLevelInfoKHR-sType-sType
  
  **sType** must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_QUALITY_LEVEL_INFO_KHR`

### 42.13.4. Retrieving Encoded Session Parameters

Any codec-specific parameters stored in video session parameters objects **may** need to be separately encoded and included in the final video bitstream data, depending on the used video compression standard. In such cases the application **must** call the `vkGetEncodedVideoSessionParametersKHR` command to retrieve the encoded parameter data from the used video session parameters object in order to be able to produce a compliant video bitstream.

Encoded parameter data **can** be retrieved from a video session parameters object created with a video encode operation using the command:
VkResult vkGetEncodedVideoSessionParametersKHR(
    VkDevice device,
    const VkVideoEncodeSessionParametersGetInfoKHR* pVideoSessionParametersInfo,
    VkVideoEncodeSessionParametersFeedbackInfoKHR* pFeedbackInfo,
    size_t* pDataSize, 
    void* pData);

- **device** is the logical device that owns the video session parameters object.
- **pVideoSessionParametersInfo** is a pointer to a VkVideoEncodeSessionParametersGetInfoKHR structure specifying the parameters of the encoded parameter data to retrieve.
- **pFeedbackInfo** is either NULL or a pointer to a VkVideoEncodeSessionParametersFeedbackInfoKHR structure in which feedback about the requested parameter data is returned.
- **pDataSize** is a pointer to a size_t value related to the amount of encode parameter data returned, as described below.
- **pData** is either NULL or a pointer to a buffer to write the encoded parameter data to.

If **pData** is NULL, then the size of the encoded parameter data, in bytes, that can be retrieved is returned in **pDataSize**. Otherwise, **pDataSize** must point to a variable set by the application to the size of the buffer, in bytes, pointed to by **pData**, and on return the variable is overwritten with the number of bytes actually written to **pData**. If **pDataSize** is less than the size of the encoded parameter data that can be retrieved, then no data will be written to **pData**, zero will be written to **pDataSize**, and **VK_INCOMPLETE** will be returned instead of **VK_SUCCESS**, to indicate that no encoded parameter data was returned.

If **pFeedbackInfo** is not NULL then the members of the VkVideoEncodeSessionParametersFeedbackInfoKHR structure and any additional structures included in its pNext chain that are applicable to the video session parameters object specified in **pVideoSessionParametersInfo::videoSessionParameters** will be filled with feedback about the requested parameter data on all successful calls to this command.

**Note:**
This includes the cases when **pData** is NULL or when **VK_INCOMPLETE** is returned by the command, and enables the application to determine whether the implementation overrode any of the requested video session parameters without actually needing to retrieve the encoded parameter data itself.

**Valid Usage (Implicit)**

- VUID-vkGetEncodedVideoSessionParametersKHR-device-parameter
  - **device** must be a valid VkDevice handle
- VUID-vkGetEncodedVideoSessionParametersKHR-pVideoSessionParametersInfo-parameter
  - **pVideoSessionParametersInfo** must be a valid pointer to a valid
The ** VkVideoEncodeSessionParametersGetInfoKHR ** structure

- **VUID-vkGetEncodedVideoSessionParametersKHR-pFeedbackInfo-parameter**
  If **pFeedbackInfo** is not **NULL**, **pFeedbackInfo** must be a valid pointer to a ** VkVideoEncodeSessionParametersFeedbackInfoKHR ** structure

- **VUID-vkGetEncodedVideoSessionParametersKHR-pDataSize-parameter**
  **pDataSize** must be a valid pointer to a **size_t** value

- **VUID-vkGetEncodedVideoSessionParametersKHR-pData-parameter**
  If the value referenced by **pDataSize** is not 0, and **pData** is not **NULL**, **pData** must be a valid pointer to an array of **pDataSize** bytes

**Return Codes**

**Success**
- VK_SUCCESS
- VK_INCOMPLETE

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The ** VkVideoEncodeSessionParametersGetInfoKHR ** structure is defined as:

```c
// Provided by VK_KHR_video_encode_queue
typedef struct VkVideoEncodeSessionParametersGetInfoKHR {
  VkStructureType sType;
  const void* pNext;
  VkVideoSessionParametersKHR videoSessionParameters;
} VkVideoEncodeSessionParametersGetInfoKHR;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **videoSessionParameters** is the **VkVideoSessionParametersKHR** object to retrieve encoded parameter data from.

Depending on the used video encode operation, additional codec-specific structures may need to be included in the **pNext** chain of this structure to identify the specific video session parameters to retrieve encoded parameter data for, as described in the corresponding sections.

**Valid Usage (Implicit)**

- **VUID-VkVideoEncodeSessionParametersGetInfoKHR-sType-sType**
  **sType** must be **VK_STRUCTURE_TYPE_VIDEO_ENCODE_SESSION_PARAMETERS_GET_INFO_KHR**

- **VUID-VkVideoEncodeSessionParametersGetInfoKHR-pNext-pNext**
Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkVideoEncodeH264SessionParametersGetInfoEXT` or `VkVideoEncodeH265SessionParametersGetInfoEXT`

- VUID-VkVideoEncodeSessionParametersGetInfoKHR-sType-unique
  The `sType` value of each struct in the `pNext` chain must be unique

- VUID-VkVideoEncodeSessionParametersGetInfoKHR-videoSessionParameters-parameter
  `videoSessionParameters` must be a valid `VkVideoSessionParametersKHR` handle

The `VkVideoEncodeSessionParametersFeedbackInfoKHR` structure is defined as:

```
// Provided by VK_KHR_video_encode_queue
typedef struct VkVideoEncodeSessionParametersFeedbackInfoKHR {
    VkStructureType      sType;
    void*                pNext;
    VkBool32             hasOverrides;
} VkVideoEncodeSessionParametersFeedbackInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `hasOverrides` indicates whether any of the requested parameter data were overridden by the implementation.

Depending on the used video encode operation, additional codec-specific structures may need to be included in the `pNext` chain of this structure to capture feedback information about the requested parameter data, as described in the corresponding sections.

**Valid Usage (Implicit)**

- VUID-VkVideoEncodeSessionParametersFeedbackInfoKHR-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_SESSION_PARAMETERS_FEEDBACK_INFO_KHR`

- VUID-VkVideoEncodeSessionParametersFeedbackInfoKHR-pNext-pNext
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkVideoEncodeH264SessionParametersFeedbackInfoEXT` or `VkVideoEncodeH265SessionParametersFeedbackInfoEXT`

- VUID-VkVideoEncodeSessionParametersFeedbackInfoKHR-sType-unique
  The `sType` value of each struct in the `pNext` chain must be unique

### 42.13.5. Video Encode Commands

To launch video encode operations, call:

```
// Provided by VK_KHR_video_encode_queue
```
void vkCmdEncodeVideoKHR(
    VkCommandBuffer       commandBuffer,
    const VkVideoEncodeInfoKHR* pEncodeInfo);

- **commandBuffer** is the command buffer to be filled with this function for encoding to generate a bitstream.
- **pEncodeInfo** is a pointer to a *VkVideoEncodeInfoKHR* structure.

Each call issues one or more video encode operations. The implicit parameter **opCount** corresponds to the number of video encode operations issued by the command. After calling this command, the *active query index* of each *active* query is incremented by **opCount**.

Currently each call to this command results in the issue of a single video encode operation.

### Valid Usage

- **VUID-vkCmdEncodeVideoKHR-opCount-07174**
  For each *active* query, the *active query index* corresponding to the query type of that query plus **opCount** must be less than or equal to the last activatable query index corresponding to the query type of that query plus one

### Valid Usage (Implicit)

- **VUID-vkCmdEncodeVideoKHR-commandBuffer-parameter**
  *commandBuffer* must be a valid *VkCommandBuffer* handle

- **VUID-vkCmdEncodeVideoKHR-pEncodeInfo-parameter**
  *pEncodeInfo* must be a valid pointer to a valid *VkVideoEncodeInfoKHR* structure

- **VUID-vkCmdEncodeVideoKHR-commandBuffer-recording**
  *commandBuffer* must be in the *recording state*

- **VUID-vkCmdEncodeVideoKHR-commandBuffer-cmdpool**
  The *VkCommandPool* that *commandBuffer* was allocated from must support encode operations

- **VUID-vkCmdEncodeVideoKHR-renderpass**
  This command must only be called outside of a render pass instance

- **VUID-vkCmdEncodeVideoKHR-videocoding**
  This command must only be called inside of a video coding scope

- **VUID-vkCmdEncodeVideoKHR-bufferlevel**
  *commandBuffer* must be a primary *VkCommandBuffer*

### Host Synchronization

- Host access to *commandBuffer* must be externally synchronized
- Host access to the *VkCommandPool* that *commandBuffer* was allocated from must be externally
The `VkVideoEncodeInfoKHR` structure is defined as:

```c
// Provided by VK_KHR_video_encode_queue
typedef struct VkVideoEncodeInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkVideoEncodeFlagsKHR flags;
    VkBuffer dstBuffer;
    VkDeviceSize dstBufferOffset;
    VkDeviceSize dstBufferRange;
    VkVideoPictureResourceInfoKHR srcPictureResource;
    const VkVideoReferenceSlotInfoKHR* pSetupReferenceSlot;
    uint32_t referenceSlotCount;
    const VkVideoReferenceSlotInfoKHR* pReferenceSlots;
    uint32_t precedingExternallyEncodedBytes;
} VkVideoEncodeInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is a pointer to a structure extending this structure. A codec-specific extension structure must be chained to specify what bitstream unit to generate with this encode operation.
- `flags` is reserved for future use.
- `dstBuffer` is the destination video bitstream buffer to write the encoded bitstream to.
- `dstBufferOffset` is the starting offset in bytes from the start of `dstBuffer` to write the encoded bitstream to. `dstBufferOffset`'s value must be aligned to `VkVideoCapabilitiesKHR::minBitstreamBufferOffsetAlignment`, as reported by the implementation.
- `dstBufferRange` is the maximum size in bytes of the encoded bitstream written to `dstBuffer`, starting from `dstBufferOffset`. `dstBufferRange`'s value must be aligned to `VkVideoCapabilitiesKHR::minBitstreamBufferSizeAlignment`, as reported by the implementation.
- `srcPictureResource` is the Picture Resource of the Input Picture to be encoded by the operation.
- `pSetupReferenceSlot` is a pointer to a `VkVideoReferenceSlotInfoKHR` structure used for generating a reconstructed reference slot and Picture Resource. `pSetupReferenceSlot->slotIndex` specifies the slot index number to use as a target for producing the Reconstructed (DPB) data. `pSetupReferenceSlot` must be one of the entries provided in `VkVideoBeginCodingInfoKHR` via the `pReferenceSlots` within the `vkCmdBeginVideoCodingKHR` command that established the Vulkan Video Encode Context for this command.
• **referenceSlotCount** is the number of Reconstructed Reference Pictures that will be used when this encoding operation is executing.

• **pReferenceSlots** is **NULL** or a pointer to an array of `VkVideoReferenceSlotInfoKHR` structures that will be used when this encoding operation is executing. Each entry in **pReferenceSlots** **must** be one of the entries provided in `VkVideoBeginCodingInfoKHR` via the **pReferenceSlots** within the `vkCmdBeginVideoCodingKHR` command that established the Vulkan Video Encode Context for this command.

• **precedingExternallyEncodedBytes** is the number of bytes externally encoded for insertion in the active video encode session overall bitstream prior to the bitstream that will be generated by the implementation for this instance of `VkVideoEncodeInfoKHR`. The value provided is used to update the implementation’s rate control algorithm for the rate control layer this instance of `VkVideoEncodeInfoKHR` belongs to, by accounting for the bitrate budget consumed by these externally encoded bytes. See `VkVideoEncodeRateControlInfoKHR` for additional information about encode rate control.

The coded size of the encode operation is specified in **codedExtent** of `srcPictureResource`.

Multiple `vkCmdEncodeVideoKHR` commands **may** be recorded within a Vulkan Video Encode Context. The execution of each `vkCmdEncodeVideoKHR` command will result in generating codec-specific bitstream units. These bitstream units are generated consecutively into the bitstream buffer specified in **dstBuffer** of a `VkVideoEncodeInfoKHR` structure within the `vkCmdBeginVideoCodingKHR` command. The produced bitstream is the sum of all these bitstream units, including any padding between the bitstream units. Any bitstream padding **must** be filled with data compliant to the codec standard so as not to cause any syntax errors during decoding of the bitstream units with the padding included. The range of the bitstream buffer written **can** be queried via video encode feedback queries.

---

**Valid Usage**

- **VUID-VkVideoEncodeInfoKHR-None-07012**
  The bound video session **must** not be in **uninitialized** state at the time the command is executed on the device

---

**Valid Usage (Implicit)**

- **VUID-VkVideoEncodeInfoKHR-sType-sType**
  `sType` **must** be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_INFO_KHR`

- **VUID-VkVideoEncodeInfoKHR-pNext-pNext**
  Each **pNext** member of any structure (including this one) in the **pNext** chain **must** be either **NULL** or a pointer to a valid instance of `VkVideoEncodeH264PictureInfoEXT` or `VkVideoEncodeH265PictureInfoEXT`

- **VUID-VkVideoEncodeInfoKHR-sType-unique**
  The `sType` value of each struct in the **pNext** chain **must** be unique

- **VUID-VkVideoEncodeInfoKHR-flags-zerobitmask**
  `flags` **must** be `0`
**VUID-VkVideoEncodeInfoKHR-dstBuffer-parameter**

*dstBuffer* must be a valid `VkBuffer` handle.

**VUID-VkVideoEncodeInfoKHR-srcPictureResource-parameter**

*srcPictureResource* must be a valid `VkVideoPictureResourceInfoKHR` structure.

**VUID-VkVideoEncodeInfoKHR-pSetupReferenceSlot-parameter**

If `pSetupReferenceSlot` is not `NULL`, `pSetupReferenceSlot` must be a valid pointer to a valid `VkVideoReferenceSlotInfoKHR` structure.

**VUID-VkVideoEncodeInfoKHR-pReferenceSlots-parameter**

If `referenceSlotCount` is not 0, `pReferenceSlots` must be a valid pointer to an array of `referenceSlotCount` valid `VkVideoReferenceSlotInfoKHR` structures.

// Provided by VK_KHR_video_encode_queue
typedef VkFlags VkVideoEncodeFlagsKHR;

`VkVideoEncodeFlagsKHR` is a bitmask type for setting a mask, but is currently reserved for future use.

The `VkVideoEncodeRateControlInfoKHR` structure is defined as:

// Provided by VK_KHR_video_encode_queue
typedef struct VkVideoEncodeRateControlInfoKHR {
    VkStructureType sType;
    const void* pNext;
    VkVideoEncodeRateControlFlagsKHR flags;
    VkVideoEncodeRateControlModeFlagBitsKHR rateControlMode;
    uint32_t layerCount;
    const VkVideoEncodeRateControlLayerInfoKHR* pLayers;
    uint32_t virtualBufferSizeInMs;
    uint32_t initialVirtualBufferSizeInMs;
} VkVideoEncodeRateControlInfoKHR;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is reserved for future use.
- **rateControlMode** is a `VkVideoEncodeRateControlModeFlagBitsKHR` value specifying the encode stream rate control mode.
- **layerCount** specifies the number of rate control layers in the video encode stream.
- **pLayers** is a pointer to an array of `VkVideoEncodeRateControlLayerInfoKHR` structures specifying the rate control configurations of `layerCount` rate control layers.
- **virtualBufferSizeInMs** is the leaky bucket model virtual buffer size in milliseconds, with respect to peak bitrate. Valid when rate control mode is `VK_VIDEO_ENCODE_RATE_CONTROL_MODE_CBR_BIT_KHR` or `VK_VIDEO_ENCODE_RATE_CONTROL_MODE_VBR_BIT_KHR`. For example, virtual buffer size is `(virtualBufferSizeInMs × maxBitrate / 1000).`
• initialVirtualBufferSizeInMs is the initial occupancy in milliseconds of the virtual buffer in the leaky bucket model. Valid when rate control mode is VK_VIDEO_ENCODE_RATE_CONTROL_MODE_CBR_BIT_KHR or VK_VIDEO_ENCODE_RATE_CONTROL_MODE_VBR_BIT_KHR.

Including this structure in the pNext chain of VkVideoCodingControlInfoKHR and including VK_VIDEO_CODING_CONTROL_ENCODE_RATE_CONTROL_BIT_KHR in VkVideoCodingControlInfoKHR::flags will define stream rate control settings for video encoding.

Additional structures providing codec-specific rate control parameters may need to be included in the pNext chain of VkVideoCodingControlInfoKHR depending on the codec profile the bound video session was created with and the parameters specified in VkVideoEncodeRateControlInfoKHRK (see Video Coding Control).

To ensure that the video session is properly initialized with stream-level rate control settings, the application must call vkCmdControlVideoCodingKHR with stream-level rate control settings at least once in execution order before the first vkCmdEncodeVideoKHR command that is executed after video session reset. If not provided, default implementation-specific stream rate control settings will be used.

Stream rate control settings can also be re-initialized during an active video encoding session. The re-initialization takes effect whenever the VkVideoEncodeRateControlInfoKHR structure is included in the pNext chain of the VkVideoCodingControlInfoKHR structure in the call to vkCmdControlVideoCodingKHR, and only impacts vkCmdEncodeVideoKHR operations that follow in execution order.

Valid Usage (Implicit)

- VUID-VkVideoEncodeRateControlInfoKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_VIDEO_ENCODE_RATE_CONTROL_INFO_KHR

- VUID-VkVideoEncodeRateControlInfoKHR-flags-zerobitmask
  flags must be 0

- VUID-VkVideoEncodeRateControlInfoKHR-rateControlMode-parameter
  If rateControlMode is not 0, rateControlMode must be a valid VkVideoEncodeRateControlModeFlagBitsKHR value

- VUID-VkVideoEncodeRateControlInfoKHR-pLayers-parameter
  If layerCount is not 0, pLayers must be a valid pointer to an array of layerCount valid VkVideoEncodeRateControlLayerInfoKHR structures

// Provided by VK_KHR_video_encode_queue
typedef VkFlags VkVideoEncodeRateControlFlagsKHR;

VkVideoEncodeRateControlFlagsKHR is a bitmask type for setting a mask, but currently reserved for future use.

The rate control modes are defined with the following enums:
typedef enum VkVideoEncodeRateControlModeFlagBitsKHR {
    VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DEFAULT_KHR = 0,
    VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DISABLED_BIT_KHR = 0x00000001,
    VK_VIDEO_ENCODE_RATE_CONTROL_MODE_CBR_BIT_KHR = 0x00000002,
    VK_VIDEO_ENCODE_RATE_CONTROL_MODE_VBR_BIT_KHR = 0x00000004,
} VkVideoEncodeRateControlModeFlagBitsKHR;

- **VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DEFAULT_KHR** specifies the use of implementation-specific rate control.
- **VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DISABLED_BIT_KHR** specifies that rate control is disabled and any quality control parameters for the encoding are provided on a per-picture basis. In this mode implementations will encode pictures independently of the output bitrate of prior video encode operations. When using an H.264 encode profile, implementations will use the QP values specified in the VkVideoEncodeH264RateControlInfoEXT structure for the encoded picture. When using an H.265 encode profile, implementations will use the QP values specified in the VkVideoEncodeH265RateControlInfoEXT structure for the encoded picture.
- **VK_VIDEO_ENCODE_RATE_CONTROL_MODE_CBR_BIT_KHR** specifies the use of constant bitrate rate control mode.
- **VK_VIDEO_ENCODE_RATE_CONTROL_MODE_VBR_BIT_KHR** specifies the use of variable bitrate rate control mode.

typedef VkFlags VkVideoEncodeRateControlModeFlagsKHR;

VkVideoEncodeRateControlModeFlagsKHR is a bitmask type for setting a mask of zero or more VkVideoEncodeRateControlModeFlagBitsKHR.

The VkVideoEncodeRateControlLayerInfoKHR structure is defined as:

typedef struct VkVideoEncodeRateControlLayerInfoKHR {
    VkStructureType      sType;
    const void*           pNext;
    uint64_t              averageBitrate;
    uint64_t              maxBitrate;
    uint32_t              frameRateNumerator;
    uint32_t              frameRateDenominator;
} VkVideoEncodeRateControlLayerInfoKHR;

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is a pointer to a structure extending this structure.
- **averageBitrate** is the average bitrate in bits/second. Valid when rate control mode is **VK_VIDEO_ENCODE_RATE_CONTROL_MODE_CBR_BIT_KHR** or **VK_VIDEO_ENCODE_RATE_CONTROL_MODE_VBR_BIT_KHR**.
maxBitrate is the peak bitrate in bits/second. Valid when rate control mode is \texttt{VK_VIDEO_ENCODE_RATE_CONTROL_MODE_VBR_BIT_KHR}.

frameRateNumerator is the numerator of the frame rate. Valid when rate control mode is \texttt{VK_VIDEO_ENCODE_RATE_CONTROL_MODE_CBR_BIT_KHR} or \texttt{VK_VIDEO_ENCODE_RATE_CONTROL_MODE_VBR_BIT_KHR}.

frameRateDenominator is the denominator of the frame rate. Valid when rate control mode is \texttt{VK_VIDEO_ENCODE_RATE_CONTROL_MODE_CBR_BIT_KHR} or \texttt{VK_VIDEO_ENCODE_RATE_CONTROL_MODE_VBR_BIT_KHR}.

A codec-specific structure specifying additional per-layer rate control settings \textbf{must} be chained to \texttt{VkVideoEncodeRateControlLayerInfoKHR}. If multiple rate control layers are enabled (\texttt{VkVideoEncodeRateControlInfoKHR::layerCount} is greater than 1), then the chained codec-specific extension structure also identifies the specific video coding layer its parent \texttt{VkVideoEncodeRateControlLayerInfoKHR} applies to. If multiple rate control layers are enabled, the number of rate control layers \textbf{must} match the number of video coding layers. The specification for an encode codec-specific extension would describe how multiple video coding layers are enabled for the corresponding codec.

Per-layer rate control settings for all enabled rate control layers \textbf{must} be initialized or re-initialized whenever stream rate control settings are provided via \texttt{VkVideoEncodeRateControlInfoKHR}. This is done by specifying settings for all enabled rate control layers in \texttt{VkVideoEncodeRateControlInfoKHR::pLayers}.

It is possible for an application to enable multiple video coding layers (via codec-specific extensions to encoding operations) while only enabling a single layer of rate control for the entire video stream. To achieve this, \texttt{layerCount} in \texttt{VkVideoEncodeRateControlInfoKHR} \textbf{must} be set to 1, and the single \texttt{VkVideoEncodeRateControlLayerInfoKHR} provided in \texttt{pLayers} would apply to all encoded segments of the video stream, regardless of which codec-defined video coding layer they belong to. In this case, the implementation decides bitrate distribution across video coding layers (if applicable to the specified stream rate control mode).

### Valid Usage (Implicit)

- VUID-VkVideoEncodeRateControlLayerInfoKHR-sType-sType \r
  \textbf{sType} \textbf{must} be \texttt{VK_STRUCTURE_TYPE_VIDEO_ENCODE_RATE_CONTROL_LAYER_INFO_KHR}

- VUID-VkVideoEncodeRateControlLayerInfoKHR-pNext-pNext
  Each \texttt{pNext} member of any structure (including this one) in the \texttt{pNext} chain \textbf{must} be either \texttt{NULL} or a pointer to a valid instance of \texttt{VkVideoEncodeH264RateControlLayerInfoEXT} or \texttt{VkVideoEncodeH265RateControlLayerInfoEXT}

- VUID-VkVideoEncodeRateControlLayerInfoKHR-sType-unique
  The \texttt{sType} value of each struct in the \texttt{pNext} chain \textbf{must} be unique
42.14. Encode H.264

The VK_EXT_video_encode_h264 extension adds H.264 codec specific structures/types needed to support H.264 encoding. Unless otherwise noted, all references to the H.264 specification are to the 2010 edition published by the ITU-T, dated March 2010. This specification is available at https://www.itu.int/rec/T-REC-H.264.

Note
Refer to the Preamble for information on how the Khronos Intellectual Property Rights Policy relates to normative references to external materials not created by Khronos.

42.14.1. H.264 encode profile

The VkVideoEncodeH264ProfileInfoEXT structure is defined as:

```c
typedef struct VkVideoEncodeH264ProfileInfoEXT {
    VkStructureType sType;
    const void* pNext;
    StdVideoH264ProfileIdc stdProfileIdc;
} VkVideoEncodeH264ProfileInfoEXT;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `stdProfileIdc` is a StdVideoH264ProfileIdc value specifying the H.264 codec profile IDC.

An H.264 encode profile is specified by including a VkVideoEncodeH264ProfileInfoEXT structure in the `pNext` chain of the VkVideoProfileInfoKHR structure when VkVideoProfileInfoKHR::videoCodecOperation is VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT.

Valid Usage (Implicit)

- VUID-VkVideoEncodeH264ProfileInfoEXT-sType-sType
  `sType` must be VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_PROFILE_INFO_EXT

42.14.2. Capabilities

When calling vkGetPhysicalDeviceVideoCapabilitiesKHR with `pVideoProfile->videoCodecOperation` specified as VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT, the VkVideoEncodeH264CapabilitiesEXT structure must be included in the `pNext` chain of the VkVideoCapabilitiesKHR structure to retrieve more capabilities specific to H.264 video encoding.

The VkVideoEncodeH264CapabilitiesEXT structure is defined as:
typedef struct VkVideoEncodeH264CapabilitiesEXT {
    VkStructureType sType;
    void* pNext;
    VkVideoEncodeH264CapabilityFlagsEXT flags;
    StdVideoH264LevelIdc maxLevelIdc;
    uint32_t maxSliceCount;
    uint32_t maxPPictureL0ReferenceCount;
    uint32_t maxBPictureL0ReferenceCount;
    uint32_t maxL1ReferenceCount;
    uint32_t maxTemporalLayerCount;
    VkBool32 expectDyadicTemporalLayerPattern;
    int32_t minQp;
    int32_t maxQp;
    VkBool32 prefersGopRemainingFrames;
    VkBool32 requiresGopRemainingFrames;
    VkVideoEncodeH264StdFlagsEXT stdSyntaxFlags;
} VkVideoEncodeH264CapabilitiesEXT;

• **sType** is a VkStructureType value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.
• **flags** is a bitmask of VkVideoEncodeH264CapabilityFlagBitsEXT indicating supported H.264 encoding capabilities.
• **maxLevelIdc** is a StdVideoH264LevelIdc value indicating the maximum H.264 level supported.
• **maxSliceCount** indicates the maximum number of slices that can be encoded for a single picture. Further restrictions may apply to the number of slices that can be encoded for a single picture depending on other capabilities and codec-specific rules.
• **maxPPictureL0ReferenceCount** indicates the maximum number of reference pictures the implementation supports in the reference list L0 for P pictures.
• **maxBPictureL0ReferenceCount** indicates the maximum number of reference pictures the implementation supports in the reference list L0 for B pictures. The reported value is 0 if encoding of B pictures is not supported.
• **maxL1ReferenceCount** reports the maximum number of reference pictures the implementation supports in the reference list L1 if encoding of B pictures is supported. The reported value is 0 if encoding of B pictures is not supported.
• **maxTemporalLayerCount** indicates the maximum number of H.264 temporal layers supported by the implementation.
• **expectDyadicTemporalLayerPattern** indicates that the implementation’s rate control algorithms expect the application to use a dyadic temporal layer pattern when encoding multiple temporal layers.
• **minQp** indicates the minimum QP value supported.
• **maxQp** indicates the maximum QP value supported.
• **prefersGopRemainingFrames** indicates that the implementation’s rate control algorithm prefers
the application to specify the number of frames of each type remaining in the current group of pictures.

- requiresGopRemainingFrames indicates that the implementation's rate control algorithm requires the application to specify the number of frames of each type remaining in the current group of pictures.

- stdSyntaxflags is a bitmask of VkVideoEncodeH264StdFlagBitsEXT indicating capabilities related to H.264 syntax elements.

When vkGetPhysicalDeviceVideoCapabilitiesKHR is called to query the capabilities with parameter videoCodecOperation specified as VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT, a VkVideoEncodeH264CapabilitiesEXT structure can be chained to VkVideoCapabilitiesKHR to retrieve H.264 extension specific capabilities.

Valid Usage (Implicit)

- VUID-VkVideoEncodeH264CapabilitiesEXT-sType-sType

  sType must be VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_CAPABILITIES_EXT

Bits which may be set in VkVideoEncodeH264CapabilitiesEXT::flags, indicating the supported H.264 encoding capabilities, are:

```c
// Provided by VK_EXT_video_encode_h264
typedef enum VkVideoEncodeH264CapabilityFlagBitsEXT {
    VK_VIDEO_ENCODE_H264_CAPABILITY_HRD_COMPLIANCE_BIT_EXT = 0x00000001,
    VK_VIDEO_ENCODE_H264_CAPABILITY_PREDICTION_WEIGHT_TABLE_GENERATED_BIT_EXT = 0x00000002,
    VK_VIDEO_ENCODE_H264_CAPABILITY_ROW_UNALIGNED_SLICE_BIT_EXT = 0x00000004,
    VK_VIDEO_ENCODE_H264_CAPABILITY_DIFFERENT_SLICE_TYPE_BIT_EXT = 0x00000008,
    VK_VIDEO_ENCODE_H264_CAPABILITY_B_FRAME_IN_L0_LIST_BIT_EXT = 0x00000010,
    VK_VIDEO_ENCODE_H264_CAPABILITY_B_FRAME_IN_L1_LIST_BIT_EXT = 0x00000020,
    VK_VIDEO_ENCODE_H264_CAPABILITY_PER_PICTURE_TYPE_MIN_MAX_QP_BIT_EXT = 0x00000040,
    VK_VIDEO_ENCODE_H264_CAPABILITY_PER_SLICE_CONSTANT_QP_BIT_EXT = 0x00000080,
    VK_VIDEO_ENCODE_H264_CAPABILITY_GENERATE_PREFIX_NALU_BIT_EXT = 0x00000100,
} VkVideoEncodeH264CapabilityFlagBitsEXT;
```

- VK_VIDEO_ENCODE_H264_CAPABILITY_HRD_COMPLIANCE_BIT_EXT indicates if the implementation guarantees generating a HRD compliant bitstream if nal_hrd_parameters_present_flag or vcl_hrd_parameters_present_flag are enabled in StdVideoH264SpsVuiflags.

- VK_VIDEO_ENCODE_H264_CAPABILITY_PREDICTION_WEIGHT_TABLE_GENERATED_BIT_EXT indicates that when weighted_pred_flag is enabled or STD_VIDEO_H264_WEIGHTED_BIPRED_IDC_EXPLICIT from StdVideoH264WeightedBipredIdc is used, the implementation is able to internally decide syntax for pred_weight_table.

- VK_VIDEO_ENCODE_H264_CAPABILITY_ROW_UNALIGNED_SLICE_BIT_EXT indicates that each slice in a frame with multiple slices may begin or finish at any offset in a macroblock row. If not supported, all slices in the frame must begin at the start of a macroblock row (and hence each
slice must finish at the end of a macroblock row).

- **VK_VIDEO_ENCODE_H264_CAPABILITY_DIFFERENT_SLICE_TYPE_BIT_EXT** indicates that when a frame is encoded with multiple slices, the implementation allows encoding each slice with a different `StdVideoEncodeH264SliceHeader::slice_type`. If not supported, all slices of the frame must be encoded with the same `slice_type` which corresponds to the picture type of the frame. For example, all slices of a P-frame would be encoded as P-slices.

- **VK_VIDEO_ENCODE_H264_CAPABILITY_B_FRAME_IN_L0_LIST_BIT_EXT** indicates support for using a B frame as L0 reference.

- **VK_VIDEO_ENCODE_H264_CAPABILITY_B_FRAME_IN_L1_LIST_BIT_EXT** indicates support for using a B frame as L1 reference.

- **VK_VIDEO_ENCODE_H264_CAPABILITY_PER_PICTURE_TYPE_MIN_MAX_QP_BIT_EXT** indicates support for specifying different QP values in the members of `VkVideoEncodeH264QpEXT`.

- **VK_VIDEO_ENCODE_H264_CAPABILITY_PER_SLICE_CONSTANT_QP_BIT_EXT** indicates support for specifying different constant QP values for each slice.

- **VK_VIDEO_ENCODE_H264_CAPABILITY_GENERATE_PREFIX_NALU_BIT_EXT** indicates support for generating prefix NALUs by setting `VkVideoEncodeH264PictureInfoEXT::generatePrefixNalu` to `VK_TRUE`.

```cpp
// Provided by VK_EXT_video_encode_h264
typedef VkFlags VkVideoEncodeH264CapabilityFlagsEXT;
```

`VkVideoEncodeH264CapabilityFlagsEXT` is a bitmask type for setting a mask of zero or more `VkVideoEncodeH264CapabilityFlagBitsEXT`.

Bits which may be set in `VkVideoEncodeH264CapabilitiesEXT::stdSyntaxFlags`, indicating the capabilities related to the H.264 syntax elements, are:

```cpp
// Provided by VK_EXT_video_encode_h264
typedef enum VkVideoEncodeH264StdFlagBitsEXT {
    VK_VIDEO_ENCODE_H264_STD_SEPARATE_COLOR_PLANE_FLAG_SET_BIT_EXT = 0x00000001,
    VK_VIDEO_ENCODE_H264_STD_QPPRIME_Y_ZERO_TRANSFORM_BYPASS_FLAG_SET_BIT_EXT = 0x00000002,
    VK_VIDEO_ENCODE_H264_STD_SCALING_MATRIX_PRESENT_FLAG_SET_BIT_EXT = 0x00000004,
    VK_VIDEO_ENCODE_H264_STD_SECOND_CHROMA_QP_INDEX_OFFSET_BIT_EXT = 0x00000008,
    VK_VIDEO_ENCODE_H264_STD_PIC_INIT_QP_MINUS26_BIT_EXT = 0x00000020,
    VK_VIDEO_ENCODE_H264_STD_WEIGHTED_PRED_FLAG_SET_BIT_EXT = 0x00000040,
    VK_VIDEO_ENCODE_H264_STD_WEIGHTED_BIPRED_IDC_EXPLICIT_BIT_EXT = 0x00000080,
    VK_VIDEO_ENCODE_H264_STD_WEIGHTED_BIPRED_IDC_IMPLICIT_BIT_EXT = 0x00000100,
    VK_VIDEO_ENCODE_H264_STD_TRANSFORM_8X8_MODE_FLAG_SET_BIT_EXT = 0x00000200,
    VK_VIDEO_ENCODE_H264_STD_DIRECT_SPATIAL_MV_PRED_FLAG_UNSET_BIT_EXT = 0x00000400,
    VK_VIDEO_ENCODE_H264_STD_ENTROPY_CODING_MODE_FLAG_UNSET_BIT_EXT = 0x00000800,
    VK_VIDEO_ENCODE_H264_STD_ENTROPY_CODING_MODE_FLAG_SET_BIT_EXT = 0x00001000,
    VK_VIDEO_ENCODE_H264_STD_DIRECT_8X8_INFERENCE_FLAG_UNSET_BIT_EXT = 0x00002000,
    VK_VIDEO_ENCODE_H264_STD_CONSTRAINED_INTRA_PRED_FLAG_SET_BIT_EXT = 0x00004000,
    VK_VIDEO_ENCODE_H264_STD_DEBLOCKING_FILTER_DISABLED_BIT_EXT = 0x00008000,
    VK_VIDEO_ENCODE_H264_STD_DEBLOCKING_FILTER_ENABLED_BIT_EXT = 0x00010000,
};
```
• VK_VIDEO_ENCODE_H264_STD_SEPARATE_COLOR_PLANE_FLAG_SET_BIT_EXT indicates if enabling separate_colour_plane_flag in StdVideoH264SpsFlags is supported.

• VK_VIDEO_ENCODE_H264_STD_QPPRIME_Y_ZERO_TRANSFORM_BYPASS_FLAG_SET_BIT_EXT indicates if enabling qpprime_y_zero_transform_bypass_flag in StdVideoH264SpsFlags is supported.

• VK_VIDEO_ENCODE_H264_STD_SCALING_MATRIX_PRESENT_FLAG_SET_BIT_EXT indicates if enabling seq_scaling_matrix_present_flag in StdVideoH264SpsFlags or pic_scaling_matrix_present_flag in StdVideoH264PpsFlags are supported.

• VK_VIDEO_ENCODE_H264_STD_CHROMA_QP_INDEX_OFFSET_BIT_EXT indicates if setting non-zero chroma_qp_index_offset in StdVideoH264PictureParameterSet is supported.

• VK_VIDEO_ENCODE_H264_STD_SECOND_CHROMA_QP_INDEX_OFFSET_BIT_EXT indicates if setting non-zero second_chroma_qp_index_offset in StdVideoH264PictureParameterSet is supported.

• VK_VIDEO_ENCODE_H264_STD_PIC_INIT_QP_MINUS26_BIT_EXT indicates if setting non-zero pic_init_qp_minus26 in StdVideoH264PictureParameterSet is supported.

• VK_VIDEO_ENCODE_H264_STD_WEIGHTED_PRED_FLAG_SET_BIT_EXT indicates if enabling weighted_pred_flag in StdVideoH264PpsFlags is supported.

• VK_VIDEO_ENCODE_H264_STD_WEIGHTED_BIPRED_IDC_EXPLICIT_BIT_EXT indicates if using STD_VIDEO_H264_WEIGHTED_BIPRED_IDC_EXPLICIT from StdVideoH264WeightedBipredIdc is supported.

• VK_VIDEO_ENCODE_H264_STD_WEIGHTED_BIPRED_IDC_IMPLICIT_BIT_EXT indicates if using STD_VIDEO_H264_WEIGHTED_BIPRED_IDC_IMPLICIT from StdVideoH264WeightedBipredIdc is supported.

• VK_VIDEO_ENCODE_H264_STD_TRANSFORM_8X8_MODE_FLAG_SET_BIT_EXT indicates if enabling transform_8x8_mode_flag in StdVideoH264PpsFlags is supported.

• VK_VIDEO_ENCODE_H264_STD_DIRECT_SPATIAL_MV_PRED_FLAG_UNSET_BIT_EXT indicates if disabling StdVideoEncodeH264SliceHeaderFlags::direct_spatial_mv_pred_flag is supported when it is present in the slice header.

• VK_VIDEO_ENCODE_H264_STD_DIRECT_8X8_INFERENCE_FLAG_UNSET_BIT_EXT indicates if disabling direct_8x8_inference_flag in StdVideoH264SpsFlags is supported.

• VK_VIDEO_ENCODE_H264_STD_CONSTRAINED_INTRA_PRED_FLAG_SET_BIT_EXT indicates if enabling constrained_intra_pred_flag in StdVideoH264PpsFlags is supported.

• VK_VIDEO_ENCODE_H264_STD_DEBLOCKING_FILTER_DISABLED_BIT_EXT indicates if using STD_VIDEO_H264_DISABLE_DEBLOCKING_FILTER_IDC_DISABLED from StdVideoH264DisableDeblockingFilterIdc is supported.

• VK_VIDEO_ENCODE_H264_STD_DEBLOCKING_FILTER_ENABLED_BIT_EXT indicates if using
from StdVideoH264DisableDeblockingFilterIdc is supported.

• VK_VIDEO_ENCODE_H264_STD_DEBLOCKING_FILTER_PARTIAL_BIT_EXT indicates if using
  STD_VIDEO_H264_DISABLE_DEBLOCKING_FILTER_IDC_PARTIAL from
  StdVideoH264DisableDeblockingFilterIdc is supported. An implementation must support at
  least one deblocking filter mode.

• VK_VIDEO_ENCODE_H264_STD_SLICE_QP_DELTA_BIT_EXT indicates whether the implementation
  supports using the application-provided value for StdVideoEncodeH264SliceHeader
  ::slice_qp_delta when that value is identical across the slices of the encoded frame.

• VK_VIDEO_ENCODE_H264_STD_DIFFERENT_SLICE_QP_DELTA_BIT_EXT indicates whether the
  implementation supports using the application-provided value for
  StdVideoEncodeH264SliceHeader::slice_qp_delta when that value is different across the slices of
  the encoded frame.

// Provided by VK_EXT_video_encode_h264
typedef VkFlags VkVideoEncodeH264StdFlagsEXT;

VkVideoEncodeH264StdFlagsEXT is a bitmask type for setting a mask of zero or more
VkVideoEncodeH264StdFlagBitsEXT.

42.14.3. H.264 Encode Quality Level Properties

When calling vkGetPhysicalDeviceVideoEncodeQualityLevelPropertiesKHR with pVideoProfile-
>videoCodecOperation specified as VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT, the
VkVideoEncodeH264QualityLevelPropertiesEXT structure can be included in the pNext chain of the
VkVideoEncodeQualityLevelPropertiesKHR structure to retrieve additional video encode quality
level properties specific to H.264 encoding.

The VkVideoEncodeH264QualityLevelPropertiesEXT structure is defined as:

// Provided by VK_EXT_video_encode_h264
typedef struct VkVideoEncodeH264QualityLevelPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    VkVideoEncodeH264RateControlFlagsEXT preferredRateControlFlags;
    uint32_t preferredGopFrameCount;
    uint32_t preferredIdrPeriod;
    uint32_t preferredConsecutiveBFrameCount;
    uint32_t preferredTemporalLayerCount;
    VkVideoEncodeH264QpEXT preferredConstantQp;
    preferredMaxL0ReferenceCount;
    preferredMaxL1ReferenceCount;
    preferredStdEntropyCodingModeFlag;
} VkVideoEncodeH264QualityLevelPropertiesEXT;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.

• preferredRateControlFlags is a bitmask of VkVideoEncodeH264RateControlFlagBitsEXT values indicating the preferred flags to use for VkVideoEncodeH264RateControlInfoEXT::flags.

• preferredGopFrameCount indicates the preferred value to use for VkVideoEncodeH264RateControlInfoEXT::gopFrameCount.

• preferredIdrPeriod indicates the preferred value to use for VkVideoEncodeH264RateControlInfoEXT::idrPeriod.

• preferredConsecutiveBFrameCount indicates the preferred value to use for VkVideoEncodeH264RateControlInfoEXT::consecutiveBFrameCount.

• preferredTemporalLayerCount indicates the preferred value to use for VkVideoEncodeH264RateControlInfoEXT::temporalLayerCount.

• preferredConstantQp indicates the preferred values to use for VkVideoEncodeH264NaluSliceInfoEXT::constantQp for each picture type when using rate control mode VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DISABLED_BIT_KHR.

• preferredMaxL0ReferenceCount indicates the preferred maximum number of reference pictures to use in the reference list L0.

• preferredMaxL1ReferenceCount indicates the preferred maximum number of reference pictures to use in the reference list L1.

• preferredStdEntropyCodingModeFlag indicates the preferred value to use for entropy_coding_mode_flag in StdVideoH264PpsFlags.

**Valid Usage (Implicit)**

- VUID-VkVideoEncodeH264QualityLevelPropertiesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_QUALITY_LEVEL_PROPERTIES_EXT

### 42.14.4. H.264 Encode Session

Additional parameters can be specified when creating a video session with an H.264 encode profile by including an instance of the VkVideoEncodeH264SessionCreateInfoEXT structure in the pNext chain of VkVideoSessionCreateInfoKHR.

The VkVideoEncodeH264SessionCreateInfoEXT structure is defined as:

```c
// Provided by VK_EXT_video_encode_h264
typedef struct VkVideoEncodeH264SessionCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkBool32 useMaxLevelIdc;
    StdVideoH264LevelIdc maxLevelIdc;
} VkVideoEncodeH264SessionCreateInfoEXT;
```

- sType is a VkStructureType value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.

• `useMaxLevelIdc` indicates whether the value of `maxLevelIdc` should be used by the implementation. When it is set to `VK_FALSE`, the implementation ignores the value of `maxLevelIdc` and uses the value of `VkVideoEncodeH264CapabilitiesEXT:maxLevelIdc`, as reported by `vkGetPhysicalDeviceVideoCapabilitiesKHR` for the video profile.

• `maxLevelIdc` provides the upper bound on the H.264 level for the video bitstreams produced by the created video session.

### Valid Usage (Implicit)

- VUID-VkVideoEncodeH264SessionCreateInfoEXT-sType-sType
  sType must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_CREATE_INFO_EXT`

---

### 42.14.5. Encoder Parameter Sets

To reduce parameter traffic during encoding, the encoder parameter set object supports storing H.264 SPS/PPS parameter sets that may be later referenced during encoding.

The `VkVideoEncodeH264SessionParametersCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_video_encode_h264
typedef struct VkVideoEncodeH264SessionParametersCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    uint32_t maxStdSPSCount;
    uint32_t maxStdPPSCount;
    const VkVideoEncodeH264SessionParametersAddInfoEXT* pParametersAddInfo;
} VkVideoEncodeH264SessionParametersCreateInfoEXT;
```

• `sType` is a `VkStructureType` value identifying this structure.

• `pNext` is `NULL` or a pointer to a structure extending this structure.

• `maxStdSPSCount` is the maximum number of SPS parameters that the `VkVideoSessionParametersKHR` can contain.

• `maxStdPPSCount` is the maximum number of PPS parameters that the `VkVideoSessionParametersKHR` can contain.

• `pParametersAddInfo` is `NULL` or a pointer to a `VkVideoEncodeH264SessionParametersAddInfoEXT` structure specifying H.264 parameters to add upon object creation.

### Valid Usage (Implicit)

- VUID-VkVideoEncodeH264SessionParametersCreateInfoEXT-sType-sType
  sType must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_PARAMETERS_CREATE_INFO_EXT`

- VUID-VkVideoEncodeH264SessionParametersCreateInfoEXT-pParametersAddInfo-
If `pParametersAddInfo` is not NULL, `pParametersAddInfo` must be a valid pointer to a valid `VkVideoEncodeH264SessionParametersAddInfoEXT` structure.

The `VkVideoEncodeH264SessionParametersAddInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_video_encode_h264
typedef struct VkVideoEncodeH264SessionParametersAddInfoEXT {
    VkStructureType sType;
    const void* pNext;
    uint32_t stdSPSCount;
    const StdVideoH264SequenceParameterSet* pStdSPSs;
    uint32_t stdPPSCount;
    const StdVideoH264PictureParameterSet* pStdPPSs;
} VkVideoEncodeH264SessionParametersAddInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `stdSPSCount` is the number of SPS elements in the `pStdSPSs`. Its value must be less than or equal to the value of `maxStdSPSCount`.
- `pStdSPSs` is a pointer to an array of `StdVideoH264SequenceParameterSet` structures representing H.264 sequence parameter sets. Each element of the array must have a unique H.264 SPS ID.
- `stdPPSCount` is the number of PPS provided in `pStdPPSs`. Its value must be less than or equal to the value of `maxStdPPSCount`.
- `pStdPPSs` is a pointer to an array of `StdVideoH264PictureParameterSet` structures representing H.264 picture parameter sets. Each element of the array must have a unique H.264 SPS-PPS ID pair.

### Valid Usage

- **VUID-VkVideoEncodeH264SessionParametersAddInfoEXT-stdSPSCount-04837**
  The values of `stdSPSCount` and `stdPPSCount` must be less than or equal to the values of `maxStdSPSCount` and `maxStdPPSCount`, respectively.

- **VUID-VkVideoEncodeH264SessionParametersAddInfoEXT-maxStdSPSCount-04838**
  When the `maxStdSPSCount` number of parameters of type `StdVideoH264SequenceParameterSet` in the Video Session Parameters object is reached, no additional parameters of that type can be added to the object. `VK_ERROR_TOO_MANY_OBJECTS` will be returned if an attempt is made to add additional data to this object at this point.

- **VUID-VkVideoEncodeH264SessionParametersAddInfoEXT-maxStdPPSCount-04839**
  When the `maxStdPPSCount` number of parameters of type `StdVideoH264PictureParameterSet` in the Video Session Parameters object is reached, no additional parameters of that type can be added to the object. `VK_ERROR_TOO_MANY_OBJECTS` will be returned if an attempt is made to add additional data to this object at this point.
Each entry to be added must have a unique, to the rest of the parameter array entries and the existing parameters in the Video Session Parameters Object that is being updated, SPS-PPS IDs.

Parameter entries that already exist in Video Session Parameters object with a particular SPS-PPS IDs cannot be replaced nor updated.

When creating a new object using a Video Session Parameters as a template, the array's parameters with the same SPS-PPS IDs as the ones from the template take precedence.

SPS/PPS parameters must comply with the limits specified in VkVideoSessionCreateInfoKHR during Video Session creation.

Valid Usage (Implicit)

- **sType** must be VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_PARAMETERS_ADD_INFO_EXT

If stdSPSCount is not 0, and pStdSPSs is not NULL, pStdSPSs must be a valid pointer to an array of stdSPSCount StdVideoH264SequenceParameterSet values.

If stdPPSCount is not 0, and pStdPPSs is not NULL, pStdPPSs must be a valid pointer to an array of stdPPSCount StdVideoH264PictureParameterSet values.

The VkVideoEncodeH264SessionParametersGetInfoEXT structure is defined as:

```c
typedef struct VkVideoEncodeH264SessionParametersGetInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkBool32 writeStdSPS;
    VkBool32 writeStdPPS;
    uint32_t stdSPSId;
    uint32_t stdPPSId;
} VkVideoEncodeH264SessionParametersGetInfoEXT;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **writeStdSPS** indicates whether the encoded H.264 sequence parameter set identified by stdSPSId is requested to be retrieved.
- **writeStdPPS** indicates whether the encoded H.264 picture parameter set identified by the pair constructed from stdSPSId and stdPPSId is requested to be retrieved.
• stdSPSId specifies the H.264 sequence parameter set ID used to identify the retrieved H.264 sequence and/or picture parameter set(s).

• stdPPSId specifies the H.264 picture parameter set ID used to identify the retrieved H.264 picture parameter set when writeStdPPS is set to VK_TRUE.

When this structure is specified in the pNext chain of the VkVideoEncodeSessionParametersGetInfoKHR structure passed to vkGetEncodedVideoSessionParametersKHR, the command will write encoded parameter data to the output buffer in the following order:

1. The H.264 sequence parameter set identified by stdSPSId, if writeStdSPS is set to VK_TRUE.
2. The H.264 picture parameter set identified by the pair constructed from stdSPSId and stdPPSId, if writeStdPPS is set to VK_TRUE.

Valid Usage (Implicit)

• VUID-VkVideoEncodeH264SessionParametersGetInfoEXT-sType-sType sType must be VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_PARAMETERS_GET_INFO_EXT

The VkVideoEncodeH264SessionParametersFeedbackInfoEXT structure is defined as:

```c
// Provided by VK_EXT_video_encode_h264
typedef struct VkVideoEncodeH264SessionParametersFeedbackInfoEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 hasStdSPSOversrides;
    VkBool32 hasStdPPSOversrides;
} VkVideoEncodeH264SessionParametersFeedbackInfoEXT;
```

• sType is a VkStructureType value identifying this structure.

• pNext is NULL or a pointer to a structure extending this structure.

• hasStdSPSOversrides indicates whether any of the parameters of the requested H.264 sequence parameter set, if one was requested via VkVideoEncodeH264SessionParametersGetInfoEXT ::writeStdSPS, were overridden by the implementation.

• hasStdPPSOversrides indicates whether any of the parameters of the requested H.264 picture parameter set, if one was requested via VkVideoEncodeH264SessionParametersGetInfoEXT ::writeStdPPS, were overridden by the implementation.

Valid Usage (Implicit)

• VUID-VkVideoEncodeH264SessionParametersFeedbackInfoEXT-sType-sType sType must be VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_PARAMETERS_FEEDBACK_INFO_EXT
42.14.6. Frame Encoding

In order to encode a frame, add a `VkVideoEncodeH264PictureInfoEXT` structure to the `pNext` chain of the `VkVideoEncodeInfoKHR` structure passed to the `vkCmdEncodeVideoKHR` command.

The `VkVideoEncodeH264PictureInfoEXT` structure representing a frame encode operation is defined as:

```
// Provided by VK_EXT_video_encode_h264
typedef struct VkVideoEncodeH264PictureInfoEXT {
    VkStructureType sType; // Type of the structure
    const void*pNext; // Pointer to a structure extending this structure
    uint32_t naluSliceEntryCount; // Number of slice NALUs in the frame
    const VkVideoEncodeH264NaluSliceInfoEXT* pNaluSliceEntries; // Pointer to an array of NALUs
    const StdVideoEncodeH264PictureInfo* pStdPictureInfo; // Pointer to a structure specifying codec-specific information
    VkBool32 generatePrefixNalu; // Whether to generate prefix NALUs
} VkVideoEncodeH264PictureInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `naluSliceEntryCount` is the number of slice NALUs in the frame.
- `pNaluSliceEntries` is a pointer to an array of `VkVideoEncodeH264NaluSliceInfoEXT` structures specifying the division of the current picture into slices and the properties of these slices. This is an ordered sequence; the NALUs are generated consecutively in `VkVideoEncodeInfoKHR::dstBuffer` in the same order as in this array.
- `pStdPictureInfo` is a pointer to a `StdVideoEncodeH264PictureInfo` structure specifying the syntax and other codec-specific information from the H.264 specification associated with this picture. The information provided must reflect the decoded picture marking operations that are applicable to this frame.
- `generatePrefixNalu` controls whether prefix NALUs are generated before slice NALUs into the target bitstream.

**Valid Usage (Implicit)**

- `VUID-VkVideoEncodeH264PictureInfoEXT-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_PICTURE_INFO_EXT`

- `VUID-VkVideoEncodeH264PictureInfoEXT-pNaluSliceEntries-parameter`  
  `pNaluSliceEntries` must be a valid pointer to an array of valid `VkVideoEncodeH264NaluSliceInfoEXT` structures

- `VUID-VkVideoEncodeH264PictureInfoEXT-pStdPictureInfo-parameter`  
  `pStdPictureInfo` must be a valid pointer to a valid `StdVideoEncodeH264PictureInfo` value

- `VUID-VkVideoEncodeH264PictureInfoEXT-naluSliceEntryCount-arraylength`  
  `naluSliceEntryCount` must be greater than 0

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The **VkVideoEncodeH264NaluSliceInfoEXT** structure representing a slice is defined as:

```c
// Provided by VK_EXT_video_encode_h264
typedef struct VkVideoEncodeH264NaluSliceInfoEXT {
    VkStructureType sType;
    const void* pNext;
    int32_t constantQp;
    const StdVideoEncodeH264SliceHeader* pStdSliceHeader;
} VkVideoEncodeH264NaluSliceInfoEXT;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **constantQp** is the QP to use for the slice if the current rate control mode configured for the video session is **VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DISABLED_BIT_KHR**.
- **pStdSliceHeader** is a pointer to a **StdVideoEncodeH264SliceHeader** structure specifying the slice header for the current slice.

### Valid Usage (Implicit)

- VUID-VkVideoEncodeH264NaluSliceInfoEXT-sType-sType
  - **sType** must be **VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_NALU_SLICE_INFO_EXT**
- VUID-VkVideoEncodeH264NaluSliceInfoEXT-pNext-pNext
  - **pNext** must be **NULL**
- VUID-VkVideoEncodeH264NaluSliceInfoEXT-pStdSliceHeader-parameter
  - **pStdSliceHeader** must be a valid pointer to a valid **StdVideoEncodeH264SliceHeader** value

The **VkVideoEncodeH264DpbSlotInfoEXT** structure, representing a reconstructed picture that is being used as a reference picture, is defined as:

```c
// Provided by VK_EXT_video_encode_h264
typedef struct VkVideoEncodeH264DpbSlotInfoEXT {
    VkStructureType sType;
    const void* pNext;
    const StdVideoEncodeH264ReferenceInfo* pStdReferenceInfo;
} VkVideoEncodeH264DpbSlotInfoEXT;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **pStdReferenceInfo** is a pointer to a **StdVideoEncodeH264ReferenceInfo** structure specifying the syntax and other codec-specific information from the H.264 specification associated with this reference picture.
42.14.7. Rate control

The `VkVideoEncodeH264RateControlInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_video_encode_h264
typedef struct VkVideoEncodeH264RateControlInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkVideoEncodeH264RateControlFlagsEXT flags;
    uint32_t gopFrameCount;
    uint32_t idrPeriod;
    uint32_t consecutiveBFrameCount;
    uint32_t temporalLayerCount;
} VkVideoEncodeH264RateControlInfoEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **flags** is a bitmask of `VkVideoEncodeH264RateControlFlagBitsEXT` specifying H.264 rate control flags.
- **gopFrameCount** is the number of frames contained within the group of pictures (GOP), starting from an intra frame and until the next intra frame. If it is set to 0, the implementation chooses a suitable value. If it is set to `UINT32_MAX`, the GOP length is treated as infinite.
- **idrPeriod** is the interval, in terms of number of frames, between two IDR frames. If it is set to 0, the implementation chooses a suitable value. If it is set to `UINT32_MAX`, the IDR period is treated as infinite.
- **consecutiveBFrameCount** is the number of consecutive B-frames between I- and/or P-frames within the GOP.
- **temporalLayerCount** specifies the number of temporal layers enabled in the stream.

In order to provide H.264-specific stream rate control parameters, add a `VkVideoEncodeH264RateControlInfoEXT` structure to the `pNext` chain of the `VkVideoEncodeRateControlInfoKHR` structure in the `pNext` chain of the `VkVideoCodingControlInfoKHR` structure passed to the `vkCmdControlVideoCodingKHR` command.

The parameters from this structure act as a guidance for implementations to apply various rate control heuristics.
It is possible to infer the picture type to be used when encoding a frame, on the basis of the values provided for `consecutiveBFrameCount`, `idrPeriod`, and `gopFrameCount`, but this inferred picture type will not be used by implementations to override the picture type provided in `vkCmdEncodeVideoKHR`. Additionally, it is not required for the video session to be reset if the inferred picture type does not match the actual picture type.

**Valid Usage (Implicit)**

- VUID-VkVideoEncodeH264RateControlInfoEXT-sType-sType
  
  `sType` **must** be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_RATE_CONTROL_INFO_EXT`

- VUID-VkVideoEncodeH264RateControlInfoEXT-flags-parameter
  
  `flags` **must** be a valid combination of `VkVideoEncodeH264RateControlFlagBitsEXT` values

Bits which **can** be set in `VkVideoEncodeH264RateControlInfoEXT::flags`, specifying H.264 rate control flags, are:

```c
// Provided by VK_EXT_video_encode_h264
typedef enum VkVideoEncodeH264RateControlFlagBitsEXT {
    VK_VIDEO_ENCODE_H264_RATE_CONTROL_ATTEMPT_HRD_COMPLIANCE_BIT_EXT = 0x00000001,
    VK_VIDEO_ENCODE_H264_RATE_CONTROL_REGULAR_GOP_BIT_EXT = 0x00000002,
    VK_VIDEO_ENCODE_H264_RATE_CONTROL_REFERENCE_PATTERN_FLAT_BIT_EXT = 0x00000004,
    VK_VIDEO_ENCODE_H264_RATE_CONTROL_REFERENCE_PATTERN_DYADIC_BIT_EXT = 0x00000008,
    VK_VIDEO_ENCODE_H264_RATE_CONTROL_TEMPORAL_LAYER_PATTERN_DYADIC_BIT_EXT = 0x00000010,
} VkVideoEncodeH264RateControlFlagBitsEXT;
```

- `VK_VIDEO_ENCODE_H264_RATE_CONTROL_ATTEMPT_HRD_COMPLIANCE_BIT_EXT` specifies that rate control **should** attempt to produce an HRD compliant bitstream.

- `VK_VIDEO_ENCODE_H264_RATE_CONTROL_REGULAR_GOP_BIT_EXT` specifies that the application intends to use a regular GOP structure according to the parameters specified in the `gopFrameCount`, `idrPeriod`, and `consecutiveBFrameCount` members of the `VkVideoEncodeH264RateControlInfoEXT` structure.

- `VK_VIDEO.Encode_H264_RATE_CONTROL_REFERENCE_PATTERN_FLAT_BIT_EXT` specifies that the application intends to follow a flat reference pattern.

- `VK_VIDEO.Encode_H264_RATE_CONTROL_REFERENCE_PATTERN_DYADIC_BIT_EXT` specifies that the application intends to follow a dyadic reference pattern.

- `VK_VIDEO.Encode_H264_RATE_CONTROL_TEMPORAL_LAYER_PATTERN_DYADIC_BIT_EXT` specifies that the application intends to follow a dyadic temporal layer pattern.

```c
// Provided by VK_EXT_video_encode_h264
typedef VkFlags VkVideoEncodeH264RateControlFlagsEXT;
```

`VkVideoEncodeH264RateControlFlagsEXT` is a bitmask type for setting a mask of zero or more `VkVideoEncodeH264RateControlFlagBitsEXT`. 
The `VkVideoEncodeH264RateControlLayerInfoEXT` structure is defined as:

```c
typedef struct VkVideoEncodeH264RateControlLayerInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkBool32 useMinQp;
    VkVideoEncodeH264QpEXT minQp;
    VkBool32 useMaxQp;
    VkVideoEncodeH264QpEXT maxQp;
    VkBool32 useMaxFrameSize;
    VkVideoEncodeH264FrameSizeEXT maxFrameSize;
} VkVideoEncodeH264RateControlLayerInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `useMinQp` indicates whether the values within `minQp` should be used by the implementation. When it is set to `VK_FALSE`, the implementation ignores the values in `minQp` and chooses suitable values.
- `minQp` provides the lower bound on the QP values for each picture type, to be used in rate control calculations.
- `useMaxQp` indicates whether the values within `maxQp` should be used by the implementation. When it is set to `VK_FALSE`, the implementation ignores the values in `maxQp` and chooses suitable values.
- `maxQp` provides the upper bound on the QP values for each picture type, to be used in rate control calculations.
- `useMaxFrameSize` indicates whether the values within `maxFrameSize` should be used by the implementation.
- `maxFrameSize` provides the upper bound on the encoded frame size for each picture type. The implementation does not guarantee the encoded frame sizes will be within the specified limits, however these limits may be used as a guide in rate control calculations. If enabled and not set properly, the `maxQp` limit may prevent the implementation from respecting the `maxFrameSize` limit.

H.264-specific per-layer rate control parameters must be specified by adding a `VkVideoEncodeH264RateControlLayerInfoEXT` structure to the `pNext` chain of each `VkVideoEncodeRateControlLayerInfoKHR` structure in a call to `vkCmdControlVideoCodingKHR` command, when the command buffer context has an active video encode H.264 session.

**Valid Usage (Implicit)**

- `VUID-VkVideoEncodeH264RateControlLayerInfoEXT-sType-sType` `sType` must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_RATE_CONTROL_LAYER_INFO_EXT`
- `VUID-VkVideoEncodeH264RateControlLayerInfoEXT-minQp-parameter`
\texttt{minQp} must be a valid \texttt{VkVideoEncodeH264QpEXT} structure

- VUID-VkVideoEncodeH264RateControlLayerInfoEXT-maxQp-parameter
  \texttt{maxQp} must be a valid \texttt{VkVideoEncodeH264QpEXT} structure
- VUID-VkVideoEncodeH264RateControlLayerInfoEXT-maxFrameSize-parameter
  \texttt{maxFrameSize} must be a valid \texttt{VkVideoEncodeH264FrameSizeEXT} structure

The \texttt{VkVideoEncodeH264QpEXT} structure is defined as:

\begin{verbatim}
// Provided by VK_EXT_video_encode_h264
typedef struct VkVideoEncodeH264QpEXT {
    int32_t qpI;
    int32_t qpP;
    int32_t qpB;
} VkVideoEncodeH264QpEXT;
\end{verbatim}

- \texttt{qpI} is the QP to be used for I-frames.
- \texttt{qpP} is the QP to be used for P-frames.
- \texttt{qpB} is the QP to be used for B-frames.

The \texttt{VkVideoEncodeH264FrameSizeEXT} structure is defined as:

\begin{verbatim}
// Provided by VK_EXT_video_encode_h264
typedef struct VkVideoEncodeH264FrameSizeEXT {
    uint32_t frameISize;
    uint32_t framePSize;
    uint32_t frameBSize;
} VkVideoEncodeH264FrameSizeEXT;
\end{verbatim}

- \texttt{frameISize} is the size in bytes to be used for I-frames.
- \texttt{framePSize} is the size in bytes to be used for P-frames.
- \texttt{frameBSize} is the size in bytes to be used for B-frames.

The \texttt{VkVideoEncodeH264GopRemainingFrameInfoEXT} structure is defined as:

\begin{verbatim}
// Provided by VK_EXT_video_encode_h264
typedef struct VkVideoEncodeH264GopRemainingFrameInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkBool32 useGopRemainingFrames;
    uint32_t gopRemainingI;
    uint32_t gopRemainingP;
    uint32_t gopRemainingB;
} VkVideoEncodeH264GopRemainingFrameInfoEXT;
\end{verbatim}
- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **useGopRemainingFrames** indicates whether the implementation's rate control algorithm should use the values specified in `gopRemainingI`, `gopRemainingP`, and `gopRemainingB`. If `useGopRemainingFrames` is `VK_FALSE`, then the values of `gopRemainingI`, `gopRemainingP`, and `gopRemainingB` are ignored.

  - **gopRemainingI** specifies the number of I-frames the implementation's rate control algorithm should assume to be remaining in the GOP prior to executing the video encode operation.
  - **gopRemainingP** specifies the number of P-frames the implementation's rate control algorithm should assume to be remaining in the GOP prior to executing the video encode operation.
  - **gopRemainingB** specifies the number of B-frames the implementation's rate control algorithm should assume to be remaining in the GOP prior to executing the video encode operation.

Setting `useGopRemainingFrames` to `VK_TRUE` and including this structure in the `pNext` chain of `VkVideoEncodeInfoKHR` is only mandatory if the `VkVideoEncodeH264CapabilitiesEXT::requiresGopRemainingFrames` reported for the used video profile is `VK_TRUE`. However, implementations may use these remaining frame counts, when specified, even when it is not required. In particular, when the application does not use a regular GOP structure, these values may provide additional guidance for the implementation's rate control algorithm.

The `VkVideoEncodeH264CapabilitiesEXT::prefersGopRemainingFrames` capability is also used to indicate that the implementation's rate control algorithm may operate more accurately if the application specifies the remaining frame counts using this structure.

As with other rate control guidance values, if the effective order and number of frames encoded by the application are not in line with the remaining frame counts specified in this structure at any given point, then the behavior of the implementation's rate control algorithm may deviate from the one expected by the application.

### Valid Usage (Implicit)

- VUID-VkVideoEncodeH264GopRemainingFrameInfoEXT-sType-sType  
  `sType` must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_GOP_REMAINING_FRAME_INFO_EXT`

### 42.15. Encode H.265

The `VK_EXT_video_encode_h265` extension adds H.265 codec-specific structures/types needed to support H.265 video encoding. Unless otherwise noted, all references to the H.265 specification are to the 2013 edition published by the ITU-T, dated April 2013. This specification is available at [https://www.itu.int/rec/T-REC-H.265](https://www.itu.int/rec/T-REC-H.265).

#### Note

Refer to the Preamble for information on how the Khronos Intellectual Property Rights Policy relates to normative references to external materials not created by Khronos.
42.15.1. H.265 encode profile

An H.265 encode profile is specified by including the VkVideoEncodeH265ProfileInfoEXT structure in the pNext chain of the VkVideoProfileInfoKHR structure when VkVideoProfileInfoKHR::videoCodecOperation is VK_VIDEO_CODEC_OPERATION_ENCODE_H265_BIT_EXT.

The VkVideoEncodeH265ProfileInfoEXT structure is defined as:

```c
typedef struct VkVideoEncodeH265ProfileInfoEXT {
    VkStructureType sType;
    const void* pNext;
    StdVideoH265ProfileIdc stdProfileIdc;
} VkVideoEncodeH265ProfileInfoEXT;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **stdProfileIdc** is a StdVideoH265ProfileIdc value specifying the H.265 codec profile IDC.

Valid Usage (Implicit)

- VUID-VkVideoEncodeH265ProfileInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_PROFILE_INFO_EXT

42.15.2. Capabilities

When calling vkGetPhysicalDeviceVideoCapabilitiesKHR with pVideoProfile->videoCodecOperation specified as VK_VIDEO_CODEC_OPERATION_ENCODE_H265_BIT_EXT, the VkVideoEncodeH265CapabilitiesEXT structure must be included in the pNext chain of the VkVideoCapabilitiesKHR structure to retrieve more capabilities specific to H.265 video encoding.

The VkVideoEncodeH265CapabilitiesEXT structure is defined as:

```c
typedef struct VkVideoEncodeH265CapabilitiesEXT {
    VkStructureType sType;
    void* pNext;
    VkVideoEncodeH265CapabilityFlagsEXT flags;
    StdVideoH265LevelIdc maxLevelIdc;
    uint32_t maxSliceSegmentCount;
    VkExtent2D maxTiles;
    VkVideoEncodeH265CtbSizeFlagsEXT ctbSizes;
    VkVideoEncodeH265TransformBlockSizeFlagsEXT transformBlockSizes;
    uint32_t maxPPictureL0ReferenceCount;
    uint32_t maxBPictureL0ReferenceCount;
    uint32_t maxL1ReferenceCount;
    uint32_t maxSubLayerCount;
} VkVideoEncodeH265CapabilitiesEXT;
```
VkBool32
expectDyadicTemporalSubLayerPattern;

int32_t
minQp;

int32_t
maxQp;

VkBool32
prefersGopRemainingFrames;

VkBool32
requiresGopRemainingFrames;

VkVideoEncodeH265StdFlagsEXT
stdSyntaxFlags;

• **sType** is a *VkStructureType* value identifying this structure.
• **pNext** is **NULL** or a pointer to a structure extending this structure.
• **flags** is a bitmask of *VkVideoEncodeH265CapabilityFlagBitsEXT* indicating supported H.265 encoding capabilities.
• **maxLevelIdc** is a *StdVideoH265LevelIdc* value indicating the maximum H.265 level supported.
• **maxSliceSegmentCount** indicates the maximum number of slice segments that *can* be encoded for a single picture. Further restrictions *may* apply to the number of slice segments that *can* be encoded for a single picture depending on other capabilities and codec-specific rules.
• **maxTiles** indicates the maximum number of H.265 tile columns and rows that *can* be encoded for a single picture. Further restrictions *may* apply to the number of H.265 tiles that *can* be encoded for a single picture depending on other capabilities and codec-specific rules.
• **ctbSizes** is a bitmask of *VkVideoEncodeH265CtbSizeFlagBitsEXT* describing the supported CTB sizes.
• **transformBlockSizes** is a bitmask of *VkVideoEncodeH265TransformBlockSizeFlagBitsEXT* describing the supported transform block sizes.
• **maxPPictureL0ReferenceCount** indicates the maximum number of reference pictures the implementation supports in the reference list L0 for P pictures.
• **maxBPictureL0ReferenceCount** indicates the maximum number of reference pictures the implementation supports in the reference list L0 for B pictures. The reported value is 0 if encoding of B pictures is not supported.
• **maxL1ReferenceCount** indicates the maximum number of reference pictures the implementation supports in the reference list L1 if encoding of B pictures is supported. The reported value is 0 if encoding of B pictures is not supported.
• **maxSubLayerCount** indicates the maximum number of H.265 sub-layers supported by the implementation.
• **expectDyadicTemporalSubLayerPattern** indicates that the implementation’s rate control algorithms expect the application to use a dyadic temporal sub-layer pattern when encoding multiple temporal sub-layers.
• **minQp** indicates the minimum QP value supported.
• **maxQp** indicates the maximum QP value supported.
• **prefersGopRemainingFrames** indicates that the implementation’s rate control algorithm prefers the application to specify the number of frames of each type remaining in the current group of pictures.
• `requiresGopRemainingFrames` indicates that the implementation's rate control algorithm requires the application to specify the number of frames of each type remaining in the current group of pictures.

• `stdSyntaxFlags` is a bitmask of `VkVideoEncodeH265StdFlagBitsEXT` indicating capabilities related to H.265 syntax elements.

---

**Valid Usage (Implicit)**

- VUID-VkVideoEncodeH265CapabilitiesEXT-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_CAPABILITIES_EXT`

---

Bits which may be set in `VkVideoEncodeH265CapabilitiesEXT::flags` indicating the supported H.265 encoding capabilities, are:

```c
// Provided by VK_EXT_video_encode_h265
typedef enum VkVideoEncodeH265CapabilityFlagBitsEXT {
    VK_VIDEO_ENCODE_H265_CAPABILITY_HRD_COMPLIANCE_BIT_EXT = 0x00000001,
    VK_VIDEO_ENCODE_H265_CAPABILITY_PREDICTION_WEIGHT_TABLE_GENERATED_BIT_EXT = 0x00000002,
    VK_VIDEO_ENCODE_H265_CAPABILITY_ROW_UNALIGNED_SLICE_SEGMENT_BIT_EXT = 0x00000004,
    VK_VIDEO_ENCODE_H265_CAPABILITY_DIFFERENT_SLICE_SEGMENT_TYPE_BIT_EXT = 0x00000008,
    VK_VIDEO_ENCODE_H265_CAPABILITY_B_FRAME_IN_L0_LIST_BIT_EXT = 0x00000010,
    VK_VIDEO_ENCODE_H265_CAPABILITY_B_FRAME_IN_L1_LIST_BIT_EXT = 0x00000020,
    VK_VIDEO_ENCODE_H265_CAPABILITY_PER_PICTURE_TYPE_MIN_MAX_QP_BIT_EXT = 0x00000040,
    VK_VIDEO_ENCODE_H265_CAPABILITY_PER_SLICE_SEGMENT_CONSTANT_QP_BIT_EXT = 0x00000080,
    VK_VIDEO_ENCODE_H265_CAPABILITY_MULTIPLE_TILES_PER_SLICE_SEGMENT_BIT_EXT = 0x00000100,
    VK_VIDEO_ENCODE_H265_CAPABILITY_MULTIPLE_SLICE_SEGMENTS_PER_TILE_BIT_EXT = 0x00000200,
} VkVideoEncodeH265CapabilityFlagBitsEXT;
```

- `VK_VIDEO_ENCODE_H265_CAPABILITY_HRD_COMPLIANCE_BIT_EXT` indicates if the implementation guarantees generating a HRD compliant bitstream if `nal_hrd_parameters_present_flag`, `vcl_hrd_parameters_present_flag`, or `sub_pic_hrd_params_present_flag` are enabled in `StdVideoH265HrdFlags`, or `vui_hrd_parameters_present_flag` is enabled in `StdVideoH265SpsVuiFlags`.

- `VK_VIDEO_ENCODE_H265_CAPABILITY_PREDICTION_WEIGHT_TABLE_GENERATED_BIT_EXT` indicates that when `weighted_pred_flag` or `weighted_bipred_flag` in `StdVideoH265PpsFlags` are enabled, the implementation is able to internally decide syntax for `pred_weight_table`.

- `VK_VIDEO_ENCODE_H265_CAPABILITY_ROW_UNALIGNED_SLICE_SEGMENT_BIT_EXT` indicates that each slice segment in a frame with a single or multiple tiles per slice may begin or finish at any offset in a CTB row. If not supported, all slice segments in such a frame must begin at the start of a CTB row (and hence each slice segment must finish at the end of a CTB row). Also indicates that each slice segment in a frame with multiple slices per tile may begin or finish at any offset within the enclosing tile’s CTB row. If not supported, slice segments in such a frame must begin at the start of the enclosing tile’s CTB row (and hence each slice segment must finish at the end of the...
• **VK_VIDEO_ENCODE_H265_CAPABILITY_DIFFERENT_SLICE_SEGMENT_TYPE_BIT_EXT** indicates that when a frame is encoded with multiple slice segments, the implementation allows encoding each slice segment with a different `StdVideoEncodeH265SliceSegmentHeader::slice_type`. If not supported, all slice segments of the frame **must** be encoded with the same `slice_type` which corresponds to the picture type of the frame. For example, all slice segments of a P-frame would be encoded as P-slices.

• **VK_VIDEO_ENCODE_H265_CAPABILITY_B_FRAME_IN_L0_LIST_BIT_EXT** indicates support for using a B frame as L0 reference.

• **VK_VIDEO_ENCODE_H265_CAPABILITY_B_FRAME_IN_L1_LIST_BIT_EXT** indicates support for using a B frame as L1 reference.

• **VK_VIDEO_ENCODE_H265_CAPABILITY_PER_PICTURE_TYPE_MIN_MAX_QP_BIT_EXT** indicates support for specifying different QP values in the members of `VkVideoEncodeH265QpEXT`.

• **VK_VIDEO_ENCODE_H265_CAPABILITY_PER_SLICE_SEGMENT_CONSTANT_QP_BIT_EXT** indicates support for specifying different constant QP values for each slice segment.

• **VK_VIDEO_ENCODE_H265_CAPABILITY_MULTIPLE_TILES_PER_SLICE_SEGMENT_BIT_EXT** indicates if encoding multiple tiles per slice segment is supported. If not set, the implementation is only able to encode a single tile for each slice segment.

• **VK_VIDEO_ENCODE_H265_CAPABILITY_PER_SLICE_SEGMENT_CONSTANT_QP_BIT_EXT** indicates if encoding multiple slice segments per tile is supported. If not set, the implementation is only able to encode a single slice segment for each tile.

```c
// Provided by VK_EXT_video_encode_h265
typedef VkFlags VkVideoEncodeH265CapabilityFlagsEXT;
```

`VkVideoEncodeH265CapabilityFlagsEXT` is a bitmask type for setting a mask of zero or more `VkVideoEncodeH265CapabilityFlagBitsEXT`.

Bits which **may** be set in `VkVideoEncodeH265CapabilitiesEXT::stdSyntaxFlags`, indicating the capabilities related to the H.265 syntax elements, are:

```c
// Provided by VK_EXT_video_encode_h265
typedef enum VkVideoEncodeH265StdFlagBitsEXT {
    VK_VIDEO_ENCODE_H265_STD_SEPARATE_COLOR_PLANE_FLAG_SET_BIT_EXT = 0x00000001,
    VK_VIDEO_ENCODE_H265_STD_SAMPLE_ADAPTIVE_OFFSET_ENABLED_FLAG_SET_BIT_EXT = 0x00000002,
    VK_VIDEO_ENCODE_H265_STD_SCALING_LIST_DATA_PRESENT_FLAG_SET_BIT_EXT = 0x00000004,
    VK_VIDEO_ENCODE_H265_STD_PCM_ENABLED_FLAG_SET_BIT_EXT = 0x00000008,
    VK_VIDEO_ENCODE_H265_STD_SPS_TEMPORAL_MVP_ENABLED_FLAG_SET_BIT_EXT = 0x00000010,
    VK_VIDEO_ENCODE_H265_STD_INIT_QP_MINUS26_BIT_EXT = 0x00000020,
    VK_VIDEO_ENCODE_H265_STD_WEIGHTED_PRED_FLAG_SET_BIT_EXT = 0x00000040,
    VK_VIDEO_ENCODE_H265_STD_WEIGHTED_BIPRED_FLAG_SET_BIT_EXT = 0x00000080,
    VK_VIDEO_ENCODE_H265_STD_LOG2_PARALLEL_MERGE_LEVEL_MINUS2_BIT_EXT = 0x00000100,
    VK_VIDEO_ENCODE_H265_STD_SIGN_DATA_HIDING_ENABLED_FLAG_SET_BIT_EXT = 0x00000200,
    VK_VIDEO_ENCODE_H265_STD_TRANSFORM_SKIP_ENABLED_FLAG_SET_BIT_EXT = 0x00000400,
    0x00000000,
} VkVideoEncodeH265StdFlagBitsEXT;
```
VK_VIDEO_ENCODE_H265_STD_TRANSFORM_SKIP_ENABLED_FLAG_UNSET_BIT_EXT = 0x00000800,
VKVIDEO.Encode.H265_STD_PPS_SLICE_CHROMA_QP_OFFSETS_PRESENT_FLAG_SET_BIT_EXT = 0x00001000,
VK_VIDEO_ENCODE_H265_STD_TRANSCODING_BYPASS_ENABLED_FLAG_SET_BIT_EXT = 0x00002000,
VK_VIDEO_ENCODE_H265_STD_CONstrained_INTRA_PRED_FLAG_SET_BIT_EXT = 0x00004000,
VK_VIDEO_ENCODE_H265_STD_ENTROPY_CODING_SYNC_ENABLED_FLAG_SET_BIT_EXT = 0x00008000,
VK_VIDEO_ENCODE_H265_STD_DEBLOCKING_FILTER_OVERRIDE_ENABLED_FLAG_SET_BIT_EXT = 0x00010000,
VK_VIDEO_ENCODE_H265_STD_DEPENDENT_SLICE_SEGMENTS_ENABLED_FLAG_SET_BIT_EXT = 0x00020000,
VK_VIDEO_ENCODE_H265_STD_DEPENDENT_SLICE_SEGMENT_FLAG_SET_BIT_EXT = 0x00040000,
VK_VIDEO_ENCODE_H265_STD_SLICE_QP_DELTA_BIT_EXT = 0x00080000,
VK_VIDEO_ENCODE_H265_STD_DIFFERENT_SLICE_QP_DELTA_BIT_EXT = 0x00100000,

VkVideoEncodeH265StdFlagBitsEXT;

- VK_VIDEO_ENCODE_H265_STD_SEPARATE_COLOR_PLANE_FLAG_SET_BIT_EXT indicates if enabling separate_colour_plane_flag in StdVideoH265SpsFlags is supported.
- VK_VIDEO_ENCODE_H265_STD_SAMPLE_ADAPTIVE_OFFSET_ENABLED_FLAG_SET_BIT_EXT indicates if enabling sample_adaptive_offset_enabled_flag in StdVideoH265SpsFlags is supported.
- VK_VIDEO_ENCODE_H265_STD_SCALING_LIST_DATA_PRESENT_FLAG_SET_BIT_EXT indicates if enabling scaling_list_enabled_flag and sps_scaling_list_data_present_flag in StdVideoH265SpsFlags, or enabling pps_scaling_list_data_present_flag in StdVideoH265PpsFlags are supported.
- VK_VIDEO_ENCODE_H265_STD_PCM_ENABLED_FLAG_SET_BIT_EXT indicates if enabling pcm_enable_flag in StdVideoH265SpsFlags is supported.
- VK_VIDEO_ENCODE_H265_STD_SPS_TEMPORAL_MVP_ENABLED_FLAG_SET_BIT_EXT indicates if enabling sps_temporal_mvp_enabled_flag in StdVideoH265SpsFlags is supported.
- VK_VIDEO_ENCODE_H265_STD_INIT_QP_MINUS26_BIT_EXT indicates if setting non-zero init_qp_minus26 in StdVideoH265PictureParameterSet is supported.
- VK_VIDEO_ENCODE_H265_STD_WEIGHTED_PRED_FLAG_SET_BIT_EXT indicates if enabling weighted_pred_flag in StdVideoH265PpsFlags is supported.
- VK_VIDEO_ENCODE_H265_STD_WEIGHTED_BIPRED_FLAG_SET_BIT_EXT indicates if enabling weighted_bipred_flag in StdVideoH265PpsFlags is supported.
- VK_VIDEO_ENCODE_H265_STD_LOG2_PARALLEL_MERGE_LEVEL_MINUS2_BIT_EXT indicates if setting non-zero value for log2_parallel_merge_level_minus2 in StdVideoH265PictureParameterSet is supported.
- VK_VIDEO_ENCODE_H265_STD_SIGN_DATA_HIDING_ENABLED_FLAG_SET_BIT_EXT indicates if enabling sign_data_hiding_enabled_flag in StdVideoH265PpsFlags is supported.
- VK_VIDEO_ENCODE_H265_STD_TRANSFORM_SKIP_ENABLED_FLAG_SET_BIT_EXT indicates if enabling transform_skip_enabled_flag in StdVideoH265PpsFlags is supported.
- VK_VIDEO_ENCODE_H265_STD_TRANSFORM_SKIP_ENABLED_FLAG_UNSET_BIT_EXT indicates if disabling transform_skip_enabled_flag in StdVideoH265PpsFlags is supported. Implementations must report at least one of VK_VIDEO_ENCODE_H265_STD_TRANSFORM_SKIP_ENABLED_FLAG_SET_BIT_EXT and VK_VIDEO_ENCODE_H265_STD_TRANSFORM_SKIP_ENABLED_FLAG_UNSET_BIT_EXT as supported.
• **VK_VIDEO_ENCODE_H265_STD_PPS_SLICE_CHROMA_QP_OFFSETS_PRESENT_FLAG_SET_BIT_EXT** indicates if enabling `pps_slice_chroma_qp_offsets_present_flag` in `StdVideoH265PpsFlags` is supported.

• **VK_VIDEO_ENCODE_H265_STD_TRANSQUANT_BYPASS_ENABLED_FLAG_SET_BIT_EXT** indicates if enabling `transquant_bypass_enabled_flag` in `StdVideoH265PpsFlags` is supported.

• **VK_VIDEO_ENCODE_H265_STD_CONstrained_INTRA_PRED_FLAG_SET_BIT_EXT** indicates if enabling `constrained_intra_pred_flag` in `StdVideoH265PpsFlags` is supported.

• **VK_VIDEO_ENCODE_H265_STD_ENTROPY_CODING_SYNC_ENABLED_FLAG_SET_BIT_EXT** indicates if enabling `entropy_coding_sync_enabled_flag` in `StdVideoH265PpsFlags` is supported.

• **VK_VIDEO_ENCODE_H265_STD_DEBLOCKING_FILTER_OVERRIDE_ENABLED_FLAG_SET_BIT_EXT** indicates if enabling `deblocking_filter_override_enabled_flag` in `StdVideoH265PpsFlags` is supported.

• **VK_VIDEO_ENCODE_H265_STD_DEPENDENT_SLICE_SEGMENTS_ENABLED_FLAG_SET_BIT_EXT** indicates if enabling `dependent_slice_segments_enabled_flag` in `StdVideoH265PpsFlags` is supported.

• **VK_VIDEO_ENCODE_H265_STD_DEPENDENT_SLICE_SEGMENT_FLAG_SET_BIT_EXT** indicates if enabling `dependent_slice_segment_flag` in `StdVideoEncodeH265SliceHeaderFlags` is supported.

• **VK_VIDEO_ENCODE_H265_STD_SLICE_QP_DELTA_BIT_EXT** indicates whether the implementation supports using the application-provided value for `StdVideoEncodeH265SliceSegmentHeader::slice_qp_delta` when that value is identical across the slice segments of the encoded frame.

• **VK_VIDEO_ENCODE_H265_STD_DIFFERENT_SLICE_QP_DELTA_BIT_EXT** indicates whether the implementation supports using the application-provided value for `StdVideoEncodeH265SliceSegmentHeader::slice_qp_delta` when that value is different across the slice segments of the encoded frame.

```c
// Provided by VK_EXT_video_encode_h265
typedef VkFlags VkVideoEncodeH265StdFlagsEXT;
```

`VkVideoEncodeH265StdFlagsEXT` is a bitmask type for setting a mask of zero or more `VkVideoEncodeH265StdFlagBitsEXT`.

```c
// Provided by VK_EXT_video_encode_h265
typedef VkFlags VkVideoEncodeH265CtbSizeFlagsEXT;
```

`VkVideoEncodeH265CtbSizeFlagsEXT` is a bitmask type for setting a mask of zero or more `VkVideoEncodeH265CtbSizeFlagBitsEXT`. Implementations **must** set at least one of `VkVideoEncodeH265CtbSizeFlagBitsEXT`.

Bits which **may** be set in `VkVideoEncodeH265CapabilitiesEXT::ctbSizes`, indicating the CTB sizes supported by the implementation, are:

```c
// Provided by VK_EXT_video_encode_h265
typedef enum VkVideoEncodeH265CtbSizeFlagBitsEXT {
    VK_VIDEO_ENCODE_H265_CTB_SIZE_16_BIT_EXT = 0x00000001,
    VK_VIDEO_ENCODE_H265_CTB_SIZE_32_BIT_EXT = 0x00000002,
    VK_VIDEO_ENCODE_H265_CTB_SIZE_64_BIT_EXT = 0x00000004,
};
```
VK_VIDEO_ENCODE_H265_CTB_SIZE_16_BIT_EXT specifies that a CTB size of 16x16 is supported.

VK_VIDEO_ENCODE_H265_CTB_SIZE_32_BIT_EXT specifies that a CTB size of 32x32 is supported.

VK_VIDEO_ENCODE_H265_CTB_SIZE_64_BIT_EXT specifies that a CTB size of 64x64 is supported.

// Provided by VK_EXT_video_encode_h265
typedef VkFlags VkVideoEncodeH265TransformBlockSizeFlagsEXT;

VkVideoEncodeH265TransformBlockSizeFlagsEXT is a bitmask type for setting a mask of zero or more VkVideoEncodeH265TransformBlockSizeFlagBitsEXT. Implementations must set at least one of VkVideoEncodeH265TransformBlockSizeFlagBitsEXT.

Bits which may be set in VkVideoEncodeH265CapabilitiesEXT::transformBlockSizes, indicating the transform block sizes supported by the implementation, are:

// Provided by VK_EXT_video_encode_h265
typedef enum VkVideoEncodeH265TransformBlockSizeFlagBitsEXT {
    VK_VIDEO_ENCODE_H265_TRANSFORM_BLOCK_SIZE_4_BIT_EXT = 0x00000001,
    VK_VIDEO_ENCODE_H265_TRANSFORM_BLOCK_SIZE_8_BIT_EXT = 0x00000002,
    VK_VIDEO_ENCODE_H265_TRANSFORM_BLOCK_SIZE_16_BIT_EXT = 0x00000004,
    VK_VIDEO_ENCODE_H265_TRANSFORM_BLOCK_SIZE_32_BIT_EXT = 0x00000008,
} VkVideoEncodeH265TransformBlockSizeFlagBitsEXT;

- VK_VIDEO_ENCODE_H265_TRANSFORM_BLOCK_SIZE_4_BIT_EXT specifies that a transform block size of 4x4 is supported.
- VK_VIDEO_ENCODE_H265_TRANSFORM_BLOCK_SIZE_8_BIT_EXT specifies that a transform block size of 8x8 is supported.
- VK_VIDEO_ENCODE_H265_TRANSFORM_BLOCK_SIZE_16_BIT_EXT specifies that a transform block size of 16x16 is supported.
- VK_VIDEO_ENCODE_H265_TRANSFORM_BLOCK_SIZE_32_BIT_EXT specifies that a transform block size of 32x32 is supported.

42.15.3. H.265 Encode Quality Level Properties

When calling vkGetPhysicalDeviceVideoEncodeQualityLevelPropertiesKHR with pVideoProfile->videoCodecOperation specified as VK_VIDEO_CODEC_OPERATION_ENCODE_H265_BIT_EXT, the VkVideoEncodeH265QualityLevelPropertiesEXT structure can be included in the pNext chain of the VkVideoEncodeQualityLevelPropertiesKHR structure to retrieve additional video encode quality level properties specific to H.265 encoding.

The VkVideoEncodeH265QualityLevelPropertiesEXT structure is defined as:

// Provided by VK_EXT_video_encode_h265
typedef struct VkVideoEncodeH265QualityLevelPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    VkVideoEncodeH265RateControlFlagsEXT preferredRateControlFlags;
    uint32_t preferredGopFrameCount;
    uint32_t preferredIdrPeriod;
    uint32_t preferredConsecutiveBFrameCount;
    VkVideoEncodeH265QpEXT preferredSubLayerCount;
    uint32_t preferredConstantQp;
    uint32_t preferredMaxL0ReferenceCount;
    uint32_t preferredMaxL1ReferenceCount;
} VkVideoEncodeH265QualityLevelPropertiesEXT;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• preferredRateControlFlags is a bitmask of VkVideoEncodeH265RateControlFlagBitsEXT values indicating the preferred flags to use for VkVideoEncodeH265RateControlInfoEXT::flags.
• preferredGopFrameCount indicates the preferred value to use for VkVideoEncodeH265RateControlInfoEXT::gopFrameCount.
• preferredIdrPeriod indicates the preferred value to use for VkVideoEncodeH265RateControlInfoEXT::idrPeriod.
• preferredConsecutiveBFrameCount indicates the preferred value to use for VkVideoEncodeH265RateControlInfoEXT::consecutiveBFrameCount.
• preferredSubLayerCount indicates the preferred value to use for VkVideoEncodeH265RateControlInfoEXT::subLayerCount.
• preferredConstantQp indicates the preferred values to use for VkVideoEncodeH265NaluSliceSegmentInfoEXT::constantQp for each picture type when using rate control mode VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DISABLED_BIT_KHR.
• preferredMaxL0ReferenceCount indicates the preferred maximum number of reference pictures to use in the reference list L0.
• preferredMaxL1ReferenceCount indicates the preferred maximum number of reference pictures to use in the reference list L1.

Valid Usage (Implicit)

• VUID-VkVideoEncodeH265QualityLevelPropertiesEXT-sType-sType sType must be VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_QUALITY_LEVEL_PROPERTIES_EXT

42.15.4. H.265 Encode Session

Additional parameters can be specified when creating a video session with an H.265 encode profile by including an instance of the VkVideoEncodeH265SessionCreateInfoEXT structure in the pNext chain of VkVideoSessionCreateInfoKHR.
The `VkVideoEncodeH265SessionCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_video_encode_h265
typedef struct VkVideoEncodeH265SessionCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkBool32 useMaxLevelIdc;
    StdVideoH265LevelIdc maxLevelIdc;
} VkVideoEncodeH265SessionCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `useMaxLevelIdc` indicates whether the value of `maxLevelIdc` should be used by the implementation. When it is set to `VK_FALSE`, the implementation ignores the value of `maxLevelIdc` and uses the value of `VkVideoEncodeH265CapabilitiesEXT::maxLevelIdc`, as reported by `vkGetPhysicalDeviceVideoCapabilitiesKHR` for the video profile.
- `maxLevelIdc` provides the upper bound on the H.265 level for the video bitstreams produced by the created video session.

### Valid Usage (Implicit)

- VUID-VkVideoEncodeH265SessionCreateInfoEXT-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_CREATE_INFO_EXT`

#### 42.15.5. Encoder H.265 Video Session Parameters Object

When creating a Video Session Parameters object, add a `VkVideoEncodeH265SessionParametersCreateInfoEXT` structure to the `pNext` chain of the `VkVideoSessionParametersCreateInfoKHR` structure passed to `vkCreateVideoSessionParametersKHR` in order to specify the H.265-specific video encoder session parameters.

The `VkVideoEncodeH265SessionParametersCreateInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_video_encode_h265
typedef struct VkVideoEncodeH265SessionParametersCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    uint32_t maxStdVPSCount;
    uint32_t maxStdSPSCount;
    uint32_t maxStdPPSCount;
    const VkVideoEncodeH265SessionParametersAddInfoEXT* pParametersAddInfo;
} VkVideoEncodeH265SessionParametersCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
• \texttt{pNext} is \texttt{NULL} or a pointer to a structure extending this structure.

• \texttt{maxStdVPSCount} is the maximum number of entries of type \texttt{StdVideoH265VideoParameterSet} within \texttt{VkVideoSessionParametersKHR}.

• \texttt{maxStdSPSCount} is the maximum number of entries of type \texttt{StdVideoH265SequenceParameterSet} within \texttt{VkVideoSessionParametersKHR}.

• \texttt{maxStdPPSCount} is the maximum number of entries of type \texttt{StdVideoH265PictureParameterSet} within \texttt{VkVideoSessionParametersKHR}.

• \texttt{pParametersAddInfo} is \texttt{NULL} or a pointer to a \texttt{VkVideoEncodeH265SessionParametersAddInfoEXT} structure specifying the video session parameters to add upon creation of this object.

When a \texttt{VkVideoSessionParametersKHR} object contains \texttt{maxStdVPSCount} \texttt{StdVideoH265VideoParameterSet} entries, no additional \texttt{StdVideoH265VideoParameterSet} entries can be added to it, and \texttt{VK_ERROR_TOO_MANY_OBJECTS} will be returned if an attempt is made to add these entries. When a \texttt{VkVideoSessionParametersKHR} object contains \texttt{maxStdSPSCount} \texttt{StdVideoH265SequenceParameterSet} entries, no additional \texttt{StdVideoH265SequenceParameterSet} entries can be added to it, and \texttt{VK_ERROR_TOO_MANY_OBJECTS} will be returned if an attempt is made to add these entries. When a \texttt{VkVideoSessionParametersKHR} object contains \texttt{maxStdPPSCount} \texttt{StdVideoH265PictureParameterSet} entries, no additional \texttt{StdVideoH265PictureParameterSet} entries can be added to it, and \texttt{VK_ERROR_TOO_MANY_OBJECTS} will be returned if an attempt is made to add these entries.

**Valid Usage (Implicit)**

• VUID-VkVideoEncodeH265SessionParametersCreateInfoEXT-sType-sType \texttt{sType} must be \texttt{VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_PARAMETERS_CREATE_INFO_EXT}

• VUID-VkVideoEncodeH265SessionParametersCreateInfoEXT-pParametersAddInfo-parameter If \texttt{pParametersAddInfo} is not \texttt{NULL}, \texttt{pParametersAddInfo} must be a valid pointer to a valid \texttt{VkVideoEncodeH265SessionParametersAddInfoEXT} structure

The \texttt{VkVideoEncodeH265SessionParametersAddInfoEXT} structure is defined as:

```c
// Provided by VK_EXT_video_encode_h265
typedef struct VkVideoEncodeH265SessionParametersAddInfoEXT {
    VkStructureType sType;
    const void* pNext;
    uint32_t stdVPSCount;
    const StdVideoH265VideoParameterSet* pStdVPSs;
    uint32_t stdSPSCount;
    const StdVideoH265SequenceParameterSet* pStdSPSs;
    uint32_t stdPPSCount;
    const StdVideoH265PictureParameterSet* pStdPPSs;
} VkVideoEncodeH265SessionParametersAddInfoEXT;
```

• \texttt{sType} is a \texttt{VkStructureType} value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.

• stdVPSCount is the number of VPS elements in pStdVPSs.

• pStdVPSs is a pointer to an array of stdVPSCount StdVideoH265VideoParameterSet structures representing H.265 video parameter sets.

• stdSPSCount is the number of SPS elements in pStdSPSs.

• pStdSPSs is a pointer to an array of stdSPSCount StdVideoH265SequenceParameterSet structures representing H.265 sequence parameter sets.

• stdPPSCount is the number of PPS elements in pStdPPSs.

• pStdPPSs is a pointer to an array of stdPPSCount StdVideoH265PictureParameterSet structures representing H.265 picture parameter sets.

---

**Valid Usage (Implicit)**

- VUID-VkVideoEncodeH265SessionParametersAddInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_PARAMETERS_ADD_INFO_EXT

- VUID-VkVideoEncodeH265SessionParametersAddInfoEXT-pStdVPSs-parameter
  If stdVPSCount is not 0, and pStdVPSs is not NULL, pStdVPSs must be a valid pointer to an array of stdVPSCount StdVideoH265VideoParameterSet values

- VUID-VkVideoEncodeH265SessionParametersAddInfoEXT-pStdSPSs-parameter
  If stdSPSCount is not 0, and pStdSPSs is not NULL, pStdSPSs must be a valid pointer to an array of stdSPSCount StdVideoH265SequenceParameterSet values

- VUID-VkVideoEncodeH265SessionParametersAddInfoEXT-pStdPPSs-parameter
  If stdPPSCount is not 0, and pStdPPSs is not NULL, pStdPPSs must be a valid pointer to an array of stdPPSCount StdVideoH265PictureParameterSet values

---

**Valid Usage**

- VUID-VkVideoEncodeH265SessionParametersAddInfoEXT-stdVPSCount-06438
  The values of stdVPSCount, stdSPSCount and stdPPSCount must be less than or equal to the values of VkVideoEncodeH265SessionParametersCreateInfoEXT::maxStdVPSCount, VkVideoEncodeH265SessionParametersCreateInfoEXT::maxStdSPSCount, and VkVideoEncodeH265SessionParametersCreateInfoEXT::maxStdPPSCount, respectively

- VUID-VkVideoEncodeH265SessionParametersAddInfoEXT-pStdVPSs-06439
  Each StdVideoH265VideoParameterSet entry in pStdVPSs must have a unique H.265 VPS ID

- VUID-VkVideoEncodeH265SessionParametersAddInfoEXT-pStdSPSs-06440
  Each StdVideoH265SequenceParameterSet entry in pStdSPSs must have a unique H.265 VPS-SPS ID pair

- VUID-VkVideoEncodeH265SessionParametersAddInfoEXT-pStdPPSs-06441
  Each StdVideoH265PictureParameterSet entry in pStdPPSs must have a unique H.265 VPS-SPS-PPS ID tuple

- VUID-VkVideoEncodeH265SessionParametersAddInfoEXT-None-06442
Each entry to be added must have a unique, to the rest of the parameter array entries and the existing parameters in the Video Session Parameters Object that is being updated, VPS-SPS-PPS IDs

- VUID-VkVideoEncodeH265SessionParametersAddInfoEXT-None-06443
  Parameter entries that already exist in Video Session Parameters object with a particular VPS-SPS-PPS IDs must not be replaced nor updated

- VUID-VkVideoEncodeH265SessionParametersAddInfoEXT-None-06444
  When creating a new object using a Video Session Parameters as a template, the array's parameters with the same VPS-SPS-PPS IDs as the ones from the template take precedence

- VUID-VkVideoEncodeH265SessionParametersAddInfoEXT-None-06445
  VPS/SPS/PPS parameters must comply with the limits specified in VkVideoSessionCreateInfoKHR during Video Session creation

The VkVideoEncodeH265SessionParametersGetInfoEXT structure is defined as:

```c
// Provided by VK_EXT_video_encode_h265
typedef struct VkVideoEncodeH265SessionParametersGetInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkBool32 writeStdVPS;
    VkBool32 writeStdSPS;
    VkBool32 writeStdPPS;
    uint32_t stdVPSId;
    uint32_t stdSPSId;
    uint32_t stdPPSId;
} VkVideoEncodeH265SessionParametersGetInfoEXT;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `writeStdVPS` indicates whether the encoded H.265 video parameter set identified by `stdVPSId` is requested to be retrieved.
- `writeStdSPS` indicates whether the encoded H.265 sequence parameter set identified by the pair constructed from `stdVPSId` and `stdSPSId` is requested to be retrieved.
- `writeStdPPS` indicates whether the encoded H.265 picture parameter set identified by the triplet constructed from `stdVPSId`, `stdSPSId`, and `stdPPSId` is requested to be retrieved.
- `stdVPSId` specifies the H.265 video parameter set ID used to identify the retrieved H.265 video, sequence, and/or picture parameter set(s).
- `stdSPSId` specifies the H.265 sequence parameter set ID used to identify the retrieved H.265 sequence and/or picture parameter set(s) when `writeStdSPS` and/or `writeStdPPS` is set to VK_TRUE.
- `stdPPSId` specifies the H.265 picture parameter set ID used to identify the retrieved H.265 picture parameter set when `writeStdPPS` is set to VK_TRUE.
The `VkVideoEncodeSessionParametersGetInfoKHR` structure passed to `vkGetEncodedVideoSessionParametersKHR`, the command will write encoded parameter data to the output buffer in the following order:

1. The H.265 video parameter set identified by `stdVPSId`, if `writeStdVPS` is set to `VK_TRUE`.
2. The H.265 sequence parameter set identified by the pair constructed from `stdVPSId` and `stdSPSId`, if `writeStdSPS` is set to `VK_TRUE`.
3. The H.265 picture parameter set identified by the triplet constructed from `stdVPSId`, `stdSPSId`, and `stdPPSId`, if `writeStdPPS` is set to `VK_TRUE`.

**Valid Usage (Implicit)**

- VUID-VkVideoEncodeH265SessionParametersGetInfoEXT-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_PARAMETERS_GET_INFO_EXT`

The `VkVideoEncodeH265SessionParametersFeedbackInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_video_encode_h265
typedef struct VkVideoEncodeH265SessionParametersFeedbackInfoEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 hasStdVPSOverrides;
    VkBool32 hasStdSPSOverrides;
    VkBool32 hasStdPPSOverrides;
} VkVideoEncodeH265SessionParametersFeedbackInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `hasStdVPSOverrides` indicates whether any of the parameters of the requested H.265 video parameter set, if one was requested via `VkVideoEncodeH265SessionParametersGetInfoEXT::writeStdVPS`, were overridden by the implementation.
- `hasStdSPSOverrides` indicates whether any of the parameters of the requested H.265 sequence parameter set, if one was requested via `VkVideoEncodeH265SessionParametersGetInfoEXT::writeStdSPS`, were overridden by the implementation.
- `hasStdPPSOverrides` indicates whether any of the parameters of the requested H.265 picture parameter set, if one was requested via `VkVideoEncodeH265SessionParametersGetInfoEXT::writeStdPPS`, were overridden by the implementation.

**Valid Usage (Implicit)**

- VUID-VkVideoEncodeH265SessionParametersFeedbackInfoEXT-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_PARAMETERS_FEEDBACK_INFO_EXT`
42.15.6. Frame Encoding

In order to encode a frame, add a `VkVideoEncodeH265PictureInfoEXT` structure to the `pNext` chain of the `VkVideoEncodeInfoKHR` structure passed to the `vkCmdEncodeVideoKHR` command.

The `VkVideoEncodeH265PictureInfoEXT` structure representing a frame encode operation is defined as:

```c
// Provided by VK_EXT_video_encode_h265
typedef struct VkVideoEncodeH265PictureInfoEXT {
  VkStructureType sType;
  const void* pNext;
  uint32_t naluSliceSegmentEntryCount;
  const VkVideoEncodeH265NaluSliceSegmentInfoEXT* pNaluSliceSegmentEntries;
  const StdVideoEncodeH265PictureInfo* pStdPictureInfo;
} VkVideoEncodeH265PictureInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `naluSliceSegmentEntryCount` is the number of slice segment NALUs in the frame.
- `pNaluSliceSegmentEntries` is a pointer to an array of `VkVideoEncodeH265NaluSliceSegmentInfoEXT` structures specifying the division of the current picture into slice segments and the properties of these slice segments.
- `pStdPictureInfo` is a pointer to a `StdVideoEncodeH265PictureInfo` structure specifying the syntax and other codec-specific information from the H.265 specification, associated with this picture.

Valid Usage (Implicit)

- VUID-VkVideoEncodeH265PictureInfoEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_PICTURE_INFO_EXT`

- VUID-VkVideoEncodeH265PictureInfoEXT-pNaluSliceSegmentEntries-parameter
  `pNaluSliceSegmentEntries` must be a valid pointer to an array of `naluSliceSegmentEntryCount` valid `VkVideoEncodeH265NaluSliceSegmentInfoEXT` structures

- VUID-VkVideoEncodeH265PictureInfoEXT-pStdPictureInfo-parameter
  `pStdPictureInfo` must be a valid pointer to a valid `StdVideoEncodeH265PictureInfo` value

- VUID-VkVideoEncodeH265PictureInfoEXT-naluSliceSegmentEntryCount-arraylength
  `naluSliceSegmentEntryCount` must be greater than 0

The `VkVideoEncodeH265NaluSliceSegmentInfoEXT` structure representing a slice segment is defined as:

```c
// Provided by VK_EXT_video_encode_h265
typedef struct VkVideoEncodeH265NaluSliceSegmentInfoEXT {
  ...
} VkVideoEncodeH265NaluSliceSegmentInfoEXT;
```
VkStructureType
  const void *
  int32_t
  const StdVideoEncodeH265SliceSegmentHeader *
} VkVideoEncodeH265NaluSliceSegmentInfoEXT;

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **constantQp** is the QP to use for the slice segment if the current rate control mode configured for the video session is `VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DISABLED_BIT_KHR`.
- **pStdSliceSegmentHeader** is a pointer to a `StdVideoEncodeH265SliceSegmentHeader` structure specifying the slice segment header for the current slice segment.

**Valid Usage (Implicit)**

- VUID-VkVideoEncodeH265NaluSliceSegmentInfoEXT-sType-sType
  **sType** must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_NALU_SLICE_SEGMENT_INFO_EXT`
- VUID-VkVideoEncodeH265NaluSliceSegmentInfoEXT-pNext-pNext
  **pNext** must be `NULL`
- VUID-VkVideoEncodeH265NaluSliceSegmentInfoEXT-pStdSliceSegmentHeader-parameter
  **pStdSliceSegmentHeader** must be a valid pointer to a valid `StdVideoEncodeH265SliceSegmentHeader` value

The `VkVideoEncodeH265DpbSlotInfoEXT` structure, representing a reconstructed picture that is being used as a reference picture, is defined as:

```c
// Provided by VK_EXT_video_encode_h265
typedef struct VkVideoEncodeH265DpbSlotInfoEXT {
    VkStructureType sType;
    const void *pNext;
    const StdVideoEncodeH265ReferenceInfo *pStdReferenceInfo;
} VkVideoEncodeH265DpbSlotInfoEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **pStdReferenceInfo** is a pointer to a `StdVideoEncodeH265ReferenceInfo` structure specifying the syntax and other codec-specific information from the H.265 specification, associated with this reference picture.

**Valid Usage (Implicit)**

- VUID-VkVideoEncodeH265DpbSlotInfoEXT-sType-sType
  **sType** must be `VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_DPB_SLOT_INFO_EXT`
42.15.7. Rate control

The `VkVideoEncodeH265RateControlInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_video_encode_h265
typedef struct VkVideoEncodeH265RateControlInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkVideoEncodeH265RateControlFlagsEXT flags;
    uint32_t gopFrameCount;
    uint32_t idrPeriod;
    uint32_t consecutiveBFrameCount;
    uint32_t subLayerCount;
} VkVideoEncodeH265RateControlInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkVideoEncodeH265RateControlFlagBitsEXT` specifying H.265 rate control flags.
- `gopFrameCount` is the number of frames contained within the group of pictures (GOP), starting from an intra frame and until the next intra frame. If it is set to 0, the implementation chooses a suitable value. If it is set to `UINT32_MAX`, the GOP length is treated as infinite.
- `idrPeriod` is the interval, in terms of number of frames, between two IDR frames. If it is set to 0, the implementation chooses a suitable value. If it is set to `UINT32_MAX`, the IDR period is treated as infinite.
- `consecutiveBFrameCount` is the number of consecutive B-frames between I- and/or P-frames within the GOP.
- `subLayerCount` specifies the number of sub layers enabled in the stream.

In order to provide H.265-specific stream rate control parameters, add a `VkVideoEncodeH265RateControlInfoEXT` structure to the `pNext` chain of the `VkVideoEncodeRateControlInfoKHR` structure in the `pNext` chain of the `VkVideoCodingControlInfoKHR` structure passed to the `vkCmdControlVideoCodingKHR` command.

The parameters from this structure act as a guidance for implementations to apply various rate control heuristics.

It is possible to infer the picture type to be used when encoding a frame, on the basis of the values provided for `consecutiveBFrameCount`, `idrPeriod`, and `gopFrameCount`, but this inferred picture type will not be used by implementations to override the picture type provided in `vkCmdEncodeVideoKHR`. Additionally, it is not required for the video session to be reset if the
Valid Usage (Implicit)

- VUID-VkVideoEncodeH265RateControlInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_RATE_CONTROL_INFO_EXT

- VUID-VkVideoEncodeH265RateControlInfoEXT-flags-parameter
  flags must be a valid combination of VkVideoEncodeH265RateControlFlagBitsEXT values.

Bits which can be set in VkVideoEncodeH265RateControlInfoEXT::flags, specifying H.265 rate control flags, are:

```c
// Provided by VK_EXT_video_encode_h265
typedef enum VkVideoEncodeH265RateControlFlagBitsEXT {
    VK_VIDEO_ENCODE_H265_RATE_CONTROL_ATTEMPT_HRD_COMPLIANCE_BIT_EXT = 0x00000001,
    VK_VIDEO_ENCODE_H265_RATE_CONTROL_REGULAR_GOP_BIT_EXT = 0x00000002,
    VK_VIDEO_ENCODE_H265_RATE_CONTROL_REFERENCE_PATTERN_FLAT_BIT_EXT = 0x00000004,
    VK_VIDEO_ENCODE_H265_RATE_CONTROL_REFERENCE_PATTERN_DYADIC_BIT_EXT = 0x00000008,
    VK_VIDEO_ENCODE_H265_RATE_CONTROL_TEMPORAL_SUB_LAYER_PATTERN_DYADIC_BIT_EXT = 0x00000010,
} VkVideoEncodeH265RateControlFlagBitsEXT;
```

- VK_VIDEO_ENCODE_H265_RATE_CONTROL_ATTEMPT_HRD_COMPLIANCE_BIT_EXT specifies that rate control should attempt to produce an HRD compliant bitstream.
- VK_VIDEO_ENCODE_H265_RATE_CONTROL_REGULAR_GOP_BIT_EXT specifies that the application intends to use a regular GOP structure according to the parameters specified in the gopFrameCount, idrPeriod, and consecutiveBFrameCount members of the VkVideoEncodeH265RateControlInfoEXT structure.
- VK_VIDEO_ENCODE_H265_RATE_CONTROL_REFERENCE_PATTERN_FLAT_BIT_EXT specifies that the application intends to follow a flat reference pattern.
- VK_VIDEO_ENCODE_H265_RATE_CONTROL_REFERENCE_PATTERN_DYADIC_BIT_EXT specifies that the application intends to follow a dyadic reference pattern.
- VK_VIDEO_ENCODE_H265_RATE_CONTROL_TEMPORAL_SUB_LAYER_PATTERN_DYADIC_BIT_EXT specifies that the application intends to follow a dyadic temporal sub-layer pattern.

```c
// Provided by VK_EXT_video_encode_h265
typedef VkFlags VkVideoEncodeH265RateControlFlagsEXT;
```

VkVideoEncodeH265RateControlFlagsEXT is a bitmask type for setting a mask of zero or more VkVideoEncodeH265RateControlFlagBitsEXT.

The VkVideoEncodeH265RateControlLayerInfoEXT structure is defined as:

```c
// Provided by VK_EXT_video_encode_h265
```
typedef struct VkVideoEncodeH265RateControlLayerInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkBool32 useMinQp;
    VkVideoEncodeH265QpEXT minQp;
    VkVideoEncodeH265QpEXT useMaxQp;
    VkVideoEncodeH265QpEXT maxQp;
    VkBool32 useMaxFrameSize;
    VkVideoEncodeH265FrameSizeEXT maxFrameSize;
} VkVideoEncodeH265RateControlLayerInfoEXT;

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **useMinQp** indicates whether the values within **minQp** should be used by the implementation. When it is set to *VK_FALSE*, the implementation ignores the values in **minQp** and chooses suitable values.
- **minQp** provides the lower bound on the QP values for each picture type, to be used in rate control calculations.
- **useMaxQp** indicates whether the values within **maxQp** should be used by the implementation. When it is set to *VK_FALSE*, the implementation ignores the values in **maxQp** and chooses suitable values.
- **maxQp** provides the upper bound on the QP values for each picture type, to be used in rate control calculations.
- **useMaxFrameSize** indicates whether the values within **maxFrameSize** should be used by the implementation.
- **maxFrameSize** provides the upper bound on the encoded frame size for each picture type. The implementation does not guarantee the encoded frame sizes will be within the specified limits, however these limits may be used as a guide in rate control calculations. If enabled and not set properly, the **maxQp** limit may prevent the implementation from respecting the **maxFrameSize** limit.

H.265-specific per-layer rate control parameters must be specified by adding a *VkVideoEncodeH265RateControlLayerInfoEXT* structure to the **pNext** chain of each *VkVideoEncodeRateControlLayerInfoKHR* structure in a call to *vkCmdControlVideoCodingKHR* command, when the command buffer context has an active video encode H.265 session.

**Valid Usage (Implicit)**

- VUID-VkVideoEncodeH265RateControlLayerInfoEXT-sType-sType
  - **sType** must be *VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_RATE_CONTROL_LAYER_INFO_EXT*

- VUID-VkVideoEncodeH265RateControlLayerInfoEXT-minQp-parameter
  - **minQp** must be a valid *VkVideoEncodeH265QpEXT* structure

- VUID-VkVideoEncodeH265RateControlLayerInfoEXT-maxQp-parameter
  - **maxQp** must be a valid *VkVideoEncodeH265QpEXT* structure
The `VkVideoEncodeH265QpEXT` structure is defined as:

```c
typedef struct VkVideoEncodeH265QpEXT {
    int32_t qpI;
    int32_t qpP;
    int32_t qpB;
} VkVideoEncodeH265QpEXT;
```

- `qpI` is the QP to be used for I-frames.
- `qpP` is the QP to be used for P-frames.
- `qpB` is the QP to be used for B-frames.

The `VkVideoEncodeH265FrameSizeEXT` structure is defined as:

```c
typedef struct VkVideoEncodeH265FrameSizeEXT {
    uint32_t frameISize;
    uint32_t framePSize;
    uint32_t frameBSize;
} VkVideoEncodeH265FrameSizeEXT;
```

- `frameISize` is the size in bytes to be used for I-frames.
- `framePSize` is the size in bytes to be used for P-frames.
- `frameBSize` is the size in bytes to be used for B-frames.

The `VkVideoEncodeH265GopRemainingFrameInfoEXT` structure is defined as:

```c
typedef struct VkVideoEncodeH265GopRemainingFrameInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkBool32 useGopRemainingFrames;
    uint32_t gopRemainingI;
    uint32_t gopRemainingP;
    uint32_t gopRemainingB;
} VkVideoEncodeH265GopRemainingFrameInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `useGopRemainingFrames` indicates whether the implementation’s rate control algorithm should
use the values specified in \texttt{gopRemainingI}, \texttt{gopRemainingP}, and \texttt{gopRemainingB}. If \texttt{useGopRemainingFrames} is \texttt{VK_FALSE}, then the values of \texttt{gopRemainingI}, \texttt{gopRemainingP}, and \texttt{gopRemainingB} are ignored.

- \texttt{gopRemainingI} specifies the number of I-frames the implementation's rate control algorithm \textbf{should} assume to be remaining in the GOP prior to executing the video encode operation.
- \texttt{gopRemainingP} specifies the number of P-frames the implementation's rate control algorithm \textbf{should} assume to be remaining in the GOP prior to executing the video encode operation.
- \texttt{gopRemainingB} specifies the number of B-frames the implementation's rate control algorithm \textbf{should} assume to be remaining in the GOP prior to executing the video encode operation.

Setting \texttt{useGopRemainingFrames} to \texttt{VK_TRUE} and including this structure in the \texttt{pNext} chain of \texttt{VkVideoEncodeInfoKHR} is only mandatory if the \texttt{VkVideoEncodeH265CapabilitiesEXT::requiresGopRemainingFrames} reported for the used video profile is \texttt{VK_TRUE}. However, implementations \textbf{may} use these remaining frame counts, when specified, even when it is not required. In particular, when the application does not use a regular GOP structure, these values \textbf{may} provide additional guidance for the implementation's rate control algorithm.

The \texttt{VkVideoEncodeH265CapabilitiesEXT::prefersGopRemainingFrames} capability is also used to indicate that the implementation's rate control algorithm \textbf{may} operate more accurately if the application specifies the remaining frame counts using this structure.

As with other rate control guidance values, if the effective order and number of frames encoded by the application are not in line with the remaining frame counts specified in this structure at any given point, then the behavior of the implementation's rate control algorithm \textbf{may} deviate from the one expected by the application.

\begin{table}[h]
\centering
\begin{tabular}{|c|}
\hline
\textbf{Valid Usage (Implicit)}
\hline
- \texttt{VUID-VkVideoEncodeH265GopRemainingFrameInfoEXT-sType-sType} \texttt{sType} \textbf{must} be \texttt{VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_GOP_REMAINING_FRAME_INFO_EXT} \\
\hline
\end{tabular}
\end{table}
Chapter 43. Optical Flow

43.1. Optical Flow Queues

VK_NV_optical_flow adds a optical flow queue type bit VK_QUEUE_OPTICAL_FLOW_BIT_NV to VkQueueFlagBits. Optical flow operations are supported by queues with an advertised queue capability of VK_QUEUE_OPTICAL_FLOW_BIT_NV. As in the case of other queue types, an application must use vkGetPhysicalDeviceQueueFamilyProperties to query whether the physical device has support for the Optical Flow Queue. When the implementation reports the VK_QUEUE_OPTICAL_FLOW_BIT_NV bit for a queue family, it advertises general support for Vulkan queue operations described in Devices and Queues.

43.2. Optical Flow Image Formats

To enumerate the supported image formats for a specific optical flow usage, call:

```c
// Provided by VK_NV_optical_flow
VkResult vkGetPhysicalDeviceOpticalFlowImageFormatsNV(
    VkPhysicalDevice physicalDevice,
    const VkOpticalFlowImageFormatInfoNV* pOpticalFlowImageFormatInfo,
    uint32_t* pFormatCount,
    VkOpticalFlowImageFormatPropertiesNV* pImageFormatProperties);
```

- `physicalDevice` is the physical device being queried.
- `pOpticalFlowImageFormatInfo` is a pointer to a VkOpticalFlowImageFormatInfoNV structure specifying the optical flow usage for which information is returned.
- `pFormatCount` is a pointer to an integer related to the number of optical flow properties available or queried, as described below.
- `pImageFormatProperties` is a pointer to an array of VkOpticalFlowImageFormatPropertiesNV structures in which supported formats and image parameters are returned.

If `pImageFormatProperties` is NULL, then the number of optical flow properties supported for the given `physicalDevice` is returned in `pFormatCount`. Otherwise, `pFormatCount` must point to a variable set by the user to the number of elements in the `pImageFormatProperties` array, and on return the variable is overwritten with the number of values actually written to `pImageFormatProperties`. If the value of `pFormatCount` is less than the number of optical flow properties supported, at most `pFormatCount` values will be written to `pImageFormatProperties`, and VK_INCOMPLETE will be returned instead of VK_SUCCESS, to indicate that not all the available values were returned. Before creating an image to be used as a optical flow frame, obtain the supported image creation parameters by querying with `vkGetPhysicalDeviceFormatProperties2` and `vkGetPhysicalDeviceImageFormatProperties2` using one of the reported formats and adding VkOpticalFlowImageFormatInfoNV to the pNext chain of VkPhysicalDeviceImageFormatInfo2. When querying the parameters with `vkGetPhysicalDeviceImageFormatProperties2` for images used for optical flow operations, the VkOpticalFlowImageFormatInfoNV::usage field should contain one or more of the bits defined in VkOpticalFlowUsageFlagBitsNV.
Valid Usage (Implicit)

- **VUID-vkGetPhysicalDeviceOpticalFlowImageFormatsNV-physicalDevice-parameter**
  physicalDevice **must** be a valid VkPhysicalDevice handle

  pOpticalFlowImageFormatInfo **must** be a valid pointer to a valid VkOpticalFlowImageFormatInfoNV structure

- **VUID-vkGetPhysicalDeviceOpticalFlowImageFormatsNV-pFormatCount-parameter**
  pFormatCount **must** be a valid pointer to a uint32_t value

  If the value referenced by pFormatCount is not 0, and pImageFormatProperties is not NULL, pImageFormatProperties **must** be a valid pointer to an array of pFormatCount VkOpticalFlowImageFormatPropertiesNV structures

Return Codes

Success
- VK_SUCCESS
- VK_INCOMPLETE

Failure
- VK_ERROR_EXTENSION_NOT_PRESENT
- VK_ERROR_INITIALIZATION_FAILED
- VK_ERROR_FORMAT_NOT_SUPPORTED

Note

**VK_FORMAT_B8G8R8A8_UNORM**, **VK_FORMAT_R8_UNORM** and **VK_FORMAT_G8_B8R8_2PLANE_420_UNORM** are initially supported for images with optical usage **VK_OPTICAL_FLOW_USAGE_INPUT_BIT_NV**.

**VK_FORMAT_R16G16_S10_5_NV** is initially supported for images with optical flow usage **VK_OPTICAL_FLOW_USAGE_OUTPUT_BIT_NV**, **VK_OPTICAL_FLOW_USAGE_HINT_BIT_NV** and **VK_OPTICAL_FLOW_USAGE_GLOBAL_FLOW_BIT_NV**.

**VK_FORMAT_R8_UINT** and **VK_FORMAT_R32_UINT** are initially supported for images with optical flow usage **VK_OPTICAL_FLOW_USAGE_COST_BIT_NV**. It is recommended to use **VK_FORMAT_R8_UINT** because of the lower bandwidth.

The **VkOpticalFlowImageFormatInfoNV** structure is defined as:

```c
// Provided by VK_NV_optical_flow
```
typedef struct VkOpticalFlowImageFormatInfoNV {
    VkStructureType sType;
    const void* pNext;
    VkOpticalFlowUsageFlagsNV usage;
} VkOpticalFlowImageFormatInfoNV;

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- usage is a bitmask of VkOpticalFlowUsageFlagBitsNV describing the intended optical flow usage of the image.

**Valid Usage (Implicit)**

- VUID-VkOpticalFlowImageFormatInfoNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_OPTICAL_FLOW_IMAGE_FORMAT_INFO_NV

- VUID-VkOpticalFlowImageFormatInfoNV-usage-parameter
  usage must be a valid combination of VkOpticalFlowUsageFlagBitsNV values

- VUID-VkOpticalFlowImageFormatInfoNV-usage-requiredbitmask
  usage must not be 0

Bits which can be set in VkOpticalFlowImageFormatInfoNV::usage, controlling optical flow usage, are:

```c
// Provided by VK_NV_optical_flow
typedef enum VkOpticalFlowUsageFlagBitsNV {
    VK_OPTICAL_FLOW_USAGE_UNKNOWN_NV = 0,
    VK_OPTICAL_FLOW_USAGE_INPUT_BIT_NV = 0x00000001,
    VK_OPTICAL_FLOW_USAGE_OUTPUT_BIT_NV = 0x00000002,
    VK_OPTICAL_FLOW_USAGE_HINT_BIT_NV = 0x00000004,
    VK_OPTICAL_FLOW_USAGE_COST_BIT_NV = 0x00000008,
    VK_OPTICAL_FLOW_USAGE_GLOBAL_FLOW_BIT_NV = 0x00000010,
} VkOpticalFlowUsageFlagBitsNV;
```

- VK_OPTICAL_FLOW_USAGE_INPUT_BIT_NV specifies that the image can be used as input or reference frame for an optical flow operation.
- VK_OPTICAL_FLOW_USAGE_OUTPUT_BIT_NV specifies that the image can be used as output flow vector map for an optical flow operation.
- VK_OPTICAL_FLOW_USAGE_HINT_BIT_NV specifies that the image can be used as hint flow vector map for an optical flow operation.
- VK_OPTICAL_FLOW_USAGE_COST_BIT_NV specifies that the image can be used as output cost map for an optical flow operation.
- VK_OPTICAL_FLOW_USAGE_GLOBAL_FLOW_BIT_NV specifies that the image can be used as global flow vector for an optical flow operation.
VkOpticalFlowUsageFlagsNV is a bitmask type for setting a mask of zero or more VkOpticalFlowUsageFlagBitsNV.

The VkOpticalFlowImageFormatPropertiesNV structure is defined as:

```c
typedef struct VkOpticalFlowImageFormatPropertiesNV {
    VkStructureType sType;
    const void* pNext;
    VkFormat format;
} VkOpticalFlowImageFormatPropertiesNV;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **format** is a VkFormat that specifies the format that can be used with the specified optical flow image usages.

**Valid Usage (Implicit)**

- VUID-VkOpticalFlowImageFormatPropertiesNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_OPTICAL_FLOW_IMAGE_FORMAT_PROPERTIES_NV
- VUID-VkOpticalFlowImageFormatPropertiesNV-pNext-pNext
  pNext must be NULL

### 43.3. Optical Flow Session

#### 43.3.1. Optical Flow Session Object

Optical flow session objects are abstracted and represented by VkOpticalFlowSessionNV handles:

```c
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkOpticalFlowSessionNV)
```

**Creating an Optical Flow Session**

To create an optical flow session object, call:

```c
VkResult vkCreateOpticalFlowSessionNV(VkDevice device, 
                                     const VkOpticalFlowSessionCreateInfoNV* createInfo, 
                                     VkAllocationCallbacks* pAllocator, 
                                     VkOpticalFlowSessionNV* pSession)
```
const VkOpticalFlowSessionCreateInfoNV* pCreateInfo,
const VkAllocationCallbacks* pAllocator,
VkOpticalFlowSessionNV* pSession);

- **device** is the logical device that creates the optical flow session object.
- **pCreateInfo** is a pointer to a `VkOpticalFlowSessionCreateInfoNV` structure containing parameters specifying the creation of the optical flow session.
- **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.
- **pSession** is a pointer to a `VkOpticalFlowSessionNV` handle specifying the optical flow session object which will be created by this function when it returns **VK_SUCCESS**

### Valid Usage (Implicit)

- **VUID-vkCreateOpticalFlowSessionNV-device-parameter**
  - `device` **must** be a valid `VkDevice` handle
- **VUID-vkCreateOpticalFlowSessionNV-pCreateInfo-parameter**
  - `pCreateInfo` **must** be a valid pointer to a valid `VkOpticalFlowSessionCreateInfoNV` structure
- **VUID-vkCreateOpticalFlowSessionNV-pAllocator-parameter**
  - If `pAllocator` is not NULL, `pAllocator` **must** be a valid pointer to a valid `VkAllocationCallbacks` structure
- **VUID-vkCreateOpticalFlowSessionNV-pSession-parameter**
  - `pSession` **must** be a valid pointer to a `VkOpticalFlowSessionNV` handle

### Return Codes

**Success**
- **VK_SUCCESS**

**Failure**
- **VK_ERROR_OUT_OF_HOST_MEMORY**
- **VK_ERROR_INITIALIZATION_FAILED**

The `VkOpticalFlowSessionCreateInfoNV` structure is defined as:

```c
// Provided by VK_NV_optical_flow
typedef struct VkOpticalFlowSessionCreateInfoNV {
    VkStructureType sType;
    void* pNext;
    uint32_t width;
    uint32_t height;
    VkFormat imageFormat;
    VkFormat flowVectorFormat;
} VkOpticalFlowSessionCreateInfoNV;
```
VkFormat costFormat;
VkOpticalFlowGridSizeFlagsNV outputGridSize;
VkOpticalFlowGridSizeFlagsNV hintGridSize;
VkOpticalFlowPerformanceLevelNV performanceLevel;
VkOpticalFlowSessionCreateFlagsNV flags;
} VkOpticalFlowSessionCreateInfoNV;

• **sType** is a **VkStructureType** value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **width** is the width in pixels of the input or reference frame to be bound to this optical flow session.

• **height** is the height in pixels of the input or reference frame to be bound to this optical flow session.

• **imageFormat** is the **VkFormat** of the input and reference frame to be bound to this optical flow session.

• **flowVectorFormat** is the **VkFormat** of the flow vector maps (output or hint) to be bound to this optical flow session.

• **costFormat** is the **VkFormat** of the cost maps to be bound to this optical flow session.

• **outputGridSize** is exactly one bit of **VkOpticalFlowGridSizeFlagsNV** specifying the grid size of the output flow and cost maps to be bound to this optical flow session. The size of the output flow and cost maps is determined by **VkOpticalFlowSessionCreateInfoNV::width** and **VkOpticalFlowSessionCreateInfoNV::height** divided by **VkOpticalFlowSessionCreateInfoNV::outputGridSize**.

• **hintGridSize** is one exactly bit of **VkOpticalFlowGridSizeFlagsNV** specifying the grid size of the hint flow vector maps to be bound to this optical flow session. The size of the hint maps is determined by **VkOpticalFlowSessionCreateInfoNV::width** and **VkOpticalFlowSessionCreateInfoNV::height** divided by **VkOpticalFlowSessionCreateInfoNV::hintGridSize**.

• **performanceLevel** is the **VkOpticalFlowPerformanceLevelNV** used for this optical flow session.

• **flags** are the **VkOpticalFlowSessionCreateFlagsNV** used for this optical flow session.

---

**Valid Usage**

- **VUID-VkOpticalFlowSessionCreateInfoNV-width-07581**
  
  width must be greater than or equal to **VkPhysicalDeviceOpticalFlowPropertiesNV::minWidth** and less than or equal to **VkPhysicalDeviceOpticalFlowPropertiesNV::maxWidth**

- **VUID-VkOpticalFlowSessionCreateInfoNV-height-07582**
  
  height must be greater than or equal to **VkPhysicalDeviceOpticalFlowPropertiesNV::minHeight** and less than or equal to **VkPhysicalDeviceOpticalFlowPropertiesNV::maxHeight**

- **VUID-VkOpticalFlowSessionCreateInfoNV-imageFormat-07583**
  
  imageFormat must be one of the formats returned by **vkGetPhysicalDeviceOpticalFlowImageFormatsNV** for VK_OPTICAL_FLOWUSAGE_INPUT_BIT_NV

- **VUID-VkOpticalFlowSessionCreateInfoNV-flowVectorFormat-07584**
flowVectorFormat must be one of the formats returned by
vkGetPhysicalDeviceOpticalFlowImageFormatsNV
for
VK_OPTICAL_FLOW_USAGE_OUTPUT_BIT_NV

- VUID-VkOpticalFlowSessionCreateInfoNV-costFormat-07585
costFormat must be one of the formats returned by
vkGetPhysicalDeviceOpticalFlowImageFormatsNV for VK_OPTICAL_FLOW_USAGE_COST_BIT_NV
if VK_OPTICAL_FLOW_SESSION_CREATE_ENABLE_COST_BIT_NV is set in flags

- VUID-VkOpticalFlowSessionCreateInfoNV-outputGridSize-07586
outputGridSize must be exactly one of the bits reported in
VkPhysicalDeviceOpticalFlowPropertiesNV::supportedOutputGridSizes

- VUID-VkOpticalFlowSessionCreateInfoNV-hintGridSize-07587
hintGridSize must be exactly one of the bits reported in
VkPhysicalDeviceOpticalFlowPropertiesNV::supportedHintGridSizes if
VK_OPTICAL_FLOW_SESSION_CREATE_ENABLE_HINT_BIT_NV is set in flags

- VUID-VkOpticalFlowSessionCreateInfoNV-flags-07588
VK_OPTICAL_FLOW_SESSION_CREATE_ENABLE_HINT_BIT_NV must not be set in flags if
VkPhysicalDeviceOpticalFlowPropertiesNV::hintSupported is VK_FALSE

- VUID-VkOpticalFlowSessionCreateInfoNV-flags-07589
VK_OPTICAL_FLOW_SESSION_CREATE_ENABLE_COST_BIT_NV must not be set in flags if
VkPhysicalDeviceOpticalFlowPropertiesNV::costSupported is VK_FALSE

- VUID-VkOpticalFlowSessionCreateInfoNV-flags-07590
VK_OPTICAL_FLOW_SESSION_CREATE_ENABLE_GLOBAL_FLOW_BIT_NV must not be set in flags if
VkPhysicalDeviceOpticalFlowPropertiesNV::globalFlowSupported is VK_FALSE

- VUID-VkOpticalFlowSessionCreateInfoNV-flags-07591
VK_OPTICAL_FLOW_SESSION_CREATE_ALLOW_REGIONS_BIT_NV must not be set in flags if
VkPhysicalDeviceOpticalFlowPropertiesNV::maxNumRegionsOfInterest is 0

- VUID-VkOpticalFlowSessionCreateInfoNV-flags-07592
VK_OPTICAL_FLOW_SESSION_CREATE_BOTH_DIRECTIONS_BIT_NV must not be set in flags if
VkPhysicalDeviceOpticalFlowPropertiesNV::bidirectionalFlowSupported is VK_FALSE

Valid Usage (Implicit)

- VUID-VkOpticalFlowSessionCreateInfoNV-sType-sType
sType must be VK_STRUCTURE_TYPE_OPTICAL_FLOW_SESSION_CREATE_INFO_NV

- VUID-VkOpticalFlowSessionCreateInfoNV-pNext-pNext
pNext must be NULL or a pointer to a valid instance of
VkOpticalFlowSessionCreatePrivateDataInfoNV

- VUID-VkOpticalFlowSessionCreateInfoNV-sType-unique
The sType value of each struct in the pNext chain must be unique

- VUID-VkOpticalFlowSessionCreateInfoNV-imageFormat-parameter
imageFormat must be a valid VkFormat value

- VUID-VkOpticalFlowSessionCreateInfoNV-flowVectorFormat-parameter
**flowVectorFormat must** be a valid **VkFormat** value

- VUID-VkOpticalFlowSessionCreateInfoNV-costFormat-parameter
  
  If `costFormat` is not 0, `costFormat` **must** be a valid **VkFormat** value

- VUID-VkOpticalFlowSessionCreateInfoNV-outputGridSize-parameter
  
  `outputGridSize` **must** be a valid combination of **VkOpticalFlowGridSizeFlagBitsNV** values

- VUID-VkOpticalFlowSessionCreateInfoNV-outputGridSize-requiredbitmask
  
  `outputGridSize` **must not** be 0

- VUID-VkOpticalFlowSessionCreateInfoNV-hintGridSize-parameter
  
  `hintGridSize` **must** be a valid combination of **VkOpticalFlowGridSizeFlagBitsNV** values

- VUID-VkOpticalFlowSessionCreateInfoNV-performanceLevel-parameter
  
  If `performanceLevel` is not 0, `performanceLevel` **must** be a valid **VkOpticalFlowPerformanceLevelNV** value

- VUID-VkOpticalFlowSessionCreateInfoNV-flags-parameter
  
  `flags` **must** be a valid combination of **VkOpticalFlowSessionCreateFlagBitsNV** values

The **VkOpticalFlowSessionCreatePrivateDataInfoNV** structure is for NV internal use only and is defined as:

```c
// Provided by VK_NV_optical_flow
typedef struct VkOpticalFlowSessionCreatePrivateDataInfoNV {
    VkStructureType sType;
    void*pNext;
    uint32_t id;
    uint32_t size;
    const void* pPrivateData;
} VkOpticalFlowSessionCreatePrivateDataInfoNV;
```

- `sType` is a **VkStructureType** value identifying this structure.
- `pNext` is **NULL** or a pointer to a structure extending this structure.
- `id` is an identifier for data which is passed at a memory location specified in `VkOpticalFlowSessionCreatePrivateDataInfoNV::pPrivateData`.
- `size` is the size of data in bytes which is passed at a memory location specified in `VkOpticalFlowSessionCreatePrivateDataInfoNV::pPrivateData`.
- `pPrivateData` is a pointer to NV internal data.

### Valid Usage (Implicit)

- VUID-VkOpticalFlowSessionCreatePrivateDataInfoNV-sType-sType
  
  `sType` **must** be **VK_STRUCTURE_TYPE_OPTICAL_FLOW_SESSION_CREATE_PRIVATE_DATA_INFO_NV**

- VUID-VkOpticalFlowSessionCreatePrivateDataInfoNV-pPrivateData-parameter
  
  `pPrivateData` **must** be a pointer value
Optical flow vectors are generated block-wise, one vector for each block of \(NxN\) pixels (referred to as grid).

Bits which can be set in `VkOpticalFlowSessionCreateInfoNV::outputGridSize` and `VkOpticalFlowSessionCreateInfoNV::hintGridSize`, or which are returned in `VkPhysicalDeviceOpticalFlowPropertiesNV::supportedOutputGridSizes` and `VkPhysicalDeviceOpticalFlowPropertiesNV::supportedHintGridSizes` controlling optical flow grid sizes, are:

```c
// Provided by VK_NV_optical_flow
typedef enum VkOpticalFlowGridSizeFlagBitsNV {
    VK_OPTICAL_FLOW_GRID_SIZE_UNKNOWN_NV = 0,
    VK_OPTICAL_FLOW_GRID_SIZE_1X1_BIT_NV = 0x00000001,
    VK_OPTICAL_FLOW_GRID_SIZE_2X2_BIT_NV = 0x00000002,
    VK_OPTICAL_FLOW_GRID_SIZE_4X4_BIT_NV = 0x00000004,
    VK_OPTICAL_FLOW_GRID_SIZE_8X8_BIT_NV = 0x00000008,
} VkOpticalFlowGridSizeFlagBitsNV;
```

- `VK_OPTICAL_FLOW_GRID_SIZE_1X1_BIT_NV` specifies that grid is 1x1 pixel.
- `VK_OPTICAL_FLOW_GRID_SIZE_2X2_BIT_NV` specifies that grid is 2x2 pixel.
- `VK_OPTICAL_FLOW_GRID_SIZE_4X4_BIT_NV` specifies that grid is 4x4 pixel.
- `VK_OPTICAL_FLOW_GRID_SIZE_8X8_BIT_NV` specifies that grid is 8x8 pixel.

```c
// Provided by VK_NV_optical_flow
typedef VkFlags VkOpticalFlowGridSizeFlagsNV;
```

`VkOpticalFlowGridSizeFlagsNV` is a bitmask type for setting a mask of zero or more `VkOpticalFlowGridSizeFlagBitsNV`.

Optical flow exposes performance levels which the user can choose based on the desired performance and quality requirement.

The optical flow performance level types are defined with the following:

```c
// Provided by VK_NV_optical_flow
typedef enum VkOpticalFlowPerformanceLevelNV {
    VK_OPTICAL_FLOW_PERFORMANCE_LEVEL_UNKNOWN_NV = 0,
    VK_OPTICAL_FLOW_PERFORMANCE_LEVEL_SLOW_NV = 1,
    VK_OPTICAL_FLOW_PERFORMANCE_LEVEL_MEDIUM_NV = 2,
    VK_OPTICAL_FLOW_PERFORMANCE_LEVEL_FAST_NV = 3,
} VkOpticalFlowPerformanceLevelNV;
```

- `VK_OPTICAL_FLOW_PERFORMANCE_LEVEL_SLOW_NV` is a level with slower performance but higher quality.
- `VK_OPTICAL_FLOW_PERFORMANCE_LEVEL_MEDIUM_NV` is a level with medium performance and medium
quality.

- **VK_OPTICAL_FLOW_PERFORMANCE_LEVEL_FAST_NV** is a preset with higher performance but lower quality.

Bits which can be set in `VkOpticalFlowSessionCreateInfoNV::flags`, controlling optical flow session operations, are:

```c
// Provided by VK_NV_optical_flow
typedef enum VkOpticalFlowSessionCreateFlagBitsNV {
    VK_OPTICAL_FLOW_SESSION_CREATE_ENABLE_HINT_BIT_NV = 0x00000001,
    VK_OPTICAL_FLOW_SESSION_CREATE_ENABLE_COST_BIT_NV = 0x00000002,
    VK_OPTICAL_FLOW_SESSION_CREATE_ENABLE_GLOBAL_FLOW_BIT_NV = 0x00000004,
    VK_OPTICAL_FLOW_SESSION_CREATE_ALLOW_REGIONS_BIT_NV = 0x00000008,
    VK_OPTICAL_FLOW_SESSION_CREATE_BOTH_DIRECTIONS_BIT_NV = 0x00000010,
} VkOpticalFlowSessionCreateFlagBitsNV;
```

- **VK_OPTICAL_FLOW_SESSION_CREATE_ENABLE_HINT_BIT_NV** specifies that a `VkImageView` with external flow vectors will be used as hints in performing the motion search and must be bound to `VK_OPTICAL_FLOW_SESSION_BINDING_POINT_HINT_NV`.

- **VK_OPTICAL_FLOW_SESSION_CREATE_ENABLE_COST_BIT_NV** specifies that the cost for the forward flow is generated in a `VkImageView` which must be bound to `VK_OPTICAL_FLOW_SESSION_BINDING_POINT_COST_NV`. Additionally, if **VK_OPTICAL_FLOW_SESSION_CREATE_BOTH_DIRECTIONS_BIT_NV** is also set, the cost for backward flow is generated in a `VkImageView` which must be bound to `VK_OPTICAL_FLOW_SESSION_BINDING_POINT_BACKWARD_COST_NV`. The cost is the confidence level of the flow vector for each grid in the frame. The Cost implies how (in)accurate the flow vector is. Higher cost value implies the flow vector to be less accurate and vice-versa.

- **VK_OPTICAL_FLOW_SESSION_CREATE_ENABLE_GLOBAL_FLOW_BIT_NV** specifies that a global flow vector is estimated from forward flow in a single pixel `VkImageView` which must be bound to `VK_OPTICAL_FLOW_SESSION_BINDING_POINT_GLOBAL_FLOW_NV`.

- **VK_OPTICAL_FLOW_SESSION_CREATE_ALLOW_REGIONS_BIT_NV** specifies that regions of interest can be specified in `VkOpticalFlowExecuteInfoNV`.

- **VK_OPTICAL_FLOW_SESSION_CREATE_BOTH_DIRECTIONS_BIT_NV** specifies that backward flow is generated in addition to forward flow which is always generated.

`VkOpticalFlowSessionCreateFlagsNV` is a bitmask type for setting a mask of zero or more `VkOpticalFlowSessionCreateFlagBitsNV`.

```c
// Provided by VK_NV_optical_flow
typedef VkFlags VkOpticalFlowSessionCreateFlagsNV;
```

### Destroying an Optical Flow Session

To destroy a optical flow session object, call:
// Provided by VK_NV_optical_flow
void vkDestroyOpticalFlowSessionNV(
    VkDevice device,
    VkOpticalFlowSessionNV session,
    const VkAllocationCallbacks* pAllocator);

• **device** is the device that was used for the creation of the optical flow session.

• **session** is the optical flow session to be destroyed.

• **pAllocator** controls host memory allocation as described in the Memory Allocation chapter.

<table>
<thead>
<tr>
<th>Valid Usage (Implicit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• VUID-vkDestroyOpticalFlowSessionNV-device-parameter</td>
</tr>
<tr>
<td>device <strong>must</strong> be a valid VkDevice handle</td>
</tr>
<tr>
<td>• VUID-vkDestroyOpticalFlowSessionNV-session-parameter</td>
</tr>
<tr>
<td>session <strong>must</strong> be a valid VkOpticalFlowSessionNV handle</td>
</tr>
<tr>
<td>• VUID-vkDestroyOpticalFlowSessionNV-pAllocator-parameter</td>
</tr>
<tr>
<td>If pAllocator is not NULL, pAllocator <strong>must</strong> be a valid pointer to a valid VkAllocationCallbacks structure</td>
</tr>
<tr>
<td>• VUID-vkDestroyOpticalFlowSessionNV-session-parent</td>
</tr>
<tr>
<td>session <strong>must</strong> have been created, allocated, or retrieved from device</td>
</tr>
</tbody>
</table>

### 43.3.2. Binding vulkan image views to an optical flow session

To bind a vulkan image to an optical flow session object, call:

// Provided by VK_NV_optical_flow
VkResult vkBindOpticalFlowSessionImageNV(
    VkDevice device,
    VkOpticalFlowSessionNV session,
    VkOpticalFlowSessionBindingPointNV bindingPoint,
    VkImageView view,
    VkImageLayout layout);

• **device** is the device which owns the optical flow session object **session**.

• **session** is the optical flow session object to which the image view is to be bound.

• **bindingPoint** specifies the binding point VkOpticalFlowSessionBindingPointNV to which the image view is bound.

• **view** is a VkImageView to be bound.

• **layout** must specify the layout that the image subresources accessible from **view** will be in at the time the optical flow vectors are calculated with vkCmdOpticalFlowExecuteNV on a VkDevice.
Valid Usage (Implicit)

- **VUID-vkBindOpticalFlowSessionImageNV-device-parameter**
  device must be a valid VkDevice handle

- **VUID-vkBindOpticalFlowSessionImageNV-session-parameter**
  session must be a valid VkOpticalFlowSessionNV handle

- **VUID-vkBindOpticalFlowSessionImageNV-bindingPoint-parameter**
  bindingPoint must be a valid VkOpticalFlowSessionBindingPointNV value

- **VUID-vkBindOpticalFlowSessionImageNV-view-parameter**
  If view is not VK_NULL_HANDLE, view must be a valid VkImageView handle

- **VUID-vkBindOpticalFlowSessionImageNV-layout-parameter**
  layout must be a valid VkImageLayout value

- **VUID-vkBindOpticalFlowSessionImageNV-session-parent**
  session must have been created, allocated, or retrieved from device

- **VUID-vkBindOpticalFlowSessionImageNV-view-parent**
  If view is a valid handle, it must have been created, allocated, or retrieved from device

Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_INITIALIZATION_FAILED

The optical flow session binding points are defined with the following:

```c
// Provided by VK_NV_optical_flow
typedef enum VkOpticalFlowSessionBindingPointNV {
    VK_OPTICAL_FLOW_SESSION_BINDING_POINT_UNKNOWN_NV = 0,
    VK_OPTICAL_FLOW_SESSION_BINDING_POINT_INPUT_NV = 1,
    VK_OPTICAL_FLOW_SESSION_BINDING_POINT_REFERENCE_NV = 2,
    VK_OPTICAL_FLOW_SESSION_BINDING_POINT_HINT_NV = 3,
    VK_OPTICAL_FLOW_SESSION_BINDING_POINT_FLOW_VECTOR_NV = 4,
    VK_OPTICAL_FLOW_SESSION_BINDING_POINT_BACKWARD_FLOW_VECTOR_NV = 5,
    VK_OPTICAL_FLOW_SESSION_BINDING_POINT_COST_NV = 6,
    VK_OPTICAL_FLOW_SESSION_BINDING_POINT_BACKWARD_COST_NV = 7,
    VK_OPTICAL_FLOW_SESSION_BINDING_POINT_GLOBAL_FLOW_NV = 8,
} VkOpticalFlowSessionBindingPointNV;
```

- **VK_OPTICAL_FLOW_SESSION_BINDING_POINT_INPUT_NV** specifies the binding point for the input frame.
• **VK_OPTICAL_FLOW_SESSION_BINDING_POINT_REFERENCE_NV** specifies the binding point for the input reference frame.

• **VK_OPTICAL_FLOW_SESSION_BINDING_POINT_HINT_NV** specifies the binding point for the optional external hint flow vectors.

• **VK_OPTICAL_FLOW_SESSION_BINDING_POINT_FLOW_VECTOR_NV** specifies the binding point for output flow vectors of default forward flow calculation.

• **VK_OPTICAL_FLOW_SESSION_BINDING_POINT_BACKWARD_FLOW_VECTOR_NV** specifies the binding point for the optional output flow vector map of optional backward flow calculation.

• **VK_OPTICAL_FLOW_SESSION_BINDING_POINT_COST_NV** specifies the binding point for the optional output cost map of default forward flow calculation.

• **VK_OPTICAL_FLOW_SESSION_BINDING_POINT_BACKWARD_COST_NV** specifies the binding point for the optional output cost map of optional backward flow calculation.

• **VK_OPTICAL_FLOW_SESSION_BINDING_POINT_GLOBAL_FLOW_NV** specifies the binding point for the optional global flow value of default forward flow calculation.

### 43.3.3. Optical Flow Execution

Default direction of flow estimation is forward which calculates the optical flow from input frame to reference frame. Optionally backward flow estimation can be additionally calculated. An output flow vector \((V_x, V_y)\) means that current pixel \((x, y)\) of input frame can be found at location \((x+V_x, y+V_y)\) in reference frame. A backward flow vector \((V_x, V_y)\) means that current pixel \((x, y)\) of reference frame can be found at location \((x+V_x, y+V_y)\) in input frame.

To calculate optical flow vectors from two input frames, call:

```c
// Provided by VK_NV_optical_flow
void vkCmdOpticalFlowExecuteNV(
    VkCommandBuffer commandBuffer, 
    VkOpticalFlowSessionNV session, 
    const VkOpticalFlowExecuteInfoNV* pExecuteInfo);
```

• **commandBuffer** is the command buffer into which the command will be recorded.

• **session** is the optical flow session object on which this command is operating.

• **pExecuteInfo** Info is a pointer to a **VkOpticalFlowExecuteInfoNV**.

#### Valid Usage (Implicit)

- **VUID-vkCmdOpticalFlowExecuteNV-commandBuffer-parameter**
  **commandBuffer** must be a valid **VkCommandBuffer** handle

- **VUID-vkCmdOpticalFlowExecuteNV-session-parameter**
  **session** must be a valid **VkOpticalFlowSessionNV** handle

- **VUID-vkCmdOpticalFlowExecuteNV-pExecuteInfo-parameter**
  **pExecuteInfo** must be a valid pointer to a valid **VkOpticalFlowExecuteInfoNV** structure
• **VUID-vkCmdOpticalFlowExecuteNV-commandBuffer-recording**
  
  commandBuffer must be in the recording state

• **VUID-vkCmdOpticalFlowExecuteNV-commandBuffer-cmdpool**

  The VkCommandPool that commandBuffer was allocated from must support optical flow operations

• **VUID-vkCmdOpticalFlowExecuteNV-renderpass**

  This command must only be called outside of a render pass instance

• **VUID-vkCmdOpticalFlowExecuteNV-videocoding**

  This command must only be called outside of a video coding scope

• **VUID-vkCmdOpticalFlowExecuteNV-commonparent**

  Both of commandBuffer, and session must have been created, allocated, or retrieved from the same VkDevice

---

**Host Synchronization**

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

---

**Command Properties**

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The VkOpticalFlowExecuteInfoNV structure is defined as:

```c
// Provided by VK_NV_optical_flow
typedef struct VkOpticalFlowExecuteInfoNV {
    VkStructureType sType;
    void* pNext;
    VkOpticalFlowExecuteFlagsNV flags;
    uint32_t regionCount;
    const VkRect2D* pRegions;
} VkOpticalFlowExecuteInfoNV;
```

• **sType** is a VkStructureType value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **flags** are the VkOpticalFlowExecuteFlagsNV used for this command.

• **regionCount** is the number of regions of interest specified in pRegions.

• **pRegions** is a pointer to regionCount VkRect2D regions of interest.
Valid Usage

- VUID-VkOpticalFlowExecuteInfoNV-regionCount-07593
  regionCount must be 0 if VK_OPTICAL_FLOW_SESSION_CREATE_ALLOW_REGIONS_BIT_NV was not set for VkOpticalFlowSessionNV on which this command is operating

Valid Usage (Implicit)

- VUID-VkOpticalFlowExecuteInfoNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_OPTICAL_FLOW_EXECUTE_INFO_NV

- VUID-VkOpticalFlowExecuteInfoNV-pNext-pNext
  pNext must be NULL

- VUID-VkOpticalFlowExecuteInfoNV-flags-parameter
  flags must be a valid combination of VkOpticalFlowExecuteFlagBitsNV values

- VUID-VkOpticalFlowExecuteInfoNV-pRegions-parameter
  If regionCount is not 0, pRegions must be a valid pointer to an array of regionCount VkRect2D structures

Bits which can be set in VkOpticalFlowExecuteInfoNV::flags, controlling optical flow execution, are:

```c
// Provided by VK_NV_optical_flow
typedef enum VkOpticalFlowExecuteFlagBitsNV {
    VK_OPTICAL_FLOW_EXECUTE_DISABLE_TEMPORAL_HINTS_BIT_NV = 0x00000001,
} VkOpticalFlowExecuteFlagBitsNV;
```

- VK_OPTICAL_FLOW_EXECUTE_DISABLE_TEMPORAL_HINTS_BIT_NV specifies that temporal hints from previously generated flow vectors are not used. If temporal hints are enabled, optical flow vectors from previous vkCmdOpticalFlowExecuteNV call are automatically used as hints for the current vkCmdOpticalFlowExecuteNV call, to take advantage of temporal correlation in a video sequence. Temporal hints should be disabled if there is a-priori knowledge of no temporal correlation (e.g. a scene change, independent successive frame pairs).

VkOpticalFlowExecuteFlagsNV is a bitmask type for setting a mask of zero or more VkOpticalFlowExecuteFlagBitsNV.

```c
// Provided by VK_NV_optical_flow
typedef VkFlags VkOpticalFlowExecuteFlagsNV;
```
Chapter 44. Execution Graphs

*Execution graphs* provide a way for applications to dispatch multiple operations dynamically from a single initial command on the host. To achieve this, a new execution graph pipeline is provided, that links together multiple shaders or pipelines which each describe one or more operations that can be dispatched within the execution graph. Each linked pipeline or shader describes an *execution node* within the graph, which *can* be dispatched dynamically from another shader within the same graph. This allows applications to describe much richer execution topologies at a finer granularity than would typically be possible with API commands alone.

### 44.1. Pipeline Creation

To create execution graph pipelines, call:

```c
// Provided by VK_AMDX_shader_enqueue
VkResult vkCreateExecutionGraphPipelinesAMDX(
    VkDevice device,
    VkPipelineCache pipelineCache,
    uint32_t createInfoCount,
    const VkExecutionGraphPipelineCreateInfoAMDX* pCreateInfos,
    const VkAllocationCallbacks* pAllocator,
    VkPipeline* pPipelines);
```

- `device` is the logical device that creates the execution graph pipelines.
- `pipelineCache` is either `VK_NULL_HANDLE`, indicating that pipeline caching is disabled; or the handle of a valid pipeline cache object, in which case use of that cache is enabled for the duration of the command.
- `createInfoCount` is the length of the `pCreateInfos` and `pPipelines` arrays.
- `pCreateInfos` is a pointer to an array of `VkExecutionGraphPipelineCreateInfoAMDX` structures.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pPipelines` is a pointer to an array of `VkPipeline` handles in which the resulting execution graph pipeline objects are returned.

The implementation will create a pipeline in each element of `pPipelines` from the corresponding element of `pCreateInfos`. If creation of any pipeline fails, that pipeline will be set to `VK_NULL_HANDLE`.

If creation fails for a pipeline create info with a `VkExecutionGraphPipelineCreateInfoAMDX::flags` value that included `VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT`, all pipelines at a greater index all automatically fail.

**Valid Usage**

- VUID-vkCreateExecutionGraphPipelinesAMDX-shaderEnqueue-09124
  The `shaderEnqueue` feature *must* be enabled
If the `flags` member of any element of `pCreateInfos` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, and the `basePipelineIndex` member of that same element is not -1, `basePipelineIndex must be less than the index into pCreateInfos that corresponds to that element.

If the `flags` member of any element of `pCreateInfos` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, the base pipeline must have been created with the `VK_PIPELINE_CREATE_ALLOW_DERIVATIVES_BIT` flag set.

If `pipelineCache` was created with `VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT`, host access to `pipelineCache must be externally synchronized`.

**Valid Usage (Implicit)**

- `device` must be a valid `VkDevice` handle.
- If `pipelineCache` is not `VK_NULL_HANDLE`, `pipelineCache must be a valid `VkPipelineCache` handle.
- `pCreateInfos` must be a valid pointer to an array of `createInfoCount` valid `VkExecutionGraphPipelineCreateInfoAMDX` structures.
- If `pAllocator` is not `NULL`, `pAllocator must be a valid pointer to a valid `VkAllocationCallbacks` structure.
- `pPipelines` must be a valid pointer to an array of `createInfoCount` `VkPipeline` handles.
- `createInfoCount` must be greater than 0.
- If `pipelineCache` is a valid handle, it must have been created, allocated, or retrieved from `device`.

**Return Codes**

**Success**
- `VK_SUCCESS`
- `VK_PIPELINE_COMPILE_REQUIRED_EXT`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`
The `VkExecutionGraphPipelineCreateInfoAMDX` structure is defined as:

```c
typedef struct VkExecutionGraphPipelineCreateInfoAMDX {
    VkStructureType sType;
    const void* pNext;
    VkPipelineCreateFlags flags;
    uint32_t stageCount;
    const VkPipelineShaderStageCreateInfo* pStages;
    const VkPipelineLibraryCreateInfoKHR* pLibraryInfo;
    VkPipelineLayout layout;
    VkPipeline basePipelineHandle;
    int32_t basePipelineIndex;
} VkExecutionGraphPipelineCreateInfoAMDX;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkPipelineCreateFlagBits` specifying how the pipeline will be generated.
- `stageCount` is the number of entries in the `pStages` array.
- `pStages` is a pointer to an array of `stageCount` `VkPipelineShaderStageCreateInfo` structures describing the set of the shader stages to be included in the execution graph pipeline.
- `pLibraryInfo` is a pointer to a `VkPipelineLibraryCreateInfoKHR` structure defining pipeline libraries to include.
- `layout` is the description of binding locations used by both the pipeline and descriptor sets used with the pipeline.
- `basePipelineHandle` is a pipeline to derive from
- `basePipelineIndex` is an index into the `pCreateInfos` parameter to use as a pipeline to derive from

The parameters `basePipelineHandle` and `basePipelineIndex` are described in more detail in Pipeline Derivatives.

Each shader stage provided when creating an execution graph pipeline (including those in libraries) is associated with a name and an index, determined by the inclusion or omission of a `VkPipelineShaderStageNodeCreateInfoAMDX` structure in its `pNext` chain.

In addition to the shader name and index, an internal "node index" is also generated for each node, which can be queried with `vkGetExecutionGraphPipelineNodeIndexAMDX`, and is used exclusively for initial dispatch of an execution graph.
Valid Usage

- **VUID-VkExecutionGraphPipelineCreateInfoAMDX-flags-07984**
  If `flags` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, and `basePipelineIndex` is -1, `basePipelineHandle` must be a valid execution graph `VkPipeline` handle.

- **VUID-VkExecutionGraphPipelineCreateInfoAMDX-flags-07985**
  If `flags` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, and `basePipelineHandle` is `VK_NULL_HANDLE`, `basePipelineIndex` must be a valid index into the calling command's `pCreateInfos` parameter.

- **VUID-VkExecutionGraphPipelineCreateInfoAMDX-flags-07986**
  If `flags` contains the `VK_PIPELINE_CREATE_DERIVATIVE_BIT` flag, and `basePipelineHandle` is `VK_NULL_HANDLE`, `basePipelineIndex` must be -1 or `basePipelineHandle` must be `VK_NULL_HANDLE`.

- **VUID-VkExecutionGraphPipelineCreateInfoAMDX-layout-07987**
  If a push constant block is declared in a shader, a push constant range in `layout` must match both the shader stage and range.

- **VUID-VkExecutionGraphPipelineCreateInfoAMDX-layout-07988**
  If a resource variables is declared in a shader, a descriptor slot in `layout` must match the shader stage.

- **VUID-VkExecutionGraphPipelineCreateInfoAMDX-layout-07990**
  If a resource variables is declared in a shader, and the descriptor type is not `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`, a descriptor slot in `layout` must match the descriptor type.

- **VUID-VkExecutionGraphPipelineCreateInfoAMDX-layout-07991**
  If a resource variables is declared in a shader as an array, a descriptor slot in `layout` must match the descriptor count.

- **VUID-VkExecutionGraphPipelineCreateInfoAMDX-flags-03365**
  `flags` must not include `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR`.

- **VUID-VkExecutionGraphPipelineCreateInfoAMDX-flags-03366**
  `flags` must not include `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR`.

- **VUID-VkExecutionGraphPipelineCreateInfoAMDX-flags-03367**
  `flags` must not include `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR`.

- **VUID-VkExecutionGraphPipelineCreateInfoAMDX-flags-03368**
  `flags` must not include `VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR`.

- **VUID-VkExecutionGraphPipelineCreateInfoAMDX-flags-03369**
  `flags` must not include `VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR`.

- **VUID-VkExecutionGraphPipelineCreateInfoAMDX-flags-03370**
  `flags` must not include `VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR`.

- **VUID-VkExecutionGraphPipelineCreateInfoAMDX-flags-03576**
  `flags` must not include `VK_PIPELINE_CREATE_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR`.
• VUID-VkExecutionGraphPipelineCreateInfoAMDX-flags-09007
  If flags includes VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV, then the
  VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV::deviceGeneratedComputePipelines feature must be enabled

• VUID-VkExecutionGraphPipelineCreateInfoAMDX-flags-09008
  If flags includes VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV, then the pNext chain must include a pointer to a valid instance of VkComputePipelineIndirectBufferInfoNV specifying the address where the pipeline’s metadata will be saved

• VUID-VkExecutionGraphPipelineCreateInfoAMDX-pipelineCreationCacheControl-02875
  If the pipelineCreationCacheControl feature is not enabled, flags must not include
  VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT or
  VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT

• VUID-VkExecutionGraphPipelineCreateInfoAMDX-stage-09128
  The stage member of any element of pStages must be VK_SHADER_STAGE_COMPUTE_BIT

• VUID-VkExecutionGraphPipelineCreateInfoAMDX-pStages-09129
  The shader code for the entry point identified by each element of pStages and the rest of the state identified by this structure must adhere to the pipeline linking rules described in the Shader Interfaces chapter

• VUID-VkExecutionGraphPipelineCreateInfoAMDX-layout-09130
  layout must be consistent with the layout of the shaders specified in pStages

• VUID-VkExecutionGraphPipelineCreateInfoAMDX-pLibraryInfo-09131
  If pLibraryInfo is not NULL, each element of its pLibraries member must have been created with a layout that is compatible with the layout in this pipeline

• VUID-VkExecutionGraphPipelineCreateInfoAMDX-layout-09132
  The number of resources in layout accessible to each shader stage that is used by the pipeline must be less than or equal to VkPhysicalDeviceLimits::maxPerStageResources

• VUID-VkExecutionGraphPipelineCreateInfoAMDX-pLibraryInfo-09133
  If pLibraryInfo is not NULL, each element of pLibraryInfo->libraries must be either a compute pipeline or an execution graph pipeline

• VUID-VkExecutionGraphPipelineCreateInfoAMDX-None-09134
  There must be no two nodes in the pipeline that share both the same shader name and index, as specified by VkPipelineShaderStageNodeCreateInfoAMDX

• VUID-VkExecutionGraphPipelineCreateInfoAMDX-None-09135
  There must be no two nodes in the pipeline that share the same shader name and have input payload declarations with different sizes

• VUID-VkExecutionGraphPipelineCreateInfoAMDX-None-09136
  There must be no two nodes in the pipeline that share the same name but have different execution models

• VUID-VkExecutionGraphPipelineCreateInfoAMDX-CoalescedInputCountAMDX-09137
  There must be no two nodes in the pipeline that share the same name where one includes CoalescedInputCountAMDX and the other does not
There must be no two nodes in the pipeline that share the same name where one includes \texttt{StaticNumWorkgroupsAMDX} and the other does not.

If an output payload declared in any shader in the pipeline has a \texttt{PayloadNodeNameAMDX} decoration with a \texttt{Node Name} that matches the shader name of any other node in the graph, the size of the output payload must match the size of the input payload in the matching node.

### Valid Usage (Implicit)

- \texttt{VK_SHADER_INDEX_UNUSED_AMDX} is a special shader index used to indicate that the created node does not override the index. In this case, the shader index is determined through other means. It is defined as:

  ```
  #define VK_SHADER_INDEX_UNUSED_AMDX (~0U)
  ```

The \texttt{VkPipelineShaderStageNodeCreateInfoAMDX} structure is defined as:

```
typedef struct VkPipelineShaderStageNodeCreateInfoAMDX {
    VkStructureType sType;
    const void* pNext;
    const char* pName;
    uint32_t index;
} VkPipelineShaderStageNodeCreateInfoAMDX;

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- pName is the shader name to use when creating a node in an execution graph. If pName is NULL, the name of the entry point specified in SPIR-V is used as the shader name.
- index is the shader index to use when creating a node in an execution graph. If index is VK_SHADER_INDEX_UNUSED_AMDX then the original index is used, either as specified by the ShaderIndexAMDX execution mode, or 0 if that too is not specified.

When included in the pNext chain of a VkPipelineShaderStageCreateInfo structure, this structure specifies the shader name and shader index of a node when creating an execution graph pipeline. If this structure is omitted, the shader name is set to the name of the entry point in SPIR-V and the shader index is set to 0.

When dispatching a node from another shader, the name is fixed at pipeline creation, but the index can be set dynamically. By associating multiple shaders with the same name but different indexes, applications can dynamically select different nodes to execute. Applications must ensure each node has a unique name and index.

Valid Usage (Implicit)

- VUID-VkPipelineShaderStageNodeCreateInfoAMDX-sType-sType
  sType must be VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_NODE_CREATE_INFO_AMDX
- VUID-VkPipelineShaderStageNodeCreateInfoAMDX-pName-parameter
  If pName is not NULL, pName must be a null-terminated UTF-8 string

To query the internal node index for a particular node in an execution graph, call:

```c
// Provided by VK_AMDX_shader_enqueue
VkResult vkGetExecutionGraphPipelineNodeIndexAMDX(
    VkDevice device,                      // Provided by VK_AMDX_shader_enqueue
    VkPipeline executionGraph,            // Provided by VK_AMDX_shader_enqueue
    const VkPipelineShaderStageNodeCreateInfoAMDX* pNodeInfo,
    uint32_t* pNodeIndex);
```

- device is the that executionGraph was created on.
- executionGraph is the execution graph pipeline to query the internal node index for.
- pNodeInfo is a pointer to a VkPipelineShaderStageNodeCreateInfoAMDX structure identifying
the name and index of the node to query.

- **pNodeIndex** is the returned internal node index of the identified node.

Once this function returns, the contents of **pNodeIndex** contain the internal node index of the identified node.

### Valid Usage

- VUID-vkGetExecutionGraphPipelineNodeIndexAMDX-pNodeInfo-09140
  **pNodeInfo->pName** must not be NULL
- VUID-vkGetExecutionGraphPipelineNodeIndexAMDX-pNodeInfo-09141
  **pNodeInfo->index** must not be VK_SHADER_INDEX_UNUSED_AMDX
- VUID-vkGetExecutionGraphPipelineNodeIndexAMDX-executionGraph-09142
  There must be a node in **executionGraph** with a shader name and index equal to **pNodeInfo->pName** and **pNodeInfo->index**

### Valid Usage (Implicit)

- VUID-vkGetExecutionGraphPipelineNodeIndexAMDX-device-parameter
  **device** must be a valid **VkDevice** handle
- VUID-vkGetExecutionGraphPipelineNodeIndexAMDX-executionGraph-parameter
  **executionGraph** must be a valid **VkPipeline** handle
- VUID-vkGetExecutionGraphPipelineNodeIndexAMDX-pNodeInfo-parameter
  **pNodeInfo** must be a valid pointer to a valid **VkPipelineShaderStageNodeCreateInfoAMDX** structure
- VUID-vkGetExecutionGraphPipelineNodeIndexAMDX-pNodeIndex-parameter
  **pNodeIndex** must be a valid pointer to a **uint32_t** value
- VUID-vkGetExecutionGraphPipelineNodeIndexAMDX-executionGraph-parent
  **executionGraph** must have been created, allocated, or retrieved from **device**

### Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY

### 44.2. Initializing Scratch Memory

Implementations may need scratch memory to manage dispatch queues or similar when executing a pipeline graph, and this is explicitly managed by the application.
To query the scratch space required to dispatch an execution graph, call:

```c
// Provided by VK_AMDX_shader_enqueue
VkResult vkGetExecutionGraphPipelineScratchSizeAMDX(
    VkDevice device,
    VkPipeline executionGraph,
    VkExecutionGraphPipelineScratchSizeAMDX* pSizeInfo);
```

- `device` is the device that `executionGraph` was created on.
- `executionGraph` is the execution graph pipeline to query the scratch space for.
- `pSizeInfo` is a pointer to a `VkExecutionGraphPipelineScratchSizeAMDX` structure that will contain the required scratch size.

After this function returns, information about the scratch space required will be returned in `pSizeInfo`.

### Valid Usage (Implicit)

- VUID-vkGetExecutionGraphPipelineScratchSizeAMDX-device-parameter device **must** be a valid `VkDevice` handle
- VUID-vkGetExecutionGraphPipelineScratchSizeAMDX-executionGraph-parameter executionGraph **must** be a valid `VkPipeline` handle
- VUID-vkGetExecutionGraphPipelineScratchSizeAMDX-pSizeInfo-parameter pSizeInfo **must** be a valid pointer to a `VkExecutionGraphPipelineScratchSizeAMDX` structure
- VUID-vkGetExecutionGraphPipelineScratchSizeAMDX-executionGraph-parent executionGraph **must** have been created, allocated, or retrieved from `device`

### Return Codes

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`

The `VkExecutionGraphPipelineScratchSizeAMDX` structure is defined as:

```c
// Provided by VK_AMDX_shader_enqueue
typedef struct VkExecutionGraphPipelineScratchSizeAMDX {
    VkStructureType sType;
    void* pNext;
    VkDeviceSize size;
}...
```
### VkExecutionGraphPipelineScratchSizeAMDX

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **size** indicates the scratch space required for dispatch the queried execution graph.

### Valid Usage (Implicit)

- `VUID-VkExecutionGraphPipelineScratchSizeAMDX-sType-sType`
  
  **sType** must be `VK_STRUCTURE_TYPE_EXECUTION_GRAPH_PIPELINE_SCRATCH_SIZE_AMDX`

To initialize scratch memory for a particular execution graph, call:

```c
// Provided by VK_AMDX_shader_enqueue
void vkCmdInitializeGraphScratchMemoryAMDX(
    VkCommandBuffer commandBuffer,  // Provided by VK_AMDX_shader_enqueue
    VkDeviceAddress scratch);       // Provided by VK_AMDX_shader_enqueue
```

- **commandBuffer** is the command buffer into which the command will be recorded.
- **scratch** is a pointer to the scratch memory to be initialized.

This command **must** be called before using **scratch** to dispatch the currently bound execution graph pipeline.

Execution of this command may modify any memory locations in the range `[scratch, scratch + size)`, where **size** is the value returned in `VkExecutionGraphPipelineScratchSizeAMDX::size` by `VkExecutionGraphPipelineScratchSizeAMDX` for the currently bound execution graph pipeline. Accesses to this memory range are performed in the `VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT` pipeline stage with the `VK_ACCESS_2_SHADER_STORAGE_READ_BIT` and `VK_ACCESS_2_SHADER_STORAGE_WRITE_BIT` access flags.

If any portion of **scratch** is modified by any command other than `vkCmdDispatchGraphAMDX`, `vkCmdDispatchGraphIndirectAMDX`, `vkCmdDispatchGraphIndirectCountAMDX`, or `vkCmdInitializeGraphScratchMemoryAMDX` with the same execution graph, it **must** be reinitialized for the execution graph again before dispatching against it.

### Valid Usage

- `VUID-vkCmdInitializeGraphScratchMemoryAMDX-scratch-09143`
  
  **scratch** must be the device address of an allocated memory range at least as large as the value of `VkExecutionGraphPipelineScratchSizeAMDX::size` returned by `VkExecutionGraphPipelineScratchSizeAMDX` for the currently bound execution graph pipeline.

- `VUID-vkCmdInitializeGraphScratchMemoryAMDX-scratch-09144`
  
  **scratch** must be a multiple of 64
### Valid Usage (Implicit)

- **VUID-vkCmdInitializeGraphScratchMemoryAMDX-commandBuffer-parameter**
  
  `commandBuffer must be a valid VkCommandBuffer handle`

- **VUID-vkCmdInitializeGraphScratchMemoryAMDX-commandBuffer-recording**
  
  `commandBuffer must be in the recording state`

- **VUID-vkCmdInitializeGraphScratchMemoryAMDX-commandBuffer-cmdpool**
  
  The `VkCommandPool` that `commandBuffer` was allocated from *must* support graphics, or compute operations

- **VUID-vkCmdInitializeGraphScratchMemoryAMDX-renderpass**
  
  This command *must* only be called outside of a render pass instance

- **VUID-vkCmdInitializeGraphScratchMemoryAMDX-videocoding**
  
  This command *must* only be called outside of a video coding scope

- **VUID-vkCmdInitializeGraphScratchMemoryAMDX-bufferlevel**
  
  `commandBuffer must be a primary VkCommandBuffer`

### Host Synchronization

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from *must* be externally synchronized

### Command Properties

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### 44.3. Dispatching a Graph

Initial dispatch of an execution graph is done from the host in the same way as any other command, and *can* be used in a similar way to compute dispatch commands, with indirect variants available.

To record an execution graph dispatch, call:

```c
// Provided by VK_AMDX_shader_enqueue
void vkCmdDispatchGraphAMDX(
    VkCommandBuffer commandBuffer,
    VkDeviceAddress scratch,
    const VkDispatchGraphCountInfoAMDX* pCountInfo);```
• **commandBuffer** is the command buffer into which the command will be recorded.
• **scratch** is a pointer to the scratch memory to be used.
• **pCountInfo** is a host pointer to a **VkDispatchGraphCountInfoAMDX** structure defining the nodes which will be initially executed.

When this command is executed, the nodes specified in **pCountInfo** are executed. Nodes executed as part of this command are not implicitly synchronized in any way against each other once they are dispatched.

For this command, all device/host pointers in substructures are treated as host pointers and read only during host execution of this command. Once this command returns, no reference to the original pointers is retained.

Execution of this command **may** modify any memory locations in the range \([\text{scratch}, \text{scratch} + \text{size})\), where **size** is the value returned in **VkExecutionGraphPipelineScratchSizeAMDX::size** by **VkExecutionGraphPipelineScratchSizeAMDX** for the currently bound execution graph pipeline. Accesses to this memory range are performed in the **VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT** pipeline stage with the **VK_ACCESS_2_SHADER_STORAGE_READ_BIT** and **VK_ACCESS_2_SHADER_STORAGE_WRITE_BIT** access flags.

### Valid Usage

- **VUID-vkCmdDispatchGraphAMDX-magFilter-04553**
  If a **VkSampler** created with **magFilter** or **minFilter** equal to **VK_FILTER_LINEAR** and **compareEnable** equal to **VK_FALSE** is used to sample a **VkImageView** as a result of this command, then the image view's format features **must** contain **VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT**

- **VUID-vkCmdDispatchGraphAMDX-mipmapMode-04770**
  If a **VkSampler** created with **mipmapMode** equal to **VK_SAMPLER_MIPMAP_MODE_LINEAR** and **compareEnable** equal to **VK_FALSE** is used to sample a **VkImageView** as a result of this command, then the image view's format features **must** contain **VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT**

- **VUID-vkCmdDispatchGraphAMDX-None-06479**
  If a **VkImageView** is sampled with depth comparison, the image view's format features **must** contain **VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT**

- **VUID-vkCmdDispatchGraphAMDX-None-02691**
  If a **VkImageView** is accessed using atomic operations as a result of this command, then the image view's format features **must** contain **VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT**

- **VUID-vkCmdDispatchGraphAMDX-None-07888**
  If a **VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER** descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features **must** contain **VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT**

- **VUID-vkCmdDispatchGraphAMDX-None-02692**
  If a **VkImageView** is sampled with **VK_FILTER_CUBIC_EXT** as a result of this command, then...
the image view's format features must contain
VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT

- VUID-vkCmdDispatchGraphAMDX-None-02693
If the VK_EXT_filter_cubic extension is not enabled and any VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, it must not have a VkImageViewType of VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

- VUID-vkCmdDispatchGraphAMDX-filterCubic-02694
Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2

- VUID-vkCmdDispatchGraphAMDX-filterCubicMinmax-02695
Any VkImageView being sampled with VK_FILTER_CUBIC_EXT with a reduction mode of either VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX as a result of this command must have a VkImageViewType and format that supports cubic filtering together with minmax filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax returned by vkGetPhysicalDeviceImageFormatProperties2

- VUID-vkCmdDispatchGraphAMDX-cubicRangeClamp-09212
If the cubicRangeClamp feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command
must not have a VkSampler ReductionModeCreateInfo
reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM

- VUID-vkCmdDispatchGraphAMDX-reductionMode-09213
Any VkImageView being sampled with a VkSamplerReductionModeCreateInfo::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM as a result of this command must sample with VK_FILTER_CUBIC_EXT

- VUID-vkCmdDispatchGraphAMDX-selectableCubicWeights-09214
If the selectableCubicWeights feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights equal to VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM

- VUID-vkCmdDispatchGraphAMDX-flags-02696
Any VkImage created with a VkImageCreateInfo::flags containing VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV sampled as a result of this command must only be sampled using a VkSamplerAddressMode of VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE

- VUID-vkCmdDispatchGraphAMDX-OpTypeImage-07027
For any VkImageView being written as a storage image where the image format field of the OpTypeImage is Unknown, the view's format features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

- VUID-vkCmdDispatchGraphAMDX-OpTypeImage-07028
For any VkImageView being read as a storage image where the image format field of the OpTypeImage is Unknown, the view's format features must contain
• VUID-vkCmdDispatchGraphAMDX-OpTypeImage-07029
  For any VkBufferView being written as a storage texel buffer where the image format field of the OpTypeImage is Unknown, the view’s buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

• VUID-vkCmdDispatchGraphAMDX-OpTypeImage-07030
  Any VkBufferView being read as a storage texel buffer where the image format field of the OpTypeImage is Unknown then the view’s buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

• VUID-vkCmdDispatchGraphAMDX-None-08600
  For each set n that is statically used by a bound shader, a descriptor set must have been bound to n at the same pipeline bind point, with a VkPipelineLayout that is compatible for set n, with the VkPipelineLayout or VkDescriptorsetLayout array that was used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

• VUID-vkCmdDispatchGraphAMDX-None-08601
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorsetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

• VUID-vkCmdDispatchGraphAMDX-maintenance4-08602
  If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorsetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

• VUID-vkCmdDispatchGraphAMDX-None-08114
  Descriptors in each bound descriptor set, specified via vkCmdBindDescriptorSets, must be valid if they are statically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was not created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

• VUID-vkCmdDispatchGraphAMDX-None-08115
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdBindDescriptorSets, the bound VkPipeline must have been created without VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

• VUID-vkCmdDispatchGraphAMDX-None-08116
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

• VUID-vkCmdDispatchGraphAMDX-None-08604
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by any
VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command

- **VUID-vkCmdDispatchGraphAMDX-None-08117**
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdSetDescriptorBufferOffsetsEXT, the bound VkPipeline must have been created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- **VUID-vkCmdDispatchGraphAMDX-None-08119**
  If a descriptor is dynamically used with a VkPipeline created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- **VUID-vkCmdDispatchGraphAMDX-None-08605**
  If a descriptor is dynamically used with a VkShaderEXT created with a VkDescriptorSetLayout that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- **VUID-vkCmdDispatchGraphAMDX-None-08606**
  If the shaderObject feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command

- **VUID-vkCmdDispatchGraphAMDX-None-08607**
  If the shaderObject is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and VK_NULL_HANDLE shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command

- **VUID-vkCmdDispatchGraphAMDX-None-08608**
  If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the VkPipeline object bound to the pipeline bind point used by this command, since that pipeline was bound

- **VUID-vkCmdDispatchGraphAMDX-None-08609**
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used to sample from any VkImage with a VkImageView of the type VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY, VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage

- **VUID-vkCmdDispatchGraphAMDX-None-08610**
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage

- **VUID-vkCmdDispatchGraphAMDX-None-08611**
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler
must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage

- VUID-vkCmdDispatchGraphAMDX-uniformBuffers-06935
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDispatchGraphAMDX-None-08612
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDispatchGraphAMDX-storageBuffers-06936
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDispatchGraphAMDX-None-08613
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDispatchGraphAMDX-commandBuffer-02707
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource

- VUID-vkCmdDispatchGraphAMDX-None-06550
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y′C′B′C conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions

- VUID-vkCmdDispatchGraphAMDX-ConstOffset-06551
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y′C′B′C conversion, that object must not use the ConstOffset and Offset operands

- VUID-vkCmdDispatchGraphAMDX-viewType-07752
  If a VkImageView is accessed as a result of this command, then the image view’s viewType must match the Dim operand of the OpTypeImage as described in Instruction/Sampler/Image View Validation

- VUID-vkCmdDispatchGraphAMDX-format-07753
  If a VkImageView is accessed as a result of this command, then the numeric type of the
image view's format and the Sampled Type operand of the OpTypeImage must match

- **VUID-vkCmdDispatchGraphAMDX-OpImageWrite-08795**
  If a VkImageView created with a format other than VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the image view's format

- **VUID-vkCmdDispatchGraphAMDX-OpImageWrite-08796**
  If a VkImageView created with the format VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have four components

- **VUID-vkCmdDispatchGraphAMDX-OpImageWrite-04469**
  If a VkBufferView is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the buffer view's format

- **VUID-vkCmdDispatchGraphAMDX-SampledType-04470**
  If a VkImageView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64

- **VUID-vkCmdDispatchGraphAMDX-SampledType-04471**
  If a VkImageView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

- **VUID-vkCmdDispatchGraphAMDX-SampledType-04472**
  If a VkBufferView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64

- **VUID-vkCmdDispatchGraphAMDX-SampledType-04473**
  If a VkBufferView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32

- **VUID-vkCmdDispatchGraphAMDX-sparseImageInt64Atomics-04474**
  If the sparseImageInt64Atomics feature is not enabled, VkImage objects created with the VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- **VUID-vkCmdDispatchGraphAMDX-sparseImageInt64Atomics-04475**
  If the sparseImageInt64Atomics feature is not enabled, VkBuffer objects created with the VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command

- **VUID-vkCmdDispatchGraphAMDX-OpImageWeightedSampleQCOM-06971**
  If OpImageWeightedSampleQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM

- **VUID-vkCmdDispatchGraphAMDX-OpImageWeightedSampleQCOM-06972**
  If OpImageWeightedSampleQCOM uses a VkImageView as a sample weight image as a result of
this command, then the image view's **format features** must contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`

- **VUID-vkCmdDispatchGraphAMDX-OpImageBoxFilterQCOM-06973**
  If `OpImageBoxFilterQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's **format features** must contain `VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM`

- **VUID-vkCmdDispatchGraphAMDX-OpImageBlockMatchSSDQCOM-06974**
  If `OpImageBlockMatchSSDQCOM` is used to read from an `VkImageView` as a result of this command, then the image view's **format features** must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`

- **VUID-vkCmdDispatchGraphAMDX-OpImageBlockMatchSADQCOM-06975**
  If `OpImageBlockMatchSADQCOM` is used to read from an `VkImageView` as a result of this command, then the image view's **format features** must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`

- **VUID-vkCmdDispatchGraphAMDX-OpImageBlockMatchWindowSSDQCOM-06976**
  If `OpImageBlockMatchWindowSSDQCOM` or `OpImageBlockMatchSSDQCOM` is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- **VUID-vkCmdDispatchGraphAMDX-OpImageBlockMatchWindow-09215**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's **format features** must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`

- **VUID-vkCmdDispatchGraphAMDX-OpImageBlockMatchWindow-09216**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's **format** must be a single-component format.

- **VUID-vkCmdDispatchGraphAMDX-OpImageBlockMatchWindow-09217**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` read from a reference image as result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation

- **VUID-vkCmdDispatchGraphAMDX-None-07288**
Any shader invocation executed by this command must terminate

- VUID-vkCmdDispatchGraphAMDX-commandBuffer-09181
  commandBuffer must not be a protected command buffer

- VUID-vkCmdDispatchGraphAMDX-commandBuffer-09182
  commandBuffer must be a primary command buffer

- VUID-vkCmdDispatchGraphAMDX-scratch-09183
  scratch must be the device address of an allocated memory range at least as large as the value of VkExecutionGraphPipelineScratchSizeAMDX::size returned by VkExecutionGraphPipelineScratchSizeAMDX for the currently bound execution graph pipeline

- VUID-vkCmdDispatchGraphAMDX-scratch-09184
  scratch must be a device address within a VkBuffer created with the VK_BUFFER_USAGE_EXECUTION_GRAPH_SCRATCH_BIT_AMDX or VK_BUFFER_USAGE_2_EXECUTION_GRAPH_SCRATCH_BIT_AMDX flag

- VUID-vkCmdDispatchGraphAMDX-scratch-09185
  Device memory in the range [scratch, scratch + VkExecutionGraphPipelineScratchSizeAMDX::size) must have been initialized with vkCmdInitializeGraphScratchMemoryAMDX using the currently bound execution graph pipeline, and not modified after that by anything other than another execution graph dispatch command

- VUID-vkCmdDispatchGraphAMDX-maxComputeWorkGroupCount-09186
  Execution of this command must not cause a node to be dispatched with a larger number of workgroups than that specified by either a MaxNumWorkgroupsAMDX decoration in the dispatched node or maxComputeWorkGroupCount

- VUID-vkCmdDispatchGraphAMDX-maxExecutionGraphShaderPayloadCount-09187
  Execution of this command must not cause any shader to initialize more than maxExecutionGraphShaderPayloadCount output payloads

- VUID-vkCmdDispatchGraphAMDX-NodeMaxPayloadsAMDX-09188
  Execution of this command must not cause any shader that declares NodeMaxPayloadsAMDX to initialize more output payloads than specified by the max number of payloads for that decoration. This requirement applies to each NodeMaxPayloadsAMDX decoration separately

- VUID-vkCmdDispatchGraphAMDX-pCountInfo-09145
  pCountInfo->infos must be a host pointer to a memory allocation at least as large as the product of count and stride

- VUID-vkCmdDispatchGraphAMDX-infos-09146
  Host memory locations at indexes in the range [infos, infos + (count*stride)), at a granularity of stride must contain valid VkDispatchGraphInfoAMDX structures in the first 24 bytes

- VUID-vkCmdDispatchGraphAMDX-pCountInfo-09147
  For each VkDispatchGraphInfoAMDX structure in pCountInfo->infos, payloads must be a host pointer to a memory allocation at least as large as the product of payloadCount and payloadStride

- VUID-vkCmdDispatchGraphAMDX-pCountInfo-09148
For each `VkDispatchGraphInfoAMDX` structure in `pCountInfo->infos`, `nodeIndex` must be a valid node index in the currently bound execution graph pipeline, as returned by `vkGetExecutionGraphPipelineNodeIndexAMDX`.

- VUID-vkCmdDispatchGraphAMDX-pCountInfo-09149
  For each `VkDispatchGraphInfoAMDX` structure in `pCountInfo->infos`, host memory locations at indexes in the range `[payloads, payloads + (payloadCount * payloadStride)]`, at a granularity of `payloadStride` must contain a payload matching the size of the input payload expected by the node in `nodeIndex` in the first bytes.

### Valid Usage (Implicit)

- VUID-vkCmdDispatchGraphAMDX-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- VUID-vkCmdDispatchGraphAMDX-pCountInfo-parameter
  `pCountInfo` must be a valid pointer to a valid `VkDispatchGraphCountInfoAMDX` structure.

- VUID-vkCmdDispatchGraphAMDX-commandBuffer-recording
  `commandBuffer` must be in the recording state.

- VUID-vkCmdDispatchGraphAMDX-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, or compute operations.

- VUID-vkCmdDispatchGraphAMDX-renderpass
  This command must only be called outside of a render pass instance.

- VUID-vkCmdDispatchGraphAMDX-videocoding
  This command must only be called outside of a video coding scope.

- VUID-vkCmdDispatchGraphAMDX-bufferlevel
  `commandBuffer` must be a primary `VkCommandBuffer`.

### Host Synchronization

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

### Command Properties

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<td>Outside</td>
<td>Graphics, Compute</td>
<td>Action</td>
</tr>
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</table>

To record an execution graph dispatch with node and payload parameters read on device, call:
```c
void vkCmdDispatchGraphIndirectAMDX(
    VkCommandBuffer   commandBuffer,  
    VkDeviceAddress   scratch,  
    const VkDispatchGraphCountInfoAMDX* pCountInfo);
```

- `commandBuffer` is the command buffer into which the command will be recorded.
- `scratch` is a pointer to the scratch memory to be used.
- `pCountInfo` is a host pointer to a `VkDispatchGraphCountInfoAMDX` structure defining the nodes which will be initially executed.

When this command is executed, the nodes specified in `pCountInfo` are executed. Nodes executed as part of this command are not implicitly synchronized in any way against each other once they are dispatched.

For this command, all device/host pointers in substructures are treated as device pointers and read during device execution of this command. All of these addresses will be read in the `VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT` pipeline stage with the `VK_ACCESS_2_SHADER_STORAGE_READ_BIT` access flag.

Execution of this command may modify any memory locations in the range `scratch`, \( scratch + size \) where \( size \) is the value returned in `VkExecutionGraphPipelineScratchSizeAMDX::size` by `VkExecutionGraphPipelineScratchSizeAMDX` for the currently bound execution graph pipeline. Accesses to this memory range are performed in the `VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT` pipeline stage with the `VK_ACCESS_2_SHADER_STORAGE_READ_BIT` and `VK_ACCESS_2_SHADER_STORAGE_WRITE_BIT` access flags.

### Valid Usage

- **VUID-vkCmdDispatchGraphIndirectAMDX-magFilter-04553**
  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- **VUID-vkCmdDispatchGraphIndirectAMDX-mipmapMode-04770**
  If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view’s format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`

- **VUID-vkCmdDispatchGraphIndirectAMDX-None-06479**
  If a `VkImageView` is sampled with depth comparison, the image view’s format features must contain `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT`

- **VUID-vkCmdDispatchGraphIndirectAMDX-None-02691**
  If a `VkImageView` is accessed using atomic operations as a result of this command, then
the image view's format features must contain VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT

- VUID-vkCmdDispatchGraphIndirectAMDX-None-07888
  If a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor is accessed using atomic operations as a result of this command, then the storage texel buffer's format features must contain VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT

- VUID-vkCmdDispatchGraphIndirectAMDX-None-02692
  If a VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT

- VUID-vkCmdDispatchGraphIndirectAMDX-None-02693
  If the VK_EXT_filter_cubic extension is not enabled and any VkImageView is sampled with VK_FILTER_CUBIC_EXT as a result of this command, it must not have a VkImageViewType of VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY

- VUID-vkCmdDispatchGraphIndirectAMDX-filterCubic-02694
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have a VkImageViewType and format that supports cubic filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic returned by vkGetPhysicalDeviceImageFormatProperties2

- VUID-vkCmdDispatchGraphIndirectAMDX-filterCubicMinmax-02695
  Any VkImageView being sampled with VK_FILTER_CUBIC_EXT with a reduction mode of either VK_SAMPLER_REDUCTION_MODE_MIN or VK_SAMPLER_REDUCTION_MODE_MAX as a result of this command must have a VkImageViewType and format that supports cubic filtering together with minmax filtering, as specified by VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax returned by vkGetPhysicalDeviceImageFormatProperties2

- VUID-vkCmdDispatchGraphIndirectAMDX-cubicRangeClamp-09212
  If the cubicRangeClamp feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must not have a VkSamplerReductionModeCreateInfo reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM

- VUID-vkCmdDispatchGraphIndirectAMDX-reductionMode-09213
  Any VkImageView being sampled with a VkSamplerReductionModeCreateInfo::reductionMode equal to VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM as a result of this command must sample with VK_FILTER_CUBIC_EXT

- VUID-vkCmdDispatchGraphIndirectAMDX-selectableCubicWeights-09214
  If the selectableCubicWeights feature is not enabled, then any VkImageView being sampled with VK_FILTER_CUBIC_EXT as a result of this command must have VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights equal to VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM

- VUID-vkCmdDispatchGraphIndirectAMDX-flags-02696
  Any VkImage created with a VkImageCreateInfo::flags containing VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV sampled as a result of this command must only be...
sampled using a VkSamplerAddressMode of VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE

- **VUID-vkCmdDispatchGraphIndirectAMDX-OpTypeImage-07027**
  For any VkImageView being written as a storage image where the image format field of the OpTypeImage is Unknown, the view’s format features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

- **VUID-vkCmdDispatchGraphIndirectAMDX-OpTypeImage-07028**
  For any VkImageView being read as a storage image where the image format field of the OpTypeImage is Unknown, the view’s format features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

- **VUID-vkCmdDispatchGraphIndirectAMDX-OpTypeImage-07029**
  For any VkBufferView being written as a storage texel buffer where the image format field of the OpTypeImage is Unknown, the view’s buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT

- **VUID-vkCmdDispatchGraphIndirectAMDX-OpTypeImage-07030**
  Any VkBufferView being read as a storage texel buffer where the image format field of the OpTypeImage is Unknown then the view’s buffer features must contain VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT

- **VUID-vkCmdDispatchGraphIndirectAMDX-None-08600**
  For each set n that is statically used by a bound shader, a descriptor set must have been bound to n at the same pipeline bind point, with a VkPipelineLayout that is compatible for set n, with the VkPipelineLayout or VkDescriptorSetLayout array that was used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- **VUID-vkCmdDispatchGraphIndirectAMDX-None-08601**
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- **VUID-vkCmdDispatchGraphIndirectAMDX-maintenance4-08602**
  If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- **VUID-vkCmdDispatchGraphIndirectAMDX-None-08114**
  Descriptors in each bound descriptor set, specified via vkCmdBindDescriptorSets, must be valid if they are statically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was not created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- **VUID-vkCmdDispatchGraphIndirectAMDX-None-08115**
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdBindDescriptorSets, the bound VkPipeline must have been created without VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT
Descriptors in bound descriptor buffers, specified via *vkCmdSetDescriptorBufferOffsetsEXT*, **must** be valid if they are dynamically used by the *VkPipeline* bound to the pipeline bind point used by this command and the bound *VkPipeline* was created with *VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT*

Descriptors in bound descriptor buffers, specified via *vkCmdSetDescriptorBufferOffsetsEXT*, **must** be valid if they are dynamically used by any *VkShaderEXT* bound to a stage corresponding to the pipeline bind point used by this command.

If the descriptors used by the *VkPipeline* bound to the pipeline bind point were specified via *vkCmdSetDescriptorBufferOffsetsEXT*, the bound *VkPipeline* **must** have been created with *VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT*

If a descriptor is dynamically used with a *VkPipeline* created with *VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT*, the descriptor memory **must** be resident.

If a descriptor is dynamically used with a *VkShaderEXT* created with a *VkDescriptorSetLayout* that was created with *VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT*, the descriptor memory **must** be resident.

If the *shaderObject* feature is not enabled, a valid pipeline **must** be bound to the pipeline bind point used by this command.

If the *shaderObject* is enabled, either a valid pipeline **must** be bound to the pipeline bind point used by this command, or a valid combination of valid and *VK_NULL_HANDLE* shader objects **must** be bound to every supported shader stage corresponding to the pipeline bind point used by this command.

If a pipeline is bound to the pipeline bind point used by this command, there **must** not have been any calls to dynamic state setting commands for any state not specified as dynamic in the *VkPipeline* object bound to the pipeline bind point used by this command, since that pipeline was bound.

If the *VkPipeline* object bound to the pipeline bind point used by this command or any *VkShaderEXT* bound to a stage corresponding to the pipeline bind point used by this command accesses a *VkSampler* object that uses unnormalized coordinates, that sampler **must** not be used to sample from any *VkImage* with a *VkImageView* of the type *VK_IMAGE_VIEW_TYPE_3D*, *VK_IMAGE_VIEW_TYPE_CUBE*, *VK_IMAGE_VIEW_TYPE_1D_ARRAY*, *VK_IMAGE_VIEW_TYPE_2D_ARRAY* or *VK_IMAGE_VIEW_TYPE_CUBE_ARRAY*, in any shader stage.

If the *VkPipeline* object bound to the pipeline bind point used by this command or any
VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage

• VUID-vkCmdDispatchGraphIndirectAMDX-None-08611
If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage

• VUID-vkCmdDispatchGraphIndirectAMDX-uniformBuffers-06935
If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDispatchGraphIndirectAMDX-None-08612
If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDispatchGraphIndirectAMDX-storageBuffers-06936
If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDispatchGraphIndirectAMDX-None-08613
If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

• VUID-vkCmdDispatchGraphIndirectAMDX-commandBuffer-02707
If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource

• VUID-vkCmdDispatchGraphIndirectAMDX-None-06550
If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y'C aC conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions

• VUID-vkCmdDispatchGraphIndirectAMDX-ConstOffset-06551
If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y'C
a conversion, that object must not use the ConstOffset and Offset operands

- **VUID-vkCmdDispatchGraphIndirectAMDX-viewType-07752**
  If a VkImageView is accessed as a result of this command, then the image view’s viewType must match the Dim operand of the OpTypeImage as described in Instruction/Sampler/Image View Validation.

- **VUID-vkCmdDispatchGraphIndirectAMDX-format-07753**
  If a VkImageView is accessed as a result of this command, then the numeric type of the image view’s format and the Sampled Type operand of the OpTypeImage must match.

- **VUID-vkCmdDispatchGraphIndirectAMDX-OpImageWrite-08795**
  If a VkImageView created with a format other than VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the image view’s format.

- **VUID-vkCmdDispatchGraphIndirectAMDX-OpImageWrite-08796**
  If a VkImageView created with the format VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have four components.

- **VUID-vkCmdDispatchGraphIndirectAMDX-OpImageWrite-04469**
  If a VkBufferView is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the buffer view’s format.

- **VUID-vkCmdDispatchGraphIndirectAMDX-SampledType-04470**
  If a VkImageView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64.

- **VUID-vkCmdDispatchGraphIndirectAMDX-SampledType-04471**
  If a VkImageView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32.

- **VUID-vkCmdDispatchGraphIndirectAMDX-SampledType-04472**
  If a VkBufferView with a VkFormat that has a 64-bit component width is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 64.

- **VUID-vkCmdDispatchGraphIndirectAMDX-SampledType-04473**
  If a VkBufferView with a VkFormat that has a component width less than 64-bit is accessed as a result of this command, the SampledType of the OpTypeImage operand of that instruction must have a Width of 32.

- **VUID-vkCmdDispatchGraphIndirectAMDX-sparseImageInt64Atomics-04474**
  If the sparseImageInt64Atomics feature is not enabled, VkImage objects created with the VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions through an OpTypeImage with a SampledType with a Width of 64 by this command.

- **VUID-vkCmdDispatchGraphIndirectAMDX-sparseImageInt64Atomics-04475**
  If the sparseImageInt64Atomics feature is not enabled, VkBuffer objects created with the VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT flag must not be accessed by atomic instructions.
through an OpTypeImage with a SampledType with a Width of 64 by this command

• VUID-vkCmdDispatchGraphIndirectAMDX-OpImageWeightedSampleQCOM-06971
  If OpImageWeightedSampleQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_WEIGHT_SAMPED_IMAGE_BIT_QCOM

• VUID-vkCmdDispatchGraphIndirectAMDX-OpImageWeightedSampleQCOM-06972
  If OpImageWeightedSampleQCOM uses a VkImageView as a sample weight image as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM

• VUID-vkCmdDispatchGraphIndirectAMDX-OpImageBoxFilterQCOM-06973
  If OpImageBoxFilterQCOM is used to sample a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPED_BIT_QCOM

• VUID-vkCmdDispatchGraphIndirectAMDX-OpImageBlockMatchSSDQCOM-06974
  If OpImageBlockMatchSSDQCOM is used to read from a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

• VUID-vkCmdDispatchGraphIndirectAMDX-OpImageBlockMatchSSDQCOM-06975
  If OpImageBlockMatchSSDQCOM is used to read from a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

• VUID-vkCmdDispatchGraphIndirectAMDX-OpImageBlockMatchSSDQCOM-06976
  If OpImageBlockMatchSSDQCOM or OpImageBlockMatchSSDQCOM is used to read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

• VUID-vkCmdDispatchGraphIndirectAMDX-OpImageWeightedSampleQCOM-06977
  If OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, or OpImageBlockMatchSSDQCOM uses a VkSampler as a result of this command, then the sampler must have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM

• VUID-vkCmdDispatchGraphIndirectAMDX-OpImageWeightedSampleQCOM-06978
  If any command other than OpImageWeightedSampleQCOM, OpImageBoxFilterQCOM, OpImageBlockMatchWindowSSDQCOM, OpImageBlockMatchWindowSADQCOM, OpImageBlockMatchGatherSSDQCOM, OpImageBlockMatchGatherSADQCOM, OpImageBlockMatchSSDQCOM, or OpImageBlockMatchSSDQCOM uses a VkSampler as a result of this command, then the sampler must not have been created with VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM

• VUID-vkCmdDispatchGraphIndirectAMDX-OpImageBlockMatchWindow-09215
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to read from a VkImageView as a result of this command, then the image view's format features must contain VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM

• VUID-vkCmdDispatchGraphIndirectAMDX-OpImageBlockMatchWindow-09216
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM instruction is used to
read from an VkImageView as a result of this command, then the image view’s format must be a single-component format.

- VUID-vkCmdDispatchGraphIndirectAMDX-OpImageBlockMatchWindow-09217
  If a OpImageBlockMatchWindow*QCOM or OpImageBlockMatchGather*QCOM read from a reference image as result of this command, then the specified reference coordinates must not fail integer texel coordinate validation

- VUID-vkCmdDispatchGraphIndirectAMDX-OpImageBlockMatchWindow-09217
  Any shader invocation executed by this command must terminate

- VUID-vkCmdDispatchGraphIndirectAMDX-commandBuffer-09181
  commandBuffer must not be a protected command buffer

- VUID-vkCmdDispatchGraphIndirectAMDX-commandBuffer-09182
  commandBuffer must be a primary command buffer

- VUID-vkCmdDispatchGraphIndirectAMDX-scratch-09183
  scratch must be the device address of an allocated memory range at least as large as the value of VkExecutionGraphPipelineScratchSizeAMDX::size returned by VkExecutionGraphPipelineScratchSizeAMDX for the currently bound execution graph pipeline

- VUID-vkCmdDispatchGraphIndirectAMDX-scratch-09184
  scratch must be a device address within a VkBuffer created with the VK_BUFFER_USAGE_EXECUTION_GRAPH_SCRATCH_BIT_AMDX or VK_BUFFER_USAGE_2_EXECUTION_GRAPH_SCRATCH_BIT_AMDX flag

- VUID-vkCmdDispatchGraphIndirectAMDX-scratch-09185
  Device memory in the range [scratch,scratch VkExecutionGraphPipelineScratchSizeAMDX::size) must have been initialized with vkCmdInitializeGraphScratchMemoryAMDX using the currently bound execution graph pipeline, and not modified after that by anything other than another execution graph dispatch command

- VUID-vkCmdDispatchGraphIndirectAMDX-maxComputeWorkGroupCount-09186
  Execution of this command must not cause a node to be dispatched with a larger number of workgroups than that specified by either a MaxNumWorkgroupsAMDX decoration in the dispatched node or maxComputeWorkGroupCount

- VUID-vkCmdDispatchGraphIndirectAMDX-maxExecutionGraphShaderPayloadCount-09187
  Execution of this command must not cause any shader to initialize more than maxExecutionGraphShaderPayloadCount output payloads

- VUID-vkCmdDispatchGraphIndirectAMDX-NodeMaxPayloadsAMDX-09188
  Execution of this command must not cause any shader that declares NodeMaxPayloadsAMDX to initialize more output payloads than specified by the max number of payloads for that decoration. This requirement applies to each NodeMaxPayloadsAMDX decoration separately

- VUID-vkCmdDispatchGraphIndirectAMDX-pCountInfo-09150
  pCountInfo->infos must be a device pointer to a memory allocation at least as large as the product of count and stride when this command is executed on the device

- VUID-vkCmdDispatchGraphIndirectAMDX-pCountInfo-09151
pCountInfo->infos must be a device address within a VkBuffer created with the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT flag

- VUID-vkCmdDispatchGraphIndirectAMDX-pCount-09152
  pCountInfo->infos must be a multiple of executionGraphDispatchAddressAlignment

- VUID-vkCmdDispatchGraphIndirectAMDX-infos-09153
  Device memory locations at indexes in the range [infos, infos + (count*stride)), at a granularity of stride must contain valid VkDispatchGraphInfoAMDX structures in the first 24 bytes when this command is executed on the device

- VUID-vkCmdDispatchGraphIndirectAMDX-pCountInfo-09154
  For each VkDispatchGraphInfoAMDX structure in pCountInfo->infos, payloads must be a device pointer to a memory allocation at least as large as the product of payloadCount and payloadStride when this command is executed on the device

- VUID-vkCmdDispatchGraphIndirectAMDX-pCountInfo-09155
  For each VkDispatchGraphInfoAMDX structure in pCountInfo->infos, payloads must be a device address within a VkBuffer created with the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT flag

- VUID-vkCmdDispatchGraphIndirectAMDX-pCountInfo-09156
  For each VkDispatchGraphInfoAMDX structure in pCountInfo->infos, payloads must be a multiple of executionGraphDispatchAddressAlignment

- VUID-vkCmdDispatchGraphIndirectAMDX-pCountInfo-09157
  For each VkDispatchGraphInfoAMDX structure in pCountInfo->infos, nodeIndex must be a valid node index in the currently bound execution graph pipeline, as returned by vkGetExecutionGraphPipelineNodeIndexAMDX when this command is executed on the device

- VUID-vkCmdDispatchGraphIndirectAMDX-pCountInfo-09158
  For each VkDispatchGraphInfoAMDX structure in pCountInfo->infos, device memory locations at indexes in the range [payloads, payloads + (payloadCount * payloadStride)), at a granularity of payloadStride must contain a payload matching the size of the input payload expected by the node in nodeIndex in the first bytes when this command is executed on the device

Valid Usage (Implicit)

- VUID-vkCmdDispatchGraphIndirectAMDX-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdDispatchGraphIndirectAMDX-pCountInfo-parameter
  pCountInfo must be a valid pointer to a valid VkDispatchGraphCountInfoAMDX structure

- VUID-vkCmdDispatchGraphIndirectAMDX-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdDispatchGraphIndirectAMDX-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics, or compute operations
• VUID-vkCmdDispatchGraphIndirectAMDX-renderpass
  This command must only be called outside of a render pass instance

• VUID-vkCmdDispatchGraphIndirectAMDX-videocoding
  This command must only be called outside of a video coding scope

• VUID-vkCmdDispatchGraphIndirectAMDX-bufferlevel
  commandBuffer must be a primary VkCommandBuffer

Host Synchronization

• Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

Command Properties

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To record an execution graph dispatch with all parameters read on device, call:

```c
// Provided by VK_AMDX_shader_enqueue
def void vkCmdDispatchGraphIndirectCountAMDX(
    VkCommandBuffer commandBuffer,
    VkDeviceAddress scratch,
    VkDeviceAddress countInfo);
```

• commandBuffer is the command buffer into which the command will be recorded.

• scratch is a pointer to the scratch memory to be used.

• countInfo is a device address of a VkDispatchGraphCountInfoAMDX structure defining the nodes which will be initially executed.

When this command is executed, the nodes specified in countInfo are executed. Nodes executed as part of this command are not implicitly synchronized in any way against each other once they are dispatched.

For this command, all pointers in substructures are treated as device pointers and read during device execution of this command. The allocation and contents of these pointers only needs to be valid during device execution. All of these addresses will be read in the VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT pipeline stage with the VK_ACCESS_2_SHADER_STORAGE_READ_BIT access flag.

Execution of this command may modify any memory locations in the range [scratch, scratch + size),
where \( \text{size} \) is the value returned in `VkExecutionGraphPipelineScratchSizeAMDX::size` by `VkExecutionGraphPipelineScratchSizeAMDX` for the currently bound execution graph pipeline. Accesses to this memory range are performed in the `VK_PIPELINE_STAGE_2_COMPUTE_SHADER_BIT` pipeline stage with the `VK_ACCESS_2_SHADER_STORAGE_READ_BIT` and `VK_ACCESS_2_SHADER_STORAGE_WRITE_BIT` access flags.

### Valid Usage

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-magFilter-04553**
  If a `VkSampler` created with `magFilter` or `minFilter` equal to `VK_FILTER_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-mipmapMode-04770**
  If a `VkSampler` created with `mipmapMode` equal to `VK_SAMPLER_MIPMAP_MODE_LINEAR` and `compareEnable` equal to `VK_FALSE` is used to sample a `VkImageView` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-None-06479**
  If a `VkImageView` is sampled with depth comparison, the image view's format features must contain `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-None-02691**
  If a `VkImageView` is accessed using atomic operations as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-None-02692**
  If a `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, then the image view's format features must contain `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-None-02693**
  If the `VK_EXT_filter_cubic` extension is not enabled and any `VkImageView` is sampled with `VK_FILTER_CUBIC_EXT` as a result of this command, it must not have a `VkImageViewType` of `VK_IMAGE_VIEW_TYPE_3D`, `VK_IMAGE_VIEW_TYPE_CUBE`, or `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-filterCubic-02694**
  Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubic` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-filterCubicMinmax-02695**
  Any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` with a reduction mode of...
either `VK_SAMPLER_REDUCTION_MODE_MIN` or `VK_SAMPLER_REDUCTION_MODE_MAX` as a result of this command must have a `VkImageViewType` and format that supports cubic filtering together with minmax filtering, as specified by `VkFilterCubicImageViewImageFormatPropertiesEXT::filterCubicMinmax` returned by `vkGetPhysicalDeviceImageFormatProperties2`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-cubicRangeClamp-09212**
  If the `cubicRangeClamp` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must not have a `VkSamplerReductionModeCreateInfo` reductionMode equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-reductionMode-09213**
  Any `VkImageView` being sampled with a `VkSamplerReductionModeCreateInfo::reductionMode` equal to `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` as a result of this command must sample with `VK_FILTER_CUBIC_EXT`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-selectableCubicWeights-09214**
  If the `selectableCubicWeights` feature is not enabled, then any `VkImageView` being sampled with `VK_FILTER_CUBIC_EXT` as a result of this command must have `VkSamplerCubicWeightsCreateInfoQCOM::cubicWeights` equal to `VK_CUBIC_FILTER_WEIGHTS_CATMULL_ROM_QCOM`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-flags-02696**
  Any `VkImage` created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV` sampled as a result of this command must only be sampled using a `VkSamplerAddressMode` of `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-OpTypeImage-07027**
  For any `VkImageView` being written as a storage image where the image format field of the `OpTypeImage` is Unknown, the view’s format features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-OpTypeImage-07028**
  For any `VkImageView` being read as a storage image where the image format field of the `OpTypeImage` is Unknown, the view’s format features must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-OpTypeImage-07029**
  For any `VkBufferView` being written as a storage texel buffer where the image format field of the `OpTypeImage` is Unknown, the view’s buffer features must contain `VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-OpTypeImage-07030**
  Any `VkBufferView` being read as a storage texel buffer where the image format field of the `OpTypeImage` is Unknown then the view’s buffer features must contain `VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT`.

- **VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08600**
  For each set n that is statically used by a bound shader, a descriptor set must have been bound to n at the same pipeline bind point, with a `VkPipelineLayout` that is compatible for set n, with the `VkPipelineLayout` or `VkDescriptorSetLayout` array that was used to create...
the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08601
  For each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdDispatchGraphIndirectCountAMDX-maintenance4-08602
  If the maintenance4 feature is not enabled, then for each push constant that is statically used by a bound shader, a push constant value must have been set for the same pipeline bind point, with a VkPipelineLayout that is compatible for push constants, with the VkPipelineLayout or VkDescriptorSetLayout and VkPushConstantRange arrays used to create the current VkPipeline or VkShaderEXT, as described in Pipeline Layout Compatibility

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08114
  Descriptors in each bound descriptor set, specified via vkCmdBindDescriptorSets, must be valid if they are statically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was not created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08115
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdBindDescriptorSets, the bound VkPipeline must have been created without VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08116
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by the VkPipeline bound to the pipeline bind point used by this command and the bound VkPipeline was created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08604
  Descriptors in bound descriptor buffers, specified via vkCmdSetDescriptorBufferOffsetsEXT, must be valid if they are dynamically used by any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08117
  If the descriptors used by the VkPipeline bound to the pipeline bind point were specified via vkCmdSetDescriptorBufferOffsetsEXT, the bound VkPipeline must have been created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08119
  If a descriptor is dynamically used with a VkPipeline created with VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must be resident

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08605
  If a descriptor is dynamically used with a VkShaderEXT created with VkDescriptorSetLayout that was created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT, the descriptor memory must
be resident

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08606
  If the shaderObject feature is not enabled, a valid pipeline must be bound to the pipeline bind point used by this command.

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08607
  If the shaderObject is enabled, either a valid pipeline must be bound to the pipeline bind point used by this command, or a valid combination of valid and VK_NULL_HANDLE shader objects must be bound to every supported shader stage corresponding to the pipeline bind point used by this command.

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08608
  If a pipeline is bound to the pipeline bind point used by this command, there must not have been any calls to dynamic state setting commands for any state not specified as dynamic in the VkPipeline object bound to the pipeline bind point used by this command, since that pipeline was bound.

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08609
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used to sample from any VkImage with a VkImageView of the type VK_IMAGE_VIEW_TYPE_3D, VK_IMAGE_VIEW_TYPE_CUBE, VK_IMAGE_VIEW_TYPE_1D_ARRAY, VK_IMAGE_VIEW_TYPE_2D_ARRAY or VK_IMAGE_VIEW_TYPE_CUBE_ARRAY, in any shader stage.

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08610
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions with ImplicitLod, Dref or Proj in their name, in any shader stage.

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08611
  If the VkPipeline object bound to the pipeline bind point used by this command or any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a VkSampler object that uses unnormalized coordinates, that sampler must not be used with any of the SPIR-V OpImageSample* or OpImageSparseSample* instructions that includes a LOD bias or any offset values, in any shader stage.

- VUID-vkCmdDispatchGraphIndirectCountAMDX-uniformBuffers-06935
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a uniform buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for uniformBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08612
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a uniform buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point.
descriptor set bound to the same pipeline bind point

- VUID-vkCmdDispatchGraphIndirectCountAMDX-storageBuffers-06936
  If any stage of the VkPipeline object bound to the pipeline bind point used by this command accesses a storage buffer, and that stage was created without enabling either VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_EXT or VK_PIPELINE_ROBUSTNESS_BUFFER_BEHAVIOR_ROBUST_BUFFER_ACCESS_2_EXT for storageBuffers, and the robustBufferAccess feature is not enabled, that stage must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-08613
  If the robustBufferAccess feature is not enabled, and any VkShaderEXT bound to a stage corresponding to the pipeline bind point used by this command accesses a storage buffer, it must not access values outside of the range of the buffer as specified in the descriptor set bound to the same pipeline bind point

- VUID-vkCmdDispatchGraphIndirectCountAMDX-commandBuffer-02707
  If commandBuffer is an unprotected command buffer and protectedNoFault is not supported, any resource accessed by bound shaders must not be a protected resource

- VUID-vkCmdDispatchGraphIndirectCountAMDX-None-06550
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y'C aCk conversion, that object must only be used with OpImageSample* or OpImageSparseSample* instructions

- VUID-vkCmdDispatchGraphIndirectCountAMDX-ConstOffset-06551
  If a bound shader accesses a VkSampler or VkImageView object that enables sampler Y'C aCk conversion, that object must not use the ConstOffset and Offset operands

- VUID-vkCmdDispatchGraphIndirectCountAMDX-viewType-07752
  If a VkImageView is accessed as a result of this command, then the image view’s viewType must match the Dim operand of the OpTypeImage as described in Instruction/Sampler/Image View Validation

- VUID-vkCmdDispatchGraphIndirectCountAMDX-format-07753
  If a VkImageView is accessed as a result of this command, then the numeric type of the image view’s format and the Sampled Type operand of the OpTypeImage must match

- VUID-vkCmdDispatchGraphIndirectCountAMDX-OpImageWrite-08795
  If a VkImageView created with a format other than VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the image view’s format

- VUID-vkCmdDispatchGraphIndirectCountAMDX-OpImageWrite-08796
  If a VkImageView created with the format VK_FORMAT_A8_UNORM_KHR is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have four components

- VUID-vkCmdDispatchGraphIndirectCountAMDX-OpImageWrite-04469
  If a VkBufferView is accessed using OpImageWrite as a result of this command, then the Type of the Texel operand of that instruction must have at least as many components as the buffer view’s format
If a `VkImageView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64.

If a `VkImageView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 32.

If a `VkBufferView` with a `VkFormat` that has a 64-bit component width is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 64.

If a `VkBufferView` with a `VkFormat` that has a component width less than 64-bit is accessed as a result of this command, the `SampledType` of the `OpTypeImage` operand of that instruction must have a `Width` of 32.

If the `sparseImageInt64Atomics` feature is not enabled, `VkImage` objects created with the `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

If the `sparseImageInt64Atomics` feature is not enabled, `VkBuffer` objects created with the `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` flag must not be accessed by atomic instructions through an `OpTypeImage` with a `SampledType` with a `Width` of 64 by this command.

If `OpImageWeightedSampleQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM`.

If `OpImageWeightedSampleQCOM` uses a `VkImageView` as a sample weight image as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM`.

If `OpImageBoxFilterQCOM` is used to sample a `VkImageView` as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM`.

If `OpImageBlockMatchSSDQCOM` is used to read from an `VkImageView` as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

If `OpImageBlockMatchSADQCOM` is used to read from an `VkImageView` as a result of this command, then the image view's `format features` must contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.
If `OpImageBlockMatchSADQCOM` or `OpImageBlockMatchSSDQCOM` is used to read from a reference image as result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation.

If `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler **must** have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

If any command other than `OpImageWeightedSampleQCOM`, `OpImageBoxFilterQCOM`, `OpImageBlockMatchWindowSSDQCOM`, `OpImageBlockMatchWindowSADQCOM`, `OpImageBlockMatchGatherSSDQCOM`, `OpImageBlockMatchGatherSADQCOM`, `OpImageBlockMatchSSDQCOM`, or `OpImageBlockMatchSADQCOM` uses a `VkSampler` as a result of this command, then the sampler **must** not have been created with `VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM`.

If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from a `VkImageView` as result of this command, then the image view's format features **must** contain `VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM`.

If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` instruction is used to read from an `VkImageView` as a result of this command, then the image view's format **must** be a single-component format.

If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` read from a reference image as result of this command, then the specified reference coordinates **must** not fail integer texel coordinate validation.

Any shader invocation executed by this command **must** terminate.

`commandBuffer` **must** not be a protected command buffer.

`commandBuffer` **must** be a primary command buffer.

`scratch` **must** be the device address of an allocated memory range at least as large as the value of `VkExecutionGraphPipelineScratchSizeAMDX::size` returned by `VkExecutionGraphPipelineScratchSizeAMDX` for the currently bound execution graph pipeline.

`scratch` **must** be a device address within a `VkBuffer` created with the `VK_BUFFER_USAGE_EXECUTION_GRAPH_SCRATCH_BIT_AMDX` or `VK_BUFFER_USAGE_2_EXECUTION_GRAPH_SCRATCH_BIT_AMDX` flag.
Device memory in the range \([\text{scratch}, \text{scratch}]\) must have been initialized with `vkCmdInitializeGraphScratchMemoryAMDX` using the currently bound execution graph pipeline, and not modified after that by anything other than another execution graph dispatch command.

Execution of this command must not cause a node to be dispatched with a larger number of workgroups than that specified by either a `MaxNumWorkgroupsAMDX` decoration in the dispatched node or `maxComputeWorkGroupCount`.

Execution of this command must not cause any shader to initialize more than `maxExecutionGraphShaderPayloadCount` output payloads.

Execution of this command must not cause any shader that declares `NodeMaxPayloadsAMDX` to initialize more output payloads than specified by the max number of payloads for that decoration. This requirement applies to each `NodeMaxPayloadsAMDX` decoration separately.

`countInfo` must be a device pointer to a memory allocation containing a valid `VkDispatchGraphCountInfoAMDX` structure when this command is executed on the device.

`countInfo` must be a device address within a `VkBuffer` created with the `VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT` flag.

`countInfo` must be a multiple of `executionGraphDispatchAddressAlignment`.

`countInfo->infos` must be a device pointer to a memory allocation at least as large as the product of `count` and `stride` when this command is executed on the device.

`countInfo->infos` must be a device address within a `VkBuffer` created with the `VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT` flag.

`countInfo->infos` must be a multiple of `executionGraphDispatchAddressAlignment`.

Device memory locations at indexes in the range \([\text{infos}, \text{infos} + (\text{count}*\text{stride})]\), at a granularity of `stride` must contain valid `VkDispatchGraphInfoAMDX` structures in the first 24 bytes when this command is executed on the device.

For each `VkDispatchGraphInfoAMDX` structure in `countInfo->infos`, payloads must be a device pointer to a memory allocation at least as large as the product of `payloadCount` and `payloadStride` when this command is executed on the device.
For each VkDispatchGraphInfoAMDX structure in countInfo->infos, payloads must be a device address within a VkBuffer created with the VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT flag

For each VkDispatchGraphInfoAMDX structure in countInfo->infos, payloads must be a multiple of executionGraphDispatchAddressAlignment

For each VkDispatchGraphInfoAMDX structure in countInfo->infos, nodeIndex must be a valid node index in the currently bound execution graph pipeline, as returned by vkGetExecutionGraphPipelineNodeIndexAMDX when this command is executed on the device

For each VkDispatchGraphInfoAMDX structure in countInfo->infos, device memory locations at indexes in the range [payloads, payloads + (payloadCount * payloadStride)], at a granularity of payloadStride must contain a payload matching the size of the input payload expected by the node in nodeIndex in the first bytes when this command is executed on the device

Valid Usage (Implicit)

commandBuffer must be a valid VkCommandBuffer handle

commandBuffer must be in the recording state

The VkCommandPool that commandBuffer was allocated from must support graphics, or compute operations

This command must only be called outside of a render pass instance

This command must only be called outside of a video coding scope

commandBuffer must be a primary VkCommandBuffer

Host Synchronization

Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized
The `VkDeviceOrHostAddressConstAMDX` union is defined as:

```c
// Provided by VK_AMDshader_enqueue
typedef union VkDeviceOrHostAddressConstAMDX {
    VkDeviceAddress deviceAddress;
    const void* hostAddress;
} VkDeviceOrHostAddressConstAMDX;
```

- `deviceAddress` is a buffer device address as returned by the `vkGetBufferDeviceAddressKHR` command.
- `hostAddress` is a const host memory address.

The `VkDispatchGraphCountInfoAMDX` structure is defined as:

```c
// Provided by VK_AMDshader_enqueue
typedef struct VkDispatchGraphCountInfoAMDX {
    uint32_t count;
    VkDeviceOrHostAddressConstAMDX infos;
    uint64_t stride;
} VkDispatchGraphCountInfoAMDX;
```

- `count` is the number of dispatches to perform.
- `infos` is the device or host address of a flat array of `VkDispatchGraphInfoAMDX` structures.
- `stride` is the byte stride between successive `VkDispatchGraphInfoAMDX` structures in `infos`.

Whether `infos` is consumed as a device or host pointer is defined by the command this structure is used in.

The `VkDispatchGraphInfoAMDX` structure is defined as:

```c
// Provided by VK_AMDshader_enqueue
typedef struct VkDispatchGraphInfoAMDX {
    uint32_t nodeIndex;
    uint32_t payloadCount;
    VkDeviceOrHostAddressConstAMDX payloads;
    uint64_t payloadStride;
} VkDispatchGraphInfoAMDX;
```
• **nodeIndex** is the index of a node in an execution graph to be dispatched.
• **payloadCount** is the number of payloads to dispatch for the specified node.
• **payloads** is a device or host address pointer to a flat array of payloads with size equal to the product of **payloadCount** and **payloadStride**
• **payloadStride** is the byte stride between successive payloads in **payloads**

Whether **payloads** is consumed as a device or host pointer is defined by the command this structure is used in.

### Valid Usage

- VUID-VkDispatchGraphInfoAMDX-payloadCount-09171
  payloadCount must be no greater than maxExecutionGraphShaderPayloadCount

### 44.4. Shader Enqueue

Compute shaders in an execution graph can use the **OpInitializeNodePayloadsAMDX** to initialize nodes for dispatch. Any node payload initialized in this way will be enqueued for dispatch once the shader is done writing to the payload. As compilers may be conservative when making this determination, shaders can further call **OpFinalizeNodePayloadsAMDX** to guarantee that the payload is no longer being written.

The **Node Name** operand of the **PayloadNodeNameAMDX** decoration on a payload identifies the shader name of the node to be enqueued, and the **Shader Index** operand of **OpInitializeNodePayloadsAMDX** identifies the shader index. A node identified in this way is dispatched as described in the following sections.

#### 44.4.1. Compute Nodes

Compute shaders added as nodes to an execution graph are executed differently based on the presence or absence of the **StaticNumWorkgroupsAMDX** or **CoalescingAMDX** execution modes.

Dispatching a compute shader node that does not declare either the **StaticNumWorkgroupsAMDX** or **CoalescingAMDX** execution mode will execute a number of workgroups in each dimension specified by the first 12 bytes of the payload, interpreted as a **VkDispatchIndirectCommand**. The same payload will be broadcast to each workgroup in the same dispatch. Additional values in the payload have no effect on execution.

Dispatching a compute shader node with the **StaticNumWorkgroupsAMDX** execution mode will enqueue a single invocation for execution. Implementations may combine multiple such dispatches into the same workgroup, up to the size of the workgroup. The number of invocations coalesced into a given
workgroup in this way can be queried via the CoalescedInputCountAMDX built-in. Any values in the payload have no effect on execution.
Chapter 45. Extending Vulkan

New functionality may be added to Vulkan via either new extensions or new versions of the core, or new versions of an extension in some cases.

This chapter describes how Vulkan is versioned, how compatibility is affected between different versions, and compatibility rules that are followed by the Vulkan Working Group.

45.1. Instance and Device Functionality

Commands that enumerate instance properties, or that accept a `VkInstance` object as a parameter, are considered instance-level functionality.

Commands that dispatch from a `VkDevice` object or a child object of a `VkDevice`, or take any of them as a parameter, are considered device-level functionality. Types defined by a device extension are also considered device-level functionality.

Commands that dispatch from `VkPhysicalDevice`, or accept a `VkPhysicalDevice` object as a parameter, are considered either instance-level or device-level functionality depending if the functionality is specified by an instance extension or device extension respectively.

Additionally, commands that enumerate physical device properties are considered device-level functionality.

**Note**
Applications usually interface to Vulkan using a loader that implements only instance-level functionality, passing device-level functionality to implementations of the full Vulkan API on the system. In some circumstances, as these may be implemented independently, it is possible that the loader and device implementations on a given installation will support different versions. To allow for this and call out when it happens, the Vulkan specification enumerates device and instance level functionality separately - they have independent version queries.

**Note**
Vulkan 1.0 initially specified new physical device enumeration functionality as instance-level, requiring it to be included in an instance extension. As the capabilities of device-level functionality require discovery via physical device enumeration, this led to the situation where many device extensions required an instance extension as well. To alleviate this extra work, `VK_KHR_get_physical_device_properties2` (and subsequently Vulkan 1.1) redefined device-level functionality to include physical device enumeration.

45.2. Core Versions

The Vulkan Specification is regularly updated with bug fixes and clarifications. Occasionally new
functionality is added to the core and at some point it is expected that there will be a desire to perform a large, breaking change to the API. In order to indicate to developers how and when these changes are made to the specification, and to provide a way to identify each set of changes, the Vulkan API maintains a version number.

45.2.1. Version Numbers

The Vulkan version number comprises four parts indicating the variant, major, minor and patch version of the Vulkan API Specification.

The **variant** indicates the variant of the Vulkan API supported by the implementation. This is always 0 for the Vulkan API.

**Note**

A non-zero variant indicates the API is a variant of the Vulkan API and applications will typically need to be modified to run against it. The variant field was a later addition to the version number, added in version 1.2.175 of the Specification. As Vulkan uses variant 0, this change is fully backwards compatible with the previous version number format for Vulkan implementations. New version number macros have been added for this change and the old macros deprecated. For existing applications using the older format and macros, an implementation with non-zero variant will decode as a very high Vulkan version. The high version number should be detectable by applications performing suitable version checking.

The **major version** indicates a significant change in the API, which will encompass a wholly new version of the specification.

The **minor version** indicates the incorporation of new functionality into the core specification.

The **patch version** indicates bug fixes, clarifications, and language improvements have been incorporated into the specification.

Compatibility guarantees made about versions of the API sharing any of the same version numbers are documented in [Core Versions](#).

The version number is used in several places in the API. In each such use, the version numbers are packed into a 32-bit integer as follows:

- The variant is a 3-bit integer packed into bits 31-29.
- The major version is a 7-bit integer packed into bits 28-22.
- The minor version number is a 10-bit integer packed into bits 21-12.
- The patch version number is a 12-bit integer packed into bits 11-0.

`VK_API_VERSION_VARIANT` extracts the API variant number from a packed version number:

```c
// Provided by VK_VERSION_1_0
```

3412
#define VK_API_VERSION_VARIANT(version) ((uint32_t)(version) >> 29U)

**VK_API_VERSION_MAJOR** extracts the API major version number from a packed version number:

```c
// Provided by VK_VERSION_1_0
#define VK_API_VERSION_MAJOR(version) (((uint32_t)(version) >> 22U) & 0x7FU)
```

**VK_VERSION_MAJOR** extracts the API major version number from a packed version number:

```c
// Provided by VK_VERSION_1_0
// DEPRECATED: This define is deprecated. VK_API_VERSION_MAJOR should be used instead.
#define VK_VERSION_MAJOR(version) ((uint32_t)(version) >> 22U)
```

**VK_API_VERSION_MINOR** extracts the API minor version number from a packed version number:

```c
// Provided by VK_VERSION_1_0
#define VK_API_VERSION_MINOR(version) (((uint32_t)(version) >> 12U) & 0x3FFU)
```

**VK_VERSION_MINOR** extracts the API minor version number from a packed version number:

```c
// Provided by VK_VERSION_1_0
// DEPRECATED: This define is deprecated. VK_API_VERSION_MINOR should be used instead.
#define VK_VERSION_MINOR(version) (((uint32_t)(version) >> 12U) & 0x3FFU)
```

**VK_API_VERSION_PATCH** extracts the API patch version number from a packed version number:

```c
// Provided by VK_VERSION_1_0
#define VK_API_VERSION_PATCH(version) ((uint32_t)(version) & 0xFFFU)
```

**VK_VERSION_PATCH** extracts the API patch version number from a packed version number:

```c
// Provided by VK_VERSION_1_0
// DEPRECATED: This define is deprecated. VK_API_VERSION_PATCH should be used instead.
#define VK_VERSION_PATCH(version) ((uint32_t)(version) & 0xFFFU)
```

**VK_MAKE_API_VERSION** constructs an API version number:

```c
// Provided by VK_VERSION_1_0
#define VK_MAKE_API_VERSION(variant, major, minor, patch) \  (((uint32_t)(variant)) << 29U) | (((uint32_t)(major)) << 22U) | \  (((uint32_t)(minor)) << 12U) | ((uint32_t)(patch))
```
• **variant** is the variant number.

• **major** is the major version number.

• **minor** is the minor version number.

• **patch** is the patch version number.

**VK_MAKE_VERSION** constructs an API version number.

```
// Provided by VK_VERSION_1_0
// DEPRECATED: This define is deprecated. VK_MAKE_API_VERSION should be used instead.
#define VK_MAKE_VERSION(major, minor, patch) 
  (((uint32_t)(major)) << 22U) | (((uint32_t)(minor)) << 12U) | 
  ((uint32_t)(patch))
```

• **major** is the major version number.

• **minor** is the minor version number.

• **patch** is the patch version number.

**VK_API_VERSION_1_0** returns the API version number for Vulkan 1.0.0.

```
// Provided by VK_VERSION_1_0
// Vulkan 1.0 version number
#define VK_API_VERSION_1_0 VK_MAKE_API_VERSION(0, 1, 0, 0)// Patch version should always be set to 0
```

**VK_API_VERSION_1_1** returns the API version number for Vulkan 1.1.0.

```
// Provided by VK_VERSION_1_1
// Vulkan 1.1 version number
#define VK_API_VERSION_1_1 VK_MAKE_API_VERSION(0, 1, 1, 0)// Patch version should always be set to 0
```

**VK_API_VERSION_1_2** returns the API version number for Vulkan 1.2.0.

```
// Provided by VK_VERSION_1_2
// Vulkan 1.2 version number
#define VK_API_VERSION_1_2 VK_MAKE_API_VERSION(0, 1, 2, 0)// Patch version should always be set to 0
```

**VK_API_VERSION_1_3** returns the API version number for Vulkan 1.3.0.

```
// Provided by VK_VERSION_1_3
// Vulkan 1.3 version number
#define VK_API_VERSION_1_3 VK_MAKE_API_VERSION(0, 1, 3, 0)// Patch version should always be set to 0
```
45.2.2. Querying Version Support

The version of instance-level functionality can be queried by calling \texttt{vkEnumerateInstanceVersion}.

The version of device-level functionality can be queried by calling \texttt{vkGetPhysicalDeviceProperties} or \texttt{vkGetPhysicalDeviceProperties2}, and is returned in \texttt{VkPhysicalDeviceProperties::apiVersion}, encoded as described in Version Numbers.

45.3. Layers

When a layer is enabled, it inserts itself into the call chain for Vulkan commands the layer is interested in. Layers can be used for a variety of tasks that extend the base behavior of Vulkan beyond what is required by the specification - such as call logging, tracing, validation, or providing additional extensions.

\textit{Note}

For example, an implementation is not expected to check that the value of enums used by the application fall within allowed ranges. Instead, a validation layer would do those checks and flag issues. This avoids a performance penalty during production use of the application because those layers would not be enabled in production.

\textit{Note}

Vulkan layers \textbf{may} wrap object handles (i.e. return a different handle value to the application than that generated by the implementation). This is generally discouraged, as it increases the probability of incompatibilities with new extensions. The validation layers wrap handles in order to track the proper use and destruction of each object. See the “Architecture of the Vulkan Loader Interfaces” document for additional information.

To query the available layers, call:

\texttt{// Provided by VK_VERSION_1_0}

\begin{verbatim}
VkResult vkEnumerateInstanceLayerProperties(
    uint32_t* pPropertyCount,
    VkLayerProperties* pProperties);
\end{verbatim}

- \texttt{pPropertyCount} is a pointer to an integer related to the number of layer properties available or queried, as described below.

- \texttt{pProperties} is either \texttt{NULL} or a pointer to an array of \texttt{VkLayerProperties} structures.

If \texttt{pProperties} is \texttt{NULL}, then the number of layer properties available is returned in \texttt{pPropertyCount}. Otherwise, \texttt{pPropertyCount} must point to a variable set by the user to the number of elements in the \texttt{pProperties} array, and on return the variable is overwritten with the number of structures actually
written to `pProperties`. If `pPropertyCount` is less than the number of layer properties available, at most `pPropertyCount` structures will be written, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available properties were returned.

The list of available layers may change at any time due to actions outside of the Vulkan implementation, so two calls to `vkEnumerateInstanceLayerProperties` with the same parameters may return different results, or retrieve different `pPropertyCount` values or `pProperties` contents. Once an instance has been created, the layers enabled for that instance will continue to be enabled and valid for the lifetime of that instance, even if some of them become unavailable for future instances.

**Valid Usage (Implicit)**

- VUID-vkEnumerateInstanceLayerProperties-pPropertyCount-parameter
  `pPropertyCount` must be a valid pointer to a `uint32_t` value

- VUID-vkEnumerateInstanceLayerProperties-pProperties-parameter
  If the value referenced by `pPropertyCount` is not 0, and `pProperties` is not `NULL`, `pProperties` must be a valid pointer to an array of `pPropertyCount` `VkLayerProperties` structures

**Return Codes**

**Success**

- `VK_SUCCESS`
- `VK_INCOMPLETE`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`

The `VkLayerProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkLayerProperties {
    char                 layerName[VK_MAX_EXTENSION_NAME_SIZE];
    uint32_t             specVersion;
    uint32_t             implementationVersion;
    char                 description[VK_MAX_DESCRIPTION_SIZE];
} VkLayerProperties;
```

- `layerName` is an array of `VK_MAX_EXTENSION_NAME_SIZE` `char` containing a null-terminated UTF-8 string which is the name of the layer. Use this name in the `ppEnabledLayerNames` array passed in the `VkInstanceCreateInfo` structure to enable this layer for an instance.

- `specVersion` is the Vulkan version the layer was written to, encoded as described in Version Numbers.
• `implementationVersion` is the version of this layer. It is an integer, increasing with backward compatible changes.

• `description` is an array of `VK_MAX_DESCRIPTION_SIZE` `char` containing a null-terminated UTF-8 string which provides additional details that can be used by the application to identify the layer.

`VK_MAX_EXTENSION_NAME_SIZE` is the length in `char` values of an array containing a layer or extension name string, as returned in `VkLayerProperties::layerName`, `VkExtensionProperties::extensionName`, and other queries.

```
#define VK_MAX_EXTENSION_NAME_SIZE 256U
```

`VK_MAX_DESCRIPTION_SIZE` is the length in `char` values of an array containing a string with additional descriptive information about a query, as returned in `VkLayerProperties::description` and other queries.

```
#define VK_MAX_DESCRIPTION_SIZE 256U
```

To enable a layer, the name of the layer should be added to the `ppEnabledLayerNames` member of `VkInstanceCreateInfo` when creating a `VkInstance`.

Loader implementations may provide mechanisms outside the Vulkan API for enabling specific layers. Layers enabled through such a mechanism are implicitly enabled, while layers enabled by including the layer name in the `ppEnabledLayerNames` member of `VkInstanceCreateInfo` are explicitly enabled. Implicitly enabled layers are loaded before explicitly enabled layers, such that implicitly enabled layers are closer to the application, and explicitly enabled layers are closer to the driver. Except where otherwise specified, implicitly enabled and explicitly enabled layers differ only in the way they are enabled, and the order in which they are loaded. Explicitly enabling a layer that is implicitly enabled results in this layer being loaded as an implicitly enabled layer; it has no additional effect.

### 45.3.1. Device Layer Deprecation

Previous versions of this specification distinguished between instance and device layers. Instance layers were only able to intercept commands that operate on `VkInstance` and `VkPhysicalDevice`, except they were not able to intercept `vkCreateDevice`. Device layers were enabled for individual devices when they were created, and could only intercept commands operating on that device or its child objects.

Device-only layers are now deprecated, and this specification no longer distinguishes between instance and device layers. Layers are enabled during instance creation, and are able to intercept all commands operating on that instance or any of its child objects. At the time of deprecation there were no known device-only layers and no compelling reason to create one.

In order to maintain compatibility with implementations released prior to device-layer deprecation, applications should still enumerate and enable device layers. The behavior of `vkEnumerateDeviceLayerProperties` and valid usage of the `ppEnabledLayerNames` member of `VkDeviceCreateInfo` maximizes compatibility with applications written to work with the previous
requirements.

To enumerate device layers, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkEnumerateDeviceLayerProperties(
    VkPhysicalDevice physicalDevice,
    uint32_t* pPropertyCount,
    VkLayerProperties* pProperties);
```

- `physicalDevice` is the physical device that will be queried.
- `pPropertyCount` is a pointer to an integer related to the number of layer properties available or queried.
- `pProperties` is either `NULL` or a pointer to an array of `VkLayerProperties` structures.

If `pProperties` is `NULL`, then the number of layer properties available is returned in `pPropertyCount`. Otherwise, `pPropertyCount` must point to a variable set by the user to the number of elements in the `pProperties` array, and on return the variable is overwritten with the number of structures actually written to `pProperties`. If `pPropertyCount` is less than the number of layer properties available, at most `pPropertyCount` structures will be written, and `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available properties were returned.

The list of layers enumerated by `vkEnumerateDeviceLayerProperties` must be exactly the sequence of layers enabled for the instance. The members of `VkLayerProperties` for each enumerated layer must be the same as the properties when the layer was enumerated by `vkEnumerateInstanceLayerProperties`.

**Note**
Due to platform details on Android, `vkEnumerateDeviceLayerProperties` may be called with `physicalDevice` equal to `NULL` during layer discovery. This behaviour will only be observed by layer implementations, and not the underlying Vulkan driver.

**Valid Usage (Implicit)**

- `VUID-vkEnumerateDeviceLayerProperties-physicalDevice-parameter`  
  `physicalDevice` must be a valid `VkPhysicalDevice` handle

- `VUID-vkEnumerateDeviceLayerProperties-pPropertyCount-parameter`  
  `pPropertyCount` must be a valid pointer to a `uint32_t` value

- `VUID-vkEnumerateDeviceLayerProperties-pProperties-parameter`  
  If the value referenced by `pPropertyCount` is not 0, and `pProperties` is not `NULL`, `pProperties` must be a valid pointer to an array of `pPropertyCount` `VkLayerProperties` structures
Return Codes

Success

• VK_SUCCESS
• VK_INCOMPLETE

Failure

• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY

The ppEnabledLayerNames and enabledLayerCount members of VkDeviceCreateInfo are deprecated and their values must be ignored by implementations. However, for compatibility, only an empty list of layers or a list that exactly matches the sequence enabled at instance creation time are valid, and validation layers should issue diagnostics for other cases.

Regardless of the enabled layer list provided in VkDeviceCreateInfo, the sequence of layers active for a device will be exactly the sequence of layers enabled when the parent instance was created.

45.4. Extensions

Extensions may define new Vulkan commands, structures, and enumerants. For compilation purposes, the interfaces defined by registered extensions, including new structures and enumerants as well as function pointer types for new commands, are defined in the Khronos-supplied vulkan_core.h together with the core API. However, commands defined by extensions may not be available for static linking - in which case function pointers to these commands should be queried at runtime as described in Command Function Pointers. Extensions may be provided by layers as well as by a Vulkan implementation.

Because extensions may extend or change the behavior of the Vulkan API, extension authors should add support for their extensions to the Khronos validation layers. This is especially important for new commands whose parameters have been wrapped by the validation layers. See the “Architecture of the Vulkan Loader Interfaces” document for additional information.

Note

To enable an instance extension, the name of the extension can be added to the ppEnabledExtensionNames member of VkInstanceCreateInfo when creating a VkInstance.

To enable a device extension, the name of the extension can be added to the ppEnabledExtensionNames member of VkDeviceCreateInfo when creating a VkDevice.

Physical-Device-Level functionality does not have any enabling mechanism and can be used as long as the VkPhysicalDevice supports the device extension as determined by vkEnumerateDeviceExtensionProperties.

Enabling an extension (with no further use of that extension) does not change the behavior of functionality exposed by the core Vulkan API or any other extension,
other than making valid the use of the commands, enums and structures defined by that extension.

Valid Usage sections for individual commands and structures do not currently contain which extensions have to be enabled in order to make their use valid, although they might do so in the future. It is defined only in the Valid Usage for Extensions section.

45.4.1. Instance Extensions

Instance extensions add new instance-level functionality to the API, outside of the core specification.

To query the available instance extensions, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkEnumerateInstanceExtensionProperties(
    const char* pLayerName,       // pLayerName is either NULL or a pointer to a null-terminated UTF-8 string naming the layer to retrieve extensions from.
    uint32_t* pPropertyCount,     // pPropertyCount is a pointer to an integer related to the number of extension properties available or queried, as described below.
    VkExtensionProperties* pProperties); // pProperties is either NULL or a pointer to an array of VkExtensionProperties structures.
```

When pLayerName parameter is NULL, only extensions provided by the Vulkan implementation or by implicitly enabled layers are returned. When pLayerName is the name of a layer, the instance extensions provided by that layer are returned.

If pProperties is NULL, then the number of extensions properties available is returned in pPropertyCount. Otherwise, pPropertyCount must point to a variable set by the user to the number of elements in the pProperties array, and on return the variable is overwritten with the number of structures actually written to pProperties. If pPropertyCount is less than the number of extension properties available, at most pPropertyCount structures will be written, and VK_INCOMPLETE will be returned instead of VK_SUCCESS, to indicate that not all the available properties were returned.

Because the list of available layers may change externally between calls to vkEnumerateInstanceExtensionProperties, two calls may retrieve different results if a pLayerName is available in one call but not in another. The extensions supported by a layer may also change between two calls, e.g. if the layer implementation is replaced by a different version between those calls.

Implementations must not advertise any pair of extensions that cannot be enabled together due to behavioral differences, or any extension that cannot be enabled against the advertised version.
Valid Usage (Implicit)

- VUID-vkEnumerateInstanceExtensionProperties-pLayerName-parameter
  If `pLayerName` is not NULL, `pLayerName` must be a null-terminated UTF-8 string

- VUID-vkEnumerateInstanceExtensionProperties-pPropertyCount-parameter
  `pPropertyCount` must be a valid pointer to a `uint32_t` value

- VUID-vkEnumerateInstanceExtensionProperties-pProperties-parameter
  If the value referenced by `pPropertyCount` is not 0, and `pProperties` is not NULL, `pProperties` must be a valid pointer to an array of `pPropertyCount` `VkExtensionProperties` structures

Return Codes

Success
- VK_SUCCESS
- VK_INCOMPLETE

Failure
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_LAYER_NOT_PRESENT

45.4.2. Device Extensions

Device extensions add new device-level functionality to the API, outside of the core specification.

To query the extensions available to a given physical device, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkEnumerateDeviceExtensionProperties(  
    VkPhysicalDevice physicalDevice,  
    const char* pLayerName,  
    uint32_t* pPropertyCount,  
    VkExtensionProperties* pProperties);
```

- `physicalDevice` is the physical device that will be queried.
- `pLayerName` is either NULL or a pointer to a null-terminated UTF-8 string naming the layer to retrieve extensions from.
- `pPropertyCount` is a pointer to an integer related to the number of extension properties available or queried, and is treated in the same fashion as the `vkEnumerateInstanceExtensionProperties` :: `pPropertyCount` parameter.
- `pProperties` is either NULL or a pointer to an array of `VkExtensionProperties` structures.
When `pLayerName` parameter is `NULL`, only extensions provided by the Vulkan implementation or by implicitly enabled layers are returned. When `pLayerName` is the name of a layer, the device extensions provided by that layer are returned.

Implementations **must** not advertise any pair of extensions that cannot be enabled together due to behavioral differences, or any extension that cannot be enabled against the advertised version.

Implementations claiming support for the Roadmap 2022 profile **must** advertise the `VK_KHR_global_priority` extension in `pProperties`.

---

**Note**

Due to platform details on Android, `vkEnumerateDeviceExtensionProperties` may be called with `physicalDevice` equal to `NULL` during layer discovery. This behaviour will only be observed by layer implementations, and not the underlying Vulkan driver.

---

### Valid Usage (Implicit)

- **VUID-vkEnumerateDeviceExtensionProperties-physicalDevice-parameter**
  - `physicalDevice` **must** be a valid `VkPhysicalDevice` handle

- **VUID-vkEnumerateDeviceExtensionProperties-pLayerName-parameter**
  - If `pLayerName` is not `NULL`, `pLayerName` **must** be a null-terminated UTF-8 string

- **VUID-vkEnumerateDeviceExtensionProperties-pPropertyCount-parameter**
  - `pPropertyCount` **must** be a valid pointer to a `uint32_t` value

- **VUID-vkEnumerateDeviceExtensionProperties-pProperties-parameter**
  - If the value referenced by `pPropertyCount` is not 0, and `pProperties` is not `NULL`, `pProperties` **must** be a valid pointer to an array of `pPropertyCount` `VkExtensionProperties` structures

---

### Return Codes

**Success**

- `VK_SUCCESS`
- `VK_INCOMPLETE`

**Failure**

- `VK_ERROR_OUT_OF_HOST_MEMORY`
- `VK_ERROR_OUT_OF_DEVICE_MEMORY`
- `VK_ERROR_LAYER_NOT_PRESENT`

---

The `VkExtensionProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkExtensionProperties {
```
• `extensionName` is an array of `VK_MAX_EXTENSION_NAME_SIZE` `char` containing a null-terminated UTF-8 string which is the name of the extension.

• `specVersion` is the version of this extension. It is an integer, incremented with backward compatible changes.

**Accessing device-level functionality from a `VkPhysicalDevice`**

Some device extensions also add support for physical-device-level functionality. Physical-device-level functionality can be used, if the required extension is supported as advertised by `vkEnumerateDeviceExtensionProperties` for a given `VkPhysicalDevice`.

**Accessing device-level functionality from a `VkDevice`**

For commands that are dispatched from a `VkDevice`, or from a child object of a `VkDevice`, device extensions must be enabled in `vkCreateDevice`.

### 45.5. Extension Dependencies

Some extensions are dependent on other extensions, or on specific core API versions, to function. To enable extensions with dependencies, any required extensions must also be enabled through the same API mechanisms when creating an instance with `vkCreateInstance` or a device with `vkCreateDevice`. Each extension which has such dependencies documents them in the appendix summarizing that extension.

If an extension is supported (as queried by `vkEnumerateInstanceExtensionProperties` or `vkEnumerateDeviceExtensionProperties`), then required extensions of that extension must also be supported for the same instance or physical device.

Any device extension that has an instance extension dependency that is not enabled by `vkCreateInstance` is considered to be unsupported, hence it must not be returned by `vkEnumerateDeviceExtensionProperties` for any `VkPhysicalDevice` child of the instance. Instance extensions do not have dependencies on device extensions.

If a required extension has been promoted to another extension or to a core API version, then as a general rule, the dependency is also satisfied by the promoted extension or core version. This will be true so long as any features required by the original extension are also required or enabled by the promoted extension or core version. However, in some cases an extension is promoted while making some of its features optional in the promoted extension or core version. In this case, the dependency may not be satisfied. The only way to be certain is to look at the descriptions of the original dependency and the promoted version in the Layers & Extensions and Core Revisions appendices.

**Note**

There is metadata in `vk.xml` describing some aspects of promotion, especially
requires, promotedto and deprecatedby attributes of <extension> tags. However, the metadata does not yet fully describe this scenario. In the future, we may extend the XML schema to describe the full set of extensions and versions satisfying a dependency.

45.6. Compatibility Guarantees (Informative)

This section is marked as informal as there is no binding responsibility on implementations of the Vulkan API - these guarantees are however a contract between the Vulkan Working Group and developers using this Specification.

45.6.1. Core Versions

Each of the major, minor, and patch versions of the Vulkan specification provide different compatibility guarantees.

Patch Versions

A difference in the patch version indicates that a set of bug fixes or clarifications have been made to the Specification. Informative enums returned by Vulkan commands that will not affect the runtime behavior of a valid application may be added in a patch version (e.g. VkVendorId).

The specification’s patch version is strictly increasing for a given major version of the specification; any change to a specification as described above will result in the patch version being increased by 1. Patch versions are applied to all minor versions, even if a given minor version is not affected by the provoking change.

Specifications with different patch versions but the same major and minor version are fully compatible with each other - such that a valid application written against one will work with an implementation of another.

Note

If a patch version includes a bug fix or clarification that could have a significant impact on developer expectations, these will be highlighted in the change log. Generally the Vulkan Working Group tries to avoid these kinds of changes, instead fixing them in either an extension or core version.

Minor Versions

Changes in the minor version of the specification indicate that new functionality has been added to the core specification. This will usually include new interfaces in the header, and may also include behavior changes and bug fixes. Core functionality may be deprecated in a minor version, but will not be obsoleted or removed.

The specification’s minor version is strictly increasing for a given major version of the specification; any change to a specification as described above will result in the minor version being increased by 1. Changes that can be accommodated in a patch version will not increase the minor version.
Specifications with a lower minor version are *backwards compatible* with an implementation of a specification with a higher minor version for core functionality and extensions issued with the KHR vendor tag. Vendor and multi-vendor extensions are not guaranteed to remain functional across minor versions, though in general they are with few exceptions - see Obsoletion for more information.

**Major Versions**

A difference in the major version of specifications indicates a large set of changes which will likely include interface changes, behavioral changes, removal of *deprecated functionality*, and the modification, addition, or replacement of other functionality.

The specification's major version is monotonically increasing; any change to the specification as described above will result in the major version being increased. Changes that can be accommodated in a patch or minor version will not increase the major version.

The Vulkan Working Group intends to only issue a new major version of the Specification in order to realise significant improvements to the Vulkan API that will necessarily require breaking compatibility.

A new major version will likely include a wholly new version of the specification to be issued - which could include an overhaul of the versioning semantics for the minor and patch versions. The patch and minor versions of a specification are therefore not meaningful across major versions. If a major version of the specification includes similar versioning semantics, it is expected that the patch and the minor version will be reset to 0 for that major version.

**45.6.2. Extensions**

A KHR extension **must** be able to be enabled alongside any other KHR extension, and for any minor or patch version of the core Specification beyond the minimum version it requires. A multi-vendor extension **should** be able to be enabled alongside any KHR extension or other multi-vendor extension, and for any minor or patch version of the core Specification beyond the minimum version it requires. A vendor extension **should** be able to be enabled alongside any KHR extension, multi-vendor extension, or other vendor extension from the same vendor, and for any minor or patch version of the core Specification beyond the minimum version it requires. A vendor extension **may** be able to be enabled alongside vendor extensions from another vendor.

The one other exception to this is if a vendor or multi-vendor extension is made obsolete by either a core version or another extension, which will be highlighted in the extension appendix.

**Promotion**

Extensions, or features of an extension, **may** be promoted to a new *core version of the API*, or a newer extension which an equal or greater number of implementors are in favour of.

When extension functionality is promoted, minor changes **may** be introduced, limited to the following:

- Naming
- Non-intrusive parameters changes
- Feature advertisement/enablement
- Combining structure parameters into larger structures
- Author ID suffixes changed or removed

**Note**
If extension functionality is promoted, there is no guarantee of direct compatibility, however it should require little effort to port code from the original feature to the promoted one.

The Vulkan Working Group endeavours to ensure that larger changes are marked as either deprecated or obsoleted as appropriate, and can do so retroactively if necessary.

Extensions that are promoted are listed as being promoted in their extension appendices, with reference to where they were promoted to.

When an extension is promoted, any backwards compatibility aliases which exist in the extension will **not** be promoted.

**Note**
As a hypothetical example, if the VK_KHR_surface extension were promoted to part of a future core version, the VK_COLOR_SPACE_SRGB_NONLINEAR_KHR token defined by that extension would be promoted to VK_COLOR_SPACE_SRGB_NONLINEAR. However, the VK_COLORSPACE_SRGB_NONLINEAR_KHR token aliases VK_COLOR_SPACE_SRGB_NONLINEAR_KHR. The VK_COLORSPACE_SRGB_NONLINEAR_KHR would not be promoted, because it is a backwards compatibility alias that exists only due to a naming mistake when the extension was initially published.

**Deprecation**
Extensions **may** be marked as deprecated when the intended use cases either become irrelevant or can be solved in other ways. Generally, a new feature will become available to solve the use case in another extension or core version of the API, but it is not guaranteed.

**Note**
Features that are intended to replace deprecated functionality have no guarantees of compatibility, and applications may require drastic modification in order to make use of the new features.

Extensions that are deprecated are listed as being deprecated in their extension appendices, with an explanation of the deprecation and any features that are relevant.

**Obsoletion**
Occasionally, an extension will be marked as obsolete if a new version of the core API or a new extension is fundamentally incompatible with it. An obsoleted extension **must** not be used with the
Extensions that are obsoleted are listed as being obsoleted in their extension appendices, with reference to what they were obsoleted by.

**Aliases**

When an extension is promoted or deprecated by a newer feature, some or all of its functionality may be replicated into the newer feature. Rather than duplication of all the documentation and definitions, the specification instead identifies the identical commands and types as aliases of one another. Each alias is mentioned together with the definition it aliases, with the older aliases marked as “equivalents”. Each alias of the same command has identical behavior, and each alias of the same type has identical meaning - they can be used interchangeably in an application with no compatibility issues.

*Note*

For promoted types, the aliased extension type is semantically identical to the new core type. The C99 headers simply typedef the older aliases to the promoted types.

For promoted command aliases, however, there are two separate entry point definitions, due to the fact that the C99 ABI has no way to alias command definitions without resorting to macros. Calling via either entry point definition will produce identical behavior within the bounds of the specification, and should still invoke the same entry point in the implementation. Debug tools may use separate entry points with different debug behavior; to write the appropriate command name to an output log, for instance.

**Special Use Extensions**

Some extensions exist only to support a specific purpose or specific class of application. These are referred to as “special use extensions”. Use of these extensions in applications not meeting the special use criteria is not recommended.

Special use cases are restricted, and only those defined below are used to describe extensions:

*Table 53. Extension Special Use Cases*

<table>
<thead>
<tr>
<th>Special Use</th>
<th>XML Tag</th>
<th>Full Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAD support</td>
<td>cadsupport</td>
<td>Extension is intended to support specialized functionality used by CAD/CAM applications.</td>
</tr>
<tr>
<td>D3D support</td>
<td>d3demulation</td>
<td>Extension is intended to support D3D emulation layers, and applications ported from D3D, by adding functionality specific to D3D.</td>
</tr>
<tr>
<td>Developer tools</td>
<td>devtools</td>
<td>Extension is intended to support developer tools such as capture-replay libraries.</td>
</tr>
<tr>
<td>Debugging tools</td>
<td>debugging</td>
<td>Extension is intended for use by applications when debugging.</td>
</tr>
</tbody>
</table>
Special Use | XML Tag | Full Description
---|---|---
OpenGL / ES support | glemutation | Extension is intended to support OpenGL and/or OpenGL ES emulation layers, and applications ported from those APIs, by adding functionality specific to those APIs.

Special use extensions are identified in the metadata for each such extension in the Layers & Extensions appendix, using the name in the “Special Use” column above.

Special use extensions are also identified in vk.xml with the short name in “XML Tag” column above, as described in the “API Extensions (extension tag)” section of the registry schema documentation.
Chapter 46. Features

Features describe functionality which is not supported on all implementations. Features are properties of the physical device. Features are optional, and must be explicitly enabled before use. Support for features is reported and enabled on a per-feature basis.

Note
Features are reported via the basic VkPhysicalDeviceFeatures structure, as well as the extensible structure VkPhysicalDeviceFeatures2, which was added in the VK_KHR_get_physical_device_properties2 extension and included in Vulkan 1.1. When new features are added in future Vulkan versions or extensions, each extension should introduce one new feature structure, if needed. This structure can be added to the pNext chain of the VkPhysicalDeviceFeatures2 structure.

For convenience, new core versions of Vulkan may introduce new unified feature structures for features promoted from extensions. At the same time, the extension's original feature structure (if any) is also promoted to the core API, and is an alias of the extension's structure. This results in multiple names for the same feature: in the original extension's feature structure and the promoted structure alias, in the unified feature structure. When a feature was implicitly supported and enabled in the extension, but an explicit name was added during promotion, then the extension itself acts as an alias for the feature as listed in the table below.

All aliases of the same feature in the core API must be reported consistently: either all must be reported as supported, or none of them. When a promoted extension is available, any corresponding feature aliases must be supported.

Table 54. Extension Feature Aliases

<table>
<thead>
<tr>
<th>Extension</th>
<th>Feature(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_KHR_shader_draw_parameters</td>
<td>shaderDrawParameters</td>
</tr>
<tr>
<td>VK_KHR_draw_indirect_count</td>
<td>drawIndirectCount</td>
</tr>
<tr>
<td>VK_KHR_sampler_mirror_clamp_to_edge</td>
<td>samplerMirrorClampToEdge</td>
</tr>
<tr>
<td>VK_EXT_descriptor_indexing</td>
<td>descriptorIndexing</td>
</tr>
<tr>
<td>VK_EXT_sampler_filter_minmax</td>
<td>samplerFilterMinmax</td>
</tr>
<tr>
<td>VK_EXT_shader_viewport_index_layer</td>
<td>shaderOutputViewportIndex, shaderOutputLayer</td>
</tr>
</tbody>
</table>

To query supported features, call:

```c
// Provided by VK_VERSION_1_0
void vkGetPhysicalDeviceFeatures(
    VkPhysicalDevice physicalDevice,
    VkPhysicalDeviceFeatures* pFeatures);
```

- `physicalDevice` is the physical device from which to query the supported features.
- `pFeatures` is a pointer to a VkPhysicalDeviceFeatures structure in which the physical device
features are returned. For each feature, a value of `VK_TRUE` specifies that the feature is supported on this physical device, and `VK_FALSE` specifies that the feature is not supported.

**Valid Usage (Implicit)**

- VUID-vkGetPhysicalDeviceFeatures-physicalDevice-parameter  
  `physicalDevice` must be a valid `VkPhysicalDevice` handle
- VUID-vkGetPhysicalDeviceFeatures-pFeatures-parameter  
  `pFeatures` must be a valid pointer to a `VkPhysicalDeviceFeatures` structure

Fine-grained features used by a logical device **must** be enabled at `VkDevice` creation time. If a feature is enabled that the physical device does not support, `VkDevice` creation will fail and return `VK_ERROR_FEATURE_NOT_PRESENT`.

The fine-grained features are enabled by passing a pointer to the `VkPhysicalDeviceFeatures` structure via the `pEnabledFeatures` member of the `VkDeviceCreateInfo` structure that is passed into the `vkCreateDevice` call. If a member of `pEnabledFeatures` is set to `VK_TRUE` or `VK_FALSE`, then the device will be created with the indicated feature enabled or disabled, respectively. Features **can** also be enabled by using the `VkPhysicalDeviceFeatures2` structure.

If an application wishes to enable all features supported by a device, it **can** simply pass in the `VkPhysicalDeviceFeatures` structure that was previously returned by `vkGetPhysicalDeviceFeatures`. To disable an individual feature, the application **can** set the desired member to `VK_FALSE` in the same structure. Setting `pEnabledFeatures` to `NULL` and not including a `VkPhysicalDeviceFeatures2` in the `pNext` chain of `VkDeviceCreateInfo` is equivalent to setting all members of the structure to `VK_FALSE`.

**Note**

Some features, such as `robustBufferAccess`, **may** incur a runtime performance cost. Application writers **should** carefully consider the implications of enabling all supported features.

To query supported features defined by the core or extensions, call:

```c
// Provided by VK_VERSION_1_1
void vkGetPhysicalDeviceFeatures2(
    VkPhysicalDevice physicalDevice,
    VkPhysicalDeviceFeatures2* pFeatures);
```

or the equivalent command

```c
// Provided by VK_KHR_get_physical_device_properties2
void vkGetPhysicalDeviceFeatures2KHR(
    VkPhysicalDevice physicalDevice,
    VkPhysicalDeviceFeatures2* pFeatures);
```
• **physicalDevice** is the physical device from which to query the supported features.
• **pFeatures** is a pointer to a `VkPhysicalDeviceFeatures2` structure in which the physical device features are returned.

Each structure in `pFeatures` and its `pNext` chain contains members corresponding to fine-grained features. `vkGetPhysicalDeviceFeatures2` writes each member to a boolean value indicating whether that feature is supported.

### Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceFeatures2-physicalDevice-parameter
  - `physicalDevice` must be a valid `VkPhysicalDevice` handle
- VUID-vkGetPhysicalDeviceFeatures2-pFeatures-parameter
  - `pFeatures` must be a valid pointer to a `VkPhysicalDeviceFeatures2` structure

The `VkPhysicalDeviceFeatures2` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceFeatures2 {
    VkStructureType sType;
    void* pNext;
    VkPhysicalDeviceFeatures features;
} VkPhysicalDeviceFeatures2;
```

or the equivalent

```c
// Provided by VK_KHR_get_physical_device_properties2
typedef VkPhysicalDeviceFeatures2 VkPhysicalDeviceFeatures2KHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `features` is a `VkPhysicalDeviceFeatures` structure describing the fine-grained features of the Vulkan 1.0 API.

The `pNext` chain of this structure is used to extend the structure with features defined by extensions. This structure **can** be used in `vkGetPhysicalDeviceFeatures2` or **can** be included in the `pNext` chain of a `VkDeviceCreateInfo` structure, in which case it controls which features are enabled on the device in lieu of `pEnabledFeatures`.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceFeatures2-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FEATURES_2`
The `VkPhysicalDeviceFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPhysicalDeviceFeatures {
    VkBool32 robustBufferAccess;
    VkBool32 fullDrawIndexUint32;
    VkBool32 imageCubeArray;
    VkBool32 independentBlend;
    VkBool32 geometryShader;
    VkBool32 tessellationShader;
    VkBool32 sampleRateShading;
    VkBool32 dualSrcBlend;
    VkBool32 logicOp;
    VkBool32 multiDrawIndirect;
    VkBool32 drawIndirectFirstInstance;
    VkBool32 depthClamp;
    VkBool32 depthBiasClamp;
    VkBool32 fillModeNonSolid;
    VkBool32 depthBounds;
    VkBool32 wideLines;
    VkBool32 largePoints;
    VkBool32 alphaToOne;
    VkBool32 multiViewport;
    VkBool32 samplerAnisotropy;
    VkBool32 textureCompressionETC2;
    VkBool32 textureCompressionASTC_LDR;
    VkBool32 textureCompressionBC;
    VkBool32 occlusionQueryPrecise;
    VkBool32 pipelineStatisticsQuery;
    VkBool32 vertexPipelineStoresAndAtomics;
    VkBool32 fragmentStoresAndAtomics;
    VkBool32 shaderTessellationAndGeometryPointSize;
    VkBool32 shaderImageGatherExtended;
    VkBool32 shaderStorageImageExtendedFormats;
    VkBool32 shaderStorageImageMultisample;
    VkBool32 shaderStorageImageReadWithoutFormat;
    VkBool32 shaderStorageImageWriteWithoutFormat;
    VkBool32 shaderUniformBufferArrayDynamicIndexing;
    VkBool32 shaderSampledImageArrayDynamicIndexing;
    VkBool32 shaderStorageBufferArrayDynamicIndexing;
    VkBool32 shaderStorageImageArrayDynamicIndexing;
    VkBool32 shaderClipDistance;
    VkBool32 shaderCullDistance;
    VkBool32 shaderFloat64;
    VkBool32 shaderInt64;
    VkBool32 shaderInt16;
    VkBool32 shaderResourceResidency;
    VkBool32 shaderResourceMinLod;
    VkBool32 sparseBinding;
    VkBool32 sparseResidencyBuffer;
};
```
This structure describes the following features:

- **robustBufferAccess** specifies that accesses to buffers are bounds-checked against the range of the buffer descriptor (as determined by `VkDescriptorBufferInfo::range`, `VkBufferViewCreateInfo::range`, or the size of the buffer). Out of bounds accesses **must** not cause application termination, and the effects of shader loads, stores, and atomics **must** conform to an implementation-dependent behavior as described below.

  ◦ A buffer access is considered to be out of bounds if any of the following are true:

    - The pointer was formed by `OpImageTexelPointer` and the coordinate is less than zero or greater than or equal to the number of whole elements in the bound range.

    - The pointer was not formed by `OpImageTexelPointer` and the object pointed to is not wholly contained within the bound range. This includes accesses performed via variable pointers where the buffer descriptor being accessed cannot be statically determined. Uninitialized pointers and pointers equal to `OpConstantNull` are treated as pointing to a zero-sized object, so all accesses through such pointers are considered to be out of bounds. Buffer accesses through buffer device addresses are not bounds-checked.

    - If the `VkPhysicalDeviceCooperativeMatrixFeaturesNV::cooperativeMatrixRobustBufferAccess` feature is not enabled, then accesses using `OpCooperativeMatrixLoadNV` and `OpCooperativeMatrixStoreNV` **may** not be bounds-checked.

    - If the `VkPhysicalDeviceCooperativeMatrixFeaturesKHR::cooperativeMatrixRobustBufferAccess` feature is not enabled, then accesses using `OpCooperativeMatrixLoadKHR` and `OpCooperativeMatrixStoreKHR` **may** not be bounds-checked.

  ◦ If a SPIR-V `OpLoad` instruction loads a structure and the tail end of the structure is out of bounds, then all members of the structure are considered out of bounds even if the members at the end are not statically used.

- If **robustBufferAccess2** is not enabled and any buffer access is determined to be out of bounds, then any other access of the same type (load, store, or atomic) to the same buffer that accesses an address less than 16 bytes away from the out of bounds address **may** also be considered out of bounds.
• If the access is a load that reads from the same memory locations as a prior store in the same shader invocation, with no other intervening accesses to the same memory locations in that shader invocation, then the result of the load may be the value stored by the store instruction, even if the access is out of bounds. If the load is Volatile, then an out of bounds load must return the appropriate out of bounds value.

• Accesses to descriptors written with a VK_NULL_HANDLE resource or view are not considered to be out of bounds. Instead, each type of descriptor access defines a specific behavior for accesses to a null descriptor.

• Out-of-bounds buffer loads will return any of the following values:

  • If the access is to a uniform buffer and robustBufferAccess2 is enabled, loads of offsets between the end of the descriptor range and the end of the descriptor range rounded up to a multiple of robustUniformBufferAccessSizeAlignment bytes must return either zero values or the contents of the memory at the offset being loaded. Loads of offsets past the descriptor range rounded up to a multiple of robustUniformBufferAccessSizeAlignment bytes must return zero values.

  • If the access is to a storage buffer and robustBufferAccess2 is enabled, loads of offsets between the end of the descriptor range and the end of the descriptor range rounded up to a multiple of robustStorageBufferAccessSizeAlignment bytes must return either zero values or the contents of the memory at the offset being loaded. Loads of offsets past the descriptor range rounded up to a multiple of robustStorageBufferAccessSizeAlignment bytes may be discarded.

  • Non-atomic accesses to storage buffers that are a multiple of 32 bits may be decomposed into 32-bit accesses that are individually bounds-checked.

  • If the access is to an index buffer and robustBufferAccess2 is enabled, zero values must be returned.

  • If the access is to a uniform texel buffer or storage texel buffer and robustBufferAccess2 is enabled, zero values must be returned, and then Conversion to RGBA is applied based on the buffer view's format.

  • Values from anywhere within the memory range(s) bound to the buffer (possibly including bytes of memory past the end of the buffer, up to the end of the bound range).

  • Zero values, or (0,0,0,x) vectors for vector reads where x is a valid value represented in the type of the vector components and may be any of:

    • 0, 1, or the maximum representable positive integer value, for signed or unsigned integer components
    • 0.0 or 1.0, for floating-point components

• Out-of-bounds writes may modify values within the memory range(s) bound to the buffer, but must not modify any other memory.

  • If robustBufferAccess2 is enabled, out of bounds writes must not modify any memory.

• Out-of-bounds atomics may modify values within the memory range(s) bound to the buffer, but must not modify any other memory, and return an undefined value.
- If `robustBufferAccess2` is enabled, out of bounds atomics **must** not modify any memory, and return an undefined value.

  - If `robustBufferAccess2` is disabled, vertex input attributes are considered out of bounds if the offset of the attribute in the bound vertex buffer range plus the size of the attribute is greater than either:

    - `vertexBufferRangeSize`, if `bindingStride == 0`;
    - `(vertexBufferRangeSize - (vertexBufferRangeSize % bindingStride))`

  where `vertexBufferRangeSize` is the byte size of the memory range bound to the vertex buffer binding and `bindingStride` is the byte stride of the corresponding vertex input binding. Further, if any vertex input attribute using a specific vertex input binding is out of bounds, then all vertex input attributes using that vertex input binding for that vertex shader invocation are considered out of bounds.

- If a vertex input attribute is out of bounds, it will be assigned one of the following values:
  - Values from anywhere within the memory range(s) bound to the buffer, converted according to the format of the attribute.
  - Zero values, format converted according to the format of the attribute.
  - Zero values, or (0,0,0,x) vectors, as described above.

  - If `robustBufferAccess2` is enabled, vertex input attributes are considered out of bounds if the offset of the attribute in the bound vertex buffer range plus the size of the attribute is greater than the byte size of the memory range bound to the vertex buffer binding.

  - If a vertex input attribute is out of bounds, the **raw data** extracted are zero values, and missing G, B, or A components are filled with (0,0,1).

  - If `robustBufferAccess` is not enabled, applications **must** not perform out of bounds accesses except under the conditions enabled by the `pipelineRobustness` feature.

- **fullDrawIndexUint32** specifies the full 32-bit range of indices is supported for indexed draw calls when using a `VkIndexType` of `VK_INDEX_TYPE_UINT32`. `maxDrawIndexedIndexValue` is the maximum index value that **may** be used (aside from the primitive restart index, which is always $2^{32} - 1$ when the `VkIndexType` is `VK_INDEX_TYPE_UINT32`). If this feature is supported, `maxDrawIndexedIndexValue` **must** be $2^{32} - 1$; otherwise it **must** be no smaller than $2^{24} - 1$. See `maxDrawIndexedIndexValue`.

- **imageCubeArray** specifies whether image views with a `VkImageViewType` of `VK_IMAGE_VIEW_TYPE_CUBE_ARRAY` **can** be created, and that the corresponding `SampledCubeArray` and `ImageCubeArray` SPIR-V capabilities **can** be used in shader code.

- **independentBlend** specifies whether the `VkPipelineColorBlendAttachmentState` settings are controlled independently per-attachment. If this feature is not enabled, the `VkPipelineColorBlendAttachmentState` settings for all color attachments **must** be identical. Otherwise, a different `VkPipelineColorBlendAttachmentState` **can** be provided for each bound color attachment.

- **geometryShader** specifies whether geometry shaders are supported. If this feature is not enabled, the `VK_SHADER_STAGE_GEOMETRY_BIT` and `VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT` enum values **must**
not be used. This also specifies whether shader modules can declare the **Geometry** capability.

- **tessellationShader** specifies whether tessellation control and evaluation shaders are supported. If this feature is not enabled, the **VK_SHADER_STAGE_TESSellation_CONTROL_BIT**, **VK_SHADER_STAGE_TESSellation_EVALUATION_BIT**, **VK_PIPELINE_STAGE_TESSellation_CONTROL_SHADER_BIT**, **VK_PIPELINE_STAGE_TESSellation_EVALUATION_SHADER_BIT**, and **VK_STRUCTURE_TYPE_PIPELINE_TESSellation_STATE_CREATE_INFO** enum values must not be used. This also specifies whether shader modules can declare the **Tessellation** capability.

- **sampleRateShading** specifies whether Sample Shading and multisample interpolation are supported. If this feature is not enabled, the **sampleShadingEnable** member of the **VkPipelineMultisampleStateCreateInfo** structure must be set to **VK_FALSE** and the **minSampleShading** member is ignored. This also specifies whether shader modules can declare the **SampleRateShading** capability.

- **dualSrcBlend** specifies whether blend operations which take two sources are supported. If this feature is not enabled, the **VK_BLEND_FACTOR_SRC1_COLOR**, **VK_BLEND_FACTOR_ONE_MINUS_SRC1_COLOR**, **VK_BLEND_FACTOR_SRC1_ALPHA**, and **VK_BLEND_FACTOR_ONE_MINUS_SRC1_ALPHA** enum values must not be used as source or destination blending factors. See **Dual-Source Blending**.

- **logicOp** specifies whether logic operations are supported. If this feature is not enabled, the **logicOpEnable** member of the **VkPipelineColorBlendStateCreateInfo** structure must be set to **VK_FALSE**, and the **logicOp** member is ignored.

- **multiDrawIndirect** specifies whether multiple draw indirect is supported. If this feature is not enabled, the **drawCount** parameter to the **vkCmdDrawIndirect** and **vkCmdDrawIndexedIndirect** commands must be 0 or 1. The **maxDrawIndirectCount** member of the **VkPhysicalDeviceLimits** structure must also be 1 if this feature is not supported. See **maxDrawIndirectCount**.

- **drawIndirectFirstInstance** specifies whether indirect drawing calls support the **firstInstance** parameter. If this feature is not enabled, the **firstInstance** member of all **VkDrawIndirectCommand** and **VkDrawIndexedIndirectCommand** structures that are provided to the **vkCmdDrawIndirect** and **vkCmdDrawIndexedIndirect** commands must be 0.

- **depthClamp** specifies whether depth clamping is supported. If this feature is not enabled, the **depthClampEnable** member of the **VkPipelineRasterizationStateCreateInfo** structure must be set to **VK_FALSE**. Otherwise, setting **depthClampEnable** to **VK_TRUE** will enable depth clamping.

- **depthBiasClamp** specifies whether depth bias clamping is supported. If this feature is not enabled, the **depthBiasClamp** member of the **VkPipelineRasterizationStateCreateInfo** structure must be set to 0.0 unless the **VK_DYNAMIC_STATE_DEPTH_BIAS** dynamic state is enabled, and the **depthBiasClamp** parameter to **vkCmdSetDepthBias** must be set to 0.0.

- **fillModeNonSolid** specifies whether point and wireframe fill modes are supported. If this feature is not enabled, the **VK_POLYGON_MODE_POINT** and **VK_POLYGON_MODE_LINE** enum values must not be used.

- **depthBounds** specifies whether depth bounds tests are supported. If this feature is not enabled, the **depthBoundsTestEnable** member of the **VkPipelineDepthStencilStateCreateInfo** structure must be set to **VK_FALSE**. When **depthBoundsTestEnable** is set to **VK_FALSE**, the **minDepthBounds** and **maxDepthBounds** members of the **VkPipelineDepthStencilStateCreateInfo** structure are ignored.

- **wideLines** specifies whether lines with width other than 1.0 are supported. If this feature is not
enabled, the `lineWidth` member of the `VkPipelineRasterizationStateCreateInfo` structure must be set to 1.0 unless the `VK_DYNAMIC_STATE_LINE_WIDTH` dynamic state is enabled, and the `lineWidth` parameter to `vkCmdSetLineWidth` must be set to 1.0. When this feature is supported, the range and granularity of supported line widths are indicated by the `lineWidthRange` and `lineWidthGranularity` members of the `VkPhysicalDeviceLimits` structure, respectively.

- `largePoints` specifies whether points with size greater than 1.0 are supported. If this feature is not enabled, only a point size of 1.0 written by a shader is supported. The range and granularity of supported point sizes are indicated by the `pointSizeRange` and `pointSizeGranularity` members of the `VkPhysicalDeviceLimits` structure, respectively.

- `alphaToOne` specifies whether the implementation is able to replace the alpha value of the fragment shader color output in the `Multisample Coverage` fragment operation. If this feature is not enabled, then the `alphaToOneEnable` member of the `VkPipelineMultisampleStateCreateInfo` structure must be set to `VK_FALSE`. Otherwise setting `alphaToOneEnable` to `VK_TRUE` will enable alpha-to-one behavior.

- `multiViewport` specifies whether more than one viewport is supported. If this feature is not enabled:
  - The `viewportCount` and `scissorCount` members of the `VkPipelineViewportStateCreateInfo` structure must be set to 1.
  - The `firstViewport` and `viewportCount` parameters to the `vkCmdSetViewport` command must be set to 0 and 1, respectively.
  - The `firstScissor` and `scissorCount` parameters to the `vkCmdSetScissor` command must be set to 0 and 1, respectively.
  - The `exclusiveScissorCount` member of the `VkPipelineViewportExclusiveScissorStateCreateInfoNV` structure must be set to 0 or 1.
  - The `firstExclusiveScissor` and `exclusiveScissorCount` parameters to the `vkCmdSetExclusiveScissorNV` command must be set to 0 and 1, respectively.

- `samplerAnisotropy` specifies whether anisotropic filtering is supported. If this feature is not enabled, the `anisotropyEnable` member of the `VkSamplerCreateInfo` structure must be `VK_FALSE`.

- `textureCompressionETC2` specifies whether all of the ETC2 and EAC compressed texture formats are supported. If this feature is enabled, then the `VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT`, `VK_FORMAT_FEATURE_BLIT_SRC_BIT` and `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT` features must be supported in `optimalTilingFeatures` for the following formats:
  - `VK_FORMAT_ETC2_R8G8B8_UNORM_BLOCK`
  - `VK_FORMAT_ETC2_R8G8B8_SRGB_BLOCK`
  - `VK_FORMAT_ETC2_R8G8B8A1_UNORM_BLOCK`
  - `VK_FORMAT_ETC2_R8G8B8A1_SRGB_BLOCK`
  - `VK_FORMAT_ETC2_R8G8B8A8_UNORM_BLOCK`
  - `VK_FORMAT_ETC2_R8G8B8A8_SRGB_BLOCK`
  - `VK_FORMAT_EAC_R11_UNORM_BLOCK`
  - `VK_FORMAT_EAC_R11_SNORM_BLOCK`
• **VK_FORMAT_EAC_R11G11_UNORM_BLOCK**
• **VK_FORMAT_EAC_R11G11_SNORM_BLOCK**

To query for additional properties, or if the feature is not enabled, *vkGetPhysicalDeviceFormatProperties* and *vkGetPhysicalDeviceImageFormatProperties* can be used to check for supported properties of individual formats as normal.

• **textureCompressionASTC_LDR** specifies whether all of the ASTC LDR compressed texture formats are supported. If this feature is enabled, then the **VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT**, **VK_FORMAT_FEATURE_BLIT_SRC_BIT** and **VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT** features **must** be supported in **optimalTilingFeatures** for the following formats:

  • **VK_FORMAT_ASTC_4x4_UNORM_BLOCK**
  • **VK_FORMAT_ASTC_4x4_SRGB_BLOCK**
  • **VK_FORMAT_ASTC_5x4_UNORM_BLOCK**
  • **VK_FORMAT_ASTC_5x4_SRGB_BLOCK**
  • **VK_FORMAT_ASTC_5x5_UNORM_BLOCK**
  • **VK_FORMAT_ASTC_5x5_SRGB_BLOCK**
  • **VK_FORMAT_ASTC_6x5_UNORM_BLOCK**
  • **VK_FORMAT_ASTC_6x5_SRGB_BLOCK**
  • **VK_FORMAT_ASTC_6x6_UNORM_BLOCK**
  • **VK_FORMAT_ASTC_6x6_SRGB_BLOCK**
  • **VK_FORMAT_ASTC_8x5_UNORM_BLOCK**
  • **VK_FORMAT_ASTC_8x5_SRGB_BLOCK**
  • **VK_FORMAT_ASTC_8x6_UNORM_BLOCK**
  • **VK_FORMAT_ASTC_8x6_SRGB_BLOCK**
  • **VK_FORMAT_ASTC_8x8_UNORM_BLOCK**
  • **VK_FORMAT_ASTC_8x8_SRGB_BLOCK**
  • **VK_FORMAT_ASTC_10x5_UNORM_BLOCK**
  • **VK_FORMAT_ASTC_10x5_SRGB_BLOCK**
  • **VK_FORMAT_ASTC_10x6_UNORM_BLOCK**
  • **VK_FORMAT_ASTC_10x6_SRGB_BLOCK**
  • **VK_FORMAT_ASTC_10x8_UNORM_BLOCK**
  • **VK_FORMAT_ASTC_10x8_SRGB_BLOCK**
  • **VK_FORMAT_ASTC_10x10_UNORM_BLOCK**
  • **VK_FORMAT_ASTC_10x10_SRGB_BLOCK**
  • **VK_FORMAT_ASTC_12x10_UNORM_BLOCK**
  • **VK_FORMAT_ASTC_12x10_SRGB_BLOCK**
• **textureCompressionBC** specifies whether all of the BC compressed texture formats are supported. If this feature is enabled, then the **VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT**, **VK_FORMAT_FEATURE_BLIT_SRC_BIT** and **VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT** features must be supported in `optimalTilingFeatures` for the following formats:

  - **VK_FORMAT_BC1_RGB_UNORM_BLOCK**
  - **VK_FORMAT_BC1_RGB_SRGB_BLOCK**
  - **VK_FORMAT_BC1_RGBA_UNORM_BLOCK**
  - **VK_FORMAT_BC1_RGBA_SRGB_BLOCK**
  - **VK_FORMAT_BC2_UNORM_BLOCK**
  - **VK_FORMAT_BC2_SRGB_BLOCK**
  - **VK_FORMAT_BC3_UNORM_BLOCK**
  - **VK_FORMAT_BC3_SRGB_BLOCK**
  - **VK_FORMAT_BC4_UNORM_BLOCK**
  - **VK_FORMAT_BC4_SNORM_BLOCK**
  - **VK_FORMAT_BC5_UNORM_BLOCK**
  - **VK_FORMAT_BC5_SNORM_BLOCK**
  - **VK_FORMAT_BC6H_UFLOAT_BLOCK**
  - **VK_FORMAT_BC6H_SFLOAT_BLOCK**
  - **VK_FORMAT_BC7_UNORM_BLOCK**
  - **VK_FORMAT_BC7_SRGB_BLOCK**

To query for additional properties, or if the feature is not enabled, `vkGetPhysicalDeviceFormatProperties` and `vkGetPhysicalDeviceImageFormatProperties` can be used to check for supported properties of individual formats as normal.

• **occlusionQueryPrecise** specifies whether occlusion queries returning actual sample counts are supported. Occlusion queries are created in a `VkQueryPool` by specifying the **queryType** of **VK_QUERY_TYPE_OCCLUSION** in the `VkQueryPoolCreateInfo` structure which is passed to `vkCreateQueryPool`. If this feature is enabled, queries of this type can enable **VK_QUERY_CONTROL_PRECISE_BIT** in the **flags** parameter to `vkCmdBeginQuery`. If this feature is not supported, the implementation supports only boolean occlusion queries. When any samples are passed, boolean queries will return a non-zero result value, otherwise a result value of zero is returned. When this feature is enabled and **VK_QUERY_CONTROL_PRECISE_BIT** is set, occlusion queries will report the actual number of samples passed.

• **pipelineStatisticsQuery** specifies whether the pipeline statistics queries are supported. If this
feature is not enabled, queries of type `VK_QUERY_TYPE_PIPELINE_STATISTICS` cannot be created, and none of the `VkQueryPipelineStatisticFlagBits` bits can be set in the `pipelineStatistics` member of the `VkQueryPoolCreateInfo` structure.

- `vertexPipelineStoresAndAtomics` specifies whether storage buffers and images support stores and atomic operations in the vertex, tessellation, and geometry shader stages. If this feature is not enabled, all storage image, storage texel buffer, and storage buffer variables used by these stages in shader modules must be decorated with the `NonWritable` decoration (or the `readonly` memory qualifier in GLSL).

- `fragmentStoresAndAtomics` specifies whether storage buffers and images support stores and atomic operations in the fragment shader stage. If this feature is not enabled, all storage image, storage texel buffer, and storage buffer variables used by the fragment stage in shader modules must be decorated with the `NonWritable` decoration (or the `readonly` memory qualifier in GLSL).

- `shaderTessellationAndGeometryPointSize` specifies whether the `PointSize` built-in decoration is available in the tessellation control, tessellation evaluation, and geometry shader stages. If this feature is not enabled, members decorated with the `PointSize` built-in decoration must not be read from or written to and all points written from a tessellation or geometry shader will have a size of 1.0. This also specifies whether shader modules can declare the `TessellationPointSize` capability for tessellation control and evaluation shaders, or if the shader modules can declare the `GeometryPointSize` capability for geometry shaders. An implementation supporting this feature must also support one or both of the `tessellationShader` or `geometryShader` features.

- `shaderImageGatherExtended` specifies whether the extended set of image gather instructions are available in shader code. If this feature is not enabled, the `OpImage*Gather` instructions do not support the `Offset` and `ConstOffsets` operands. This also specifies whether shader modules can declare the `ImageGatherExtended` capability.

- `shaderStorageImageExtendedFormats` specifies whether all the “storage image extended formats” below are supported; if this feature is supported, then the `VK_FORMAT_FEATURE_STORAGE_IMAGE_BIT` must be supported in `optimalTilingFeatures` for the following formats:
  
  - `VK_FORMAT_R16G16_SFLOAT`
  - `VK_FORMAT_B10G11R11_UFLOAT_PACK32`
  - `VK_FORMAT_R16_SFLOAT`
  - `VK_FORMAT_R16G16B16A16_UNORM`
  - `VK_FORMAT_A2B10G10R10_UNORM_PACK32`
  - `VK_FORMAT_R16G16_UNORM`
  - `VK_FORMAT_R8G8_SFLOAT`
  - `VK_FORMAT_R16G16B16A16_SNORM`
  - `VK_FORMAT_R16G16_SNORM`
  - `VK_FORMAT_R8G8_SNORM`
  - `VK_FORMAT_R16_SNORM`
  - `VK_FORMAT_R16_G16B16A16_SFLOAT`
- VK_FORMAT_R8_SNORM
- VK_FORMAT_R16G16_SINT
- VK_FORMAT_R8G8_SINT
- VK_FORMAT_R16_SINT
- VK_FORMAT_R8_SINT
- VK_FORMAT_A2B10G10R10_UINT_PACK32
- VK_FORMAT_R16G16_UINT
- VK_FORMAT_R8G8_UINT
- VK_FORMAT_R16_UINT
- VK_FORMAT_R8_UINT

Note

The shaderStorageImageExtendedFormats feature only adds a guarantee of format support, which is specified for the whole physical device. Therefore enabling or disabling the feature via vkCreateDevice has no practical effect.

To query for additional properties, or if the feature is not supported, vkGetPhysicalDeviceFormatProperties and vkGetPhysicalDeviceImageFormatProperties can be used to check for supported properties of individual formats, as usual rules allow.

VK_FORMAT_R32G32_UINT, VK_FORMAT_R32G32_SINT, and VK_FORMAT_R32G32_SFLOAT from StorageImageExtendedFormats SPIR-V capability, are already covered by core Vulkan mandatory format support.

- shaderStorageImageMultisample specifies whether multisampled storage images are supported. If this feature is not enabled, images that are created with a usage that includes VK_IMAGE_USAGE_STORAGE_BIT must be created with samples equal to VK_SAMPLE_COUNT_1_BIT. This also specifies whether shader modules can declare the StorageImageMultisample and ImageMSArray capabilities.

- shaderStorageImageReadWriteWithoutFormat specifies whether storage images and storage texel buffers require a format qualifier to be specified when reading. shaderStorageImageReadWriteWithoutFormat applies only to formats listed in the storage without format list.

- shaderStorageImageWriteWithoutFormat specifies whether storage images and storage texel buffers require a format qualifier to be specified when writing. shaderStorageImageWriteWithoutFormat applies only to formats listed in the storage without format list.

- shaderUniformBufferArrayDynamicIndexing specifies whether arrays of uniform buffers can be indexed by dynamically uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER or VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC must be indexed only by constant integral expressions when aggregated into arrays in shader code. This also specifies whether shader modules can declare the UniformBufferArrayDynamicIndexing capability.
•\texttt{shaderSampledImageArrayDynamicIndexing} specifies whether arrays of samplers or sampled images can be indexed by dynamically uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of\texttt{VK_DESCRIPTOR_TYPE_SAMPLER, VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER, or VK_DESCRIPTOR_TYPE_SAMP}led\texttt{IMAGE} must be indexed only by constant integral expressions when aggregated into arrays in shader code. This also specifies whether shader modules can declare the \texttt{SampledImageArrayDynamicIndexing} capability.

•\texttt{shaderStorageBufferArrayDynamicIndexing} specifies whether arrays of storage buffers can be indexed by dynamically uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of\texttt{VK_DESCRIPTOR_TYPE_STORAGE_BUFFER or VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC} must be indexed only by constant integral expressions when aggregated into arrays in shader code. This also specifies whether shader modules can declare the \texttt{StorageBufferArrayDynamicIndexing} capability.

•\texttt{shaderStorageImageArrayDynamicIndexing} specifies whether arrays of storage images can be indexed by dynamically uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of\texttt{VK_DESCRIPTOR_TYPE_STORAGE_IMAGE} must be indexed only by constant integral expressions when aggregated into arrays in shader code. This also specifies whether shader modules can declare the \texttt{StorageImageArrayDynamicIndexing} capability.

•\texttt{shaderClipDistance} specifies whether clip distances are supported in shader code. If this feature is not enabled, any members decorated with the \texttt{ClipDistance} built-in decoration must not be read from or written to in shader modules. This also specifies whether shader modules can declare the \texttt{ClipDistance} capability.

•\texttt{shaderCullDistance} specifies whether cull distances are supported in shader code. If this feature is not enabled, any members decorated with the \texttt{CullDistance} built-in decoration must not be read from or written to in shader modules. This also specifies whether shader modules can declare the \texttt{CullDistance} capability.

•\texttt{shaderFloat64} specifies whether 64-bit floats (doubles) are supported in shader code. If this feature is not enabled, 64-bit floating-point types must not be used in shader code. This also specifies whether shader modules can declare the \texttt{Float64} capability. Declaring and using 64-bit floats is enabled for all storage classes that SPIR-V allows with the \texttt{Float64} capability.

•\texttt{shaderInt64} specifies whether 64-bit integers (signed and unsigned) are supported in shader code. If this feature is not enabled, 64-bit integer types must not be used in shader code. This also specifies whether shader modules can declare the \texttt{Int64} capability. Declaring and using 64-bit integers is enabled for all storage classes that SPIR-V allows with the \texttt{Int64} capability.

•\texttt{shaderInt16} specifies whether 16-bit integers (signed and unsigned) are supported in shader code. If this feature is not enabled, 16-bit integer types must not be used in shader code. This also specifies whether shader modules can declare the \texttt{Int16} capability. However, this only enables a subset of the storage classes that SPIR-V allows for the \texttt{Int16} SPIR-V capability: Declaring and using 16-bit integers in the Private, Workgroup (for non-Block variables), and Function storage classes is enabled, while declaring them in the interface storage classes (e.g., UniformConstant, Uniform, StorageBuffer, Input, Output, and PushConstant) is not enabled.

•\texttt{shaderResourceResidency} specifies whether image operations that return resource residency information are supported in shader code. If this feature is not enabled, the \texttt{OpImageSparse\*} instructions must not be used in shader code. This also specifies whether shader modules can declare the \texttt{SparseResidency} capability. The feature requires at least one of the \texttt{sparseResidency\*}
features to be supported.

- **shaderResourceMinLod** specifies whether image operations specifying the minimum resource LOD are supported in shader code. If this feature is not enabled, the `MinLod` image operand **must** not be used in shader code. This also specifies whether shader modules **can** declare the `MinLod` capability.

- **sparseBinding** specifies whether resource memory **can** be managed at opaque sparse block level instead of at the object level. If this feature is not enabled, resource memory **must** be bound only on a per-object basis using the `vkBindBufferMemory` and `vkBindImageMemory` commands. In this case, buffers and images **must** not be created with `VK_BUFFER_CREATE_SPARSE_BINDING_BIT` and `VK_IMAGE_CREATE_SPARSE_BINDING_BIT` set in the `flags` member of the `VkBufferCreateInfo` and `VkImageCreateInfo` structures, respectively. Otherwise resource memory **can** be managed as described in Sparse Resource Features.

- **sparseResidencyBuffer** specifies whether the device **can** access partially resident buffers. If this feature is not enabled, buffers **must** not be created with `VK_BUFFER_CREATE_SPARSE_RESIDENCY_BIT` set in the `flags` member of the `VkBufferCreateInfo` structure.

- **sparseResidencyImage2D** specifies whether the device **can** access partially resident 2D images with 1 sample per pixel. If this feature is not enabled, images with an `imageType` of `VK_IMAGE_TYPE_2D` and `samples` set to `VK_SAMPLE_COUNT_1_BIT` **must** not be created with `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` set in the `flags` member of the `VkImageCreateInfo` structure.

- **sparseResidencyImage3D** specifies whether the device **can** access partially resident 3D images. If this feature is not enabled, images with an `imageType` of `VK_IMAGE_TYPE_3D` **must** not be created with `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` set in the `flags` member of the `VkImageCreateInfo` structure.

- **sparseResidency2Samples** specifies whether the physical device **can** access partially resident 2D images with 2 samples per pixel. If this feature is not enabled, images with an `imageType` of `VK_IMAGE_TYPE_2D` and `samples` set to `VK_SAMPLE_COUNT_2_BIT` **must** not be created with `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` set in the `flags` member of the `VkImageCreateInfo` structure.

- **sparseResidency4Samples** specifies whether the physical device **can** access partially resident 2D images with 4 samples per pixel. If this feature is not enabled, images with an `imageType` of `VK_IMAGE_TYPE_2D` and `samples` set to `VK_SAMPLE_COUNT_4_BIT` **must** not be created with `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` set in the `flags` member of the `VkImageCreateInfo` structure.

- **sparseResidency8Samples** specifies whether the physical device **can** access partially resident 2D images with 8 samples per pixel. If this feature is not enabled, images with an `imageType` of `VK_IMAGE_TYPE_2D` and `samples` set to `VK_SAMPLE_COUNT_8_BIT` **must** not be created with `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` set in the `flags` member of the `VkImageCreateInfo` structure.

- **sparseResidency16Samples** specifies whether the physical device **can** access partially resident 2D images with 16 samples per pixel. If this feature is not enabled, images with an `imageType` of `VK_IMAGE_TYPE_2D` and `samples` set to `VK_SAMPLE_COUNT_16_BIT` **must** not be created with `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT` set in the `flags` member of the `VkImageCreateInfo` structure.
• **sparseResidencyAliased** specifies whether the physical device can correctly access data aliased into multiple locations. If this feature is not enabled, the `VK_BUFFER_CREATE_SPARSE_ALIASED_BIT` and `VK_IMAGE_CREATE_SPARSE_ALIASED_BIT` enum values must not be used in flags members of the `VkBufferCreateInfo` and `VkImageCreateInfo` structures, respectively.

• **variableMultisampleRate** specifies whether all pipelines that will be bound to a command buffer during a subpass which uses no attachments must have the same value for `VkPipelineMultisampleStateCreateInfo::rasterizationSamples`. If set to `VK_TRUE`, the implementation supports variable multisample rates in a subpass which uses no attachments. If set to `VK_FALSE`, then all pipelines bound in such a subpass must have the same multisample rate. This has no effect in situations where a subpass uses any attachments.

• **inheritedQueries** specifies whether a secondary command buffer may be executed while a query is active.

The `VkPhysicalDeviceVulkan11Features` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceVulkan11Features {
  VkStructureType sType;
  void* pNext;
  VkBool32 storageBuffer16BitAccess;
  VkBool32 uniformAndStorageBuffer16BitAccess;
  VkBool32 storagePushConstant16;
  VkBool32 storageInputOutput16;
  VkBool32 multiview;
  VkBool32 multiviewGeometryShader;
  VkBool32 multiviewTessellationShader;
  VkBool32 variablePointersStorageBuffer;
  VkBool32 variablePointers;
  VkBool32 protectedMemory;
  VkBool32 samplerYcbcrConversion;
  VkBool32 shaderDrawParameters;
} VkPhysicalDeviceVulkan11Features;
```

This structure describes the following features:

• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **storageBuffer16BitAccess** specifies whether objects in the `StorageBuffer`, `ShaderRecordBufferKHR`, or `PhysicalStorageBuffer` storage class with the `Block` decoration can have 16-bit integer and 16-bit floating-point members. If this feature is not enabled, 16-bit integer or 16-bit floating-point members must not be used in such objects. This also specifies whether shader modules can declare the `StorageBuffer16BitAccess` capability.

• **uniformAndStorageBuffer16BitAccess** specifies whether objects in the `Uniform` storage class with the `Block` decoration can have 16-bit integer and 16-bit floating-point members. If this feature is not enabled, 16-bit integer or 16-bit floating-point members must not be used in such objects. This also specifies whether shader modules can declare the `UniformAndStorageBuffer16BitAccess` capability.
- `storagePushConstant16` specifies whether objects in the `PushConstant` storage class can have 16-bit integer and 16-bit floating-point members. If this feature is not enabled, 16-bit integer or floating-point members must not be used in such objects. This also specifies whether shader modules can declare the `StoragePushConstant16` capability.

- `storageInputOutput16` specifies whether objects in the `Input` and `Output` storage classes can have 16-bit integer and 16-bit floating-point members. If this feature is not enabled, 16-bit integer or floating-point members must not be used in such objects. This also specifies whether shader modules can declare the `StorageInputOutput16` capability.

- `multiview` specifies whether the implementation supports multiview rendering within a render pass. If this feature is not enabled, the view mask of each subpass must always be zero.

- `multiviewGeometryShader` specifies whether the implementation supports multiview rendering within a render pass, with geometry shaders. If this feature is not enabled, then a pipeline compiled against a subpass with a non-zero view mask must not include a geometry shader.

- `multiviewTessellationShader` specifies whether the implementation supports multiview rendering within a render pass, with tessellation shaders. If this feature is not enabled, then a pipeline compiled against a subpass with a non-zero view mask must not include any tessellation shaders.

- `variablePointersStorageBuffer` specifies whether the implementation supports the SPIR-V `VariablePointersStorageBuffer` capability. When this feature is not enabled, shader modules must not declare the `SPV_KHR_variable_pointers` extension or the `VariablePointersStorageBuffer` capability.

- `variablePointers` specifies whether the implementation supports the SPIR-V `VariablePointers` capability. When this feature is not enabled, shader modules must not declare the `VariablePointers` capability.

- `protectedMemory` specifies whether protected memory is supported.

- `samplerYcbcrConversion` specifies whether the implementation supports sampler Y’C_bC_r conversion. If `samplerYcbcrConversion` is `VK_FALSE`, sampler Y’C_bC_r conversion is not supported, and samplers using sampler Y’C_bC_r conversion must not be used.

- `shaderDrawParameters` specifies whether the implementation supports the SPIR-V `DrawParameters` capability. When this feature is not enabled, shader modules must not declare the `SPV_KHR_shader_draw_parameters` extension or the `DrawParameters` capability.

If the ` VkPhysicalDeviceVulkan11Features` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceVulkan11Features` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

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**Valid Usage (Implicit)**

- `VUID-VkPhysicalDeviceVulkan11Features-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_1_FEATURES`
The `VkPhysicalDeviceVulkan12Features` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceVulkan12Features {
    VkStructureType sType;
    void* pNext;
    VkBool32 samplerMirrorClampToEdge;
    VkBool32 drawIndirectCount;
    VkBool32 storageBuffer8BitAccess;
    VkBool32 uniformAndStorageBuffer8BitAccess;
    VkBool32 storagePushConstant8;
    VkBool32 shaderBufferInt64Atomics;
    VkBool32 shaderSharedInt64Atomics;
    VkBool32 shaderFloat16;
    VkBool32 shaderInt8;
    VkBool32 descriptorIndexing;
    VkBool32 shaderInputAttachmentArrayDynamicIndexing;
    VkBool32 shaderUniformTexelBufferArrayDynamicIndexing;
    VkBool32 shaderStorageTexelBufferArrayDynamicIndexing;
    VkBool32 shaderUniformBufferArrayNonUniformIndexing;
    VkBool32 shaderSampledImageArrayNonUniformIndexing;
    VkBool32 shaderStorageBufferArrayNonUniformIndexing;
    VkBool32 shaderInputAttachmentArrayNonUniformIndexing;
    VkBool32 shaderUniformTexelBufferArrayNonUniformIndexing;
    VkBool32 descriptorBindingUniformBufferUpdateAfterBind;
    VkBool32 descriptorBindingSampledImageUpdateAfterBind;
    VkBool32 descriptorBindingStorageImageUpdateAfterBind;
    VkBool32 descriptorBindingStorageBufferUpdateAfterBind;
    VkBool32 descriptorBindingUniformTexelBufferUpdateAfterBind;
    VkBool32 descriptorBindingStorageTexelBufferUpdateAfterBind;
    VkBool32 descriptorBindingUpdateUnusedWhilePending;
    VkBool32 descriptorBindingPartiallyBound;
    VkBool32 descriptorBindingVariableDescriptorCount;
    VkBool32 runtimeDescriptorArray;
    VkBool32 samplerFilterMinmax;
    VkBool32 scalarBlockLayout;
    VkBool32 imagelessFramebuffer;
    VkBool32 uniformBufferStandardLayout;
    VkBool32 shaderSubgroupExtendedTypes;
    VkBool32 separateDepthStencilLayouts;
    VkBool32 hostQueryReset;
    VkBool32 timelineSemaphore;
    VkBool32 bufferDeviceAddress;
    VkBool32 bufferDeviceAddressCaptureReplay;
    VkBool32 bufferDeviceAddressMultiDevice;
    VkBool32 vulkanMemoryModel;
    VkBool32 vulkanMemoryModelDeviceScope;
    VkBool32 vulkanMemoryModelAvailabilityVisibilityChains;
}
```
This structure describes the following features:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.

- `samplerMirrorClampToEdge` indicates whether the implementation supports the `VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE` sampler address mode. If this feature is not enabled, the `VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE` sampler address mode must not be used.

- `drawIndirectCount` indicates whether the implementation supports the `vkCmdDrawIndirectCount` and `vkCmdDrawIndexedIndirectCount` functions. If this feature is not enabled, these functions must not be used.

- `storageBuffer8BitAccess` indicates whether objects in the `StorageBuffer`, `ShaderRecordBufferKHR`, or `PhysicalStorageBuffer` storage class with the `Block` decoration can have 8-bit integer members. If this feature is not enabled, 8-bit integer members must not be used in such objects. This also indicates whether shader modules can declare the `StorageBuffer8BitAccess` capability.

- `uniformAndStorageBuffer8BitAccess` indicates whether objects in the `Uniform` storage class with the `Block` decoration can have 8-bit integer members. If this feature is not enabled, 8-bit integer members must not be used in such objects. This also indicates whether shader modules can declare the `UniformAndStorageBuffer8BitAccess` capability.

- `storagePushConstant8` indicates whether objects in the `PushConstant` storage class can have 8-bit integer members. If this feature is not enabled, 8-bit integer members must not be used in such objects. This also indicates whether shader modules can declare the `StoragePushConstant8` capability.

- `shaderBufferInt64Atomics` indicates whether shaders can perform 64-bit unsigned and signed integer atomic operations on buffers.

- `shaderSharedInt64Atomics` indicates whether shaders can perform 64-bit unsigned and signed integer atomic operations on shared and payload memory.

- `shaderFloat16` indicates whether 16-bit floats (halves) are supported in shader code. This also indicates whether shader modules can declare the `Float16` capability. However, this only enables a subset of the storage classes that SPIR-V allows for the `Float16` SPIR-V capability: Declaring and using 16-bit floats in the `Private`, `Workgroup` (for non-Block variables), and `Function` storage classes is enabled, while declaring them in the interface storage classes (e.g., `UniformConstant`, `Uniform`, `StorageBuffer`, `Input`, `Output`, and `PushConstant`) is not enabled.

- `shaderInt8` indicates whether 8-bit integers (signed and unsigned) are supported in shader code. This also indicates whether shader modules can declare the `Int8` capability. However, this only enables a subset of the storage classes that SPIR-V allows for the `Int8` SPIR-V capability: Declaring and using 8-bit integers in the `Private`, `Workgroup` (for non-Block variables), and `Function` storage classes is enabled, while declaring them in the interface storage classes (e.g.,
UniformConstant, Uniform, StorageBuffer, Input, Output, and PushConstant) is not enabled.

- **descriptorIndexing** indicates whether the implementation supports the minimum set of descriptor indexing features as described in the Feature Requirements section. Enabling the descriptorIndexing member when vkCreateDevice is called does not imply the other minimum descriptor indexing features are also enabled. Those other descriptor indexing features **must** be enabled individually as needed by the application.

- **shaderInputAttachmentArrayDynamicIndexing** indicates whether arrays of input attachments **can** be indexed by dynamically uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT **must** be indexed only by constant integral expressions when aggregated into arrays in shader code. This also indicates whether shader modules **can** declare the InputAttachmentArrayDynamicIndexing capability.

- **shaderUniformTexelBufferArrayDynamicIndexing** indicates whether arrays of uniform texel buffers **can** be indexed by dynamically uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER **must** be indexed only by constant integral expressions when aggregated into arrays in shader code. This also indicates whether shader modules **can** declare the UniformTexelBufferArrayDynamicIndexing capability.

- **shaderStorageTexelBufferArrayDynamicIndexing** indicates whether arrays of storage texel buffers **can** be indexed by dynamically uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER **must** be indexed only by constant integral expressions when aggregated into arrays in shader code. This also indicates whether shader modules **can** declare the StorageTexelBufferArrayDynamicIndexing capability.

- **shaderUniformBufferArrayNonUniformIndexing** indicates whether arrays of uniform buffers **can** be indexed by non-uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER or VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC **must** not be indexed by non-uniform integer expressions when aggregated into arrays in shader code. This also indicates whether shader modules **can** declare the UniformBufferArrayNonUniformIndexing capability.

- **shaderSampledImageArrayNonUniformIndexing** indicates whether arrays of samplers or sampled images **can** be indexed by non-uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of VK_DESCRIPTOR_TYPE_SAMPLER, VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER, or VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE **must** not be indexed by non-uniform integer expressions when aggregated into arrays in shader code. This also indicates whether shader modules **can** declare the SampledImageArrayNonUniformIndexing capability.

- **shaderStorageBufferArrayNonUniformIndexing** indicates whether arrays of storage buffers **can** be indexed by non-uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of VK_DESCRIPTOR_TYPE_STORAGE_BUFFER or VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC **must** not be indexed by non-uniform integer expressions when aggregated into arrays in shader code. This also indicates whether shader modules **can** declare the StorageBufferArrayNonUniformIndexing capability.

- **shaderStorageImageArrayNonUniformIndexing** indicates whether arrays of storage images **can** be indexed by non-uniform integer expressions in shader code. If this feature is not enabled,
resources with a descriptor type of `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE` must not be indexed by non-uniform integer expressions when aggregated into arrays in shader code. This also indicates whether shader modules can declare the `StorageImageArrayNonUniformIndexing` capability.

- `shaderInputAttachmentArrayNonUniformIndexing` indicates whether arrays of input attachments can be indexed by non-uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of `VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT` must not be indexed by non-uniform integer expressions when aggregated into arrays in shader code. This also indicates whether shader modules can declare the `InputAttachmentArrayNonUniformIndexing` capability.

- `shaderUniformTexelBufferArrayNonUniformIndexing` indicates whether arrays of uniform texel buffers can be indexed by non-uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of `VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER` must not be indexed by non-uniform integer expressions when aggregated into arrays in shader code. This also indicates whether shader modules can declare the `UniformTexelBufferArrayNonUniformIndexing` capability.

- `shaderStorageTexelBufferArrayNonUniformIndexing` indicates whether arrays of storage texel buffers can be indexed by non-uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER` must not be indexed by non-uniform integer expressions when aggregated into arrays in shader code. This also indicates whether shader modules can declare the `StorageTexelBufferArrayNonUniformIndexing` capability.

- `descriptorBindingUniformBufferUpdateAfterBind` indicates whether the implementation supports updating uniform buffer descriptors after a set is bound. If this feature is not enabled, `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT` must not be used with `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER`.

- `descriptorBindingSampledImageUpdateAfterBind` indicates whether the implementation supports updating sampled image descriptors after a set is bound. If this feature is not enabled, `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT` must not be used with `VK_DESCRIPTOR_TYPE_SAMPLER`, `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`, or `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE`.

- `descriptorBindingStorageImageUpdateAfterBind` indicates whether the implementation supports updating storage image descriptors after a set is bound. If this feature is not enabled, `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT` must not be used with `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE`.

- `descriptorBindingStorageBufferUpdateAfterBind` indicates whether the implementation supports updating storage buffer descriptors after a set is bound. If this feature is not enabled, `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT` must not be used with `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER`.

- `descriptorBindingUniformTexelBufferUpdateAfterBind` indicates whether the implementation supports updating uniform texel buffer descriptors after a set is bound. If this feature is not enabled, `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT` must not be used with `VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER`.

- `descriptorBindingStorageTexelBufferUpdateAfterBind` indicates whether the implementation supports updating storage texel buffer descriptors after a set is bound. If this feature is not enabled, `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT` must not be used with `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER`. 
supports updating storage texel buffer descriptors after a set is bound. If this feature is not enabled, **VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT** must not be used with **VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER**.

- **descriptorBindingUpdateUnusedWhilePending** indicates whether the implementation supports updating descriptors while the set is in use. If this feature is not enabled, **VK_DESCRIPTOR_BINDING_UPDATE_UNUSED_WHILE_PENDING_BIT** must not be used.

- **descriptorBindingPartiallyBound** indicates whether the implementation supports statically using a descriptor set binding in which some descriptors are not valid. If this feature is not enabled, **VK_DESCRIPTOR_BINDING_PARTIALLY_BOUND_BIT** must not be used.

- **descriptorBindingVariableDescriptorCount** indicates whether the implementation supports descriptor sets with a variable-sized last binding. If this feature is not enabled, **VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT** must not be used.

- **runtimeDescriptorArray** indicates whether the implementation supports the SPIR-V **RuntimeDescriptorArray** capability. If this feature is not enabled, descriptors must not be declared in runtime arrays.

- **samplerFilterMinmax** indicates whether the implementation supports a minimum set of required formats supporting min/max filtering as defined by the **filterMinmaxSingleComponentFormats** property minimum requirements. If this feature is not enabled, then **VkSamplerReductionModeCreateInfo** must only use **VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE**.

- **scalarBlockLayout** indicates that the implementation supports the layout of resource blocks in shaders using **scalar alignment**.

- **imagelessFramebuffer** indicates that the implementation supports specifying the image view for attachments at render pass begin time via **VkRenderPassAttachmentBeginInfo**.

- **uniformBufferStandardLayout** indicates that the implementation supports the same layouts for uniform buffers as for storage and other kinds of buffers. See **Standard Buffer Layout**.

- **shaderSubgroupExtendedTypes** is a boolean specifying whether subgroup operations can use 8-bit integer, 16-bit integer, 64-bit integer, 16-bit floating-point, and vectors of these types in **group operations** with **subgroup scope**, if the implementation supports the types.

- **separateDepthStencilLayouts** indicates whether the implementation supports a **VkImageMemoryBarrier** for a depth/stencil image with only one of **VK_IMAGE_ASPECT_DEPTH_BIT** or **VK_IMAGE_ASPECT_STENCIL_BIT** set, and whether **VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL**, **VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL**, **VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL**, or **VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL** can be used.

- **hostQueryReset** indicates that the implementation supports resetting queries from the host with **vkResetQueryPool**.

- **timelineSemaphore** indicates whether semaphores created with a **VkSemaphoreType** of **VK_SEMAPHORE_TYPE_TIMELINE** are supported.

- **bufferDeviceAddress** indicates that the implementation supports accessing buffer memory in shaders as storage buffers via an address queried from **vkGetBufferDeviceAddress**.

- **bufferDeviceAddressCaptureReplay** indicates that the implementation supports saving and reusing buffer and device addresses, e.g. for trace capture and replay.
• bufferDeviceAddressMultiDevice indicates that the implementation supports the bufferDeviceAddress, rayTracingPipeline and rayQuery features for logical devices created with multiple physical devices. If this feature is not supported, buffer and acceleration structure addresses must not be queried on a logical device created with more than one physical device.

• vulkanMemoryModel indicates whether shader modules can declare the VulkanMemoryModel capability.

• vulkanMemoryModelDeviceScope indicates whether the Vulkan Memory Model can use Device scope synchronization. This also indicates whether shader modules can declare the VulkanMemoryModelDeviceScope capability.

• vulkanMemoryModelAvailabilityVisibilityChains indicates whether the Vulkan Memory Model can use availability and visibility chains with more than one element.

• shaderOutputViewportIndex indicates whether the implementation supports the ShaderViewportIndex SPIR-V capability enabling variables decorated with the ViewportIndex built-in to be exported from mesh, vertex or tessellation evaluation shaders. If this feature is not enabled, the ViewportIndex built-in decoration must not be used on outputs in mesh, vertex or tessellation evaluation shaders.

• shaderOutputLayer indicates whether the implementation supports the ShaderLayer SPIR-V capability enabling variables decorated with the Layer built-in to be exported from mesh, vertex or tessellation evaluation shaders. If this feature is not enabled, the Layer built-in decoration must not be used on outputs in mesh, vertex or tessellation evaluation shaders.

• If subgroupBroadcastDynamicId is VK_TRUE, the “Id” operand of OpGroupNonUniformBroadcast can be dynamically uniform within a subgroup, and the “Index” operand of OpGroupNonUniformQuadBroadcast can be dynamically uniform within the derivative group. If it is VK_FALSE, these operands must be constants.

If the VkPhysicalDeviceVulkan12Features structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceVulkan12Features can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceVulkan12Features-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_2_FEATURES

The VkPhysicalDeviceVulkan13Features structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceVulkan13Features {
    VkStructureType  sType;
    void*             pNext;
    VkBool32          robustImageAccess;
    VkBool32          inlineUniformBlock;
    VkBool32          descriptorBindingInlineUniformBlockUpdateAfterBind;
    VkBool32          pipelineCreationCacheControl;
} VkPhysicalDeviceVulkan13Features;
```
This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **robustImageAccess** indicates whether image accesses are tightly bounds-checked against the dimensions of the image view. Invalid texels resulting from out of bounds image loads will be replaced as described in [Texel Replacement](#), with either (0,0,1) or (0,0,0) values inserted for missing G, B, or A components based on the format.
- **inlineUniformBlock** indicates whether the implementation supports inline uniform block descriptors. If this feature is not enabled, `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK` must not be used.
- **descriptorBindingInlineUniformBlockUpdateAfterBind** indicates whether the implementation supports updating inline uniform block descriptors after a set is bound. If this feature is not enabled, `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT` must not be used with `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK`.
- **pipelineCreationCacheControl** indicates that the implementation supports:
  - The following can be used in `Vk*PipelineCreateInfo::flags`:
    - `VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT`
    - `VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT`
  - The following can be used in `VkPipelineCacheCreateInfo::flags`:
    - `VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT`
- **privateData** indicates whether the implementation supports private data. See [Private Data](#).
- **shaderDemoteToHelperInvocation** indicates whether the implementation supports the SPIR-V DemoteToHelperInvocationEXT capability.
- **shaderTerminateInvocation** specifies whether the implementation supports SPIR-V modules that use the SPV_KHR_terminate_invocation extension.
- **subgroupSizeControl** indicates whether the implementation supports controlling shader subgroup sizes via the `VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT` flag and the `VkPipelineShaderStageRequiredSubgroupSizeCreateInfo` structure.
• `computeFullSubgroups` indicates whether the implementation supports requiring full subgroups in compute, mesh, or task shaders via the `VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT` flag.

• `synchronization2` indicates whether the implementation supports the new set of synchronization commands introduced in `VK_KHR_synchronization2`.

• `textureCompressionASTC_HDR` indicates whether all of the ASTC HDR compressed texture formats are supported. If this feature is enabled, then the `VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT`, `VK_FORMAT_FEATURE_BLIT_SRC_BIT` and `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT` features must be supported in `optimalTilingFeatures` for the following formats:
  - `VK_FORMAT_ASTC_4x4_SFLOAT_BLOCK`
  - `VK_FORMAT_ASTC_5x4_SFLOAT_BLOCK`
  - `VK_FORMAT_ASTC_5x5_SFLOAT_BLOCK`
  - `VK_FORMAT_ASTC_6x5_SFLOAT_BLOCK`
  - `VK_FORMAT_ASTC_6x6_SFLOAT_BLOCK`
  - `VK_FORMAT_ASTC_8x5_SFLOAT_BLOCK`
  - `VK_FORMAT_ASTC_8x6_SFLOAT_BLOCK`
  - `VK_FORMAT_ASTC_8x8_SFLOAT_BLOCK`
  - `VK_FORMAT_ASTC_10x5_SFLOAT_BLOCK`
  - `VK_FORMAT_ASTC_10x6_SFLOAT_BLOCK`
  - `VK_FORMAT_ASTC_10x8_SFLOAT_BLOCK`
  - `VK_FORMAT_ASTC_10x10_SFLOAT_BLOCK`
  - `VK_FORMAT_ASTC_12x10_SFLOAT_BLOCK`
  - `VK_FORMAT_ASTC_12x12_SFLOAT_BLOCK`

To query for additional properties, or if the feature is not enabled, `vkGetPhysicalDeviceFormatProperties` and `vkGetPhysicalDeviceImageFormatProperties` can be used to check for supported properties of individual formats as normal.

• `shaderZeroInitializeWorkgroupMemory` specifies whether the implementation supports initializing a variable in Workgroup storage class.

• `dynamicRendering` specifies that the implementation supports dynamic render pass instances using the `vkCmdBeginRendering` command.

• `shaderIntegerDotProduct` specifies whether shader modules can declare the `DotProductInputAllKHR`, `DotProductInput4x8BitKHR`, `DotProductInput4x8BitPackedKHR` and `DotProductKHR` capabilities.

• `maintenance4` indicates that the implementation supports the following:
  - The application may destroy a `VkPipelineLayout` object immediately after using it to create another object.
  - `LocalSizeId` can be used as an alternative to `LocalSize` to specify the local workgroup size with specialization constants.
◦ Images created with identical creation parameters will always have the same alignment requirements.

◦ The size memory requirement of a buffer or image is never greater than that of another buffer or image created with a greater or equal size.

◦ Push constants do not have to be initialized before they are dynamically accessed.

◦ The interface matching rules allow a larger output vector to match with a smaller input vector, with additional values being discarded.

If the `VkPhysicalDeviceVulkan13Features` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceVulkan13Features` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceVulkan13Features-sType-sType`

  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_3_FEATURES`

The `VkPhysicalDeviceVariablePointersFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceVariablePointersFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 variablePointersStorageBuffer;
    VkBool32 variablePointers;
} VkPhysicalDeviceVariablePointersFeatures;
```

```c
// Provided by VK_VERSION_1_1
typedef VkPhysicalDeviceVariablePointersFeatures
    VkPhysicalDeviceVariablePointerFeatures;
```

or the equivalent

```c
// Provided by VK_KHR_variable_pointers
typedef VkPhysicalDeviceVariablePointersFeatures
    VkPhysicalDeviceVariablePointersFeaturesKHR;
```

```c
// Provided by VK_KHR_variable_pointers
typedef VkPhysicalDeviceVariablePointersFeatures
    VkPhysicalDeviceVariablePointersFeaturesKHR;
```

This structure describes the following features:
• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **variablePointersStorageBuffer** specifies whether the implementation supports the SPIR-V `VariablePointersStorageBuffer` capability. When this feature is not enabled, shader modules **must** not declare the `SPV_KHR_variable_pointers` extension or the `VariablePointersStorageBuffer` capability.

• **variablePointers** specifies whether the implementation supports the SPIR-V `VariablePointers` capability. When this feature is not enabled, shader modules **must** not declare the `VariablePointers` capability.

If the `VkPhysicalDeviceVariablePointersFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceVariablePointersFeatures` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage

- **VUID-VkPhysicalDeviceVariablePointersFeatures-variablePointers-01431**
  If `variablePointers` is enabled then `variablePointersStorageBuffer` **must** also be enabled

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceVariablePointersFeatures-sType-sType**
  `sType` **must** be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VARIABLE_POINTERS_FEATURES`

The `VkPhysicalDeviceMultiviewFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceMultiviewFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 multiview;
    VkBool32 multiviewGeometryShader;
    VkBool32 multiviewTessellationShader;
} VkPhysicalDeviceMultiviewFeatures;
```

or the equivalent

```c
// Provided by VK_KHR_multiview
typedef VkPhysicalDeviceMultiviewFeatures VkPhysicalDeviceMultiviewFeaturesKHR;
```

This structure describes the following features:
• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **multiview** specifies whether the implementation supports multiview rendering within a render pass. If this feature is not enabled, the view mask of each subpass **must** always be zero.

• **multiviewGeometryShader** specifies whether the implementation supports multiview rendering within a render pass, with *geometry shaders*. If this feature is not enabled, then a pipeline compiled against a subpass with a non-zero view mask **must** not include a geometry shader.

• **multiviewTessellationShader** specifies whether the implementation supports multiview rendering within a render pass, with *tessellation shaders*. If this feature is not enabled, then a pipeline compiled against a subpass with a non-zero view mask **must** not include any tessellation shaders.

If the `VkPhysicalDeviceMultiviewFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceMultiviewFeatures` **can** also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage

- **VUID-VkPhysicalDeviceMultiviewFeatures-multiviewGeometryShader-00580**
  If `multiviewGeometryShader` is enabled then **multiview** **must** also be enabled

- **VUID-VkPhysicalDeviceMultiviewFeatures-multiviewTessellationShader-00581**
  If `multiviewTessellationShader` is enabled then **multiview** **must** also be enabled

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceMultiviewFeatures-sType-sType**
  `sType` **must** be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_FEATURES`
This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **shaderBufferFloat32Atomics** indicates whether shaders can perform 32-bit floating-point load, store and exchange atomic operations on storage buffers.
- **shaderBufferFloat32AtomicAdd** indicates whether shaders can perform 32-bit floating-point add atomic operations on storage buffers.
- **shaderBufferFloat64Atomics** indicates whether shaders can perform 64-bit floating-point load, store and exchange atomic operations on storage buffers.
- **shaderBufferFloat64AtomicAdd** indicates whether shaders can perform 64-bit floating-point add atomic operations on storage buffers.
- **shaderSharedFloat32Atomics** indicates whether shaders can perform 32-bit floating-point load, store and exchange atomic operations on shared and payload memory.
- **shaderSharedFloat32AtomicAdd** indicates whether shaders can perform 32-bit floating-point add atomic operations on shared and payload memory.
- **shaderSharedFloat64Atomics** indicates whether shaders can perform 64-bit floating-point load, store and exchange atomic operations on shared and payload memory.
- **shaderSharedFloat64AtomicAdd** indicates whether shaders can perform 64-bit floating-point add atomic operations on shared and payload memory.
- **shaderImageFloat32Atomics** indicates whether shaders can perform 32-bit floating-point load, store and exchange atomic image operations.
- **shaderImageFloat32AtomicAdd** indicates whether shaders can perform 32-bit floating-point add atomic image operations.
- **sparseImageFloat32Atomics** indicates whether 32-bit floating-point load, store and exchange atomic operations can be used on sparse images.
- **sparseImageFloat32AtomicAdd** indicates whether 32-bit floating-point add atomic operations can be used on sparse images.

If the `VkPhysicalDeviceShaderAtomicFloatFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceShaderAtomicFloatFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceShaderAtomicFloatFeaturesEXT-sType-sType

  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ATOMIC_FLOAT_FEATURES_EXT`

The `VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_shader_atomic_float2
typedef struct VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT {
    VkStructureType     sType;
    void*               pNext;
    VkBool32            shaderBufferFloat16Atomics;
    VkBool32            shaderBufferFloat16AtomicAdd;
    VkBool32            shaderBufferFloat16AtomicMinMax;
    VkBool32            shaderBufferFloat32AtomicMinMax;
    VkBool32            shaderBufferFloat64AtomicMinMax;
    VkBool32            shaderSharedFloat16Atomics;
    VkBool32            shaderSharedFloat16AtomicAdd;
    VkBool32            shaderSharedFloat16AtomicMinMax;
    VkBool32            shaderSharedFloat32AtomicMinMax;
    VkBool32            shaderSharedFloat64AtomicMinMax;
    VkBool32            shaderImageFloat32AtomicMinMax;
    VkBool32            sparseImageFloat32AtomicMinMax;
} VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT;
```

This structure describes the following features:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `shaderBufferFloat16Atomics` indicates whether shaders can perform 16-bit floating-point load, store, and exchange atomic operations on storage buffers.
- `shaderBufferFloat16AtomicAdd` indicates whether shaders can perform 16-bit floating-point add atomic operations on storage buffers.
- `shaderBufferFloat16AtomicMinMax` indicates whether shaders can perform 16-bit floating-point min and max atomic operations on storage buffers.
- `shaderBufferFloat32AtomicMinMax` indicates whether shaders can perform 32-bit floating-point min and max atomic operations on storage buffers.
- `shaderBufferFloat64AtomicMinMax` indicates whether shaders can perform 64-bit floating-point min and max atomic operations on storage buffers.
- `shaderSharedFloat16Atomics` indicates whether shaders can perform 16-bit floating-point load, store and exchange atomic operations on shared and payload memory.
- `shaderSharedFloat16AtomicAdd` indicates whether shaders can perform 16-bit floating-point add atomic operations on shared and payload memory.
• `shaderSharedFloat16AtomicMinMax` indicates whether shaders can perform 16-bit floating-point min and max atomic operations on shared and payload memory.

• `shaderSharedFloat32AtomicMinMax` indicates whether shaders can perform 32-bit floating-point min and max atomic operations on shared and payload memory.

• `shaderSharedFloat64AtomicMinMax` indicates whether shaders can perform 64-bit floating-point min and max atomic operations on shared and payload memory.

• `shaderImageFloat32AtomicMinMax` indicates whether shaders can perform 32-bit floating-point min and max atomic image operations.

• `sparseImageFloat32AtomicMinMax` indicates whether 32-bit floating-point min and max atomic operations can be used on sparse images.

If the `VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

## Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ATOMIC_FLOAT_2_FEATURES_EXT`
integer atomic operations on buffers.

- **shaderSharedInt64Atomics** indicates whether shaders can perform 64-bit unsigned and signed integer atomic operations on shared and payload memory.

If the **VkPhysicalDeviceShaderAtomicInt64Features** structure is included in the **pNext** chain of the **VkPhysicalDeviceFeatures2** structure passed to **vkGetPhysicalDeviceFeatures2**, it is filled in to indicate whether each corresponding feature is supported. **VkPhysicalDeviceShaderAtomicInt64Features** can also be used in the **pNext** chain of **VkDeviceCreateInfo** to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceShaderAtomicInt64Features-sType-sType**
  
  **sType** must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ATOMIC_INT64_FEATURES**

The **VkPhysicalDeviceShaderImageAtomicInt64FeaturesEXT** structure is defined as:

```c
// Provided by VK_EXT_shader_image_atomic_int64
typedef struct VkPhysicalDeviceShaderImageAtomicInt64FeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderImageInt64Atomics;
    VkBool32 sparseImageInt64Atomics;
} VkPhysicalDeviceShaderImageAtomicInt64FeaturesEXT;
```

This structure describes the following features:

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **shaderImageInt64Atomics** indicates whether shaders can support 64-bit unsigned and signed integer atomic operations on images.
- **sparseImageInt64Atomics** indicates whether 64-bit integer atomics can be used on sparse images.

If the **VkPhysicalDeviceShaderImageAtomicInt64FeaturesEXT** structure is included in the **pNext** chain of the **VkPhysicalDeviceFeatures2** structure passed to **vkGetPhysicalDeviceFeatures2**, it is filled in to indicate whether each corresponding feature is supported. **VkPhysicalDeviceShaderImageAtomicInt64FeaturesEXT** can also be used in the **pNext** chain of **VkDeviceCreateInfo** to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceShaderImageAtomicInt64FeaturesEXT-sType-sType**

  **sType** must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_IMAGE_ATOMIC_INT64_FEATURES_EXT**
The `VkPhysicalDevice8BitStorageFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDevice8BitStorageFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 storageBuffer8BitAccess;
    VkBool32 uniformAndStorageBuffer8BitAccess;
    VkBool32 storagePushConstant8;
} VkPhysicalDevice8BitStorageFeatures;
```

or the equivalent

```c
// Provided by VK_KHR_8bit_storage
typedef VkPhysicalDevice8BitStorageFeatures VkPhysicalDevice8BitStorageFeaturesKHR;
```

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **storageBuffer8BitAccess** indicates whether objects in the `StorageBuffer`, `ShaderRecordBufferKHR`, or `PhysicalStorageBuffer` storage class with the `Block` decoration can have 8-bit integer members. If this feature is not enabled, 8-bit integer members must not be used in such objects. This also indicates whether shader modules can declare the `StorageBuffer8BitAccess` capability.
- **uniformAndStorageBuffer8BitAccess** indicates whether objects in the `Uniform` storage class with the `Block` decoration can have 8-bit integer members. If this feature is not enabled, 8-bit integer members must not be used in such objects. This also indicates whether shader modules can declare the `UniformAndStorageBuffer8BitAccess` capability.
- **storagePushConstant8** indicates whether objects in the `PushConstant` storage class can have 8-bit integer members. If this feature is not enabled, 8-bit integer members must not be used in such objects. This also indicates whether shader modules can declare the `StoragePushConstant8` capability.

If the `VkPhysicalDevice8BitStorageFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDevice8BitStorageFeatures` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDevice8BitStorageFeatures-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_8BIT_STORAGE_FEATURES`

The `VkPhysicalDevice16BitStorageFeatures` structure is defined as:
This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.

- **storageBuffer16BitAccess** specifies whether objects in the StorageBuffer, ShaderRecordBufferKHR, or PhysicalStorageBuffer storage class with the Block decoration can have 16-bit integer and 16-bit floating-point members. If this feature is not enabled, 16-bit integer or 16-bit floating-point members must not be used in such objects. This also specifies whether shader modules can declare the StorageBuffer16BitAccess capability.

- **uniformAndStorageBuffer16BitAccess** specifies whether objects in the Uniform storage class with the Block decoration can have 16-bit integer and 16-bit floating-point members. If this feature is not enabled, 16-bit integer or 16-bit floating-point members must not be used in such objects. This also specifies whether shader modules can declare the UniformAndStorageBuffer16BitAccess capability.

- **storagePushConstant16** specifies whether objects in the PushConstant storage class can have 16-bit integer and 16-bit floating-point members. If this feature is not enabled, 16-bit integer or floating-point members must not be used in such objects. This also specifies whether shader modules can declare the StoragePushConstant16 capability.

- **storageInputOutput16** specifies whether objects in the Input and Output storage classes can have 16-bit integer and 16-bit floating-point members. If this feature is not enabled, 16-bit integer or 16-bit floating-point members must not be used in such objects. This also specifies whether shader modules can declare the StorageInputOutput16 capability.

If the `VkPhysicalDevice16BitStorageFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDevice16BitStorageFeatures` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.
Valid Usage (Implicit)

- VUID-VkPhysicalDevice16BitStorageFeatures-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_16BIT_STORAGE_FEATURES

The VkPhysicalDeviceShaderFloat16Int8Features structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceShaderFloat16Int8Features {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderFloat16;
    VkBool32 shaderInt8;
} VkPhysicalDeviceShaderFloat16Int8Features;
```

or the equivalent

```c
// Provided by VK_KHR_shader_float16_int8
typedef VkPhysicalDeviceShaderFloat16Int8Features
    VkPhysicalDeviceShaderFloat16Int8FeaturesKHR;
```

This structure describes the following features:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **shaderFloat16** indicates whether 16-bit floats (halves) are supported in shader code. This also indicates whether shader modules can declare the Float16 capability. However, this only enables a subset of the storage classes that SPIR-V allows for the Float16 SPIR-V capability: Declaring and using 16-bit floats in the Private, Workgroup (for non-Block variables), and Function storage classes is enabled, while declaring them in the interface storage classes (e.g., UniformConstant, Uniform, StorageBuffer, Input, Output, and PushConstant) is not enabled.
- **shaderInt8** indicates whether 8-bit integers (signed and unsigned) are supported in shader code. This also indicates whether shader modules can declare the Int8 capability. However, this only enables a subset of the storage classes that SPIR-V allows for the Int8 SPIR-V capability: Declaring and using 8-bit integers in the Private, Workgroup (for non-Block variables), and Function storage classes is enabled, while declaring them in the interface storage classes (e.g., UniformConstant, Uniform, StorageBuffer, Input, Output, and PushConstant) is not enabled.

If the VkPhysicalDeviceShaderFloat16Int8Features structure is included in the pNext chain of the
VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceShaderFloat16Int8Features can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceShaderFloat16Int8Features-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_FLOAT16_INT8_FEATURES

The VkPhysicalDeviceShaderClockFeaturesKHR structure is defined as:

```c
// Provided by VK_KHR_shader_clock
typedef struct VkPhysicalDeviceShaderClockFeaturesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderSubgroupClock;
    VkBool32 shaderDeviceClock;
} VkPhysicalDeviceShaderClockFeaturesKHR;
```

This structure describes the following features:

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- shaderSubgroupClock indicates whether shaders can perform Subgroup scoped clock reads.
- shaderDeviceClock indicates whether shaders can perform Device scoped clock reads.

If the VkPhysicalDeviceShaderClockFeaturesKHR structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceShaderClockFeaturesKHR can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceShaderClockFeaturesKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CLOCK_FEATURES_KHR

The VkPhysicalDeviceSamplerYcbcrConversionFeatures structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceSamplerYcbcrConversionFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 samplerYcbcrConversion;
} VkPhysicalDeviceSamplerYcbcrConversionFeatures;
```
or the equivalent

```cpp
// Provided by VK_KHR_sampler_ycbcr_conversion
typedef VkPhysicalDeviceSamplerYcbcrConversionFeatures
VkPhysicalDeviceSamplerYcbcrConversionFeaturesKHR;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **samplerYcbcrConversion** specifies whether the implementation supports sampler Y’C_bC_r conversion. If `samplerYcbcrConversion` is `VK_FALSE`, sampler Y’C_bC_r conversion is not supported, and samplers using sampler Y’C_bC_r conversion must not be used.

If the `VkPhysicalDeviceSamplerYcbcrConversionFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported.

`VkPhysicalDeviceSamplerYcbcrConversionFeatures` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceSamplerYcbcrConversionFeatures-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SAMPLER_YCBCR_CONVERSION_FEATURES`

The `VkPhysicalDeviceProtectedMemoryFeatures` structure is defined as:

```cpp
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceProtectedMemoryFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 protectedMemory;
} VkPhysicalDeviceProtectedMemoryFeatures;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **protectedMemory** specifies whether protected memory is supported.

If the `VkPhysicalDeviceProtectedMemoryFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to
indicate whether each corresponding feature is supported. 

**VkPhysicalDeviceProtectedMemoryFeatures** can also be used in the **pNext** chain of **VkDeviceCreateInfo** to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceProtectedMemoryFeatures-sType-sType**  
  *sType* must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PROTECTED_MEMORY_FEATURES**

The **VkPhysicalDeviceBlendOperationAdvancedFeaturesEXT** structure is defined as:

```c
// Provided by VK_EXT_blend_operation_advanced
typedef struct VkPhysicalDeviceBlendOperationAdvancedFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 advancedBlendCoherentOperations;
} VkPhysicalDeviceBlendOperationAdvancedFeaturesEXT;
```

This structure describes the following feature:

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is **NULL** or a pointer to a structure extending this structure.
- **advancedBlendCoherentOperations** specifies whether blending using *advanced blend operations* is guaranteed to execute atomically and in *primitive order*. If this is **VK_TRUE**, **VK_ACCESS_COLOR_ATTACHMENT_READ_NONCOHERENT_BIT_EXT** is treated the same as **VK_ACCESS_COLOR_ATTACHMENT_READ_BIT**, and advanced blending needs no additional synchronization over basic blending. If this is **VK_FALSE**, then memory dependencies are required to guarantee order between two advanced blending operations that occur on the same sample.

If the **VkPhysicalDeviceBlendOperationAdvancedFeaturesEXT** structure is included in the **pNext** chain of the **VkPhysicalDeviceFeatures2** structure passed to **vkGetPhysicalDeviceFeatures2**, it is filled in to indicate whether each corresponding feature is supported. **VkPhysicalDeviceBlendOperationAdvancedFeaturesEXT** can also be used in the **pNext** chain of **VkDeviceCreateInfo** to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceBlendOperationAdvancedFeaturesEXT-sType-sType**  
  *sType* must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BLEND_OPERATION_ADVANCED_FEATURES_EXT**

The **VkPhysicalDeviceConditionalRenderingFeaturesEXT** structure is defined as:

```c
// Provided by VK_EXT_conditional_rendering
typedef struct VkPhysicalDeviceConditionalRenderingFeaturesEXT {
    // Structure definition...
} VkPhysicalDeviceConditionalRenderingFeaturesEXT;
```
This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **conditionalRendering** specifies whether conditional rendering is supported.
- **inheritedConditionalRendering** specifies whether a secondary command buffer can be executed while conditional rendering is active in the primary command buffer.

If the `VkPhysicalDeviceConditionalRenderingFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceConditionalRenderingFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceConditionalRenderingFeaturesEXT-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CONDITIONAL_RENDERING_FEATURES_EXT`

The `VkPhysicalDeviceShaderDrawParametersFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceShaderDrawParametersFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderDrawParameters;
} VkPhysicalDeviceShaderDrawParametersFeatures;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **shaderDrawParameters** specifies whether the implementation supports the SPIR-V DrawParameters capability. When this feature is not enabled, shader modules must not declare the
If the `VkPhysicalDeviceShaderDrawParametersFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceShaderDrawParametersFeatures` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceShaderDrawParametersFeatures-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_DRAW_PARAMETERS_FEATURES`.

The `VkPhysicalDeviceMeshShaderFeaturesNV` structure is defined as:

```c
typedef struct VkPhysicalDeviceMeshShaderFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 taskShader;
    VkBool32 meshShader;
} VkPhysicalDeviceMeshShaderFeaturesNV;
```

This structure describes the following features:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `taskShader` specifies whether task shaders are supported. If this feature is not enabled, the `VK_SHADER_STAGE_TASK_BIT_NV` and `VK_PIPELINE_STAGE_TASK_SHADER_BIT_NV` enum values must not be used.
- `meshShader` specifies whether mesh shaders are supported. If this feature is not enabled, the `VK_SHADER_STAGE_MESH_BIT_NV` and `VK_PIPELINE_STAGE_MESH_SHADER_BIT_NV` enum values must not be used.

If the `VkPhysicalDeviceMeshShaderFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceMeshShaderFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceMeshShaderFeaturesNV-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MESH_SHADER_FEATURES_NV`.

The `VkPhysicalDeviceMeshShaderFeaturesEXT` structure is defined as:
// Provided by VK_EXT_mesh_shader

typedef struct VkPhysicalDeviceMeshShaderFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 taskShader;
    VkBool32 meshShader;
    VkBool32 multiviewMeshShader;
    VkBool32 primitiveFragmentShadingRateMeshShader;
    VkBool32 meshShaderQueries;
} VkPhysicalDeviceMeshShaderFeaturesEXT;

• **sType** is a VkStructureType value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **taskShader** specifies whether task shaders are supported. If this feature is not enabled, the VK_SHADER_STAGE_TASK_BIT_EXT and VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT enum values **must** not be used.

• **meshShader** specifies whether mesh shaders are supported. If this feature is not enabled, the VK_SHADER_STAGE_MESH_BIT_EXT and VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT enum values **must** not be used.

• **multiviewMeshShader** specifies whether the implementation supports multiview rendering within a render pass, with mesh shaders. If this feature is not enabled, then a pipeline compiled against a subpass with a non-zero view mask **must** not include a mesh shader.

• **primitiveFragmentShadingRateMeshShader** indicates that the implementation supports the primitive fragment shading rate in mesh shaders.

• **meshShaderQueries** indicates that the implementation supports creating query pools using the VK_QUERY_TYPE_MESH_PRIMITIVES_GENERATED_EXT query type and statistic queries containing the VK_QUERY_PIPELINE_STATISTIC_TASK_SHADER_INVOCATIONS_BIT_EXT and VK_QUERY_PIPELINE_STATISTIC_MESH_SHADER_INVOCATIONS_BIT_EXT flags.

If the VkPhysicalDeviceMeshShaderFeaturesEXT structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceMeshShaderFeaturesEXT can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

The corresponding features of the VkPhysicalDeviceMeshShaderFeaturesNV structure **must** match those in VkPhysicalDeviceMeshShaderFeaturesEXT.

**Valid Usage**

• VUID-VkPhysicalDeviceMeshShaderFeaturesEXT-multiviewMeshShader-07032
  If multiviewMeshShader is enabled then VkPhysicalDeviceMultiviewFeaturesKHR::multiview **must** also be enabled

• VUID-VkPhysicalDeviceMeshShaderFeaturesEXT-primitiveFragmentShadingRateMeshShader-07033
  If primitiveFragmentShadingRateMeshShader is enabled then
VkPhysicalDeviceFragmentShadingRateFeaturesKHR::primitiveFragmentShadingRate must also be enabled

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceMeshShaderFeaturesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MESH_SHADER_FEATURES_EXT

The VkPhysicalDeviceMemoryDecompressionFeaturesNV structure is defined as:

```c
// Provided by VK_NV_memory_decompression
typedef struct VkPhysicalDeviceMemoryDecompressionFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 memoryDecompression;
} VkPhysicalDeviceMemoryDecompressionFeaturesNV;
```

This structure describes the following features:

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `memoryDecompression` indicates whether memory decompression is supported.

If the VkPhysicalDeviceMemoryDecompressionFeaturesNV structure is included in the `pNext` chain of the VkPhysicalDeviceFeatures2 structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceMemoryDecompressionFeaturesNV can also be used in the `pNext` chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceMemoryDecompressionFeaturesNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_DECOMPRESSION_FEATURES_NV

The VkPhysicalDeviceDescriptorIndexingFeatures structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceDescriptorIndexingFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderInputAttachmentArrayDynamicIndexing;
    VkBool32 shaderUniformTexelBufferArrayDynamicIndexing;
    VkBool32 shaderStorageTexelBufferArrayDynamicIndexing;
    VkBool32 shaderUniformBufferArrayNonUniformIndexing;
} VkPhysicalDeviceDescriptorIndexingFeatures;
```
VkBool32 shaderSampledImageArrayNonUniformIndexing;
VkBool32 shaderStorageBufferArrayNonUniformIndexing;
VkBool32 shaderStorageImageArrayNonUniformIndexing;
VkBool32 shaderInputAttachmentArrayNonUniformIndexing;
VkBool32 shaderUniformTexelBufferArrayNonUniformIndexing;
VkBool32 shaderStorageTexelBufferArrayNonUniformIndexing;
VkBool32 descriptorBindingUniformBufferUpdateAfterBind;
VkBool32 descriptorBindingSampledImageUpdateAfterBind;
VkBool32 descriptorBindingStorageImageUpdateAfterBind;
VkBool32 descriptorBindingStorageBufferUpdateAfterBind;
VkBool32 descriptorBindingUniformTexelBufferUpdateAfterBind;
VkBool32 descriptorBindingStorageTexelBufferUpdateAfterBind;
VkBool32 descriptorBindingUpdateUnusedWhilePending;
VkBool32 descriptorBindingPartiallyBound;
VkBool32 descriptorBindingVariableDescriptorCount;
VkBool32 runtimeDescriptorArray;
}

VkPhysicalDeviceDescriptorIndexingFeatures

or the equivalent

// Provided by VK_EXT_descriptor_indexing
typedef VkPhysicalDeviceDescriptorIndexingFeatures
VkPhysicalDeviceDescriptorIndexingFeaturesEXT;

This structure describes the following features:

- **sType** is a *VkStructureType* value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.

- **shaderInputAttachmentArrayDynamicIndexing** indicates whether arrays of input attachments can be indexed by dynamically uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of *VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT* must be indexed only by constant integral expressions when aggregated into arrays in shader code. This also indicates whether shader modules can declare the *InputAttachmentArrayDynamicIndexing* capability.

- **shaderUniformTexelBufferArrayDynamicIndexing** indicates whether arrays of uniform texel buffers can be indexed by dynamically uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of *VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER* must be indexed only by constant integral expressions when aggregated into arrays in shader code. This also indicates whether shader modules can declare the *UniformTexelBufferArrayDynamicIndexing* capability.

- **shaderStorageTexelBufferArrayDynamicIndexing** indicates whether arrays of storage texel buffers can be indexed by dynamically uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of *VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER* must be indexed only by constant integral expressions when aggregated into arrays in shader code. This also indicates whether shader modules can declare the *StorageTexelBufferArrayDynamicIndexing* capability.
• **shaderUniformBufferArrayNonUniformIndexing** indicates whether arrays of uniform buffers can be indexed by non-uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER` or `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC` must not be indexed by non-uniform integer expressions when aggregated into arrays in shader code. This also indicates whether shader modules can declare the `UniformBufferArrayNonUniformIndexing` capability.

• **shaderSampledImageArrayNonUniformIndexing** indicates whether arrays of samplers or sampled images can be indexed by non-uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of `VK_DESCRIPTOR_TYPE_SAMPLER`, `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`, or `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE` must not be indexed by non-uniform integer expressions when aggregated into arrays in shader code. This also indicates whether shader modules can declare the `SampledImageArrayNonUniformIndexing` capability.

• **shaderStorageBufferArrayNonUniformIndexing** indicates whether arrays of storage buffers can be indexed by non-uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER` or `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC` must not be indexed by non-uniform integer expressions when aggregated into arrays in shader code. This also indicates whether shader modules can declare the `StorageBufferArrayNonUniformIndexing` capability.

• **shaderStorageImageArrayNonUniformIndexing** indicates whether arrays of storage images can be indexed by non-uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE` must not be indexed by non-uniform integer expressions when aggregated into arrays in shader code. This also indicates whether shader modules can declare the `StorageImageArrayNonUniformIndexing` capability.

• **shaderInputAttachmentArrayNonUniformIndexing** indicates whether arrays of input attachments can be indexed by non-uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of `VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT` must not be indexed by non-uniform integer expressions when aggregated into arrays in shader code. This also indicates whether shader modules can declare the `InputAttachmentArrayNonUniformIndexing` capability.

• **shaderUniformTexelBufferArrayNonUniformIndexing** indicates whether arrays of uniform texel buffers can be indexed by non-uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of `VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER` must not be indexed by non-uniform integer expressions when aggregated into arrays in shader code. This also indicates whether shader modules can declare the `UniformTexelBufferArrayNonUniformIndexing` capability.

• **shaderStorageTexelBufferArrayNonUniformIndexing** indicates whether arrays of storage texel buffers can be indexed by non-uniform integer expressions in shader code. If this feature is not enabled, resources with a descriptor type of `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER` must not be indexed by non-uniform integer expressions when aggregated into arrays in shader code. This also indicates whether shader modules can declare the `StorageTexelBufferArrayNonUniformIndexing` capability.

• **descriptorBindingUniformBufferUpdateAfterBind** indicates whether the implementation supports updating uniform buffer descriptors after a set is bound. If this feature is not enabled,
VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT must not be used with
VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER.

• descriptorBindingSampledImageUpdateAfterBind indicates whether the implementation supports
  updating sampled image descriptors after a set is bound. If this feature is not enabled,
  VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT must not be used with
  VK_DESCRIPTOR_TYPE_SAMPLER, VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER, or
  VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE.

• descriptorBindingStorageImageUpdateAfterBind indicates whether the implementation supports
  updating storage image descriptors after a set is bound. If this feature is not enabled,
  VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT must not be used with
  VK_DESCRIPTOR_TYPE_STORAGE_IMAGE.

• descriptorBindingStorageBufferUpdateAfterBind indicates whether the implementation supports
  updating storage buffer descriptors after a set is bound. If this feature is not enabled,
  VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT must not be used with
  VK_DESCRIPTOR_TYPE_STORAGE_BUFFER.

• descriptorBindingUniformTexelBufferUpdateAfterBind indicates whether the implementation
  supports updating uniform texel buffer descriptors after a set is bound. If this feature is not
  enabled, VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT must not be used with
  VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER.

• descriptorBindingStorageTexelBufferUpdateAfterBind indicates whether the implementation
  supports updating storage texel buffer descriptors after a set is bound. If this feature is not
  enabled, VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT must not be used with
  VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER.

• descriptorBindingUpdateUnusedWhilePending indicates whether the implementation supports
  updating descriptors while the set is in use. If this feature is not enabled,
  VK_DESCRIPTOR_BINDING_UPDATE_UNUSED_WHILE_PENDING_BIT must not be used.

• descriptorBindingPartiallyBound indicates whether the implementation supports statically
  using a descriptor set binding in which some descriptors are not valid. If this feature is not
  enabled, VK_DESCRIPTOR_BINDING_PARTIALLY_BOUND_BIT must not be used.

• descriptorBindingVariableDescriptorCount indicates whether the implementation supports
  descriptor sets with a variable-sized last binding. If this feature is not enabled,
  VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT must not be used.

• runtimeDescriptorArray indicates whether the implementation supports the SPIR-V
  RuntimeDescriptorArray capability. If this feature is not enabled, descriptors must not be
  declared in runtime arrays.

If the VkPhysicalDeviceDescriptorIndexingFeatures structure is included in the pNext chain of the
VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to
indicate whether each corresponding feature is supported. VkPhysicalDeviceDescriptorIndexingFeatures can also be used in the pNext chain of
VkDeviceCreateInfo to selectively enable these features.
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDescriptorIndexingFeatures-sType-sType
  
  
  
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_INDEXING_FEATURES

The VkPhysicalDeviceCopyMemoryIndirectFeaturesNV structure is defined as:

```c
// Provided by VK_NV_copy_memory_indirect
typedef struct VkPhysicalDeviceCopyMemoryIndirectFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 indirectCopy;
} VkPhysicalDeviceCopyMemoryIndirectFeaturesNV;
```

This structure describes the following features:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **indirectCopy** indicates whether indirect copies are supported.

If the VkPhysicalDeviceCopyMemoryIndirectFeaturesNV structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceCopyMemoryIndirectFeaturesNV can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceCopyMemoryIndirectFeaturesNV-sType-sType
  
  
  
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COPY_MEMORY_INDIRECT_FEATURES_NV

The VkPhysicalDeviceVertexAttributeDivisorFeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_vertex_attribute_divisor
typedef struct VkPhysicalDeviceVertexAttributeDivisorFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 vertexAttributeInstanceRateDivisor;
    VkBool32 vertexAttributeInstanceRateZeroDivisor;
} VkPhysicalDeviceVertexAttributeDivisorFeaturesEXT;
```

This structure describes the following features:

- **sType** is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.

• vertexAttributeInstanceRateDivisor specifies whether vertex attribute fetching may be repeated in case of instanced rendering.

• vertexAttributeInstanceRateZeroDivisor specifies whether a zero value for VkVertexInputBindingDivisorDescriptionEXT::divisor is supported.

If the VkPhysicalDeviceVertexAttributeDivisorFeaturesEXT structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceVertexAttributeDivisorFeaturesEXT can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceVertexAttributeDivisorFeaturesEXT-sType-sType 
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VERTEX_ATTRIBUTE_DIVISOR_FEATURES_EXT

The VkPhysicalDeviceASTCDecodeFeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_astc_decode_mode
typedef struct VkPhysicalDeviceASTCDecodeFeaturesEXT {
  VkStructureType sType;
  void* pNext;
  VkBool32 decodeModeSharedExponent;
} VkPhysicalDeviceASTCDecodeFeaturesEXT;
```

This structure describes the following feature:

• sType is a VkStructureType value identifying this structure.

• pNext is NULL or a pointer to a structure extending this structure.

• decodeModeSharedExponent indicates whether the implementation supports decoding ASTC compressed formats to VK_FORMAT_E5B9G9R9_UFLOAT_PACK32 internal precision.

If the VkPhysicalDeviceASTCDecodeFeaturesEXT structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceASTCDecodeFeaturesEXT can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceASTCDecodeFeaturesEXT-sType-sType 
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ASTC_DECODE_FEATURES_EXT

The VkPhysicalDeviceTransformFeedbackFeaturesEXT structure is defined as:
This structure describes the following features:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `transformFeedback` indicates whether the implementation supports transform feedback and shader modules can declare the `TransformFeedback` capability.
- `geometryStreams` indicates whether the implementation supports the `GeometryStreams` SPIR-V capability.

If the `VkPhysicalDeviceTransformFeedbackFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceTransformFeedbackFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceTransformFeedbackFeaturesEXT-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TRANSFORM_FEEDBACK_FEATURES_EXT`

The `VkPhysicalDeviceVulkanMemoryModelFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceVulkanMemoryModelFeatures {
    VkStructureType sType;
    void*pNext;
    VkBool32 vulkanMemoryModel;
    VkBool32 vulkanMemoryModelDeviceScope;
    VkBool32 vulkanMemoryModelAvailabilityVisibilityChains;
} VkPhysicalDeviceVulkanMemoryModelFeatures;
```

or the equivalent

```c
// Provided by VK_KHR_vulkan_memory_model
typedef VkPhysicalDeviceVulkanMemoryModelFeaturesKHR;
```
This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.

- `vulkanMemoryModel` indicates whether shader modules can declare the `VulkanMemoryModel` capability.
- `vulkanMemoryModelDeviceScope` indicates whether the Vulkan Memory Model can use device scope synchronization. This also indicates whether shader modules can declare the `VulkanMemoryModelDeviceScope` capability.
- `vulkanMemoryModelAvailabilityVisibilityChains` indicates whether the Vulkan Memory Model can use availability and visibility chains with more than one element.

If the `VkPhysicalDeviceVulkanMemoryModelFeaturesKHR` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceVulkanMemoryModelFeaturesKHR` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceVulkanMemoryModelFeatures-sType-sType
  
  **sType** must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_MEMORY_MODEL_FEATURES`.

The `VkPhysicalDeviceInlineUniformBlockFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceInlineUniformBlockFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 inlineUniformBlock;
    VkBool32 descriptorBindingInlineUniformBlockUpdateAfterBind;
} VkPhysicalDeviceInlineUniformBlockFeatures;
```

or the equivalent

```c
// Provided by VK_EXT_inline_uniform_block
typedef VkPhysicalDeviceInlineUniformBlockFeatures
VkPhysicalDeviceInlineUniformBlockFeaturesEXT;
```

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
• inlineUniformBlock indicates whether the implementation supports inline uniform block descriptors. If this feature is not enabled, `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK` must not be used.

• descriptorBindingInlineUniformBlockUpdateAfterBind indicates whether the implementation supports updating inline uniform block descriptors after a set is bound. If this feature is not enabled, `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT` must not be used with `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK`.

If the `VkPhysicalDeviceInlineUniformBlockFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceInlineUniformBlockFeatures` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceInlineUniformBlockFeatures-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INLINE_UNIFORM_BLOCK_FEATURES`

The `VkPhysicalDeviceRepresentativeFragmentTestFeaturesNV` structure is defined as:

```c
// Provided by VK_NV_representative_fragment_test
typedef struct VkPhysicalDeviceRepresentativeFragmentTestFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 representativeFragmentTest;
} VkPhysicalDeviceRepresentativeFragmentTestFeaturesNV;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `representativeFragmentTest` indicates whether the implementation supports the representative fragment test. See `Representative Fragment Test`.

If the `VkPhysicalDeviceRepresentativeFragmentTestFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceRepresentativeFragmentTestFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceRepresentativeFragmentTestFeaturesNV-sType-sType
  
  `sType` must be
The `VkPhysicalDeviceExclusiveScissorFeaturesNV` structure is defined as:

```c
// Provided by VK_NV_scissor_exclusive
typedef struct VkPhysicalDeviceExclusiveScissorFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 exclusiveScissor;
} VkPhysicalDeviceExclusiveScissorFeaturesNV;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `exclusiveScissor` indicates that the implementation supports the exclusive scissor test.

See [Exclusive Scissor Test](#) for more information.

If the `VkPhysicalDeviceExclusiveScissorFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceExclusiveScissorFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceExclusiveScissorFeaturesNV-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXCLUSIVE_SCISSOR_FEATURES_NV`

The `VkPhysicalDeviceCornerSampledImageFeaturesNV` structure is defined as:

```c
// Provided by VK_NV_corner_sampled_image
typedef struct VkPhysicalDeviceCornerSampledImageFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 cornerSampledImage;
} VkPhysicalDeviceCornerSampledImageFeaturesNV;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `cornerSampledImage` specifies whether images can be created with a `VkImageCreateInfo::flags` containing `VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV`. See [Corner-Sampled Images](#).
If the `VkPhysicalDeviceCornerSampledImageFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceCornerSampledImageFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceCornerSampledImageFeaturesNV-sType-sType**
  
  `sType` **must** be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CORNER_SAMPLED_IMAGE_FEATURES_NV`

The `VkPhysicalDeviceComputeShaderDerivativesFeaturesNV` structure is defined as:

```c
// Provided by VK_NV_compute_shader_derivatives
typedef struct VkPhysicalDeviceComputeShaderDerivativesFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 computeDerivativeGroupQuads;
    VkBool32 computeDerivativeGroupLinear;
} VkPhysicalDeviceComputeShaderDerivativesFeaturesNV;
```

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **computeDerivativeGroupQuads** indicates that the implementation supports the `ComputeDerivativeGroupQuadsNV` SPIR-V capability.
- **computeDerivativeGroupLinear** indicates that the implementation supports the `ComputeDerivativeGroupLinearNV` SPIR-V capability.

See **Quad shader scope** for more information.

If the `VkPhysicalDeviceComputeShaderDerivativesFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceComputeShaderDerivativesFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceComputeShaderDerivativesFeaturesNV-sType-sType**
  
  `sType` **must** be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COMPUTE_SHADER_DERIVATIVES_FEATURES_NV`

The `VkPhysicalDeviceFragmentShaderBarycentricFeaturesKHR` structure is defined as:

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typedef struct VkPhysicalDeviceFragmentShaderBarycentricFeaturesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 fragmentShaderBarycentric;
} VkPhysicalDeviceFragmentShaderBarycentricFeaturesKHR;

or the equivalent

typedef VkPhysicalDeviceFragmentShaderBarycentricFeaturesKHR
VkPhysicalDeviceFragmentShaderBarycentricFeaturesNV;

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `fragmentShaderBarycentric` indicates that the implementation supports the `BaryCoordKHR` and `BaryCoordNoPerspKHR` SPIR-V fragment shader built-ins and supports the `PerVertexKHR` SPIR-V decoration on fragment shader input variables.

See [Barycentric Interpolation](#) for more information.

If the `VkPhysicalDeviceFragmentShaderBarycentricFeaturesKHR` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceFragmentShaderBarycentricFeaturesKHR` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceFragmentShaderBarycentricFeaturesKHR-sType-sType` 
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADER_BARYCENTRIC_FEATURES_KHR`

The `VkPhysicalDeviceShaderImageFootprintFeaturesNV` structure is defined as:

// Provided by VK_NV_shader_image_footprint
typedef struct VkPhysicalDeviceShaderImageFootprintFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 imageFootprint;
} VkPhysicalDeviceShaderImageFootprintFeaturesNV;

This structure describes the following feature:
• sType is a VkStructureType value identifying this structure.

• pNext is NULL or a pointer to a structure extending this structure.

• imageFootprint specifies whether the implementation supports the ImageFootprintNV SPIR-V capability.

See Texel Footprint Evaluation for more information.

If the VkPhysicalDeviceShaderImageFootprintFeaturesNV structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceShaderImageFootprintFeaturesNV can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceShaderImageFootprintFeaturesNV-sType-sType

sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_IMAGE_FOOTPRINT_FEATURES_NV

The VkPhysicalDeviceShadingRateImageFeaturesNV structure is defined as:

```c
// Provided by VK_NV_shading_rate_image
typedef struct VkPhysicalDeviceShadingRateImageFeaturesNV {
    VkStructureType   sType;
    void*             pNext;
    VkBool32          shadingRateImage;
    VkBool32          shadingRateCoarseSampleOrder;
} VkPhysicalDeviceShadingRateImageFeaturesNV;
```

This structure describes the following features:

• sType is a VkStructureType value identifying this structure.

• pNext is NULL or a pointer to a structure extending this structure.

• shadingRateImage indicates that the implementation supports the use of a shading rate image to derive an effective shading rate for fragment processing. It also indicates that the implementation supports the ShadingRateNV SPIR-V execution mode.

• shadingRateCoarseSampleOrder indicates that the implementation supports a user-configurable ordering of coverage samples in fragments larger than one pixel.

See Shading Rate Image for more information.

If the VkPhysicalDeviceShadingRateImageFeaturesNV structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceShadingRateImageFeaturesNV can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceShadingRateImageFeaturesNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADING_RATE_IMAGE_FEATURES_NV

The `VkPhysicalDeviceFragmentDensityMapFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_fragment_density_map
typedef struct VkPhysicalDeviceFragmentDensityMapFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 fragmentDensityMap;
    VkBool32 fragmentDensityMapDynamic;
    VkBool32 fragmentDensityMapNonSubsampledImages;
} VkPhysicalDeviceFragmentDensityMapFeaturesEXT;
```

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **fragmentDensityMap** specifies whether the implementation supports render passes with a fragment density map attachment. If this feature is not enabled and the **pNext** chain of `VkRenderPassCreateInfo` includes a `VkRenderPassFragmentDensityMapCreateInfoEXT` structure, fragmentDensityMapAttachment must be `VK_ATTACHMENT_UNUSED`.
- **fragmentDensityMapDynamic** specifies whether the implementation supports dynamic fragment density map image views. If this feature is not enabled, `VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DYNAMIC_BIT_EXT` must not be included in `VkImageViewCreateInfo::flags`.
- **fragmentDensityMapNonSubsampledImages** specifies whether the implementation supports regular non-subsampled image attachments with fragment density map render passes. If this feature is not enabled, render passes with a fragment density map attachment must only have subsampled attachments bound.

If the `VkPhysicalDeviceFragmentDensityMapFeaturesEXT` structure is included in the **pNext** chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceFragmentDensityMapFeaturesEXT` can also be used in the **pNext** chain of `VkDeviceCreateInfo` to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceFragmentDensityMapFeaturesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_FEATURES_EXT
The `VkPhysicalDeviceFragmentDensityMap2FeaturesEXT` structure is defined as:

```
// Provided by VK_EXT_fragment_density_map2
typedef struct VkPhysicalDeviceFragmentDensityMap2FeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 fragmentDensityMapDeferred;
} VkPhysicalDeviceFragmentDensityMap2FeaturesEXT;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **fragmentDensityMapDeferred** specifies whether the implementation supports deferred reads of fragment density map image views. If this feature is not enabled, `VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DEFERRED_BIT_EXT` must not be included in `VkImageViewCreateInfo::flags`.

If the `VkPhysicalDeviceFragmentDensityMap2FeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceFragmentDensityMap2FeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceFragmentDensityMap2FeaturesEXT-sType-sType
  **sType** must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_2_FEATURES_EXT`

The `VkPhysicalDeviceFragmentDensityMapOffsetFeaturesQCOM` structure is defined as:

```
// Provided by VK_QCOM_fragment_density_map_offset
typedef struct VkPhysicalDeviceFragmentDensityMapOffsetFeaturesQCOM {
    VkStructureType sType;
    void* pNext;
    VkBool32 fragmentDensityMapOffset;
} VkPhysicalDeviceFragmentDensityMapOffsetFeaturesQCOM;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **fragmentDensityMapOffsets** specifies whether the implementation supports fragment density map offsets
If the `VkPhysicalDeviceFragmentDensityMapOffsetFeaturesQCOM` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceFragmentDensityMapOffsetFeaturesQCOM` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceFragmentDensityMapOffsetFeaturesQCOM-sType-sType must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_OFFSET_FEATURES_QCOM`

The `VkPhysicalDeviceInvocationMaskFeaturesHUAWEI` structure is defined as:

```c
// Provided by VK_HUAWEI_invocation_mask
typedef struct VkPhysicalDeviceInvocationMaskFeaturesHUAWEI {
    VkStructureType sType;
    void* pNext;
    VkBool32 invocationMask;
} VkPhysicalDeviceInvocationMaskFeaturesHUAWEI;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `invocationMask` indicates that the implementation supports the use of an invocation mask image to optimize the ray dispatch.

If the `VkPhysicalDeviceInvocationMaskFeaturesHUAWEI` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceInvocationMaskFeaturesHUAWEI` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceInvocationMaskFeaturesHUAWEI-sType-sType must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INVOCATION_MASK_FEATURES_HUAWEI`

The `VkPhysicalDeviceScalarBlockLayoutFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceScalarBlockLayoutFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 scalarBlockLayout;
} VkPhysicalDeviceScalarBlockLayoutFeatures;
```
VkBool32 scalarBlockLayout;
} VkPhysicalDeviceScalarBlockLayoutFeatures;

or the equivalent

// Provided by VK_EXT_scalar_block_layout
typedef VkPhysicalDeviceScalarBlockLayoutFeatures
VkPhysicalDeviceScalarBlockLayoutFeaturesEXT;

This structure describes the following feature:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **scalarBlockLayout** indicates that the implementation supports the layout of resource blocks in shaders using scalar alignment.

If the VkPhysicalDeviceScalarBlockLayoutFeatures structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceScalarBlockLayoutFeatures can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceScalarBlockLayoutFeatures-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SCALAR_BLOCK_LAYOUT_FEATURES

The VkPhysicalDeviceUniformBufferStandardLayoutFeatures structure is defined as:

// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceUniformBufferStandardLayoutFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 uniformBufferStandardLayout;
} VkPhysicalDeviceUniformBufferStandardLayoutFeatures;

or the equivalent

// Provided by VK_KHR_uniform_buffer_standard_layout
typedef VkPhysicalDeviceUniformBufferStandardLayoutFeatures
VkPhysicalDeviceUniformBufferStandardLayoutFeaturesKHR;

This structure describes the following feature:
• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **uniformBufferStandardLayout** indicates that the implementation supports the same layouts for uniform buffers as for storage and other kinds of buffers. See [Standard Buffer Layout](#).

If the `VkPhysicalDeviceUniformBufferStandardLayoutFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceUniformBufferStandardLayoutFeatures` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

---

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceUniformBufferStandardLayoutFeatures-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_UNIFORM_BUFFER_STANDARD_LAYOUT_FEATURES`

The `VkPhysicalDeviceDepthClipEnableFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_depth_clip_enable
typedef struct VkPhysicalDeviceDepthClipEnableFeaturesEXT {
    VkStructureType   sType;
    void*             pNext;
    VkBool32          depthClipEnable;
} VkPhysicalDeviceDepthClipEnableFeaturesEXT;
```

This structure describes the following feature:

• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **depthClipEnable** indicates that the implementation supports setting the depth clipping operation explicitly via the `VkPipelineRasterizationDepthClipStateCreateInfoEXT` pipeline state. Otherwise depth clipping is only enabled when `VkPipelineRasterizationStateCreateInfo::depthClampEnable` is set to `VK_FALSE`.

If the `VkPhysicalDeviceDepthClipEnableFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceDepthClipEnableFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

---

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceDepthClipEnableFeaturesEXT-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_CLIP_ENABLE_FEATURES_EXT`
The `VkPhysicalDeviceMemoryPriorityFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_memory_priority
typedef struct VkPhysicalDeviceMemoryPriorityFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 memoryPriority;
} VkPhysicalDeviceMemoryPriorityFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `memoryPriority` indicates that the implementation supports memory priorities specified at memory allocation time via `VkMemoryPriorityAllocateInfoEXT`.

If the `VkPhysicalDeviceMemoryPriorityFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceMemoryPriorityFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- `VUID-VkPhysicalDeviceMemoryPriorityFeaturesEXT-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_PRIORITY_FEATURES_EXT`

The `VkPhysicalDeviceBufferDeviceAddressFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceBufferDeviceAddressFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 bufferDeviceAddress;
    VkBool32 bufferDeviceAddressCaptureReplay;
    VkBool32 bufferDeviceAddressMultiDevice;
} VkPhysicalDeviceBufferDeviceAddressFeatures;
```

or the equivalent

```c
// Provided by VK_KHR_buffer_device_address
typedef VkPhysicalDeviceBufferDeviceAddressFeatures
    VkPhysicalDeviceBufferDeviceAddressFeaturesKHR;
```

This structure describes the following features:
• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **bufferDeviceAddress** indicates that the implementation supports accessing buffer memory in shaders as storage buffers via an address queried from `vkGetBufferDeviceAddress`.

• **bufferDeviceAddressCaptureReplay** indicates that the implementation supports saving and reusing buffer and device addresses, e.g. for trace capture and replay.

• **bufferDeviceAddressMultiDevice** indicates that the implementation supports the `bufferDeviceAddress`, `rayTracingPipeline` and `rayQuery` features for logical devices created with multiple physical devices. If this feature is not supported, buffer and acceleration structure addresses **must** not be queried on a logical device created with more than one physical device.

**Note**
`bufferDeviceAddressMultiDevice` exists to allow certain legacy platforms to be able to support `bufferDeviceAddress` without needing to support shared GPU virtual addresses for multi-device configurations.

See `vkGetBufferDeviceAddress` for more information.

If the `VkPhysicalDeviceBufferDeviceAddressFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceBufferDeviceAddressFeatures` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceBufferDeviceAddressFeatures-sType-sType**

  **sType** must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BUFFER_DEVICE_ADDRESS_FEATURES`.

The `VkPhysicalDeviceBufferDeviceAddressFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_buffer_device_address
typedef struct VkPhysicalDeviceBufferDeviceAddressFeaturesEXT {
    VkStructureType      sType;
    void*                pNext;
    VkBool32             bufferDeviceAddress;
    VkBool32             bufferDeviceAddressCaptureReplay;
    VkBool32             bufferDeviceAddressMultiDevice;
} VkPhysicalDeviceBufferDeviceAddressFeaturesEXT;
```

```c
// Provided by VK_EXT_buffer_device_address
typedef VkPhysicalDeviceBufferDeviceAddressFeaturesEXT
    VkPhysicalDeviceBufferDeviceAddressFeaturesEXT;
```
This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **bufferDeviceAddress** indicates that the implementation supports accessing buffer memory in shaders as storage buffers via an address queried from `vkGetBufferDeviceAddressEXT`.
- **bufferDeviceAddressCaptureReplay** indicates that the implementation supports saving and reusing buffer addresses, e.g. for trace capture and replay.
- **bufferDeviceAddressMultiDevice** indicates that the implementation supports the `bufferDeviceAddress` feature for logical devices created with multiple physical devices. If this feature is not supported, buffer addresses **must** not be queried on a logical device created with more than one physical device.

If the `VkPhysicalDeviceBufferDeviceAddressFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceBufferDeviceAddressFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Note**

The `VkPhysicalDeviceBufferDeviceAddressFeaturesEXT` structure has the same members as the `VkPhysicalDeviceBufferDeviceAddressFeatures` structure, but the functionality indicated by the members is expressed differently. The features indicated by the `VkPhysicalDeviceBufferDeviceAddressFeatures` structure requires additional flags to be passed at memory allocation time, and the capture and replay mechanism is built around opaque capture addresses for buffer and memory objects.

**Valid Usage (Implicit)**

- `VUID-VkPhysicalDeviceBufferDeviceAddressFeaturesEXT-sType-sType`  
  `sType` **must** be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BUFFER_DEVICE_ADDRESS_FEATURES_EXT`

The `VkPhysicalDeviceDedicatedAllocationImageAliasingFeaturesNV` structure is defined as:

```c
// Provided by VK_NV_dedicated_allocation_image_aliasing
typedef struct VkPhysicalDeviceDedicatedAllocationImageAliasingFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 dedicatedAllocationImageAliasing;
} VkPhysicalDeviceDedicatedAllocationImageAliasingFeaturesNV;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
pNext is NULL or a pointer to a structure extending this structure.

dedicatedAllocationImageAliasing indicates that the implementation supports aliasing of compatible image objects on a dedicated allocation.

If the VkPhysicalDeviceDedicatedAllocationImageAliasingFeaturesNV structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceDedicatedAllocationImageAliasingFeaturesNV can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDedicatedAllocationImageAliasingFeaturesNV-sType-sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEDICATED_ALLOCATION_IMAGE_ALIASING_FEATURES_NV

The VkPhysicalDeviceImagelessFramebufferFeatures structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceImagelessFramebufferFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 imagelessFramebuffer;
} VkPhysicalDeviceImagelessFramebufferFeatures;
```

or the equivalent

```c
// Provided by VK_KHR_imageless_framebuffer
typedef VkPhysicalDeviceImagelessFramebufferFeatures
VkPhysicalDeviceImagelessFramebufferFeaturesKHR;
```

This structure describes the following feature:

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- imagelessFramebuffer indicates that the implementation supports specifying the image view for attachments at render pass begin time via VkRenderPassAttachmentBeginInfo.

If the VkPhysicalDeviceImagelessFramebufferFeatures structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceImagelessFramebufferFeatures can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceImagelessFramebufferFeatures-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGELESS_FRAMEBUFFER_FEATURES

The `VkPhysicalDeviceFragmentShaderInterlockFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_fragment_shader_interlock
typedef struct VkPhysicalDeviceFragmentShaderInterlockFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 fragmentShaderSampleInterlock;
    VkBool32 fragmentShaderPixelInterlock;
    VkBool32 fragmentShaderShadingRateInterlock;
} VkPhysicalDeviceFragmentShaderInterlockFeaturesEXT;
```

This structure describes the following features:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `fragmentShaderSampleInterlock` indicates that the implementation supports the `FragmentShaderSampleInterlockEXT` SPIR-V capability.
- `fragmentShaderPixelInterlock` indicates that the implementation supports the `FragmentShaderPixelInterlockEXT` SPIR-V capability.
- `fragmentShaderShadingRateInterlock` indicates that the implementation supports the `FragmentShaderShadingRateInterlockEXT` SPIR-V capability.

If the `VkPhysicalDeviceFragmentShaderInterlockFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceFragmentShaderInterlockFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceFragmentShaderInterlockFeaturesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADER_INTERLOCK_FEATURES_EXT

The `VkPhysicalDeviceCooperativeMatrixFeaturesNV` structure is defined as:

```c
// Provided by VK_NV_cooperative_matrix
typedef struct VkPhysicalDeviceCooperativeMatrixFeaturesNV {
    VkStructureType sType;
} VkPhysicalDeviceCooperativeMatrixFeaturesNV;
```
This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **cooperativeMatrix** indicates that the implementation supports the `CooperativeMatrixNV` SPIR-V capability.
- **cooperativeMatrixRobustBufferAccess** indicates that the implementation supports robust buffer access for SPIR-V `OpCooperativeMatrixLoadNV` and `OpCooperativeMatrixStoreNV` instructions.

If the `VkPhysicalDeviceCooperativeMatrixFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceCooperativeMatrixFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- [VUID-VkPhysicalDeviceCooperativeMatrixFeaturesNV-sType-sType](#)

  The `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COOPERATIVE_MATRIX_FEATURES_NV`.

The `VkPhysicalDeviceCooperativeMatrixFeaturesKHR` structure is defined as:

```c
// Provided by VK_KHR_cooperative_matrix
typedef struct VkPhysicalDeviceCooperativeMatrixFeaturesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 cooperativeMatrix;
    VkBool32 cooperativeMatrixRobustBufferAccess;
} VkPhysicalDeviceCooperativeMatrixFeaturesKHR;
```

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **cooperativeMatrix** indicates that the implementation supports the `CooperativeMatrixKHR` SPIR-V capability.
- **cooperativeMatrixRobustBufferAccess** indicates that the implementation supports robust buffer access for SPIR-V `OpCooperativeMatrixLoadKHR` and `OpCooperativeMatrixStoreKHR` instructions.

If the `VkPhysicalDeviceCooperativeMatrixFeaturesKHR` structure is included in the `pNext` chain of the
VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceCooperativeMatrixFeaturesKHR can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceCooperativeMatrixFeaturesKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COOPERATIVE_MATRIX_FEATURES_KHR

The VkPhysicalDeviceYcbcrImageArraysFeaturesEXT structure is defined as:

```
// Provided by VK_EXT_ycbcr_image_arrays
typedef struct VkPhysicalDeviceYcbcrImageArraysFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 ycbcrImageArrays;
} VkPhysicalDeviceYcbcrImageArraysFeaturesEXT;
```

This structure describes the following feature:

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- ycbcrImageArrays indicates that the implementation supports creating images with a format that requires Y’CbCr conversion and has multiple array layers.

If the VkPhysicalDeviceYcbcrImageArraysFeaturesEXT structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceYcbcrImageArraysFeaturesEXT can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceYcbcrImageArraysFeaturesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_YCBCR_IMAGE_arrays_FEATURES_EXT

The VkPhysicalDeviceShaderSubgroupExtendedTypesFeatures structure is defined as:

```
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceShaderSubgroupExtendedTypesFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderSubgroupExtendedTypes;
} VkPhysicalDeviceShaderSubgroupExtendedTypesFeatures;
```
or the equivalent

```
// Provided by VK_KHR_shader_subgroupExtendedTypesFeatures

typedef VkPhysicalDeviceShaderSubgroupExtendedTypesFeatures
    VkPhysicalDeviceShaderSubgroupExtendedTypesFeaturesKHR;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **shaderSubgroupExtendedTypes** is a boolean specifying whether subgroup operations can use 8-bit integer, 16-bit integer, 64-bit integer, 16-bit floating-point, and vectors of these types in group operations with subgroup scope, if the implementation supports the types.

If the `VkPhysicalDeviceShaderSubgroupExtendedTypesFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceShaderSubgroupExtendedTypesFeatures` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceShaderSubgroupExtendedTypesFeatures-sType-sType must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_SUBGROUP_EXTENDED_TYPES_FEATURES`

The `VkPhysicalDeviceHostQueryResetFeatures` structure is defined as:

```
// Provided by VK_VERSION_1_2

typedef struct VkPhysicalDeviceHostQueryResetFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 hostQueryReset;
} VkPhysicalDeviceHostQueryResetFeatures;
```

or the equivalent

```
// Provided by VK_EXT_host_query_reset

typedef VkPhysicalDeviceHostQueryResetFeatures
    VkPhysicalDeviceHostQueryResetFeaturesEXT;
```

This structure describes the following feature:
• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• hostQueryReset indicates that the implementation supports resetting queries from the host with vkResetQueryPool.

If the VkPhysicalDeviceHostQueryResetFeatures structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceHostQueryResetFeatures can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

**Valid Usage (Implicit)**

• VUID-VkPhysicalDeviceHostQueryResetFeatures-sType-sType

sType must be VK_STRUCTURE_TYPE_PHYSICAL DEVICE HOST_QUERY_RESET FEATURES

The VkPhysicalDeviceShaderIntegerFunctions2FeaturesINTEL structure is defined as:

```
// Provided by VK_INTEL_shader_integer_functions2
typedef struct VkPhysicalDeviceShaderIntegerFunctions2FeaturesINTEL {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderIntegerFunctions2;
} VkPhysicalDeviceShaderIntegerFunctions2FeaturesINTEL;
```

This structure describes the following feature:

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• shaderIntegerFunctions2 indicates that the implementation supports the IntegerFunctions2INTEL SPIR-V capability.

If the VkPhysicalDeviceShaderIntegerFunctions2FeaturesINTEL structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceShaderIntegerFunctions2FeaturesINTEL can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

**Valid Usage (Implicit)**

• VUID-VkPhysicalDeviceShaderIntegerFunctions2FeaturesINTEL-sType-sType

sType must be VK_STRUCTURE_TYPE_PHYSICAL DEVICE_SHADER_INTEGER_FUNCTIONS_2 FEATURES_INTEL

The VkPhysicalDeviceCoverageReductionModeFeaturesNV structure is defined as:
typedef struct VkPhysicalDeviceCoverageReductionModeFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 coverageReductionMode;
} VkPhysicalDeviceCoverageReductionModeFeaturesNV;

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **coverageReductionMode** indicates whether the implementation supports coverage reduction modes. See Coverage Reduction.

If the `VkPhysicalDeviceCoverageReductionModeFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceCoverageReductionModeFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceCoverageReductionModeFeaturesNV-sType-sType` **sType** must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COVERAGE_REDUCTION_MODE_FEATURES_NV`

The `VkPhysicalDeviceTimelineSemaphoreFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceTimelineSemaphoreFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 timelineSemaphore;
} VkPhysicalDeviceTimelineSemaphoreFeatures;
```

or the equivalent

```c
// Provided by VK_KHR_timeline_semaphore
typedef VkPhysicalDeviceTimelineSemaphoreFeatures
    VkPhysicalDeviceTimelineSemaphoreFeaturesKHR;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
• **timelineSemaphore** indicates whether semaphores created with a **VkSemaphoreType** of **VK_SEMAPHORE_TYPE_TIMELINE** are supported.

If the **VkPhysicalDeviceTimelineSemaphoreFeatures** structure is included in the **pNext** chain of the **VkPhysicalDeviceFeatures2** structure passed to **vkGetPhysicalDeviceFeatures2**, it is filled in to indicate whether each corresponding feature is supported. **VkPhysicalDeviceTimelineSemaphoreFeatures** can also be used in the **pNext** chain of **VkDeviceCreateInfo** to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceTimelineSemaphoreFeatures-sType-sType**
  - **sType** must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TIMELINE_SEMAPHORE_FEATURES**

The **VkPhysicalDeviceExternalMemoryScreenBufferFeaturesQNX** structure is defined as:

```c
// Provided by VK_QNX_external_memory_screen_buffer
typedef struct VkPhysicalDeviceExternalMemoryScreenBufferFeaturesQNX {
    VkStructureType sType;
    void* pNext;
    VkBool32 screenBufferImport;
} VkPhysicalDeviceExternalMemoryScreenBufferFeaturesQNX;
```

The members of the **VkPhysicalDeviceExternalMemoryScreenBufferFeaturesQNX** structure describe the following features:

- **screenBufferImport** indicates whether QNX Screen buffer import functionality is supported. If **screenBufferImport** is set to **VK_TRUE**, **VkDeviceMemory** supports importing **_screen_buffer** from applications. In this case, the application is responsible for the resource management of the **_screen_buffer**.

**Table 55. Functionality supported for QNX Screen Buffer features**

<table>
<thead>
<tr>
<th>Features</th>
<th>Functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>screenBufferImport</td>
<td>VkImportScreenBufferInfoQNX</td>
</tr>
<tr>
<td>Always supported</td>
<td>vkGetScreenBufferPropertiesQNX, VkScreenBufferPropertiesQNX,</td>
</tr>
<tr>
<td></td>
<td>VkScreenBufferFormatPropertiesQNX, VkExternalFormatQNX</td>
</tr>
</tbody>
</table>

1 Functionality in this row is always available.

The **Functionality supported for QNX Screen buffer features** table summarizes the functionality enabled by the **VkPhysicalDeviceExternalMemoryScreenBufferFeaturesQNX** structure. Each entry in the body of the table summarizes the functionality that **can** be used when the given features are supported and enabled. This summarizes Valid Usage statements that are added elsewhere in this
specification.

If the `VkPhysicalDeviceExternalMemoryScreenBufferFeaturesQNX` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceExternalMemoryScreenBufferFeaturesQNX` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceExternalMemoryScreenBufferFeaturesQNX-sType-sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_MEMORY_SCREEN_BUFFER_FEATURES_QNX`

The `VkPhysicalDeviceIndexTypeUint8FeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_index_type_uint8
typedef struct VkPhysicalDeviceIndexTypeUint8FeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 indexTypeUint8;
} VkPhysicalDeviceIndexTypeUint8FeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `indexTypeUint8` indicates that `VK_INDEX_TYPE_UINT8_EXT` can be used with `vkCmdBindIndexBuffer2KHR` and `vkCmdBindIndexBuffer`.

If the `VkPhysicalDeviceIndexTypeUint8FeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceIndexTypeUint8FeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceIndexTypeUint8FeaturesEXT-sType-sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INDEX_TYPE_UINT8_FEATURES_EXT`

The `VkPhysicalDevicePrimitiveTopologyListRestartFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_primitive_topology_list_restart
typedef struct VkPhysicalDevicePrimitiveTopologyListRestartFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 isListRestartSupported;
    VkBool32 isListRestartMirroringSupported;
} VkPhysicalDevicePrimitiveTopologyListRestartFeaturesEXT;
```
This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **primitiveTopologyListRestart** indicates that list type primitives, `VK_PRIMITIVE_TOPOLOGY_POINT_LIST`, `VK_PRIMITIVE_TOPOLOGY_LINE_LIST`, `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST`, `VK_PRIMITIVE_TOPOLOGY_LINE_LIST_WITH_ADJACENCY` and `VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST_WITH_ADJACENCY`, can use the primitive restart index value in index buffers.
- **primitiveTopologyPatchListRestart** indicates that the `VK_PRIMITIVE_TOPOLOGY_PATCH_LIST` topology can use the primitive restart index value in index buffers.

If the `VkPhysicalDevicePrimitiveTopologyListRestartFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDevicePrimitiveTopologyListRestartFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDevicePrimitiveTopologyListRestartFeaturesEXT-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRIMITIVE_TOPOLOGY_LIST_RESTART_FEATURES_EXT`

The `VkPhysicalDeviceShaderSMBuiltinsFeaturesNV` structure is defined as:

```c
// Provided by VK_NV_shader_sm_builtins
typedef struct VkPhysicalDeviceShaderSMBuiltinsFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderSMBuiltins;
} VkPhysicalDeviceShaderSMBuiltinsFeaturesNV;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **shaderSMBuiltins** indicates whether the implementation supports the SPIR-V `ShaderSMBuiltinsNV` capability.
If the `VkPhysicalDeviceShader SMBuiltinsFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceShader SMBuiltinsFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceShader SMBuiltinsFeaturesNV-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_SM_BUILTINS_FEATURES_NV`

The `VkPhysicalDeviceSeparateDepthStencilLayoutsFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceSeparateDepthStencilLayoutsFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 separateDepthStencilLayouts;
} VkPhysicalDeviceSeparateDepthStencilLayoutsFeatures;
```

or the equivalent

```c
// Provided by VK_KHR_separate_depth_stencil_layouts
typedef VkPhysicalDeviceSeparateDepthStencilLayoutsFeatures
    VkPhysicalDeviceSeparateDepthStencilLayoutsFeaturesKHR;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `separateDepthStencilLayouts` indicates whether the implementation supports a `VkImageMemoryBarrier` for a depth/stencil image with only one of `VK_IMAGE_ASPECT_DEPTH_BIT` or `VK_IMAGE_ASPECT_STENCIL_BIT` set, and whether `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL`, `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL`, `VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL`, or `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL` can be used.

If the `VkPhysicalDeviceSeparateDepthStencilLayoutsFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceSeparateDepthStencilLayoutsFeatures` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)
The `VkPhysicalDevicePipelineExecutablePropertiesFeaturesKHR` structure is defined as:

```c
// Provided by VK_KHR_pipeline_executable_properties
typedef struct VkPhysicalDevicePipelineExecutablePropertiesFeaturesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 pipelineExecutableInfo;
} VkPhysicalDevicePipelineExecutablePropertiesFeaturesKHR;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `pipelineExecutableInfo` indicates that the implementation supports reporting properties and statistics about the pipeline executables associated with a compiled pipeline.

If the `VkPhysicalDevicePipelineExecutablePropertiesFeaturesKHR` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDevicePipelineExecutablePropertiesFeaturesKHR` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDevicePipelineExecutablePropertiesFeaturesKHR-sType-sType must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_EXECUTABLE_PROPERTIES_FEATURES_KHR`

The `VkPhysicalDeviceShaderDemoteToHelperInvocationFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceShaderDemoteToHelperInvocationFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderDemoteToHelperInvocation;
} VkPhysicalDeviceShaderDemoteToHelperInvocationFeatures;
```

or the equivalent

```c
// Provided by VK_EXT_shader_demote_to_helper_invocation
typedef VkPhysicalDeviceShaderDemoteToHelperInvocationFeatures
```
This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **shaderDemoteToHelperInvocation** indicates whether the implementation supports the SPIR-V DemoteToHelperInvocationEXT capability.

If the `VkPhysicalDeviceShaderDemoteToHelperInvocationFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceShaderDemoteToHelperInvocationFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceShaderDemoteToHelperInvocationFeatures-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_DEMOTE_TO_HELPER_INVOCATION_FEATURES`.

The `VkPhysicalDeviceTexelBufferAlignmentFeaturesEXT` structure is defined as:

```c
typedef struct VkPhysicalDeviceTexelBufferAlignmentFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 texelBufferAlignment;
} VkPhysicalDeviceTexelBufferAlignmentFeaturesEXT;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **texelBufferAlignment** indicates whether the implementation uses more specific alignment requirements advertised in `VkPhysicalDeviceTexelBufferAlignmentProperties` rather than `VkPhysicalDeviceLimits::minTexelBufferOffsetAlignment`.

If the `VkPhysicalDeviceTexelBufferAlignmentFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceTexelBufferAlignmentFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceTexelBufferAlignmentFeaturesEXT-sType-sType
  sType **must** be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXEL_BUFFER_ALIGNMENT_FEATURES_EXT`

The `VkPhysicalDeviceAttachmentFeedbackLoopDynamicStateFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_attachment_feedback_loop_dynamic_state
typedef struct VkPhysicalDeviceAttachmentFeedbackLoopDynamicStateFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 attachmentFeedbackLoopDynamicState;
} VkPhysicalDeviceAttachmentFeedbackLoopDynamicStateFeaturesEXT;
```

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **attachmentFeedbackLoopDynamicState** specifies whether dynamic feedback loops are supported.

If the `VkPhysicalDeviceAttachmentFeedbackLoopDynamicStateFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceAttachmentFeedbackLoopDynamicStateFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceAttachmentFeedbackLoopDynamicStateFeaturesEXT-sType-sType
  sType **must** be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ATTACHMENT_FEEDBACK_LOOP_DYNAMIC_STATE_FEATURES_EXT`

The `VkPhysicalDeviceTextureCompressionASTCHDRFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceTextureCompressionASTCHDRFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 textureCompressionASTC_HDR;
} VkPhysicalDeviceTextureCompressionASTCHDRFeatures;
```

or the equivalent

```c
// Provided by VK_EXT_texture_compression_astc_hdr
```
typedef VkPhysicalDeviceTextureCompressionASTCHDRFeatures
VkPhysicalDeviceTextureCompressionASTCHDRFeaturesEXT;

This structure describes the following feature:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.

- **textureCompressionASTC_HDR** indicates whether all of the ASTC HDR compressed texture formats are supported. If this feature is enabled, then the VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT, VK_FORMAT_FEATURE_BLIT_SRC_BIT and VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT features must be supported in optimalTilingFeatures for the following formats:
  - VK_FORMAT_ASTC_4x4_SFLOAT_BLOCK
  - VK_FORMAT_ASTC_5x4_SFLOAT_BLOCK
  - VK_FORMAT_ASTC_5x5_SFLOAT_BLOCK
  - VK_FORMAT_ASTC_6x5_SFLOAT_BLOCK
  - VK_FORMAT_ASTC_6x6_SFLOAT_BLOCK
  - VK_FORMAT_ASTC_8x5_SFLOAT_BLOCK
  - VK_FORMAT_ASTC_8x6_SFLOAT_BLOCK
  - VK_FORMAT_ASTC_8x8_SFLOAT_BLOCK
  - VK_FORMAT_ASTC_10x5_SFLOAT_BLOCK
  - VK_FORMAT_ASTC_10x6_SFLOAT_BLOCK
  - VK_FORMAT_ASTC_10x8_SFLOAT_BLOCK
  - VK_FORMAT_ASTC_10x10_SFLOAT_BLOCK
  - VK_FORMAT_ASTC_12x10_SFLOAT_BLOCK
  - VK_FORMAT_ASTC_12x12_SFLOAT_BLOCK

To query for additional properties, or if the feature is not enabled, vkGetPhysicalDeviceFormatProperties and vkGetPhysicalDeviceImageFormatProperties can be used to check for supported properties of individual formats as normal.

If the VkPhysicalDeviceTextureCompressionASTCHDRFeatures structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceTextureCompressionASTCHDRFeatures can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceTextureCompressionASTCHDRFeatures-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXTURE_COMPRESSION_ASTC_HDR_FEATURES
The **VkPhysicalDeviceLineRasterizationFeaturesEXT** structure is defined as:

```c
// Provided by VK_EXT_line_rasterization
typedef struct VkPhysicalDeviceLineRasterizationFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 rectangularLines;
    VkBool32 bresenhamLines;
    VkBool32 smoothLines;
    VkBool32 stippledRectangularLines;
    VkBool32 stippledBresenhamLines;
    VkBool32 stippledSmoothLines;
} VkPhysicalDeviceLineRasterizationFeaturesEXT;
```

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **rectangularLines** indicates whether the implementation supports rectangular line rasterization.
- **bresenhamLines** indicates whether the implementation supports Bresenham-style line rasterization.
- **smoothLines** indicates whether the implementation supports smooth line rasterization.
- **stippledRectangularLines** indicates whether the implementation supports stippled line rasterization with `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_EXT` lines.
- **stippledBresenhamLines** indicates whether the implementation supports stippled line rasterization with `VK_LINE_RASTERIZATION_MODE_BRESENHAM_EXT` lines.
- **stippledSmoothLines** indicates whether the implementation supports stippled line rasterization with `VK_LINE_RASTERIZATION_MODE_RECTANGULAR_SMOOTH_EXT` lines.

If the `VkPhysicalDeviceLineRasterizationFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceLineRasterizationFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- **VUID-VkPhysicalDeviceLineRasterizationFeaturesEXT-sType-sType**

  `sType` **must** be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_LINE_RASTERIZATION_FEATURES_EXT`

The **VkPhysicalDeviceSubgroupSizeControlFeatures** structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceSubgroupSizeControlFeatures {
```
VkStructureType sType;
void* pNext;
VkBool32 subgroupSizeControl;
VkBool32 computeFullSubgroups;
} VkPhysicalDeviceSubgroupSizeControlFeatures;

or the equivalent

// Provided by VK_EXT_subgroup_size_control
typedef VkPhysicalDeviceSubgroupSizeControlFeatures VkPhysicalDeviceSubgroupSizeControlFeaturesEXT;

This structure describes the following features:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **subgroupSizeControl** indicates whether the implementation supports controlling shader subgroup sizes via the VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT flag and the VkPipelineShaderStageRequiredSubgroupSizeCreateInfo structure.
- **computeFullSubgroups** indicates whether the implementation supports requiring full subgroups in compute, mesh, or task shaders via the VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT flag.

If the VkPhysicalDeviceSubgroupSizeControlFeatures structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceSubgroupSizeControlFeatures can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

**Note**

The VkPhysicalDeviceSubgroupSizeControlFeaturesEXT structure was added in version 2 of the VK_EXT_subgroup_size_control extension. Version 1 implementations of this extension will not fill out the features structure but applications may assume that both subgroupSizeControl and computeFullSubgroups are supported if the extension is supported. (See also the Feature Requirements section.) Applications are advised to add a VkPhysicalDeviceSubgroupSizeControlFeaturesEXT structure to the pNext chain of VkDeviceCreateInfo to enable the features regardless of the version of the extension supported by the implementation. If the implementation only supports version 1, it will safely ignore the VkPhysicalDeviceSubgroupSizeControlFeaturesEXT structure.

Vulkan 1.3 implementations always support the features structure.
The `VkPhysicalDeviceCoherentMemoryFeaturesAMD` structure is defined as:

```c
// Provided by VK_AMD_device_coherent_memory
typedef struct VkPhysicalDeviceCoherentMemoryFeaturesAMD {
    VkStructureType sType;
    void* pNext;
    VkBool32 deviceCoherentMemory;
} VkPhysicalDeviceCoherentMemoryFeaturesAMD;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `deviceCoherentMemory` indicates that the implementation supports device coherent memory.

If the `VkPhysicalDeviceCoherentMemoryFeaturesAMD` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceCoherentMemoryFeaturesAMD` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

The `VkPhysicalDeviceAccelerationStructureFeaturesKHR` structure is defined as:

```c
// Provided by VK_KHR_acceleration_structure
typedef struct VkPhysicalDeviceAccelerationStructureFeaturesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 accelerationStructure;
    VkBool32 accelerationStructureCaptureReplay;
    VkBool32 accelerationStructureIndirectBuild;
    VkBool32 accelerationStructureHostCommands;
    VkBool32 descriptorBindingAccelerationStructureUpdateAfterBind;
} VkPhysicalDeviceAccelerationStructureFeaturesKHR;
```

This structure describes the following features:
- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **accelerationStructure** indicates whether the implementation supports the acceleration structure functionality. See Acceleration Structures.
- **accelerationStructureCaptureReplay** indicates whether the implementation supports saving and reusing acceleration structure device addresses, e.g. for trace capture and replay.
- **accelerationStructureIndirectBuild** indicates whether the implementation supports indirect acceleration structure build commands, e.g. `vkCmdBuildAccelerationStructuresIndirectKHR`.
- **accelerationStructureHostCommands** indicates whether the implementation supports host side acceleration structure commands, e.g. `vkBuildAccelerationStructuresKHR`, `vkCopyAccelerationStructureKHR`, `vkCopyMemoryToAccelerationStructureKHR`, `vkCopyAccelerationStructureToMemoryKHR`, `vkWriteAccelerationStructuresPropertiesKHR`.
- **descriptorBindingAccelerationStructureUpdateAfterBind** indicates whether the implementation supports updating acceleration structure descriptors after a set is bound. If this feature is not enabled, `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT` must not be used with `VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR`.

If the `VkPhysicalDeviceAccelerationStructureFeaturesKHR` structure is included in the **pNext** chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceAccelerationStructureFeaturesKHR` can also be used in the **pNext** chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceAccelerationStructureFeaturesKHR-sType-sType
  
  **sType** must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ACCELERATION_STRUCTURE_FEATURES_KHR`

The `VkPhysicalDeviceRayTracingPipelineFeaturesKHR` structure is defined as:

```c
// Provided by VK_KHR_ray_tracing_pipeline
typedef struct VkPhysicalDeviceRayTracingPipelineFeaturesKHR {
    VkStructureType   sType;
    void*             pNext;
    VkBool32          rayTracingPipeline;
    VkBool32          rayTracingPipelineShaderGroupHandleCaptureReplay;
    VkBool32          rayTracingPipelineShaderGroupHandleCaptureReplayMixed;
    VkBool32          rayTraversalPrimitiveCulling;
} VkPhysicalDeviceRayTracingPipelineFeaturesKHR;
```

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **rayTracingPipeline** indicates whether the implementation supports the ray tracing pipeline functionality. See Ray Tracing.

• **rayTracingPipelineShaderGroupHandleCaptureReplay** indicates whether the implementation supports saving and reusing shader group handles, e.g. for trace capture and replay.

• **rayTracingPipelineShaderGroupHandleCaptureReplayMixed** indicates whether the implementation supports reuse of shader group handles being arbitrarily mixed with creation of non-reused shader group handles. If this is **VK_FALSE**, all reused shader group handles **must** be specified before any non-reused handles **may** be created.

• **rayTracingPipelineTraceRaysIndirect** indicates whether the implementation supports indirect ray tracing commands, e.g. **vkCmdTraceRaysIndirectKHR**.

• **rayTraversalPrimitiveCulling** indicates whether the implementation supports **primitive culling** during ray traversal.

If the **VkPhysicalDeviceRayTracingPipelineFeaturesKHR** structure is included in the **pNext** chain of the **VkPhysicalDeviceFeatures2** structure passed to **vkGetPhysicalDeviceFeatures2**, it is filled in to indicate whether each corresponding feature is supported. **VkPhysicalDeviceRayTracingPipelineFeaturesKHR** can also be used in the **pNext** chain of **VkDeviceCreateInfo** to selectively enable these features.

### Valid Usage

- **VUID-VkPhysicalDeviceRayTracingPipelineFeaturesKHR-rayTracingPipelineShaderGroupHandleCaptureReplayMixed-03575**

  If **rayTracingPipelineShaderGroupHandleCaptureReplayMixed** is **VK_TRUE**, **rayTracingPipelineShaderGroupHandleCaptureReplay** **must** also be **VK_TRUE**

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceRayTracingPipelineFeaturesKHR-sType-sType**

  **sType** **must** be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_PIPELINE_FEATURES_KHR**

The **VkPhysicalDeviceRayQueryFeaturesKHR** structure is defined as:

```c
// Provided by VK_KHR_ray_query
typedef struct VkPhysicalDeviceRayQueryFeaturesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 rayQuery;
} VkPhysicalDeviceRayQueryFeaturesKHR;
```

This structure describes the following feature:

- **sType** is a **VkStructureType** value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.

• **rayQuery** indicates whether the implementation supports ray query (**OpRayQueryProceedKHR**) functionality.

If the **VkPhysicalDeviceRayQueryFeaturesKHR** structure is included in the **pNext** chain of the ** VkPhysicalDeviceFeatures2** structure passed to **vkGetPhysicalDeviceFeatures2**, it is filled in to indicate whether each corresponding feature is supported. **VkPhysicalDeviceRayQueryFeaturesKHR** can also be used in the **pNext** chain of **VkDeviceCreateInfo** to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceRayQueryFeaturesKHR-sType-sType**  
  - **sType** must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_QUERY_FEATURES_KHR**

The **VkPhysicalDeviceRayTracingMaintenance1FeaturesKHR** structure is defined as:

```c
// Provided by VK_KHR_ray_tracing_maintenance1
typedef struct VkPhysicalDeviceRayTracingMaintenance1FeaturesKHR {
  VkStructureType sType;
  void* pNext;
  VkBool32 rayTracingMaintenance1;
  VkBool32 rayTracingPipelineTraceRaysIndirect2;
} VkPhysicalDeviceRayTracingMaintenance1FeaturesKHR;
```

This structure describes the following features:

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **rayTracingMaintenance1** indicates that the implementation supports the following:
  - The **CullMaskKHR** SPIR-V builtin using the **SPV_KHR_ray_cull_mask** SPIR-V extension.
  - Additional acceleration structure property queries:  
    - **VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_BOTTOM_LEVEL_POINTERS_KHR** and  
    - **VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SIZE_KHR**.
  - A new access flag **VK_ACCESS_2_SHADER_BINDING_TABLE_READ_BIT_KHR**.
  - A new pipeline stage flag bit **VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR**.
- **rayTracingPipelineTraceRaysIndirect2** indicates whether the implementation supports the extended indirect ray tracing command **vkCmdTraceRaysIndirect2KHR**.

If the **VkPhysicalDeviceRayTracingMaintenance1FeaturesKHR** structure is included in the **pNext** chain of the **VkPhysicalDeviceFeatures2** structure passed to **vkGetPhysicalDeviceFeatures2**, it is filled in to indicate whether each corresponding feature is supported. **VkPhysicalDeviceRayTracingMaintenance1FeaturesKHR** can also be used in the **pNext** chain of **VkDeviceCreateInfo** to selectively enable these features.
The `VkPhysicalDeviceExtendedDynamicStateFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_extended_dynamic_state
typedef struct VkPhysicalDeviceExtendedDynamicStateFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 extendedDynamicState;
} VkPhysicalDeviceExtendedDynamicStateFeaturesEXT;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **extendedDynamicState** indicates that the implementation supports the following dynamic states:

  - `VK_DYNAMIC_STATE_CULL_MODE`
  - `VK_DYNAMIC_STATE_FRONT_FACE`
  - `VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY`
  - `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT`
  - `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT`
  - `VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE`
  - `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE`
  - `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE`
  - `VK_DYNAMIC_STATE_DEPTHCOMPARE_OP`
  - `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE`
  - `VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE`
  - `VK_DYNAMIC_STATE_STENCILOP`

If the `VkPhysicalDeviceExtendedDynamicStateFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceExtendedDynamicStateFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.
The `VkPhysicalDeviceExtendedDynamicState2FeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_extended_dynamic_state2
typedef struct VkPhysicalDeviceExtendedDynamicState2FeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 extendedDynamicState2;
    VkBool32 extendedDynamicState2LogicOp;
    VkBool32 extendedDynamicState2PatchControlPoints;
} VkPhysicalDeviceExtendedDynamicState2FeaturesEXT;
```

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **extendedDynamicState2** indicates that the implementation supports the following dynamic states:
  - `VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE`
  - `VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE`
  - `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE`
- **extendedDynamicState2LogicOp** indicates that the implementation supports the following dynamic state:
  - `VK_DYNAMIC_STATE_LOGIC_OP_EXT`
- **extendedDynamicState2PatchControlPoints** indicates that the implementation supports the following dynamic state:
  - `VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT`

If the `VkPhysicalDeviceExtendedDynamicState2FeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceExtendedDynamicState2FeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.
The VkPhysicalDeviceExtendedDynamicState3FeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_extended_dynamic_state3
typedef struct VkPhysicalDeviceExtendedDynamicState3FeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 extendedDynamicState3TessellationDomainOrigin;
    VkBool32 extendedDynamicState3DepthClampEnable;
    VkBool32 extendedDynamicState3PolygonMode;
    VkBool32 extendedDynamicState3RasterizationSamples;
    VkBool32 extendedDynamicState3SampleMask;
    VkBool32 extendedDynamicState3AlphaToCoverageEnable;
    VkBool32 extendedDynamicState3AlphaToOneEnable;
    VkBool32 extendedDynamicState3LogicOpEnable;
    VkBool32 extendedDynamicState3ColorBlendEnable;
    VkBool32 extendedDynamicState3ColorWriteMask;
    VkBool32 extendedDynamicState3RasterizationStream;
    VkBool32 extendedDynamicState3ConservativeRasterizationMode;
    VkBool32 extendedDynamicState3ExtraPrimitiveOverestimationSize;
    VkBool32 extendedDynamicState3SampleLocationsEnable;
    VkBool32 extendedDynamicState3ColorBlendAdvanced;
    VkBool32 extendedDynamicState3ProvokingVertexMode;
    VkBool32 extendedDynamicState3LineRasterizationMode;
    VkBool32 extendedDynamicState3LineStippleEnable;
    VkBool32 extendedDynamicState3DepthClipNegativeOneToOne;
    VkBool32 extendedDynamicState3ViewportWScalingEnable;
    VkBool32 extendedDynamicState3ViewportSwizzle;
    VkBool32 extendedDynamicState3CoverageToColorEnable;
    VkBool32 extendedDynamicState3CoverageToColorLocation;
    VkBool32 extendedDynamicState3CoverageModulationMode;
    VkBool32 extendedDynamicState3CoverageModulationTableEnable;
    VkBool32 extendedDynamicState3CoverageModulationTable;
    VkBool32 extendedDynamicState3CoverageReductionMode;
    VkBool32 extendedDynamicState3RepresentativeFragmentTestEnable;
    VkBool32 extendedDynamicState3ShadingRateImageEnable;
} VkPhysicalDeviceExtendedDynamicState3FeaturesEXT;
```

This structure describes the following features:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **extendedDynamicState3TessellationDomainOrigin** indicates that the implementation supports the following dynamic state:
  - VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT
- **extendedDynamicState3DepthClampEnable** indicates that the implementation supports the following dynamic state:
- VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT
- extendedDynamicState3PolygonMode indicates that the implementation supports the following dynamic state:
  - VK_DYNAMIC_STATE_POLYGON_MODE_EXT
- extendedDynamicState3RasterizationSamples indicates that the implementation supports the following dynamic state:
  - VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT
- extendedDynamicState3SampleMask indicates that the implementation supports the following dynamic state:
  - VK_DYNAMIC_STATE_SAMPLE_MASK_EXT
- extendedDynamicState3AlphaToCoverageEnable indicates that the implementation supports the following dynamic state:
  - VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT
- extendedDynamicState3AlphaToOneEnable indicates that the implementation supports the following dynamic state:
  - VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT
- extendedDynamicState3LogicOpEnable indicates that the implementation supports the following dynamic state:
  - VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT
- extendedDynamicState3ColorBlendEnable indicates that the implementation supports the following dynamic state:
  - VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT
- extendedDynamicState3ColorBlendEquation indicates that the implementation supports the following dynamic state:
  - VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT
- extendedDynamicState3ColorWriteMask indicates that the implementation supports the following dynamic state:
  - VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT
- extendedDynamicState3RasterizationStream indicates that the implementation supports the following dynamic state:
  - VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT
- extendedDynamicState3ConservativeRasterizationMode indicates that the implementation supports the following dynamic state:
  - VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT
- extendedDynamicState3ExtraPrimitiveOverestimationSize indicates that the implementation supports the following dynamic state:
  - VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT
- extendedDynamicState3DepthClipEnable indicates that the implementation supports the following
dynamic state:
  ◦ VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT

extendedDynamicState3SampleLocationsEnable indicates that the implementation supports the following dynamic state:
  ◦ VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT

extendedDynamicState3ColorBlendAdvanced indicates that the implementation supports the following dynamic state:
  ◦ VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT

extendedDynamicState3ProvokingVertexMode indicates that the implementation supports the following dynamic state:
  ◦ VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT

extendedDynamicState3LineRasterizationMode indicates that the implementation supports the following dynamic state:
  ◦ VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT

extendedDynamicState3LineStippleEnable indicates that the implementation supports the following dynamic state:
  ◦ VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT

extendedDynamicState3DepthClipNegativeOneToOne indicates that the implementation supports the following dynamic state:
  ◦ VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT

extendedDynamicState3ViewportWScalingEnable indicates that the implementation supports the following dynamic state:
  ◦ VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV

extendedDynamicState3ViewportSwizzle indicates that the implementation supports the following dynamic state:
  ◦ VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV

extendedDynamicState3CoverageToColorEnable indicates that the implementation supports the following dynamic state:
  ◦ VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV

extendedDynamicState3CoverageToColorLocation indicates that the implementation supports the following dynamic state:
  ◦ VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV

extendedDynamicState3CoverageModulationMode indicates that the implementation supports the following dynamic state:
  ◦ VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV

extendedDynamicState3CoverageModulationTableEnable indicates that the implementation supports the following dynamic state:
  ◦ VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV
• `extendedDynamicState3CoverageModulationTable` indicates that the implementation supports the following dynamic state:
  ◦ `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV`

• `extendedDynamicState3CoverageReductionMode` indicates that the implementation supports the following dynamic state:
  ◦ `VK_DYNAMIC_STATE_COVERAGE_REDUCTION_MODE_NV`

• `extendedDynamicState3RepresentativeFragmentTestEnable` indicates that the implementation supports the following dynamic state:
  ◦ `VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV`

• `extendedDynamicState3ShadingRateImageEnable` indicates that the implementation supports the following dynamic state:
  ◦ `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV`

If the `VkPhysicalDeviceExtendedDynamicState3FeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceExtendedDynamicState3FeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceExtendedDynamicState3FeaturesEXT-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTENDED_DYNAMIC_STATE_3_FEATURES_EXT`

The `VkPhysicalDeviceDeviceGeneratedCommandsFeaturesNV` structure is defined as:

```c
// Provided by VK_NV_device_generated_commands
typedef struct VkPhysicalDeviceDeviceGeneratedCommandsFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 deviceGeneratedCommands;
} VkPhysicalDeviceDeviceGeneratedCommandsFeaturesNV;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `deviceGeneratedCommands` indicates whether the implementation supports functionality to generate commands on the device. See Device-Generated Commands.

If the `VkPhysicalDeviceDeviceGeneratedCommandsFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported.
VkPhysicalDeviceDeviceGeneratedCommandsFeaturesNV can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDeviceGeneratedCommandsFeaturesNV-sType-sType
  
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEVICE_GENERATED_COMMANDSFEATURES_NV

The VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV structure is defined as:

```c
// Provided by VK_NV_device_generated_commands_compute
typedef struct VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 deviceGeneratedCompute;
    VkBool32 deviceGeneratedComputePipelines;
    VkBool32 deviceGeneratedComputeCaptureReplay;
} VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV;
```

This structure describes the following features:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **deviceGeneratedCompute** indicates whether the implementation supports functionality to generate dispatch commands and push constants for the compute pipeline on the device. See Device-Generated Commands.
- **deviceGeneratedComputePipelines** indicates whether the implementation supports functionality to generate commands to bind compute pipelines on the device. See Device-Generated Commands.
- **deviceGeneratedComputeCaptureReplay** indicates whether the implementation supports functionality to capture compute pipeline address and reuse later for replay in Device-Generated Commands.

If the VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV-sType-sType
  
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEVICE_GENERATED_COMMANDSCOMPUTEFEATURES_NV
The `VkPhysicalDeviceDiagnosticsConfigFeaturesNV` structure is defined as:

```c
typedef struct VkPhysicalDeviceDiagnosticsConfigFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 diagnosticsConfig;
} VkPhysicalDeviceDiagnosticsConfigFeaturesNV;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `diagnosticsConfig` indicates whether the implementation supports the ability to configure diagnostic tools.

If the `VkPhysicalDeviceDiagnosticsConfigFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceDiagnosticsConfigFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceDiagnosticsConfigFeaturesNV-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DIAGNOSTICS_CONFIG_FEATURES_NV`

The `VkPhysicalDeviceDeviceMemoryReportFeaturesEXT` structure is defined as:

```c
typedef struct VkPhysicalDeviceDeviceMemoryReportFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 deviceMemoryReport;
} VkPhysicalDeviceDeviceMemoryReportFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `deviceMemoryReport` indicates whether the implementation supports the ability to register device memory report callbacks.

If the `VkPhysicalDeviceDeviceMemoryReportFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to
indicate whether each corresponding feature is supported. 

VkPhysicalDeviceDeviceMemoryReportFeaturesEXT can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDeviceMemoryReportFeaturesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEVICE_MEMORY_REPORT_FEATURES_EXT

The VkPhysicalDeviceGlobalPriorityQueryFeaturesKHR structure is defined as:

```c
// Provided by VK_KHR_global_priority
typedef struct VkPhysicalDeviceGlobalPriorityQueryFeaturesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 globalPriorityQuery;
} VkPhysicalDeviceGlobalPriorityQueryFeaturesKHR;
```

or the equivalent

```c
// Provided by VK_EXT_global_priority_query
typedef VkPhysicalDeviceGlobalPriorityQueryFeaturesKHR
VkPhysicalDeviceGlobalPriorityQueryFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `globalPriorityQuery` indicates whether the implementation supports the ability to query global queue priorities.

If the VkPhysicalDeviceGlobalPriorityQueryFeaturesKHR structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceGlobalPriorityQueryFeaturesKHR can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceGlobalPriorityQueryFeaturesKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GLOBAL_PRIORITY_QUERY_FEATURES_KHR

The VkPhysicalDevicePipelineCreationCacheControlFeatures structure is defined as:

3520
typedef struct VkPhysicalDevicePipelineCreationCacheControlFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 pipelineCreationCacheControl;
} VkPhysicalDevicePipelineCreationCacheControlFeatures;

or the equivalent

typedef VkPhysicalDevicePipelineCreationCacheControlFeatures VkPhysicalDevicePipelineCreationCacheControlFeaturesEXT;

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **pipelineCreationCacheControl** indicates that the implementation supports:
  - The following can be used in `Vk*PipelineCreateInfo::flags`:
    - `VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT`
    - `VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT`
  - The following can be used in `VkPipelineCacheCreateInfo::flags`:
    - `VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT`

If the `VkPhysicalDevicePipelineCreationCacheControlFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDevicePipelineCreationCacheControlFeatures` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- `VUID-VkPhysicalDevicePipelineCreationCacheControlFeatures-sType-sType` `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_CREATION_CACHE_CONTROL_FEATURES`

The `VkPhysicalDeviceZeroInitializeWorkgroupMemoryFeatures` structure is defined as:

// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceZeroInitializeWorkgroupMemoryFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderZeroInitializeWorkgroupMemory;
} VkPhysicalDeviceZeroInitializeWorkgroupMemoryFeatures;
or the equivalent

```c
// Provided by VK_KHR_zero_initialize_workgroup_memory
typedef VkPhysicalDeviceZeroInitializeWorkgroupMemoryFeatures
VkPhysicalDeviceZeroInitializeWorkgroupMemoryFeaturesKHR;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `shaderZeroInitializeWorkgroupMemory` specifies whether the implementation supports initializing a variable in Workgroup storage class.

If the `VkPhysicalDeviceZeroInitializeWorkgroupMemoryFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceZeroInitializeWorkgroupMemoryFeatures` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- `VUID-VkPhysicalDeviceZeroInitializeWorkgroupMemoryFeatures-sType-sType
  sType must be
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ZERO_INITIALIZE_WORKGROUP_MEMORY_FEATURES`

The `VkPhysicalDevicePrivateDataFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDevicePrivateDataFeatures {
  VkStructureType sType;
  void* pNext;
  VkBool32 privateData;
} VkPhysicalDevicePrivateDataFeatures;
```

or the equivalent

```c
// Provided by VK_EXT_private_data
typedef VkPhysicalDevicePrivateDataFeatures VkPhysicalDevicePrivateDataFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.

• `privateData` indicates whether the implementation supports private data. See `Private Data`.

If the `VkPhysicalDevicePrivateDataFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDevicePrivateDataFeatures` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

Valid Usage (Implicit)

• `VUID-VkPhysicalDevicePrivateDataFeatures-sType-sType`

  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRIVATE_DATA_FEATURES`

The `VkPhysicalDeviceShaderSubgroupUniformControlFlowFeaturesKHR` structure is defined as:

```
// Provided by VK_KHR_shader_subgroup_uniform_control_flow
typedef struct VkPhysicalDeviceShaderSubgroupUniformControlFlowFeaturesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderSubgroupUniformControlFlow;
} VkPhysicalDeviceShaderSubgroupUniformControlFlowFeaturesKHR;
```

This structure describes the following feature:

• `sType` is a `VkStructureType` value identifying this structure.

• `pNext` is `NULL` or a pointer to a structure extending this structure.

• `shaderSubgroupUniformControlFlow` specifies whether the implementation supports the shader execution mode `SubgroupUniformControlFlowKHR`

If the `VkPhysicalDeviceShaderSubgroupUniformControlFlowFeaturesKHR` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceShaderSubgroupUniformControlFlowFeaturesKHR` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

Valid Usage (Implicit)

• `VUID-VkPhysicalDeviceShaderSubgroupUniformControlFlowFeaturesKHR-sType-sType`

  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_SUBGROUP_UNIFORM_CONTROL_FLOW_FEATURES_KHR`

The `VkPhysicalDeviceRobustness2FeaturesEXT` structure is defined as:

```
// Provided by VK_EXT_robustness2
```
typedef struct VkPhysicalDeviceRobustness2FeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 robustBufferAccess2;
    VkBool32 robustImageAccess2;
    VkBool32 nullDescriptor;
} VkPhysicalDeviceRobustness2FeaturesEXT;

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **robustBufferAccess2** indicates whether buffer accesses are tightly bounds-checked against the range of the descriptor. Uniform buffers must be bounds-checked to the range of the descriptor, where the range is rounded up to a multiple of `robustUniformBufferAccessSizeAlignment`. Storage buffers must be bounds-checked to the range of the descriptor, where the range is rounded up to a multiple of `robustStorageBufferAccessSizeAlignment`. Out of bounds buffer loads will return zero values, and image load, sample, and atomic operations from texel buffers will have (0,0,1) values inserted for missing G, B, or A components based on the format.
- **robustImageAccess2** indicates whether image accesses are tightly bounds-checked against the dimensions of the image view. Out of bounds image load, sample, and atomic operations from images will return zero values, with (0,0,1) values inserted for missing G, B, or A components based on the format.
- **nullDescriptor** indicates whether descriptors can be written with a `VK_NULL_HANDLE` resource or view, which are considered valid to access and act as if the descriptor were bound to nothing.

If the `VkPhysicalDeviceRobustness2FeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceRobustness2FeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage

- **VUID-VkPhysicalDeviceRobustness2FeaturesEXT-robustBufferAccess2-04000**
  If `robustBufferAccess2` is enabled then `robustBufferAccess` must also be enabled

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceRobustness2FeaturesEXT-sType-sType**
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ROBUSTNESS_2_FEATURES_EXT`
typedef struct VkPhysicalDeviceImageRobustnessFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 robustImageAccess;
} VkPhysicalDeviceImageRobustnessFeatures;

or the equivalent

typedef VkPhysicalDeviceImageRobustnessFeatures VkPhysicalDeviceImageRobustnessFeaturesEXT;

This structure describes the following feature:

• **sType** is a VkStructureType value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.
• **robustImageAccess** indicates whether image accesses are tightly bounds-checked against the dimensions of the image view. Invalid texels resulting from out of bounds image loads will be replaced as described in Texel Replacement, with either (0,0,1) or (0,0,0) values inserted for missing G, B, or A components based on the format.

If the VkPhysicalDeviceImageRobustnessFeatures structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceImageRobustnessFeatures can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

**Valid Usage (Implicit)**

• VUID-VkPhysicalDeviceImageRobustnessFeatures-sType-sType
  
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_ROBUSTNESS_FEATURES

The VkPhysicalDeviceShaderTerminateInvocationFeatures structure is defined as:

// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceShaderTerminateInvocationFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderTerminateInvocation;
} VkPhysicalDeviceShaderTerminateInvocationFeatures;

or the equivalent
typedef VkPhysicalDeviceShaderTerminateInvocationFeatures 
VkPhysicalDeviceShaderTerminateInvocationFeaturesKHR;

This structure describes the following feature:

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• shaderTerminateInvocation specifies whether the implementation supports SPIR-V modules that 
use the SPV_KHR_terminate_invocation extension.

If the VkPhysicalDeviceShaderTerminateInvocationFeatures structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceShaderTerminateInvocationFeatures-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_TERMINATE_INVOCATION_FEATURES

The VkPhysicalDeviceCustomBorderColorFeaturesEXT structure is defined as:

typedef struct VkPhysicalDeviceCustomBorderColorFeaturesEXT {
  VkStructureType sType;
  void* pNext;
  VkBool32 customBorderColors;
  VkBool32 customBorderColorWithoutFormat;
} VkPhysicalDeviceCustomBorderColorFeaturesEXT;

This structure describes the following features:

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• customBorderColors indicates that the implementation supports providing a borderColor value with one of the following values at sampler creation time:
  ◦ VK_BORDER_COLOR_FLOAT_CUSTOM_EXT
  ◦ VK_BORDER_COLOR_INT_CUSTOM_EXT
• customBorderColorWithoutFormat indicates that explicit formats are not required for custom border colors and the value of the format member of the VkSamplerCustomBorderColorCreateInfoEXT structure may be VK_FORMAT_UNDEFINED. If this
feature bit is not set, applications must provide the VkFormat of the image view(s) being sampled by this sampler in the format member of the VkSamplerCustomBorderColorCreateInfoEXT structure.

If the VkPhysicalDeviceCustomBorderColorFeaturesEXT structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceCustomBorderColorFeaturesEXT can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceCustomBorderColorFeaturesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CUSTOM_BORDER_COLOR_FEATURES_EXT

The VkPhysicalDeviceBorderColorSwizzleFeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_border_color_swizzle
typedef struct VkPhysicalDeviceBorderColorSwizzleFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 borderColorSwizzle;
    VkBool32 borderColorSwizzleFromImage;
} VkPhysicalDeviceBorderColorSwizzleFeaturesEXT;
```

This structure describes the following features:

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- borderColorSwizzle indicates that defined values are returned by sampled image operations when used with a sampler that uses a VK_BORDER_COLOR_FLOAT_OPAQUE_BLACK, VK_BORDER_COLOR_INT_OPAQUE_BLACK, VK_BORDER_COLOR_FLOAT_CUSTOM_EXT, or VK_BORDER_COLOR_INT_CUSTOM_EXT borderColor and an image view that uses a non-identity component mapping, when either borderColorSwizzleFromImage is enabled or the VkSamplerBorderColorComponentMappingCreateInfoEXT is specified.
- borderColorSwizzleFromImage indicates that the implementation will return the correct border color values from sampled image operations under the conditions expressed above, without the application having to specify the border color component mapping when creating the sampler object. If this feature bit is not set, applications can chain a VkSamplerBorderColorComponentMappingCreateInfoEXT structure when creating samplers for use with image views that do not have an identity swizzle and, when those samplers are combined with image views using the same component mapping, sampled image operations that use opaque black or custom border colors will return the correct border color values.

If the VkPhysicalDeviceBorderColorSwizzleFeaturesEXT structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to
indicate whether each corresponding feature is supported. 

VkPhysicalDeviceBorderColorSwizzleFeaturesEXT can also be used in the pNext chain of 

VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceBorderColorSwizzleFeaturesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BORDER_COLOR_SWIZZLE_FEATURES_EXT

The VkPhysicalDevicePortabilitySubsetFeaturesKHR structure is defined as:

```c
// Provided by VK_KHR_portability_subset
typedef struct VkPhysicalDevicePortabilitySubsetFeaturesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 constantAlphaColorBlendFactors;
    VkBool32 events;
    VkBool32 imageViewFormatReinterpretation;
    VkBool32 imageViewFormatSwizzle;
    VkBool32 imageView2DOn3DImage;
    VkBool32 multisampleArrayImage;
    VkBool32 mutableComparisonSamplers;
    VkBool32 pointPolygons;
    VkBool32 samplerMipLodBias;
    VkBool32 separateStencilMaskRef;
    VkBool32 shaderSampleRateInterpolationFunctions;
    VkBool32 tessellationIsolines;
    VkBool32 tessellationPointMode;
    VkBool32 triangleFans;
    VkBool32 vertexAttributeAccessBeyondStride;
} VkPhysicalDevicePortabilitySubsetFeaturesKHR;
```

This structure describes the following features:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **constantAlphaColorBlendFactors** indicates whether this implementation supports constant alpha Blend Factors used as source or destination color Blending.
- **events** indicates whether this implementation supports synchronization using Events.
- **imageViewFormatReinterpretation** indicates whether this implementation supports a VkImageView being created with a texel format containing a different number of components, or a different number of bits in each component, than the texel format of the underlying VkImage.
- **imageViewFormatSwizzle** indicates whether this implementation supports remapping format components using VkImageViewCreateInfo::components.
- **imageView2DOn3DImage** indicates whether this implementation supports a VkImage being created
with the `VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT` flag set, permitting a 2D or 2D array image view to be created on a 3D `VkImage`.

- `multisampleArrayImage` indicates whether this implementation supports a `VkImage` being created as a 2D array with multiple samples per texel.

- `mutableComparisonSamplers` indicates whether this implementation allows descriptors with comparison samplers to be updated.

- `pointPolygons` indicates whether this implementation supports Rasterization using a point Polygon Mode.

- `samplerMipLodBias` indicates whether this implementation supports setting a mipmap LOD bias value when creating a sampler.

- `separateStencilMaskRef` indicates whether this implementation supports separate front and back Stencil Test reference values.

- `shaderSampleRateInterpolationFunctions` indicates whether this implementation supports fragment shaders which use the `InterpolationFunction` capability and the extended instructions `InterpolateAtCentroid`, `InterpolateAtOffset`, and `InterpolateAtSample` from the GLSL.std.450 extended instruction set. This member is only meaningful if the `sampleRateShading` feature is supported.

- `tessellationIsolines` indicates whether this implementation supports isoline output from the Tessellation stage of a graphics pipeline. This member is only meaningful if `tessellationShader` are supported.

- `tessellationPointMode` indicates whether this implementation supports point output from the Tessellation stage of a graphics pipeline. This member is only meaningful if `tessellationShader` are supported.

- `triangleFans` indicates whether this implementation supports Triangle Fans primitive topology.

- `vertexAttributeAccessBeyondStride` indicates whether this implementation supports accessing a vertex input attribute beyond the stride of the corresponding vertex input binding.

If the `VkPhysicalDevicePortabilitySubsetFeaturesKHR` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDevicePortabilitySubsetFeaturesKHR` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- `VUID-VkPhysicalDevicePortabilitySubsetFeaturesKHR-sType-sType` `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PORTABILITY_SUBSET_FEATURES_KHR`

The `VkPhysicalDevicePerformanceQueryFeaturesKHR` structure is defined as:

```c
// Provided by VK_KHR_performance_query
typedef struct VkPhysicalDevicePerformanceQueryFeaturesKHR {
    VkStructureType sType;
} VkPhysicalDevicePerformanceQueryFeaturesKHR;
```
This structure describes the following features:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **performanceCounterQueryPools** indicates whether the implementation supports performance counter query pools.
- **performanceCounterMultipleQueryPools** indicates whether the implementation supports using multiple performance query pools in a primary command buffer and secondary command buffers executed within it.

If the VkPhysicalDevicePerformanceQueryFeaturesKHR structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDevicePerformanceQueryFeaturesKHR can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDevicePerformanceQueryFeaturesKHR-sType-sType

  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PERFORMANCE_QUERY_FEATURES_KHR

The VkPhysicalDevice4444FormatsFeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_4444_formats
typedef struct VkPhysicalDevice4444FormatsFeaturesEXT {
    VkStructureType    sType;
    void*              pNext;
    VkBool32           formatA4R4G4B4;
    VkBool32           formatA4B4G4R4;
} VkPhysicalDevice4444FormatsFeaturesEXT;
```

This structure describes the following features:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **formatA4R4G4B4** indicates that the implementation must support using a VkFormat of VK_FORMAT_A4R4G4B4_UNORM_PACK16_EXT with at least the following VkFormatFeatureFlagBits:
  - VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT
  - VK_FORMAT_FEATURE_BLIT_SRC_BIT
• VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

• formatA4B4G4R4 indicates that the implementation must support using a VkFormat of VK_FORMAT_A4B4G4R4_UNORM_PACK16_EXT with at least the following VkFormatFeatureFlagBits:
  ◦ VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT
  ◦ VK_FORMAT_FEATURE_BLIT_SRC_BIT
  ◦ VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT

If the VkPhysicalDevice4444FormatsFeaturesEXT structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDevice4444FormatsFeaturesEXT can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

• VUID-VkPhysicalDevice4444FormatsFeaturesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_4444_FORMATS_FEATURES_EXT

Note
Although the formats defined by the VK_EXT_4444_formats extension were promoted to Vulkan 1.3 as optional formats, the VkPhysicalDevice4444FormatsFeaturesEXT structure was not promoted to Vulkan 1.3.

The VkPhysicalDeviceMutableDescriptorTypeFeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_mutable_descriptor_type
typedef struct VkPhysicalDeviceMutableDescriptorTypeFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 mutableDescriptorType;
} VkPhysicalDeviceMutableDescriptorTypeFeaturesEXT;
```

or the equivalent

```c
// Provided by VK_VALVE_mutable_descriptor_type
typedef VkPhysicalDeviceMutableDescriptorTypeFeaturesEXT
    VkPhysicalDeviceMutableDescriptorTypeFeaturesVALVE;
```

This structure describes the following feature:

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• mutableDescriptorType indicates that the implementation must support using the VkDescriptorType of VK_DESCRIPTOR_TYPE_MUTABLE_EXT with at least the following descriptor
types, where any combination of the types **must** be supported:

- **VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE**
- **VK_DESCRIPTOR_TYPE_STORAGE_IMAGE**
- **VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER**
- **VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER**
- **VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER**
- **VK_DESCRIPTOR_TYPE_STORAGE_BUFFER**

**Additionally, mutableDescriptorType** indicates that:

- Non-uniform descriptor indexing **must** be supported if all descriptor types in a **VkMutableDescriptorTypeListEXT** for **VK_DESCRIPTOR_TYPE_MUTABLE_EXT** have the corresponding non-uniform indexing features enabled in **VkPhysicalDeviceDescriptorIndexingFeatures**.

- **VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT** with descriptorType of **VK_DESCRIPTOR_TYPE_MUTABLE_EXT** relaxes the list of required descriptor types to the descriptor types which have the corresponding update-after-bind feature enabled in **VkPhysicalDeviceDescriptorIndexingFeatures**.

- Dynamically uniform descriptor indexing **must** be supported if all descriptor types in a **VkMutableDescriptorTypeListEXT** for **VK_DESCRIPTOR_TYPE_MUTABLE_EXT** have the corresponding dynamic indexing features enabled.

- **VK_DESCRIPTOR_SET_LAYOUT_CREATE_HOST_ONLY_POOL_BIT_EXT** **must** be supported.

- **VK_DESCRIPTOR_POOL_CREATE_HOST_ONLY_BIT_EXT** **must** be supported.

If the **VkPhysicalDeviceMutableDescriptorTypeFeaturesEXT** structure is included in the **pNext** chain of the **VkPhysicalDeviceFeatures2** structure passed to **vkGetPhysicalDeviceFeatures2**, it is filled in to indicate whether each corresponding feature is supported. **VkPhysicalDeviceMutableDescriptorTypeFeaturesEXT** can also be used in the **pNext** chain of **VkDeviceCreateInfo** to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceMutableDescriptorTypeFeaturesEXT-sType-sType** **sType** must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MUTABLE_DESCRIPTOR_TYPE_FEATURES_EXT**

The **VkPhysicalDeviceDepthClipControlFeaturesEXT** structure is defined as:

```c
// Provided by VK_EXT_depth_clip_control
typedef struct VkPhysicalDeviceDepthClipControlFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 depthClipControl;
} VkPhysicalDeviceDepthClipControlFeaturesEXT;
```
This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **depthClipControl** indicates that the implementation supports setting `VkPipelineViewportDepthClipControlCreateInfoEXT::negativeOneToOne` to `VK_TRUE`.

If the `VkPhysicalDeviceDepthClipControlFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceDepthClipControlFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceDepthClipControlFeaturesEXT-sType-sType**
  - **sType** must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_CLIP_CONTROL_FEATURES_EXT`

The `VkPhysicalDeviceWorkgroupMemoryExplicitLayoutFeaturesKHR` structure is defined as:

```c
// Provided by VK_KHR_workgroup_memory_explicit_layout
typedef struct VkPhysicalDeviceWorkgroupMemoryExplicitLayoutFeaturesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 workgroupMemoryExplicitLayout;
    VkBool32 workgroupMemoryExplicitLayoutScalarBlockLayout;
    VkBool32 workgroupMemoryExplicitLayout8BitAccess;
    VkBool32 workgroupMemoryExplicitLayout16BitAccess;
} VkPhysicalDeviceWorkgroupMemoryExplicitLayoutFeaturesKHR;
```

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **workgroupMemoryExplicitLayout** indicates whether the implementation supports the SPIR-V WorkgroupMemoryExplicitLayoutKHR capability.
- **workgroupMemoryExplicitLayoutScalarBlockLayout** indicates whether the implementation supports scalar alignment for laying out Workgroup Blocks.
- **workgroupMemoryExplicitLayout8BitAccess** indicates whether objects in the Workgroup storage class with the **Block** decoration can have 8-bit integer members. If this feature is not enabled, 8-bit integer members must not be used in such objects. This also indicates whether shader modules can declare the WorkgroupMemoryExplicitLayout8BitAccessKHR capability.
- **workgroupMemoryExplicitLayout16BitAccess** indicates whether objects in the Workgroup storage class with the **Block** decoration can have 16-bit integer and 16-bit floating-point members. If this feature is not enabled, 16-bit integer and 16-bit floating-point members must not be used in such objects.
feature is not enabled, 16-bit integer or 16-bit floating-point members must not be used in such objects. This also indicates whether shader modules can declare the WorkgroupMemoryExplicitLayout16BitAccessKHR capability.

If the VkPhysicalDeviceWorkgroupMemoryExplicitLayoutFeaturesKHR structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceWorkgroupMemoryExplicitLayoutFeaturesKHR can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceWorkgroupMemoryExplicitLayoutFeaturesKHR-sType-sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_WORKGROUP_MEMORY_EXPLICIT_LAYOUT_FEATURES_KHR

The VkPhysicalDeviceSynchronization2Features structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceSynchronization2Features {
    VkStructureType    sType;
    void*               pNext;
    VkBool32            synchronization2;
} VkPhysicalDeviceSynchronization2Features;
```

or the equivalent

```c
// Provided by VK_KHR_synchronization2
typedef VkPhysicalDeviceSynchronization2Features
VkPhysicalDeviceSynchronization2FeaturesKHR;
```

This structure describes the following feature:

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `synchronization2` indicates whether the implementation supports the new set of synchronization commands introduced in VK_KHR_synchronization2.

If the VkPhysicalDeviceSynchronization2Features structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceSynchronization2Features can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceSynchronization2Features-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SYNCHRONIZATION_2_FEATURES

The VkPhysicalDeviceVertexInputDynamicStateFeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_vertex_input_dynamic_state
typedef struct VkPhysicalDeviceVertexInputDynamicStateFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 vertexInputDynamicState;
} VkPhysicalDeviceVertexInputDynamicStateFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `vertexInputDynamicState` indicates that the implementation supports the following dynamic states:
  - VK_DYNAMIC_STATE_VERTEX_INPUT_EXT

If the VkPhysicalDeviceVertexInputDynamicStateFeaturesEXT structure is included in the `pNext` chain of the VkPhysicalDeviceFeatures2 structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceVertexInputDynamicStateFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceVertexInputDynamicStateFeaturesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VERTEX_INPUT_DYNAMIC_STATE_FEATURES_EXT

The VkPhysicalDevicePrimitivesGeneratedQueryFeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_primitives_generated_query
typedef struct VkPhysicalDevicePrimitivesGeneratedQueryFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 primitivesGeneratedQuery;
    VkBool32 primitivesGeneratedQueryWithRasterizerDiscard;
    VkBool32 primitivesGeneratedQueryWithNonZeroStreams;
} VkPhysicalDevicePrimitivesGeneratedQueryFeaturesEXT;
```
This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **primitivesGeneratedQuery** indicates whether the implementation supports the
  `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT` query type.
- **primitivesGeneratedQueryWithRasterizerDiscard** indicates whether the implementation supports
  this query when rasterization discard is enabled.
- **primitivesGeneratedQueryWithNonZeroStreams** indicates whether the implementation supports
  this query with a non-zero index in `vkCmdBeginQueryIndexedEXT`.

If the `VkPhysicalDevicePrimitivesGeneratedQueryFeaturesEXT` structure is included in the **pNext** chain
of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to
indicate whether each corresponding feature is supported. `VkPhysicalDevicePrimitivesGeneratedQueryFeaturesEXT` can also be used in the **pNext** chain of
`VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- **VUID-VkPhysicalDevicePrimitivesGeneratedQueryFeaturesEXT-sType-sType**  
  must be  
  `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRIMITIVES_GENERATED_QUERY_FEATURES_EXT`

The `VkPhysicalDeviceFragmentShadingRateFeaturesKHR` structure is defined as:

```c
// Provided by VK_KHR_fragment_shading_rate  
typedef struct VkPhysicalDeviceFragmentShadingRateFeaturesKHR {  
  VkStructureType sType;  
  void* pNext;  
  VkBool32 pipelineFragmentShadingRate;  
  VkBool32 primitiveFragmentShadingRate;  
  VkBool32 attachmentFragmentShadingRate;  
} VkPhysicalDeviceFragmentShadingRateFeaturesKHR;
```

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **pipelineFragmentShadingRate** indicates that the implementation supports the pipeline fragment shading rate.
- **primitiveFragmentShadingRate** indicates that the implementation supports the primitive fragment shading rate.
- **attachmentFragmentShadingRate** indicates that the implementation supports the attachment fragment shading rate.
If the `VkPhysicalDeviceFragmentShadingRateFeaturesKHR` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceFragmentShadingRateFeaturesKHR` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceFragmentShadingRateFeaturesKHR-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADING_RATE_FEATURES_KHR`

The `VkPhysicalDeviceLegacyDitheringFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_legacy_dithering
typedef struct VkPhysicalDeviceLegacyDitheringFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 legacyDithering;
} VkPhysicalDeviceLegacyDitheringFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `legacyDithering` indicates whether the implementation supports Legacy Dithering.

If the `VkPhysicalDeviceLegacyDitheringFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceLegacyDitheringFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceLegacyDitheringFeaturesEXT-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_LEGACY_DITHERING_FEATURES_EXT`

The `VkPhysicalDeviceFragmentShadingRateEnumsFeaturesNV` structure is defined as:

```c
// Provided by VK_NV_fragment_shading_rateEnums
typedef struct VkPhysicalDeviceFragmentShadingRateEnumsFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 fragmentShadingRateEnums;
    VkBool32 supersampleFragmentShadingRates;
} VkPhysicalDeviceFragmentShadingRateEnumsFeaturesNV;
```
This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **fragmentShadingRateEnums** indicates that the implementation supports specifying fragment shading rates using the `VkFragmentShadingRateNV` enumerated type.
- **supersampleFragmentShadingRates** indicates that the implementation supports fragment shading rate enum values indicating more than one invocation per fragment.
- **noInvocationFragmentShadingRates** indicates that the implementation supports a fragment shading rate enum value indicating that no fragment shaders should be invoked when that shading rate is used.

If the `VkPhysicalDeviceFragmentShadingRateEnumsFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceFragmentShadingRateEnumsFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- `VUID-VkPhysicalDeviceFragmentShadingRateEnumsFeaturesNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADING_RATE_ENUMS_FEATURES_NV`

The `VkPhysicalDeviceInheritedViewportScissorFeaturesNV` structure is defined as:

```c
// Provided by VK_NV_inherited_viewport_scissor
typedef struct VkPhysicalDeviceInheritedViewportScissorFeaturesNV {
  VkStructureType sType;
  void* pNext;
  VkBool32 inheritedViewportScissor2D;
} VkPhysicalDeviceInheritedViewportScissorFeaturesNV;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **inheritedViewportScissor2D** indicates whether secondary command buffers can inherit most of the dynamic state affected by `VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT`, `VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT`, `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT`, `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT`, `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT`, etc.
VK_DYNAMIC_STATE_VIEWPORT or VK_DYNAMIC_STATE_SCISSOR, from a primary command buffer.

If the VkPhysicalDeviceInheritedViewportScissorFeaturesNV structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceInheritedViewportScissorFeaturesNV can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceInheritedViewportScissorFeaturesNV-sType-sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INHERITED_VIEWPORT_SCISSOR_FEATURES_NV

The VkPhysicalDevicePipelineProtectedAccessFeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_pipeline_protected_access
typedef struct VkPhysicalDevicePipelineProtectedAccessFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 pipelineProtectedAccess;
} VkPhysicalDevicePipelineProtectedAccessFeaturesEXT;
```

This structure describes the following feature:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **pipelineProtectedAccess** indicates whether the implementation supports specifying protected access on individual pipelines.

If the VkPhysicalDevicePipelineProtectedAccessFeaturesEXT structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDevicePipelineProtectedAccessFeaturesEXT can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDevicePipelineProtectedAccessFeaturesEXT-sType-sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_PROTECTED_ACCESS_FEATURES_EXT

The VkPhysicalDeviceYcbcr2Plane444FormatsFeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_ycbcr_2plane_444_formats
```
typedef struct VkPhysicalDeviceYcbcr2Plane444FormatsFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 ycbcr2plane444Formats;
} VkPhysicalDeviceYcbcr2Plane444FormatsFeaturesEXT;

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **ycbcr2plane444Formats** indicates that the implementation supports the following 2-plane 444 Y′C′B′C′R formats:
  - `VK_FORMAT_G8_B8R8_2PLANE_444_UNORM`
  - `VK_FORMAT_G10X6_B10X6R10X6_2PLANE_444_UNORM_3PACK16`
  - `VK_FORMAT_G12X4_B12X4R12X4_2PLANE_444_UNORM_3PACK16`
  - `VK_FORMAT_G16_B16R16_2PLANE_444_UNORM`

If the `VkPhysicalDeviceYcbcr2Plane444FormatsFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceYcbcr2Plane444FormatsFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceYcbcr2Plane444FormatsFeaturesEXT-sType-sType** `sType` **must** be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_YCBCR_2_PLANE_444_FORMATS_FEATURES_EXT`

### Note

Although the formats defined by the `VK_EXT_ycbcr_2plane_444_formats` were promoted to Vulkan 1.3 as optional formats, the `VkPhysicalDeviceYcbcr2Plane444FormatsFeaturesEXT` structure was not promoted to Vulkan 1.3.

The `VkPhysicalDeviceColorWriteEnableFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_color_write_enable
typedef struct VkPhysicalDeviceColorWriteEnableFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 colorWriteEnable;
} VkPhysicalDeviceColorWriteEnableFeaturesEXT;
```
This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `colorWriteEnable` indicates that the implementation supports the dynamic state `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT`.

If the `VkPhysicalDeviceColorWriteEnableFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceColorWriteEnableFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- `VUID-VkPhysicalDeviceColorWriteEnableFeaturesEXT-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COLOR_WRITE_ENABLE_FEATURES_EXT`

The `VkPhysicalDevicePipelinePropertiesFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_pipeline_properties
typedef struct VkPhysicalDevicePipelinePropertiesFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 pipelinePropertiesIdentifier;
} VkPhysicalDevicePipelinePropertiesFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `pipelinePropertiesIdentifier` indicates that the implementation supports querying a unique pipeline identifier.

If the `VkPhysicalDevicePipelinePropertiesFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDevicePipelinePropertiesFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- `VUID-VkPhysicalDevicePipelinePropertiesFeaturesEXT-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_PROPERTIES_FEATURES_EXT`
The `VkPhysicalDeviceProvokingVertexFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_provoking_vertex
typedef struct VkPhysicalDeviceProvokingVertexFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 provokingVertexLast;
    VkBool32 transformFeedbackPreservesProvokingVertex;
} VkPhysicalDeviceProvokingVertexFeaturesEXT;
```

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **provokingVertexLast** indicates whether the implementation supports the `VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT` provoking vertex mode for flat shading.
- **transformFeedbackPreservesProvokingVertex** indicates that the order of vertices within each primitive written by transform feedback will preserve the provoking vertex. This does not apply to triangle fan primitives when `transformFeedbackPreservesTriangleFanProvokingVertex` is `VK_FALSE`. `transformFeedbackPreservesProvokingVertex` must be `VK_FALSE` when the `VK_EXT_transform_feedback` extension is not supported.

If the `VkPhysicalDeviceProvokingVertexFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceProvokingVertexFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

When `VkPhysicalDeviceProvokingVertexFeaturesEXT` is in the `pNext` chain of `VkDeviceCreateInfo` but the `transformFeedback` feature is not enabled, the value of `transformFeedbackPreservesProvokingVertex` is ignored.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceProvokingVertexFeaturesEXT-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PROVOKING_VERTEX_FEATURES_EXT`

The `VkPhysicalDeviceDescriptorBufferFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_descriptor_buffer
typedef struct VkPhysicalDeviceDescriptorBufferFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 descriptorBuffer;
    VkBool32 descriptorBufferCaptureReplay;
    VkBool32 descriptorBufferImageLayoutIgnored;
} VkPhysicalDeviceDescriptorBufferFeaturesEXT;
```
This structure describes the following feature:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **descriptorBuffer** indicates that the implementation supports putting shader-accessible descriptors directly in memory.
- **descriptorBufferCaptureReplay** indicates that the implementation supports capture and replay when using descriptor buffers. If this is VK_TRUE, all resources created with
  
  VK_BUFFER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT,  
  VK_IMAGE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT,  
  VK_IMAGE_VIEW_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT,  
  VK_SAMPLER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT,  
  or  
  VK_ACCELERATION_STRUCTURE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT must be created before resources of the same types without those flags.
- **descriptorBufferImageLayoutIgnored** indicates that the implementation will ignore imageLayout in VkDescriptorImageInfo when calling vkGetDescriptorEXT.
- **descriptorBufferPushDescriptors** indicates that the implementation supports using push descriptors with descriptor buffers.

If the VkPhysicalDeviceDescriptorBufferFeaturesEXT structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceDescriptorBufferFeaturesEXT can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDescriptorBufferFeaturesEXT-sType-sType

  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_BUFFER_FEATURES_EXT

The VkPhysicalDevicePageableDeviceLocalMemoryFeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_pageable_device_local_memory
typedef struct VkPhysicalDevicePageableDeviceLocalMemoryFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 pageableDeviceLocalMemory;
} VkPhysicalDevicePageableDeviceLocalMemoryFeaturesEXT;
```

This structure describes the following feature:

- **sType** is a VkStructureType value identifying this structure.
• `pNext` is NULL or a pointer to a structure extending this structure.

• `pageableDeviceLocalMemory` indicates that the implementation supports pageable device-local memory and may transparently move device-local memory allocations to host-local memory to better share device-local memory with other applications.

If the `VkPhysicalDevicePageableDeviceLocalMemoryFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDevicePageableDeviceLocalMemoryFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PAGEABLE_DEVICE_LOCAL_MEMORY_FEATURES_EXT` must be `sType`.

The `VkPhysicalDeviceMultiDrawFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_multi_draw
typedef struct VkPhysicalDeviceMultiDrawFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 multiDraw;
} VkPhysicalDeviceMultiDrawFeaturesEXT;
```

This structure describes the following features:

• `sType` is a `VkStructureType` value identifying this structure.

• `pNext` is NULL or a pointer to a structure extending this structure.

• `multiDraw` indicates that the implementation supports `vkCmdDrawMultiEXT` and `vkCmdDrawMultiIndexedEXT`.

If the `VkPhysicalDeviceMultiDrawFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceMultiDrawFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTI_DRAW_FEATURES_EXT` must be `sType`.

The `VkPhysicalDeviceRayTracingMotionBlurFeaturesNV` structure is defined as:

### Valid Usage (Implicit)

- `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_MOTION BLUR_FEATURES_NV` must be `sType`.

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typedef struct VkPhysicalDeviceRayTracingMotionBlurFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 rayTracingMotionBlur;
    VkBool32 rayTracingMotionBlurPipelineTraceRaysIndirect;
} VkPhysicalDeviceRayTracingMotionBlurFeaturesNV;

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **rayTracingMotionBlur** indicates whether the implementation supports the motion blur feature.
- **rayTracingMotionBlurPipelineTraceRaysIndirect** indicates whether the implementation supports indirect ray tracing commands with the motion blur feature enabled.

If the `VkPhysicalDeviceRayTracingMotionBlurFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported.

The `VkPhysicalDeviceOpacityMicromapFeaturesEXT` structure is defined as:

typedef struct VkPhysicalDeviceOpacityMicromapFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 micromap;
    VkBool32 micromapCaptureReplay;
    VkBool32 micromapHostCommands;
} VkPhysicalDeviceOpacityMicromapFeaturesEXT;

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **micromap** indicates whether the implementation supports the micromap array feature.
- **micromapCaptureReplay** indicates whether the implementation supports capture and replay of
addresses for micromap arrays.

- `micromapHostCommands` indicates whether the implementation supports host side micromap array commands.

If the `VkPhysicalDeviceOpacityMicromapFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceOpacityMicromapFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceOpacityMicromapFeaturesEXT-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_OPACITY_MICROMAP_FEATURES_EXT`

The `VkPhysicalDeviceDisplacementMicromapFeaturesNV` structure is defined as:

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceOpacityMicromapFeaturesEXT-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_OPACITY_MICROMAP_FEATURES_EXT`

If the `VkPhysicalDeviceDisplacementMicromapFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceDisplacementMicromapFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDisplacementMicromapFeaturesNV-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DISPLACEMENT_MICROMAP_FEATURES_NV`

The `VkPhysicalDeviceSubpassShadingFeaturesHUAWEI` structure is defined as:

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDisplacementMicromapFeaturesNV-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DISPLACEMENT_MICROMAP_FEATURES_NV`
typedef struct VkPhysicalDeviceSubpassShadingFeaturesHUAWEI {
    VkStructureType sType;
    void* pNext;
    VkBool32 subpassShading;
} VkPhysicalDeviceSubpassShadingFeaturesHUAWEI;

This structure describes the following feature:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **subpassShading** specifies whether subpass shading is supported.

If the VkPhysicalDeviceSubpassShadingFeaturesHUAWEI structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceSubpassShadingFeaturesHUAWEI can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceSubpassShadingFeaturesHUAWEI-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBPASS_SHADING_FEATURES_HUAWEI

The VkPhysicalDeviceExternalMemoryRDMAFeaturesNV structure is defined as:

```c
// Provided by VK_NV_external_memory_rdma
typedef struct VkPhysicalDeviceExternalMemoryRDMAFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 externalMemoryRDMA;
} VkPhysicalDeviceExternalMemoryRDMAFeaturesNV;
```

This structure describes the following feature:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **externalMemoryRDMA** indicates whether the implementation has support for the VK_MEMORY_PROPERTY_RDMA_CAPABLE_BIT_NV memory property and the VK_EXTERNAL_MEMORY_HANDLE_TYPE_RDMA_ADDRESS_BIT_NV external memory handle type.

If the VkPhysicalDeviceExternalMemoryRDMAFeaturesNV structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceExternalMemoryRDMAFeaturesNV can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceExternalMemoryRDMAFeaturesNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_MEMORY_RDMA_FEATURES_NV

The `VkPhysicalDevicePresentIdFeaturesKHR` structure is defined as:

```c
// Provided by VK_KHR_present_id
typedef struct VkPhysicalDevicePresentIdFeaturesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 presentId;
} VkPhysicalDevicePresentIdFeaturesKHR;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **presentId** indicates that the implementation supports specifying present ID values in the `VkPresentIdKHR` extension to the `VkPresentInfoKHR` struct.

If the `VkPhysicalDevicePresentIdFeaturesKHR` structure is included in the **pNext** chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDevicePresentIdFeaturesKHR` can also be used in the **pNext** chain of `VkDeviceCreateInfo` to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDevicePresentIdFeaturesKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRESENT_ID_FEATURES_KHR

The `VkPhysicalDevicePresentWaitFeaturesKHR` structure is defined as:

```c
// Provided by VK_KHR_present_wait
typedef struct VkPhysicalDevicePresentWaitFeaturesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 presentWait;
} VkPhysicalDevicePresentWaitFeaturesKHR;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
• presentWait indicates that the implementation supports vkWaitForPresentKHR.

If the VkPhysicalDevicePresentWaitFeaturesKHR structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDevicePresentWaitFeaturesKHR can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

• VUID-VkPhysicalDevicePresentWaitFeaturesKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRESENT_WAIT_FEATURES_KHR

The VkPhysicalDeviceHostImageCopyFeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_host_image_copy
typedef struct VkPhysicalDeviceHostImageCopyFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 hostImageCopy;
} VkPhysicalDeviceHostImageCopyFeaturesEXT;
```

This structure describes the following feature:

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• hostImageCopy indicates that the implementation supports copying from host memory to images using the vkCopyMemoryToImageEXT command, copying from images to host memory using the vkCopyImageToMemoryEXT command, and copying between images using the vkCopyImageToImageEXT command.

If the VkPhysicalDeviceHostImageCopyFeaturesEXT structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceHostImageCopyFeaturesEXT can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceHostImageCopyFeaturesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_HOST_IMAGE_COPY_FEATURES_EXT

The VkPhysicalDevicePresentBarrierFeaturesNV structure is defined as:

```c
// Provided by VK_NV_present_barrier
typedef struct VkPhysicalDevicePresentBarrierFeaturesNV {
```
This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `presentBarrier` indicates that the implementation supports the present barrier feature.

If the `VkPhysicalDevicePresentBarrierFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDevicePresentBarrierFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDevicePresentBarrierFeaturesNV-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRESENT_BARRIER_FEATURES_NV`

The `VkPhysicalDeviceShaderIntegerDotProductFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceShaderIntegerDotProductFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderIntegerDotProduct;
} VkPhysicalDeviceShaderIntegerDotProductFeatures;
```

or the equivalent

```c
// Provided by VK_KHR_shader_integer_dot_product
typedef VkPhysicalDeviceShaderIntegerDotProductFeatures
    VkPhysicalDeviceShaderIntegerDotProductFeaturesKHR;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `shaderIntegerDotProduct` specifies whether shader modules can declare the `DotProductInputAllKHR`, `DotProductInput4x8BitKHR`, `DotProductInput4x8BitPackedKHR` and `DotProductKHR` capabilities.
If the `VkPhysicalDeviceShaderIntegerDotProductFeatures` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceShaderIntegerDotProductFeatures` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

---

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceShaderIntegerDotProductFeatures-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_INTEGER_DOT_PRODUCT_FEATURES`

The `VkPhysicalDeviceMaintenance4Features` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceMaintenance4Features {
    VkStructureType sType;
    void* pNext;
    VkBool32 maintenance4;
} VkPhysicalDeviceMaintenance4Features;
```

or the equivalent

```c
// Provided by VK_KHR_maintenance4
typedef VkPhysicalDeviceMaintenance4Features VkPhysicalDeviceMaintenance4FeaturesKHR;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `maintenance4` indicates that the implementation supports the following:
  - The application `may` destroy a `VkPipelineLayout` object immediately after using it to create another object.
  - `LocalSizeId` can be used as an alternative to `LocalSize` to specify the local workgroup size with specialization constants.
  - Images created with identical creation parameters will always have the same alignment requirements.
  - The size memory requirement of a buffer or image is never greater than that of another buffer or image created with a greater or equal size.
  - Push constants do not have to be initialized before they are dynamically accessed.
  - The interface matching rules allow a larger output vector to match with a smaller input vector, with additional values being discarded.
If the `VkPhysicalDeviceMaintenance4Features` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceMaintenance4Features` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceMaintenance4Features-sType-sType
  sType must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_4_FEATURES`

The `VkPhysicalDeviceMaintenance5FeaturesKHR` structure is defined as:

```c
// Provided by VK_KHR_maintenance5
typedef struct VkPhysicalDeviceMaintenance5FeaturesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 maintenance5;
} VkPhysicalDeviceMaintenance5FeaturesKHR;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `maintenance5` indicates that the implementation supports the following:
  - The ability to expose support for the optional format `VK_FORMAT_A1B5G5R5_UNORM_PACK16_KHR`.
  - The ability to expose support for the optional format `VK_FORMAT_A8_UNORM_KHR`.
  - A property to indicate that multisample coverage operations are performed after sample counting in EarlyFragmentTests mode.
  - Creating a `VkBufferView` with a subset of the associated `VkBuffer` usage using `VkBufferUsageFlags2CreateInfoKHR`.
  - A new function `vkCmdBindIndexBuffer2KHR`, allowing a range of memory to be bound as an index buffer.
  - `vkGetDeviceProcAddr` will return `NULL` for function pointers of core functions for versions higher than the version requested by the application.
  - `vkCmdBindVertexBuffers2` supports using `VK_WHOLE_SIZE` in the `pSizes` parameter.
  - If `PointSize` is not written, a default value of `1.0` is used for the size of points.
  - `VkShaderModuleCreateInfo` can be added as a chained structure to pipeline creation via `VkPipelineShaderStageCreateInfo`, rather than having to create a shader module.
  - A function `vkGetRenderingAreaGranularityKHR` to query the optimal render area for a dynamic rendering instance.
  - A property to indicate that depth/stencil texturing operations with `VK_COMPONENT_SWIZZLE_ONE
```
have defined behavior.

- `vkGetDeviceImageSubresourceLayoutKHR` allows an application to perform a `vkGetImageSubresourceLayout` query without having to create an image.
- `VK_REMAINING_ARRAY_LAYERS` as the `layerCount` member of `VkImageSubresourceLayers`.
- A property to indicate whether `PointSize` controls the final rasterization of polygons if `polygon mode` is `VK_POLYGON_MODE_POINT`.
- Two properties to indicate the non-strict line rasterization algorithm used.
- Two new flags words `VkPipelineCreateFlagBits2KHR` and `VkBufferUsageFlagBits2KHR`.
- Physical-device-level functions can now be called with any value in the valid range for a type beyond the defined enumerants, such that applications can avoid checking individual features, extensions, or versions before querying supported properties of a particular enumerant.
- Copies between images of any type are allowed, with 1D images treated as 2D images with a height of 1.

If the `VkPhysicalDeviceMaintenance5FeaturesKHR` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceMaintenance5FeaturesKHR` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceMaintenance5FeaturesKHR-sType-sType

  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_5_FEATURES_KHR`.

The `VkPhysicalDeviceDynamicRenderingFeatures` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceDynamicRenderingFeatures {
    VkStructureType sType;
    void* pNext;
    VkBool32 dynamicRendering;
} VkPhysicalDeviceDynamicRenderingFeatures;
```

or the equivalent

```c
// Provided by VK_KHR_dynamic_rendering
typedef VkPhysicalDeviceDynamicRenderingFeatures VkPhysicalDeviceDynamicRenderingFeaturesKHR;
```

This structure describes the following feature:
• *sType* is a VkStructureType value identifying this structure.

• *pNext* is NULL or a pointer to a structure extending this structure.

• dynamicRendering specifies that the implementation supports dynamic render pass instances using the vkCmdBeginRendering command.

If the VkPhysicalDeviceDynamicRenderingFeatures structure is included in the *pNext* chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceDynamicRenderingFeatures can also be used in the *pNext* chain of VkDeviceCreateInfo to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDynamicRenderingFeatures-sType-sType

  *sType* must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DYNAMIC_RENDERING_FEATURES

The VkPhysicalDeviceRGBA10X6FormatsFeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_rgba10x6_formats
typedef struct VkPhysicalDeviceRGBA10X6FormatsFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 formatRgba10x6WithoutYCbCrSampler;
} VkPhysicalDeviceRGBA10X6FormatsFeaturesEXT;
```

This structure describes the following feature:

• *sType* is a VkStructureType value identifying this structure.

• *pNext* is NULL or a pointer to a structure extending this structure.

• formatRgba10x6WithoutYCbCrSampler indicates that VK_FORMAT_R10X6G10X6B10X6A10X6_UNORM_4PACK16 can be used with a VkImageView with subresourceRange.aspectMask equal to VK_IMAGE_ASPECT_COLOR_BIT without a sampler Y′C′_bC′_r conversion enabled.

If the VkPhysicalDeviceRGBA10X6FormatsFeaturesEXT structure is included in the *pNext* chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceRGBA10X6FormatsFeaturesEXT can also be used in the *pNext* chain of VkDeviceCreateInfo to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceRGBA10X6FormatsFeaturesEXT-sType-sType

  *sType* must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RGBA10X6_FORMATS_FEATURES_EXT
The `VkPhysicalDevicePipelineRobustnessFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_pipeline_robustness
typedef struct VkPhysicalDevicePipelineRobustnessFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 pipelineRobustness;
} VkPhysicalDevicePipelineRobustnessFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `pipelineRobustness` indicates that robustness can be requested on a per-pipeline-stage granularity.

Note

Enabling `pipelineRobustness` may, on some platforms, incur a minor performance cost when `robustBufferAccess` is disabled, even for pipelines which do not make use of any robustness features. If robustness is not needed, `pipelineRobustness` should not be enabled by an application.

If the `VkPhysicalDevicePipelineRobustnessFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDevicePipelineRobustnessFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

Valid Usage (Implicit)

- `VUID-VkPhysicalDevicePipelineRobustnessFeaturesEXT-sType-sType` 
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_ROBUSTNESS_FEATURES_EXT`

The `VkPhysicalDeviceImageViewMinLodFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_image_view_min_lod
typedef struct VkPhysicalDeviceImageViewMinLodFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 minLod;
} VkPhysicalDeviceImageViewMinLodFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.

• **minLod** indicates whether the implementation supports clamping the minimum LOD value during Image Level(s) Selection, Texel Gathering and Integer Texel Coordinate Operations with a given **VkImageView** by **VkImageViewMinLodCreateInfoEXT::minLod**.

If the **VkPhysicalDeviceImageViewMinLodFeaturesEXT** structure is included in the **pNext** chain of the **VkPhysicalDeviceFeatures2** structure passed to **vkGetPhysicalDeviceFeatures2**, it is filled in to indicate whether each corresponding feature is supported. **VkPhysicalDeviceImageViewMinLodFeaturesEXT** can also be used in the **pNext** chain of **VkDeviceCreateInfo** to selectively enable these features.

---

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceImageViewMinLodFeaturesEXT-sType-sType**
  
  **sType** must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_VIEW_MIN_LOD_FEATURES_EXT**

---

The **VkPhysicalDeviceRasterizationOrderAttachmentAccessFeaturesEXT** structure is defined as:

```c
// Provided by VK_EXT_rasterization_order_attachment_access
typedef struct VkPhysicalDeviceRasterizationOrderAttachmentAccessFeaturesEXT {
    VkStructureType   sType;
    void*             pNext;
    VkBool32          rasterizationOrderColorAttachmentAccess;
    VkBool32          rasterizationOrderDepthAttachmentAccess;
    VkBool32          rasterizationOrderStencilAttachmentAccess;
} VkPhysicalDeviceRasterizationOrderAttachmentAccessFeaturesEXT;
```

or the equivalent

```c
// Provided by VK_ARM_rasterization_order_attachment_access
typedef VkPhysicalDeviceRasterizationOrderAttachmentAccessFeaturesEXT
    VkPhysicalDeviceRasterizationOrderAttachmentAccessFeaturesARM;
```

This structure describes the following features:

- **sType** is a **VkStructureType** value identifying this structure.

- **pNext** is NULL or a pointer to a structure extending this structure.

- **rasterizationOrderColorAttachmentAccess** indicates that rasterization order access to color and input attachments is supported by the implementation.

- **rasterizationOrderDepthAttachmentAccess** indicates that rasterization order access to the depth aspect of depth/stencil and input attachments is supported by the implementation.

- **rasterizationOrderStencilAttachmentAccess** indicates that rasterization order access to the stencil aspect of depth/stencil and input attachments is supported by the implementation.
If the `VkPhysicalDeviceRasterizationOrderAttachmentAccessFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceRasterizationOrderAttachmentAccessFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- `VUID-VkPhysicalDeviceRasterizationOrderAttachmentAccessFeaturesEXT-sType-sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_FEATURES_EXT`

The `VkPhysicalDeviceSubpassMergeFeedbackFeaturesEXT` structure is defined as:

```c
typedef struct VkPhysicalDeviceSubpassMergeFeedbackFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 subpassMergeFeedback;
} VkPhysicalDeviceSubpassMergeFeedbackFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `subpassMergeFeedback` indicates whether the implementation supports feedback of subpass merging.

If the `VkPhysicalDeviceSubpassMergeFeedbackFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceSubpassMergeFeedbackFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- `VUID-VkPhysicalDeviceSubpassMergeFeedbackFeaturesEXT-sType-sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBPASS_MERGE_FEEDBACK_FEATURES_EXT`

The `VkPhysicalDeviceLinearColorAttachmentFeaturesNV` structure is defined as:

```c
typedef struct VkPhysicalDeviceLinearColorAttachmentFeaturesNV {
    VkStructureType sType;
    void* pNext;
} VkPhysicalDeviceLinearColorAttachmentFeaturesNV;
```

// Provided by VK_NV_linear_color_attachment
This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **linearColorAttachment** indicates whether the implementation supports renderable Linear Color Attachment

If the `VkPhysicalDeviceLinearColorAttachmentFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceLinearColorAttachmentFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceLinearColorAttachmentFeaturesNV-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_LINEAR_COLOR_ATTACHMENT_FEATURES_NV`

The `VkPhysicalDeviceAttachmentFeedbackLoopLayoutFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_attachment_feedback_loop_layout
typedef struct VkPhysicalDeviceAttachmentFeedbackLoopLayoutFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 attachmentFeedbackLoopLayout;
} VkPhysicalDeviceAttachmentFeedbackLoopLayoutFeaturesEXT;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **attachmentFeedbackLoopLayout** indicates whether the implementation supports using `VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT` image layout for images created with `VK_IMAGE_USAGE_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT`.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceAttachmentFeedbackLoopLayoutFeaturesEXT-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ATTACHMENT_FEEDBACK_LOOP_LAYOUT_FEATURES_EXT`
The `VkPhysicalDeviceGraphicsPipelineLibraryFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_graphics_pipeline_library
typedef struct VkPhysicalDeviceGraphicsPipelineLibraryFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 graphicsPipelineLibrary;
} VkPhysicalDeviceGraphicsPipelineLibraryFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `graphicsPipelineLibrary` indicates that the implementation supports graphics pipeline libraries.

If the `VkPhysicalDeviceGraphicsPipelineLibraryFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceGraphicsPipelineLibraryFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceGraphicsPipelineLibraryFeaturesEXT-sType-sType` `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GRAPHICS_PIPELINE_LIBRARY_FEATURES_EXT`.

The `VkPhysicalDeviceMultisampledRenderToSingleSampledFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_multisampled_render_to_single_sampled
typedef struct VkPhysicalDeviceMultisampledRenderToSingleSampledFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 multisampledRenderToSingleSampled;
} VkPhysicalDeviceMultisampledRenderToSingleSampledFeaturesEXT;
```

This structure describes the following features:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `multisampledRenderToSingleSampled` indicates that the implementation supports multisampled rendering to single-sampled render pass attachments.

If the `VkPhysicalDeviceMultisampledRenderToSingleSampledFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it...
is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceMultisampledRenderToSingleSampledFeaturesEXT can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceMultisampledRenderToSingleSampledFeaturesEXT-sType-sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_FEATURES_EXT

The VkPhysicalDeviceImage2DViewOf3DFeaturesEXT structure is defined as:

```c
typedef struct VkPhysicalDeviceImage2DViewOf3DFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 image2DViewOf3D;
    VkBool32 sampler2DViewOf3D;
} VkPhysicalDeviceImage2DViewOf3DFeaturesEXT;
```

This structure describes the following features:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **image2DViewOf3D** indicates that the implementation supports using a 2D view of a 3D image in a descriptor of type VK_DESCRIPTOR_TYPE_STORAGE_IMAGE if the image is created using VK_IMAGE_CREATE_2D_VIEW_COMPATIBLE_BIT_EXT.
- **sampler2DViewOf3D** indicates that the implementation supports using a 2D view of a 3D image in a descriptor of type VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE or VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER if the image is created using VK_IMAGE_CREATE_2D_VIEW_COMPATIBLE_BIT_EXT.

If the VkPhysicalDeviceImage2DViewOf3DFeaturesEXT structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceImage2DViewOf3DFeaturesEXT can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceImage2DViewOf3DFeaturesEXT-sType-sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_2D_VIEW_OF_3D_FEATURES_EXT

The VkPhysicalDeviceImageSlicedViewOf3DFeaturesEXT structure is defined as:
typedef struct VkPhysicalDeviceImageSlicedViewOf3DFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 imageSlicedViewOf3D;
} VkPhysicalDeviceImageSlicedViewOf3DFeaturesEXT;

The members of the VkPhysicalDeviceImageSlicedViewOf3DFeaturesEXT structure describe the following features:

- `imageSlicedViewOf3D` indicates that the implementation supports using a sliced view of a 3D image in a descriptor of type `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE` by using a `VkImageViewSlicedCreateInfoEXT` structure when creating the view.

If the `VkPhysicalDeviceImageSlicedViewOf3DFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceImageSlicedViewOf3DFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceImageSlicedViewOf3DFeaturesEXT-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_SLICED_VIEW_OF_3D_FEATURES_EXT`

The `VkPhysicalDeviceImageCompressionControlFeaturesEXT` structure is defined as:

typedef struct VkPhysicalDeviceImageCompressionControlFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 imageCompressionControl;
} VkPhysicalDeviceImageCompressionControlFeaturesEXT;

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `imageCompressionControl` indicates that the implementation supports providing controls for image compression at image creation time.

If the `VkPhysicalDeviceImageCompressionControlFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceImageCompressionControlFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceImageCompressionControlFeaturesEXT-sType-sType must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_COMPRESSION_CONTROL_FEATURES_EXT`.

The `VkPhysicalDeviceImageCompressionControlSwapchainFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_image_compression_control_swapchain
typedef struct VkPhysicalDeviceImageCompressionControlSwapchainFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 imageCompressionControlSwapchain;
} VkPhysicalDeviceImageCompressionControlSwapchainFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `imageCompressionControlSwapchain` indicates that the implementation supports controlling image controls per swapchain and querying image compression properties per surface.

If the `VkPhysicalDeviceImageCompressionControlSwapchainFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceImageCompressionControlSwapchainFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceImageCompressionControlSwapchainFeaturesEXT-sType-sType must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_COMPRESSION_CONTROL_SWAPCHAIN_FEATURES_EXT`.

The `VkPhysicalDeviceRayTracingPositionFetchFeaturesKHR` structure is defined as:

```c
// Provided by VK_KHR_ray_tracing_position_fetch
typedef struct VkPhysicalDeviceRayTracingPositionFetchFeaturesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 rayTracingPositionFetch;
} VkPhysicalDeviceRayTracingPositionFetchFeaturesKHR;
```

This structure describes the following feature:
• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **rayTracingPositionFetch** indicates that the implementation supports fetching the object space vertex positions of a hit triangle.

If the `VkPhysicalDeviceRayTracingPositionFetchFeaturesKHR` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceRayTracingPositionFetchFeaturesKHR` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceRayTracingPositionFetchFeaturesKHR-sType-sType**
  - `sType` must be
    - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_POSITION_FETCH_FEATURES_KHR`

The `VkPhysicalDeviceShaderEarlyAndLateFragmentTestsFeaturesAMD` structure is defined as:

```c
// Provided by VK_AMD_shader_early_and_late_fragment_tests
typedef struct VkPhysicalDeviceShaderEarlyAndLateFragmentTestsFeaturesAMD {
  VkStructureType sType;
  void* pNext;
  VkBool32 shaderEarlyAndLateFragmentTests;
} VkPhysicalDeviceShaderEarlyAndLateFragmentTestsFeaturesAMD;
```

This structure describes the following feature:

• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **shaderEarlyAndLateFragmentTests** indicates whether the implementation supports the EarlyAndLateFragmentTestsAMD Execution Mode.

If the `VkPhysicalDeviceShaderEarlyAndLateFragmentTestsFeaturesAMD` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceShaderEarlyAndLateFragmentTestsFeaturesAMD` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceShaderEarlyAndLateFragmentTestsFeaturesAMD-sType-sType**
  - `sType` must be
    - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_EARLY_AND_LATE_FRAGMENT_TESTS_FEATURES_AMD`
The `VkPhysicalDeviceNonSeamlessCubeMapFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_non_seamless_cube_map
typedef struct VkPhysicalDeviceNonSeamlessCubeMapFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 nonSeamlessCubeMap;
} VkPhysicalDeviceNonSeamlessCubeMapFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `nonSeamlessCubeMap` indicates that the implementation supports `VK_SAMPLER_CREATE_NON_SEAMLESS_CUBE_MAP_BIT_EXT`.

If the `VkPhysicalDeviceNonSeamlessCubeMapFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceNonSeamlessCubeMapFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceNonSeamlessCubeMapFeaturesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL DEVICE NON SEAMLESS_CUBE_MAP_FEATURES_EXT`

The `VkPhysicalDeviceShaderModuleIdentifierFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_shader_module_identifier
typedef struct VkPhysicalDeviceShaderModuleIdentifierFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderModuleIdentifier;
} VkPhysicalDeviceShaderModuleIdentifierFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `shaderModuleIdentifier` indicates whether the implementation supports querying an identifier of a `VkShaderModule` or `VkShaderModuleCreateInfo` structure, and creating pipelines from identifiers only.

If the `VkPhysicalDeviceShaderModuleIdentifierFeaturesEXT` structure is included in the `pNext` chain of
the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceShaderModuleIdentifierFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceShaderModuleIdentifierFeaturesEXT-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_MODULE_IDENTIFIER_FEATURES_EXT`

The `VkPhysicalDeviceTilePropertiesFeaturesQCOM` structure is defined as:

```c
// Provided by VK_QCOM_tile_properties
typedef struct VkPhysicalDeviceTilePropertiesFeaturesQCOM {
    VkStructureType sType;
    void* pNext;
    VkBool32 tileProperties;
} VkPhysicalDeviceTilePropertiesFeaturesQCOM;
```

This structure describes the following features:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `tileProperties` indicates that the implementation supports queries for returning tile properties.

If the `VkPhysicalDeviceTilePropertiesFeaturesQCOM` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceTilePropertiesFeaturesQCOM` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceTilePropertiesFeaturesQCOM-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TILE_PROPERTIES_FEATURES_QCOM`

The `VkPhysicalDeviceImageProcessingFeaturesQCOM` structure is defined as:

```c
// Provided by VK_QCOM_image_processing
typedef struct VkPhysicalDeviceImageProcessingFeaturesQCOM {
    VkStructureType sType;
    void* pNext;
    VkBool32 textureSampleWeighted;
    VkBool32 textureBoxFilter;
    VkBool32 textureBlockMatch;
} VkPhysicalDeviceImageProcessingFeaturesQCOM;
```
This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **textureSampleWeighted** indicates that the implementation supports shader modules that declare the `TextureSampleWeightedQCOM` capability.
- **textureBoxFilter** indicates that the implementation supports shader modules that declare the `TextureBoxFilterQCOM` capability.
- **textureBlockMatch** indicates that the implementation supports shader modules that declare the `TextureBlockMatchQCOM` capability.

If the `VkPhysicalDeviceImageProcessingFeaturesQCOM` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceImageProcessingFeaturesQCOM` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceImageProcessingFeaturesQCOM-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_PROCESSING_FEATURES_QCOM`

The `VkPhysicalDeviceImageProcessing2FeaturesQCOM` structure is defined as:

```c
// Provided by VK_QCOM_image_processing2
typedef struct VkPhysicalDeviceImageProcessing2FeaturesQCOM {
    VkStructureType sType;
    void* pNext;
    VkBool32 textureBlockMatch2;
} VkPhysicalDeviceImageProcessing2FeaturesQCOM;
```

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **textureBlockMatch2** indicates that the implementation supports shader modules that declare the `TextureBlockMatch2QCOM` capability.

If the `VkPhysicalDeviceImageProcessing2FeaturesQCOM` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceImageProcessing2FeaturesQCOM` can also be used in the `pNext` chain of
VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceImageProcessing2FeaturesQCOM-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_PROCESSING_2_FEATURES_QCOM

The VkPhysicalDeviceDepthClampZeroOneFeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_depth_clamp_zero_one
typedef struct VkPhysicalDeviceDepthClampZeroOneFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 depthClampZeroOne;
} VkPhysicalDeviceDepthClampZeroOneFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `depthClampZeroOne` indicates that the implementation supports clamping the depth to a range of 0 to 1.

If the VkPhysicalDeviceDepthClampZeroOneFeaturesEXT structure is included in the `pNext` chain of the VkPhysicalDeviceFeatures2 structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceDepthClampZeroOneFeaturesEXT can also be used in the `pNext` chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDepthClampZeroOneFeaturesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_CLAMP_ZERO_ONE_FEATURES_EXT

The VkPhysicalDeviceShaderTileImageFeaturesEXT structure is defined as:

```c
// Provided by VK_EXT_shader_tile_image
typedef struct VkPhysicalDeviceShaderTileImageFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderTileImageColorReadAccess;
    VkBool32 shaderTileImageDepthReadAccess;
    VkBool32 shaderTileImageStencilReadAccess;
} VkPhysicalDeviceShaderTileImageFeaturesEXT;
```
The members of the `VkPhysicalDeviceShaderTileImageFeaturesEXT` structure describe the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- `shaderTileImageColorReadAccess` indicates that the implementation supports the `TileImageColorReadAccessEXT` SPIR-V capability.
- `shaderTileImageDepthReadAccess` indicates that the implementation supports the `TileImageDepthReadAccessEXT` SPIR-V capability.
- `shaderTileImageStencilReadAccess` indicates that the implementation supports the `TileImageStencilReadAccessEXT` SPIR-V capability.

If the `VkPhysicalDeviceShaderTileImageFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceShaderTileImageFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceShaderTileImageFeaturesEXT-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_TILE_IMAGE_FEATURES_EXT`.

The `VkPhysicalDeviceDepthBiasControlFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_depth_bias_control
typedef struct VkPhysicalDeviceDepthBiasControlFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 depthBiasControl;
    VkBool32 leastRepresentableValueForceUnormRepresentation;
    VkBool32 floatRepresentation;
    VkBool32 depthBiasExact;
} VkPhysicalDeviceDepthBiasControlFeaturesEXT;
```

This structure describes the following feature:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- `depthBiasControl` indicates whether the implementation supports the `vkCmdSetDepthBias2EXT` command and the `VkDepthBiasRepresentationInfoEXT` structure.
- `leastRepresentableValueForceUnormRepresentation` indicates whether the implementation supports using the `VK_DEPTH_BIAS_REPRESENTATION_LEAST_REPRESENTABLE_VALUE_FORCE_UNORM_EXT` depth bias representation.
• `floatRepresentation` indicates whether the implementation supports using the `VK_DEPTH_BIAS_REPRESENTATION_FLOAT_EXT` depth bias representation.

• `depthBiasExact` indicates whether the implementation supports forcing depth bias to not be scaled to ensure a minimum resolvable difference using `VkDepthBiasRepresentationInfoEXT::depthBiasExact`.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceDepthBiasControlFeaturesEXT-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_BIAS_CONTROL_FEATURES_EXT`

The `VkPhysicalDeviceAddressBindingReportFeaturesEXT` structure is defined as:

```c
typedef struct VkPhysicalDeviceAddressBindingReportFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 reportAddressBinding;
} VkPhysicalDeviceAddressBindingReportFeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `reportAddressBinding` indicates whether this implementation supports reporting the binding of GPU virtual address ranges to Vulkan objects.

If the `VkPhysicalDeviceAddressBindingReportFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceAddressBindingReportFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceAddressBindingReportFeaturesEXT-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ADDRESS_BINDING_REPORT_FEATURES_EXT`

The `VkPhysicalDeviceOpticalFlowFeaturesNV` structure is defined as:

```c
typedef struct VkPhysicalDeviceOpticalFlowFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 opticalFlow;
} VkPhysicalDeviceOpticalFlowFeaturesNV;
```
This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `opticalFlow` indicates whether the implementation supports optical flow.

If the `VkPhysicalDeviceOpticalFlowFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceOpticalFlowFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceOpticalFlowFeaturesNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_OPTICAL_FLOW_FEATURES_NV`

The `VkPhysicalDeviceFaultFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_device_fault
typedef struct VkPhysicalDeviceFaultFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 deviceFault;
    VkBool32 deviceFaultVendorBinary;
} VkPhysicalDeviceFaultFeaturesEXT;
```

The members of the `VkPhysicalDeviceFaultFeaturesEXT` structure describe the following features:

- `deviceFault` indicates that the implementation supports the reporting of device fault information.
- `deviceFaultVendorBinary` indicates that the implementation supports the generation of vendor-specific binary crash dumps. These may provide additional information when imported into vendor-specific external tools.

If the `VkPhysicalDeviceFaultFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceFaultFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceFaultFeaturesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FAULT_FEATURES_EXT`
The `VkPhysicalDevicePipelineLibraryGroupHandlesFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_pipeline_library_group_handles
typedef struct VkPhysicalDevicePipelineLibraryGroupHandlesFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 pipelineLibraryGroupHandles;
} VkPhysicalDevicePipelineLibraryGroupHandlesFeaturesEXT;
```

This structure describes the following features:

- `pipelineLibraryGroupHandles` indicates whether the implementation supports querying group handles directly from a ray tracing pipeline library, and guarantees bitwise identical group handles for such libraries when linked into other pipelines.

If the `VkPhysicalDevicePipelineLibraryGroupHandlesFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDevicePipelineLibraryGroupHandlesFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDevicePipelineLibraryGroupHandlesFeaturesEXT-sType-sType` `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_LIBRARY_GROUP_HANDLES_FEATURES_EXT`.

The `VkPhysicalDeviceShaderObjectFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_shader_object
typedef struct VkPhysicalDeviceShaderObjectFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderObject;
} VkPhysicalDeviceShaderObjectFeaturesEXT;
```

This structure describes the following feature:

- `shaderObject` indicates whether the implementation supports shader objects.

If the `VkPhysicalDeviceShaderObjectFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceShaderObjectFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.
Valid Usage (Implicit)

• VUID-VkPhysicalDeviceShaderObjectFeaturesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_OBJECT_FEATURES_EXT

The `VkPhysicalDeviceShaderCoreBuiltinsFeaturesARM` structure is defined as:

```c
// Provided by VK_ARM_shader_core_builtins
typedef struct VkPhysicalDeviceShaderCoreBuiltinsFeaturesARM {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderCoreBuiltins;
} VkPhysicalDeviceShaderCoreBuiltinsFeaturesARM;
```

This structure describes the following feature:

• `sType` is a `VkStructureType` value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.
• `shaderCoreBuiltins` indicates whether the implementation supports the SPIR-V CoreBuiltinsARM capability.

If the `VkPhysicalDeviceShaderCoreBuiltinsFeaturesARM` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceShaderCoreBuiltinsFeaturesARM` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceShaderCoreBuiltinsFeaturesARM-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CORE_BUILTINS_FEATURES_ARM

The `VkPhysicalDeviceFrameBoundaryFeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_frame_boundary
typedef struct VkPhysicalDeviceFrameBoundaryFeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 frameBoundary;
} VkPhysicalDeviceFrameBoundaryFeaturesEXT;
```

This structure describes the following feature:

• `sType` is a `VkStructureType` value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.
• `frameBoundary` indicates whether the implementation supports frame boundary information.

If the `VkPhysicalDeviceFrameBoundaryFeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceFrameBoundaryFeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceFrameBoundaryFeaturesEXT-sType-sType`
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAME_BOUNDARY_FEATURES_EXT`

The `VkPhysicalDeviceSwapchainMaintenance1FeaturesEXT` structure is defined as:

```c
// Provided by VK_EXT_swapchain_maintenance1
typedef struct VkPhysicalDeviceSwapchainMaintenance1FeaturesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 swapchainMaintenance1;
} VkPhysicalDeviceSwapchainMaintenance1FeaturesEXT;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `swapchainMaintenance1` indicates that the implementation supports the following:
  - `VkSwapchainPresentFenceInfoEXT`, specifying a fence that is signaled when the resources associated with a present operation can be safely destroyed.
  - `VkSwapchainPresentModesCreateInfoEXT` and `VkSwapchainPresentModeInfoEXT`, allowing the swapchain to switch present modes without a need for recreation.
  - `VkSwapchainPresentScalingCreateInfoEXT`, specifying the scaling behavior of the swapchain in presence of window resizing.
  - The `VK_SWAPCHAIN_CREATE_DEFERRED_MEMORY_ALLOCATION_BIT_EXT` flag, allowing the implementation to defer the allocation of swapchain image memory until first acquisition.
  - `vkReleaseSwapchainImagesEXT`, allowing acquired swapchain images to be released without presenting them.

If the `VkPhysicalDeviceSwapchainMaintenance1FeaturesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceSwapchainMaintenance1FeaturesEXT` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceSwapchainMaintenance1FeaturesEXT-sType-sType
  
sType **must** be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SWAPCHAIN_MAINTENANCE_1_FEATURES_EXT

The **VkPhysicalDeviceDynamicRenderingUnusedAttachmentsFeaturesEXT** structure is defined as:

```c
// Provided by VK_EXT_dynamic_rendering_unused_attachments
typedef struct VkPhysicalDeviceDynamicRenderingUnusedAttachmentsFeaturesEXT {
    VkStructureType   sType;
    void*             pNext;
    VkBool32          dynamicRenderingUnusedAttachments;
} VkPhysicalDeviceDynamicRenderingUnusedAttachmentsFeaturesEXT;
```

This structure describes the following feature:

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **dynamicRenderingUnusedAttachments** indicates that the implementation supports binding graphics pipelines within a render pass instance where any pipeline **VkPipelineRenderingCreateInfo**::pColorAttachmentFormats element with a format other than VK_FORMAT_UNDEFINED is allowed with a corresponding **VkRenderingInfo**::pColorAttachments element with an imageView equal to VK_NULL_HANDLE, or any pipeline **VkPipelineRenderingCreateInfo**::pColorAttachmentFormats element with a VK_FORMAT_UNDEFINED format is allowed with a corresponding **VkRenderingInfo**::pColorAttachments element with a non-VK_NULL_HANDLE imageView. Also a **VkPipelineRenderingCreateInfo**::depthAttachmentFormat other than VK_FORMAT_UNDEFINED is allowed with a VK_NULL_HANDLE **VkRenderingInfo**::pDepthAttachment, or a **VkPipelineRenderingCreateInfo**::depthAttachmentFormat of VK_FORMAT_UNDEFINED is allowed with a non-VK_NULL_HANDLE **VkRenderingInfo**::pDepthAttachment. Also a **VkPipelineRenderingCreateInfo**::stencilAttachmentFormat other than VK_FORMAT_UNDEFINED is allowed with a VK_NULL_HANDLE **VkRenderingInfo**::pDepthAttachment, or a **VkPipelineRenderingCreateInfo**::stencilAttachmentFormat of VK_FORMAT_UNDEFINED is allowed with a non-VK_NULL_HANDLE **VkRenderingInfo**::pDepthAttachment. Any writes to a **VkRenderingInfo**::pColorAttachments, **VkRenderingInfo**::pDepthAttachment, or **VkRenderingInfo**::pStencilAttachment with VK_NULL_HANDLE are discarded.

If the **VkPhysicalDeviceDynamicRenderingUnusedAttachmentsFeaturesEXT** structure is included in the **pNext** chain of the **VkPhysicalDeviceFeatures2** structure passed to **vkGetPhysicalDeviceFeatures2**, it is filled in to indicate whether each corresponding feature is supported. **VkPhysicalDeviceDynamicRenderingUnusedAttachmentsFeaturesEXT** can also be used in the **pNext** chain of **VkDeviceCreateInfo** to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDynamicRenderingUnusedAttachmentsFeaturesEXT-sType-sType

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The `VkPhysicalDeviceRayTracingInvocationReorderFeaturesNV` structure is defined as:

```c
typedef struct VkPhysicalDeviceRayTracingInvocationReorderFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 rayTracingInvocationReorder;
} VkPhysicalDeviceRayTracingInvocationReorderFeaturesNV;
```

This structure describes the following feature:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `rayTracingInvocationReorder` indicates that the implementation supports SPV_NV_shader_invocation_reorder.

If the `VkPhysicalDeviceRayTracingInvocationReorderFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceRayTracingInvocationReorderFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

The `VkPhysicalDeviceMultiviewPerViewViewportsFeaturesQCOM` structure is defined as:

```c
typedef struct VkPhysicalDeviceMultiviewPerViewViewportsFeaturesQCOM {
    VkStructureType sType;
    void* pNext;
    VkBool32 multiviewPerViewViewports;
} VkPhysicalDeviceMultiviewPerViewViewportsFeaturesQCOM;
```

This structure describes the following features:

- `multiviewPerViewViewports` indicates that the implementation supports multiview per-view viewports.
If the `VkPhysicalDeviceMultiviewPerViewViewportsFeaturesQCOM` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceMultiviewPerViewViewportsFeaturesQCOM` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceMultiviewPerViewViewportsFeaturesQCOM-sType-sType must be
  `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_PER_VIEW_VIEWPORTS_FEATURES_QCOM`

The `VkPhysicalDeviceMultiviewPerViewRenderAreasFeaturesQCOM` structure is defined as:

```c
// Provided by VK_QCOM_multiview_per_view_render_areas
typedef struct VkPhysicalDeviceMultiviewPerViewRenderAreasFeaturesQCOM {
    VkStructureType sType;
    void* pNext;
    VkBool32 multiviewPerViewRenderAreas;
} VkPhysicalDeviceMultiviewPerViewRenderAreasFeaturesQCOM;
```

This structure describes the following features:

- `multiviewPerViewRenderAreas` indicates that the implementation supports multiview per-view render areas.

If the `VkPhysicalDeviceMultiviewPerViewRenderAreasFeaturesQCOM` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceMultiviewPerViewRenderAreasFeaturesQCOM` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceMultiviewPerViewRenderAreasFeaturesQCOM-sType-sType must be
  `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_PER_VIEW_RENDER_AREAS_FEATURES_QCOM`

The `VkPhysicalDeviceClusterCullingShaderFeaturesHUAWEI` structure is defined as:

```c
// Provided by VK_HUAWEI_cluster_culling_shader
typedef struct VkPhysicalDeviceClusterCullingShaderFeaturesHUAWEI {
    VkStructureType sType;
    void* pNext;
    VkBool32 clustercullingShader;
    VkBool32 multiviewClusterCullingShader;
} VkPhysicalDeviceClusterCullingShaderFeaturesHUAWEI;
```
- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **clusterCullingShader** specifies whether cluster culling shader is supported.
- **multiviewClusterCullingShader** specifies whether multiview is supported.

If the `VkPhysicalDeviceClusterCullingShaderFeaturesHUAWEI` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceClusterCullingShaderFeaturesHUAWEI` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceClusterCullingShaderFeaturesHUAWEI-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CLUSTER_CULLING_SHADER_FEATURES_HUAWEI`.

The `VkPhysicalDeviceShaderEnqueueFeaturesAMDX` structure is defined as:

```c
// Provided by VK_AMDX_shader_enqueue
typedef struct VkPhysicalDeviceShaderEnqueueFeaturesAMDX {
    VkStructureType sType;
    void* pNext;
    VkBool32 shaderEnqueue;
} VkPhysicalDeviceShaderEnqueueFeaturesAMDX;
```

This structure describes the following feature:

- **shaderEnqueue** indicates whether the implementation supports execution graphs.

If the `VkPhysicalDeviceShaderEnqueueFeaturesAMDX` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceShaderEnqueueFeaturesAMDX` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceShaderEnqueueFeaturesAMDX-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ENQUEUE_FEATURES_AMDX`.

The `VkPhysicalDeviceCubicClampFeaturesQCOM` structure is defined as:

```c
// Provided by VK_QCOM_cubic_clamp
typedef struct VkPhysicalDeviceCubicClampFeaturesQCOM {
    VkStructureType sType;
    void* pNext;
    VkBool32 cubicClamp;
} VkPhysicalDeviceCubicClampFeaturesQCOM;
```
typedef struct VkPhysicalDeviceCubicClampFeaturesQCOM {
    VkStructureType sType;
    void* pNext;
    VkBool32 cubicRangeClamp;
} VkPhysicalDeviceCubicClampFeaturesQCOM;

This structure describes the following features:

- **cubicRangeClamp** indicates that the implementation supports cubic filtering in combination with a texel range clamp.

If the `VkPhysicalDeviceCubicClampFeaturesQCOM` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceCubicClampFeaturesQCOM` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

**Valid Usage (Implicit)**

- `VUID-VkPhysicalDeviceCubicClampFeaturesQCOM-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CUBIC_CLAMP_FEATURES_QCOM`

The `VkPhysicalDeviceYcbcrDegammaFeaturesQCOM` structure is defined as:

typedef struct VkPhysicalDeviceYcbcrDegammaFeaturesQCOM {
    VkStructureType sType;
    void* pNext;
    VkBool32 ycbcrDegamma;
} VkPhysicalDeviceYcbcrDegammaFeaturesQCOM;

This structure describes the following features:

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **ycbcrDegamma** indicates whether the implementation supports $Y'C_B'C_R$ degamma.

If the `VkPhysicalDeviceYcbcrDegammaFeaturesQCOM` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceYcbcrDegammaFeaturesQCOM` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceYcbcrDegammaFeaturesQCOM-sType-sType
  
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_YCBCR_DEGAMMA_FEATURES_QCOM

The VkPhysicalDeviceCubicWeightsFeaturesQCOM structure is defined as:

```c
// Provided by VK_QCOM_filter_cubic_weights
typedef struct VkPhysicalDeviceCubicWeightsFeaturesQCOM {
    VkStructureType sType;
    void* pNext;
    VkBool32 selectableCubicWeights;
} VkPhysicalDeviceCubicWeightsFeaturesQCOM;
```

This structure describes the following feature:

- selectableCubicWeights indicates that the implementation supports the selection of filter cubic weights.

If the VkPhysicalDeviceCubicWeightsFeaturesQCOM structure is included in the pNext chain of the VkPhysicalDeviceFeatures2 structure passed to vkGetPhysicalDeviceFeatures2, it is filled in to indicate whether each corresponding feature is supported. VkPhysicalDeviceCubicWeightsFeaturesQCOM can also be used in the pNext chain of VkDeviceCreateInfo to selectively enable these features.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceCubicWeightsFeaturesQCOM-sType-sType
  
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CUBIC_WEIGHTS_FEATURES_QCOM

The VkPhysicalDeviceDescriptorPoolOverallocationFeaturesNV structure is defined as:

```c
// Provided by VK_NV_descriptor_pool_overallocation
typedef struct VkPhysicalDeviceDescriptorPoolOverallocationFeaturesNV {
    VkStructureType sType;
    void* pNext;
    VkBool32 descriptorPoolOverallocation;
} VkPhysicalDeviceDescriptorPoolOverallocationFeaturesNV;
```

This structure describes the following feature:

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- descriptorPoolOverallocation indicates that the implementation allows the application to opt into descriptor pool overallocation by creating the descriptor pool with
If the `VkPhysicalDeviceDescriptorPoolOverallocationFeaturesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceFeatures2` structure passed to `vkGetPhysicalDeviceFeatures2`, it is filled in to indicate whether each corresponding feature is supported. `VkPhysicalDeviceDescriptorPoolOverallocationFeaturesNV` can also be used in the `pNext` chain of `VkDeviceCreateInfo` to selectively enable these features.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceDescriptorPoolOverallocationFeaturesNV-sType-sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_POOL_OVERALLOCATION_FEATURES_NV`

### 46.1. Feature Requirements

All Vulkan graphics implementations **must** support the following features:

- `robustBufferAccess`, unless the `VK_KHR_portability_subset` extension is enabled.
- `multiview`, if Vulkan 1.1 is supported.
- `shaderDrawParameters`, if the `VK_KHR_shader_draw_parameters` extension is supported.
- `uniformBufferStandardLayout`, if Vulkan 1.2 or the `VK_KHR_uniform_buffer_standard_layout` extension is supported.
- `variablePointersStorageBuffer`, if the `VK_KHR_variable_pointers` extension is supported.
- `storageBuffer8BitAccess`, if the `VK_KHR_8bit_storage` extension is supported.
- `storageBuffer8BitAccess`, if `uniformAndStorageBuffer8BitAccess` is enabled.
- If the `descriptorIndexing` feature is supported, or if the `VK_EXT_descriptor_indexing` extension is supported:
  - `shaderSampledImageArrayDynamicIndexing`
  - `shaderStorageBufferArrayDynamicIndexing`
  - `shaderUniformTexelBufferArrayDynamicIndexing`
  - `shaderStorageTexelBufferArrayDynamicIndexing`
  - `descriptorBindingSampledImageNonUniformIndexing`
  - `descriptorBindingStorageBufferNonUniformIndexing`
  - `descriptorBindingUniformTexelBufferNonUniformIndexing`
  - `descriptorBindingSampledImageUpdateAfterBind`
  - `descriptorBindingStorageImageUpdateAfterBind`
  - `descriptorBindingStorageBufferUpdateAfterBind` (see also `robustBufferAccessUpdateAfterBind`)
  - `descriptorBindingUniformTexelBufferUpdateAfterBind` (see also `robustBufferAccessUpdateAfterBind`)

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robustBufferAccessUpdateAfterBind
• descriptorBindingStorageTexelBufferUpdateAfterBind (see also
  robustBufferAccessUpdateAfterBind)
• descriptorBindingUpdateUnusedWhilePending
• descriptorBindingPartiallyBound
• runtimeDescriptorArray
• If Vulkan 1.3 is supported:
  • vulkanMemoryModel
  • vulkanMemoryModelDeviceScope
• inlineUniformBlock, if Vulkan 1.3 or the VK_EXT_inline_uniform_block extension is supported.
• descriptorBindingInlinedUniformBlockUpdateAfterBind, if Vulkan 1.3 or the
  VK_EXT_inline_uniform_block extension is supported; and if the descriptorIndexing feature is
  supported, or the VK_EXT_descriptor_indexing extension is supported.
• scalarBlockLayout, if the VK_EXT_scalar_block_layout extension is supported.
• subgroupBroadcastDynamicId, if Vulkan 1.2 is supported.
• samplerMirrorClampToEdge, if the VK_KHR_sampler_mirror_clamp_to_edge extension is supported.
• drawIndirectCount, if the VK_KHR_draw_indirect_count extension is supported.
• samplerFilterMinmax, if the VK_EXT_sampler_filter_minmax extension is supported.
• shaderOutputViewportIndex, if the VK_EXT_shader_viewport_index_layer extension is supported.
• shaderOutputLayer, if the VK_EXT_shader_viewport_index_layer extension is supported.
• subgroupSizeControl, if Vulkan 1.3 or the VK_EXT_subgroup_size_control extension is supported.
• computeFullSubgroups, if Vulkan 1.3 or the VK_EXT_subgroup_size_control extension is supported.
• deviceMemoryReport, if the VK_EXT_device_memory_report extension is supported.
• globalPriorityQuery, if the VK_EXT_global_priority_query extension is supported.
• globalPriorityQuery, if the VK_KHR_global_priority extension is supported.
• imagelessFramebuffer, if Vulkan 1.2 or the VK_KHR_imageless_framebuffer extension is supported.
• separateDepthStencilLayouts, if Vulkan 1.2 or the VK_KHR_separate_depthStencil_layouts extension is supported.
• hostQueryReset, if Vulkan 1.2 or the VK_EXT_host_query_reset extension is supported.
• timelineSemaphore, if Vulkan 1.2 or the VK_KHR_timeline_semaphore extension is supported.
• If the VK_KHR_acceleration_structure extension is supported:
  • accelerationStructure
  • All the features required by the descriptorIndexing feature if Vulkan 1.2 is supported, or the
    VK_EXT_descriptor_indexing extension.
  • descriptorBindingAccelerationStructureUpdateAfterBind
  • bufferDeviceAddress from Vulkan 1.2 or the VK_KHR_buffer_device_address extension.
• If the VK_KHR_ray_tracing_pipeline extension is supported:
  ◦ rayTracingPipeline
  ◦ rayTracingPipelineTraceRaysIndirect
  ◦ rayTraversalPrimitiveCulling, if rayQuery is supported
  ◦ the VK_KHR_pipeline_library extension must be supported.
  
• rayQuery, if the VK_KHR_ray_query extension is supported.

• pipelineCreationCacheControl, if Vulkan 1.3 or the VK_EXT_pipeline_creation_cache_control extension is supported.

• shaderSubgroupExtendedTypes, if Vulkan 1.2 or the VK_KHR_shader_subgroup_extended_types extension is supported.

• samplerYcbcrConversion, if the VK_KHR_sampler_ycbcr_conversion extension is supported.

• pipelineExecutableInfo, if the VK_KHR_pipeline_executable_properties extension is supported.

• textureCompressionASTC_HDR, if the VK_EXT_texture_compression_astc_hdr extension is supported.

• depthClipEnable, if the VK_EXT_depth_clip_enable extension is supported.

• memoryPriority, if the VK_EXT_memory_priority extension is supported.

• ycbcrImageArrays, if the VK_EXT_ycbcr_image_arrays extension is supported.

• indexTypeUint8, if the VK_EXT_index_type_uint8 extension is supported.

• primitiveTopologyListRestart, if the VK_EXT_primitive_topology_list_restart extension is supported.

• shaderDemoteToHelperInvocation, if Vulkan 1.3 or the VK_EXT_shader_demote_to_helper_invocation extension is supported.

• texelBufferAlignment, if Vulkan 1.3 or the VK_EXT_texel_buffer_alignment extension is supported.

• vulkanMemoryModel, if the VK_KHR_vulkan_memory_model extension is supported.

• bufferDeviceAddress, if Vulkan 1.3 or the VK_KHR_buffer_device_address extension is supported.

• performanceCounterQueryPools, if the VK_KHR_performance_query extension is supported.

• transformFeedback, if the VK_EXT_transform_feedback extension is supported.

• conditionalRendering, if the VK_EXT_conditional_rendering extension is supported.

• vertexAttributeInstanceRateDivisor, if the VK_EXT_vertex_attribute_divisor extension is supported.

• fragmentDensityMap, if the VK_EXT_fragment_density_map extension is supported.

• shaderSubgroupClock, if the VK_KHR_shader_clock extension is supported.

• shaderBufferInt64Atomics, if the VK_KHR_shader_atomic_int64 extension is supported.

• shaderInt64, if the shaderSharedInt64Atomics or shaderBufferInt64Atomics features are supported.

• shaderFloat16 or shaderInt8, if the VK_KHR_shader_float16_int8 extension is supported.

• fragmentShaderSampleInterlock or fragmentShaderPixelInterlock or fragmentShaderShadingRateInterlock, if the VK_EXT_fragment_shader_interlock extension is supported.
• rectangularLines or bresenhamLines or smoothLines or stippledRectangularLines or stippledBresenhamLines or stippledSmoothLines, if the VK_EXT_line_rasterization extension is supported.

• storageBuffer16BitAccess, if the VK_KHR_16bit_storage extension is supported.

• storageBuffer16BitAccess, if uniformAndStorageBuffer16BitAccess is enabled.

• robustImageAccess, if Vulkan 1.3 or the VK_EXT_image_robustness extension is supported.

• formatA4R4G4B4, if the VK_EXT_4444_formats extension is supported.

• mutableDescriptorType, if the VK_EXT_mutable_descriptor_type or VK_VALVE_mutable_descriptor_type extension is supported.

• shaderInt64 and shaderImageInt64Atomics, if the VK_EXT_shader_image_atomic_int64 extension is supported.

• shaderImageInt64Atomics, if the sparseImageInt64Atomics feature is supported.

• shaderImageFloat32Atomics, if the sparseImageFloat32Atomics feature is supported.

• shaderImageFloat32AtomicAdd, if the sparseImageFloat32AtomicAdd feature is supported.

• primitivesGeneratedQuery, if the VK_EXT_primitives_generated_query extension is supported.

• pipelineFragmentShadingRate, if the VK_KHR_fragment_shading_rate extension is supported.

• pipelineProtectedAccess, if the VK_EXT_pipeline_protected_access extension is supported.

• legacyDithering, if the VK_EXT_legacy_dithering extension is supported.

• shaderTerminateInvocation if Vulkan 1.3 or the VK_KHR_shader_terminate_invocation extension is supported.

• shaderZeroInitializeWorkgroupMemory, if Vulkan 1.3 or the VK_KHR_zero_initialize_workgroup_memory extension is supported.

• workgroupMemoryExplicitLayout, if the VK_KHR_workgroup_memory_explicit_layout extension is supported.

• vertexInputDynamicState, if the VK_EXT_vertex_input_dynamic_state extension is supported.

• synchronization2 if Vulkan 1.3 or the VK_KHR_synchronization2 extension is supported.

• provokingVertexLast, if the VK_EXT_provoking_vertex extension is supported.

• descriptorBuffer, if the VK_EXT_descriptor_buffer extension is supported.

• shaderSubgroupUniformControlFlow, if the VK_KHR_shader_subgroup_uniform_control_flow extension is supported.

• borderColorSwizzle if the VK_EXT_border_color_swizzle extension is supported.

• multiDraw, if the VK_EXT_multi_draw extension is supported.

• shaderImageFloat32AtomicMinMax, if the sparseImageFloat32AtomicMinMax feature is supported.

• presentId, if the VK_KHR_present_id extension is supported.

• presentWait, if the VK_KHR_present_wait extension is supported.

• hostImageCopy, if the VK_EXT_host_image_copy extension is supported.

• shaderIntegerDotProduct if Vulkan 1.3 or the VK_KHR_shader_integer_dot_product extension is supported.
• **maintenance4**, if Vulkan 1.3 or the **VK_KHR_maintenance4** extension is supported.
• **maintenance5**, if the **VK_KHR_maintenance5** extension is supported.
• **image2DViewOf3D**, if the **VK_EXT_image_2d_view_of_3d** extension is supported.
• **imageSlicedViewOf3D**, if the **VK_EXT_image_sliced_view_of_3d** extension is supported.
• **privateData**, if Vulkan 1.3 or the **VK_EXT_private_data** extension is supported.
• **extendedDynamicState**, if the **VK_EXT_extended_dynamic_state** extension is supported.
• **extendedDynamicState2**, if the **VK_EXT_extended_dynamic_state2** extension is supported.
• **depthClipControl**, if the **VK_EXT_depth_clip_control** extension is supported.
• **minLod**, if the **VK_EXT_image_view_min_lod** extension is supported.
• **linearColorAttachment**, if the **VK_NV_linear_color_attachment** extension is supported.
• **presentBarrier**, if the **VK_NV_present_barrier** extension is supported.
• **graphicsPipelineLibrary**, if the **VK_EXT_graphics_pipeline_library** extension is supported.
• **dynamicRendering**, if Vulkan 1.3 or the **VK_KHR_dynamic_rendering** extension is supported.
• **taskShader** and **meshShader**, if the **VK_EXT_mesh_shader** extension is supported.
• **primitiveFragmentShadingRate** if **primitiveFragmentShadingRateMeshShader** feature is supported.
• **subpassMergeFeedback**, if the **VK_EXT_subpass_merge_feedback** extension is supported.
• **rayTracingMaintenance1**, if the **VK_KHR_ray_tracing_maintenance1** extension is supported.
• **colorWriteEnable**, if the **VK_EXT_color_write_enable** extension is supported.
• **multisampledRenderToSingleSampled**, if the **VK_EXT_multisampled_render_to_single_sampled** extension is supported.
• **imageCompressionControl**, if the **VK_EXT_image_compression_control** extension is supported.
• **imageCompressionControlSwapchain**, if the **VK_EXT_image_compression_control_swapchain** extension is supported.
• **shaderEarlyAndLateFragmentTests**, if the **VK_AMD_shader_early_and_late_fragment_tests** extension is supported.
• **nonSeamlessCubeMap**, if the **VK_EXT_non_seamless_cube_map** extension is supported.
• **shaderModuleIdentifier**, if **VK_EXT_shader_module_identifier** extension is supported.
• **pipelineRobustness**, if the **VK_EXT_pipeline_robustness** extension is supported.
• **textureSampleWeighted**, **TextureBlockMatch**, and **TextureBoxFilter** if **VK_QCOM_image_processing** extension is supported.
• **TextureBlockMatch2** if **VK_QCOM_image_processing2** extension is supported.
• **tileProperties** if **VK_QCOM_tile_properties** extension is supported.
• **attachmentFeedbackLoopLayout**, if the **VK_EXT_attachment_feedback_loop_layout** extension is supported.
• **depthClampZeroOne**, if the **VK_EXT_depth_clamp_zero_one** extension is supported.
• **deviceFault**, if the **VK_EXT_device_fault** extension is supported.

• **reportAddressBinding**, if the **VK_EXT_device_address_binding_report** extension is supported.

• **micromap**, if the **VK_EXT_opacity_micromap** extension is supported.

• **frameBoundary**, if the **VK_EXT_frame_boundary** extension is supported.

• **displacementMicromap**, if the **VK_NV_displacement_micromap** extension is supported.

• **pipelineLibraryGroupHandles**, if the **VK_EXT_pipeline_library_group_handles** extension is supported.

• **swapchainMaintenance1**, if the **VK_EXT_swapchain_maintenance1** extension is supported.

• **tessellationShader**, if the **extendedDynamicState3TessellationDomainOrigin** feature is supported.

• **depthClamp**, if the **extendedDynamicState3DepthClampEnable** feature is supported.

• **fillModeNonSolid**, if the **extendedDynamicState3PolygonMode** feature is supported.

• **alphaToOne**, if the **extendedDynamicState3AlphaToOneEnable** feature is supported.

• **logicOp**, if the **extendedDynamicState3LogicOpEnable** feature is supported.

• **geometryStreams**, if the **extendedDynamicState3RasterizationStream** feature is supported.

• **VK_EXT_conservative_rasterization** extension, if the **extendedDynamicState3ConservativeRasterizationMode** feature is supported.

• **VK_EXT_conservative_rasterization** extension, if the **extendedDynamicState3ExtraPrimitiveOverestimationSize** feature is supported.

• **VK_EXT_sample_locations** extension, if the **extendedDynamicState3SampleLocationsEnable** feature is supported.

• **VK_EXT_blend_operation_advanced** extension, if the **extendedDynamicState3ColorBlendAdvanced** feature is supported.

• **provokingVertexLast**, if the **extendedDynamicState3ProvokingVertexMode** feature is supported.

• **VK_EXT_line_rasterization** extension, if the **extendedDynamicState3LineRasterizationMode** feature is supported.

• **VK_EXT_line_rasterization** extension, if the **extendedDynamicState3LineStippleEnable** feature is supported.

• **depthClipControl**, if the **extendedDynamicState3DepthClipNegativeOneToOne** feature is supported.

• **VK_NV_clip_space_w_scaling** extension, if the **extendedDynamicState3ViewportWScalingEnable** feature is supported.

• **VK_NV_viewport_swizzle** extension, if the **extendedDynamicState3ViewportSwizzle** feature is supported.

• **VK_NV_fragment_coverage_to_color** extension, if the **extendedDynamicState3CoverageToColorEnable** feature is supported.

• **VK_NV_fragment_coverage_to_color** extension, if the **extendedDynamicState3CoverageToColorLocation** feature is supported.

• **VK_NV_framebuffer_mixed_samples** extension, if the **extendedDynamicState3CoverageModulationMode** feature is supported.
VK_NV_framebuffer_mixed_samples extension, if the extendedDynamicState3CoverageModulationTableEnable feature is supported.

VK_NV_framebuffer_mixed_samples extension, if the extendedDynamicState3CoverageModulationTable feature is supported.

coverageReductionMode, if the extendedDynamicState3CoverageReductionMode feature is supported.

representativeFragmentTest, if the extendedDynamicState3RepresentativeFragmentTestEnable feature is supported.

shadingRateImage, if the extendedDynamicState3ShadingRateImageEnable feature is supported.

multiviewPerViewViewports, if the VK_QCOM_multiview_per_view_viewports extension is supported.

attachmentFeedbackLoopDynamicState, if the VK_EXT_attachment_feedback_loop_dynamic_state extension is supported.

rayTracingPositionFetch, if the VK_KHR_ray_tracing_position_fetch extension is supported.

shaderObject, if the VK_EXT_shader_object extension is supported.

shaderTileImageColorReadAccess, if the VK_EXT_shader_tile_image extension is supported.

depthBiasControl, if the VK_EXT_depth_bias_control extension is supported.

deviceGeneratedCompute, if the VK_NV_device_generated_commands_compute extension is supported.

shaderEnqueue if the VK_AMDX_shader_enqueue extension is supported.

cooperativeMatrix if the VK_KHR_cooperative_matrix extension is supported.

ycbcrDegamma, if the VK_QCOM_ycbcr_degamma extension is supported.

descriptorPoolOverallocation, if the VK_NV_descriptor_pool_overallocation extension is supported.

All other features defined in the Specification are optional.

46.2. Profile Features

46.2.1. Roadmap 2022

Implementations that claim support for the Roadmap 2022 profile must support the following features:

- fullDrawIndexUint32
- imageCubeArray
- independentBlend
- sampleRateShading
- drawIndirectFirstInstance
- depthClamp
- depthBiasClamp
- samplerAnisotropy
• occlusionQueryPrecise
• fragmentStoresAndAtomics
• shaderStorageImageExtendedFormats
• shaderUniformBufferArrayDynamicIndexing
• shaderSampledImageArrayDynamicIndexing
• shaderStorageBufferArrayDynamicIndexing
• shaderStorageImageArrayDynamicIndexing
• samplerYcbcrConversion
• samplerMirrorClampToEdge
• descriptorIndexing
• shaderUniformTexelBufferArrayDynamicIndexing
• shaderStorageTexelBufferArrayDynamicIndexing
• shaderUniformBufferArrayNonUniformIndexing
• shaderSampledImageArrayNonUniformIndexing
• shaderStorageBufferArrayNonUniformIndexing
• shaderStorageImageArrayNonUniformIndexing
• shaderUniformTexelBufferArrayNonUniformIndexing
• shaderStorageTexelBufferArrayNonUniformIndexing
• descriptorBindingSampledImageUpdateAfterBind
• descriptorBindingStorageImageUpdateAfterBind
• descriptorBindingStorageBufferUpdateAfterBind
• descriptorBindingUniformTexelBufferUpdateAfterBind
• descriptorBindingStorageTexelBufferUpdateAfterBind
• descriptorBindingUpdateUnusedWhilePending
• descriptorBindingPartiallyBound
• descriptorBindingVariableDescriptorCount
• runtimeDescriptorArray
• scalarBlockLayout
Chapter 47. Limits

Limits are implementation-dependent minimums, maximums, and other device characteristics that an application may need to be aware of.

**Note**

Limits are reported via the basic `VkPhysicalDeviceLimits` structure as well as the extensible structure `VkPhysicalDeviceProperties2`, which was added in `VK_KHR_get_physical_device_properties2` and included in Vulkan 1.1. When limits are added in future Vulkan versions or extensions, each extension should introduce one new limit structure, if needed. This structure can be added to the `pNext` chain of the `VkPhysicalDeviceProperties2` structure.

The `VkPhysicalDeviceLimits` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkPhysicalDeviceLimits {
    uint32_t maxImageDimension1D;
    uint32_t maxImageDimension2D;
    uint32_t maxImageDimension3D;
    uint32_t maxImageDimensionCube;
    uint32_t maxImageArrayLayers;
    uint32_t maxTexelBufferElements;
    uint32_t maxUniformBufferRange;
    uint32_t maxStorageBufferRange;
    uint32_t maxPushConstantsSize;
    uint32_t maxMemoryAllocationCount;
    uint32_t maxSamplerAllocationCount;
    VkDeviceSize bufferImageGranularity;
    VkDeviceSize sparseAddressSpaceSize;
    uint32_t maxBoundDescriptorSets;
    uint32_t maxPerStageDescriptorSamplers;
    uint32_t maxPerStageDescriptorUniformBuffers;
    uint32_t maxPerStageDescriptorStorageBuffers;
    uint32_t maxPerStageDescriptorSampledImages;
    uint32_t maxPerStageDescriptorStorageImages;
    uint32_t maxPerStageDescriptorInputAttachments;
    uint32_t maxPerStageResources;
    uint32_t maxDescriptorSetSamplers;
    uint32_t maxDescriptorSetUniformBuffers;
    uint32_t maxDescriptorSetUniformBuffersDynamic;
    uint32_t maxDescriptorSetStorageBuffers;
    uint32_t maxDescriptorSetStorageBuffersDynamic;
    uint32_t maxDescriptorSetSampledImages;
    uint32_t maxDescriptorSetStorageImages;
    uint32_t maxDescriptorSetInputAttachments;
    uint32_t maxVertexInputAttributes;
    uint32_t maxVertexInputBindings;
    uint32_t maxVertexInputAttributeOffset;
};
```
uint32_t maxVertexInputBindingStride;
uint32_t maxVertexOutputComponents;
uint32_t maxTessellationGenerationLevel;
uint32_t maxTessellationPatchSize;
uint32_t maxTessellationControlPerVertexInputComponents;
uint32_t maxTessellationControlPerVertexOutputComponents;
uint32_t maxTessellationControlPerPatchOutputComponents;
uint32_t maxTessellationControlTotalOutputComponents;
uint32_t maxTessellationEvaluationInputComponents;
uint32_t maxTessellationEvaluationOutputComponents;
uint32_t maxGeometryShaderInvocations;
uint32_t maxGeometryInputComponents;
uint32_t maxGeometryOutputComponents;
uint32_t maxGeometryOutputVertices;
uint32_t maxGeometryTotalOutputComponents;
uint32_t maxFragmentInputComponents;
uint32_t maxFragmentOutputAttachments;
uint32_t maxFragmentDualSrcAttachments;
uint32_t maxFragmentCombinedOutputResources;
uint32_t maxComputeSharedMemorySize;
uint32_t maxComputeWorkGroupCount[3];
uint32_t maxComputeWorkGroupInvocations;
uint32_t maxComputeWorkGroupSize[3];
uint32_t subPixelPrecisionBits;
uint32_t subTexelPrecisionBits;
uint32_t mipmapPrecisionBits;
uint32_t maxDrawIndexedIndexValue;
uint32_t maxDrawIndirectCount;
float maxSamplerLodBias;
float maxSamplerAnisotropy;
uint32_t maxViewports;
uint32_t maxViewportDimensions[2];
float viewportBoundsRange[2];
uint32_t viewportSubPixelBits;
size_t minMemoryMapAlignment;
VkDeviceSize minTexelBufferOffsetAlignment;
VkDeviceSize minUniformBufferOffsetAlignment;
VkDeviceSize minStorageBufferOffsetAlignment;
int32_t minTexelOffset;
uint32_t maxTexelOffset;
int32_t minTexelGatherOffset;
uint32_t maxTexelGatherOffset;
float minInterpolationOffset;
float maxInterpolationOffset;
uint32_t subPixelInterpolationOffsetBits;
uint32_t maxFramebufferWidth;
uint32_t maxFramebufferHeight;
uint32_t maxFramebufferLayers;
VkSampleCountFlags framebufferColorSampleCounts;
VkSampleCountFlags framebufferDepthSampleCounts;
VkSampleCountFlags framebufferStencilSampleCounts;
VkSampleCountFlags framebufferNoAttachmentsSampleCounts;
uint32_t maxColorAttachments;
VkSampleCountFlags sampledImageColorSampleCounts;
VkSampleCountFlags sampledImageIntegerSampleCounts;
VkSampleCountFlags sampledImageDepthSampleCounts;
VkSampleCountFlags sampledImageStencilSampleCounts;
VkSampleCountFlags storageImageSampleCounts;
uint32_t maxSampleMaskWords;
VkBool32 timestampComputeAndGraphics;
float timestampPeriod;
uint32_t maxClipDistances;
uint32_t maxCullDistances;
uint32_t maxCombinedClipAndCullDistances;
uint32_t discreteQueuePriorities;
float pointSizeRange[2];
float lineWidthRange[2];
float pointSizeGranularity;
float lineWidthGranularity;
VkBool32 strictLines;
VkBool32 standardSampleLocations;
VkDeviceSize optimalBufferCopyOffsetAlignment;
VkDeviceSize optimalBufferCopyRowPitchAlignment;
VkDeviceSize nonCoherentAtomSize;
}

VkPhysicalDeviceLimits

The **VkPhysicalDeviceLimits** are properties of the physical device. These are available in the **limits** member of the **VkPhysicalDeviceProperties** structure which is returned from **vkGetPhysicalDeviceProperties**.

- **maxImageDimension1D** is the largest dimension (width) that is guaranteed to be supported for all images created with an **imageType** of **VK_IMAGE_TYPE_1D**. Some combinations of image parameters (format, usage, etc.) **may** allow support for larger dimensions, which **can** be queried using **vkGetPhysicalDeviceImageFormatProperties**.

- **maxImageDimension2D** is the largest dimension (width or height) that is guaranteed to be supported for all images created with an **imageType** of **VK_IMAGE_TYPE_2D** and without **VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT** set in **flags**. Some combinations of image parameters (format, usage, etc.) **may** allow support for larger dimensions, which **can** be queried using **vkGetPhysicalDeviceImageFormatProperties**.

- **maxImageDimension3D** is the largest dimension (width, height, or depth) that is guaranteed to be supported for all images created with an **imageType** of **VK_IMAGE_TYPE_3D**. Some combinations of image parameters (format, usage, etc.) **may** allow support for larger dimensions, which **can** be queried using **vkGetPhysicalDeviceImageFormatProperties**.

- **maxImageDimensionCube** is the largest dimension (width or height) that is guaranteed to be supported for all images created with an **imageType** of **VK_IMAGE_TYPE_2D** and with **VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT** set in **flags**. Some combinations of image parameters (format, usage, etc.) **may** allow support for larger dimensions, which **can** be queried using **vkGetPhysicalDeviceImageFormatProperties**.
• **maxImageArrayLayers** is the maximum number of layers (arrayLayers) for an image.

• **maxTexelBufferElements** is the maximum number of addressable texels for a buffer view created on a buffer which was created with the `VK_BUFFER_USAGE_UNIFORM_TEXEL_BUFFER_BIT` or `VK_BUFFER_USAGE_STORAGE_TEXEL_BUFFER_BIT` set in the `usage` member of the `VkBufferCreateInfo` structure.

• **maxUniformBufferRange** is the maximum value that can be specified in the `range` member of a `VkDescriptorBufferInfo` structure passed to `vkUpdateDescriptorSets` for descriptors of type `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER` or `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC`.

• **maxStorageBufferRange** is the maximum value that can be specified in the `range` member of a `VkDescriptorBufferInfo` structure passed to `vkUpdateDescriptorSets` for descriptors of type `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER` or `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC`.

• **maxPushConstantsSize** is the maximum size, in bytes, of the pool of push constant memory. For each of the push constant ranges indicated by the `pPushConstantRanges` member of the `VkPipelineLayoutCreateInfo` structure, 

  

  \[(offset + size)\text{ must be less than or equal to this limit.}\]

• **maxMemoryAllocationCount** is the maximum number of device memory allocations, as created by `vkAllocateMemory`, which can simultaneously exist.

• **maxSamplerAllocationCount** is the maximum number of sampler objects, as created by `vkCreateSampler`, which can simultaneously exist on a device.

• **bufferImageGranularity** is the granularity, in bytes, at which buffer or linear image resources, and optimal image resources can be bound to adjacent offsets in the same `VkDeviceMemory` object without aliasing. See **Buffer-Image Granularity** for more details.

• **sparseAddressSpaceSize** is the total amount of address space available, in bytes, for sparse memory resources. This is an upper bound on the sum of the sizes of all sparse resources, regardless of whether any memory is bound to them.

• **maxBoundDescriptorSets** is the maximum number of descriptor sets that can be simultaneously used by a pipeline. All `DescriptorSet` decorations in shader modules must have a value less than `maxBoundDescriptorSets`. See **Descriptor Sets**.

• **maxPerStageDescriptorSamplers** is the maximum number of samplers that can be accessible to a single shader stage in a pipeline layout. Descriptors with a type of `VK_DESCRIPTOR_TYPE_SAMPLER` or `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER` count against this limit. Only descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set count against this limit. A descriptor is accessible to a shader stage when the `stageFlags` member of the `VkDescriptorSetLayoutBinding` structure has the bit for that shader stage set. See **Sampler** and **Combined Image Sampler**.

• **maxPerStageDescriptorUniformBuffers** is the maximum number of uniform buffers that can be accessible to a single shader stage in a pipeline layout. Descriptors with a type of `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER` or `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC` count against this limit. Only descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set count against this limit. A descriptor is accessible to a shader stage when the `stageFlags` member of the `VkDescriptorSetLayoutBinding` structure has the bit for that shader stage set. See **Uniform Buffer** and **Dynamic Uniform Buffer**.
• **maxPerStageDescriptorStorageBuffers** is the maximum number of storage buffers that can be accessible to a single shader stage in a pipeline layout. Descriptors with a type of `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER` or `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC` count against this limit. Only descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set count against this limit. A descriptor is accessible to a pipeline shader stage when the `stageFlags` member of the `VkDescriptorsetLayoutBinding` structure has the bit for that shader stage set. See Storage Buffer and Dynamic Storage Buffer.

• **maxPerStageDescriptorSampledImages** is the maximum number of sampled images that can be accessible to a single shader stage in a pipeline layout. Descriptors with a type of `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`, `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE`, or `VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER` count against this limit. Only descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set count against this limit. A descriptor is accessible to a pipeline shader stage when the `stageFlags` member of the `VkDescriptorsetLayoutBinding` structure has the bit for that shader stage set. See Combined Image Sampler, Sampled Image, and Uniform Texel Buffer.

• **maxPerStageDescriptorStorageImages** is the maximum number of storage images that can be accessible to a single shader stage in a pipeline layout. Descriptors with a type of `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE`, or `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER` count against this limit. Only descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set count against this limit. A descriptor is accessible to a pipeline shader stage when the `stageFlags` member of the `VkDescriptorsetLayoutBinding` structure has the bit for that shader stage set. See Storage Image and Storage Texel Buffer.

• **maxPerStageDescriptorInputAttachments** is the maximum number of input attachments that can be accessible to a single shader stage in a pipeline layout. Descriptors with a type of `VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT` count against this limit. Only descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set count against this limit. A descriptor is accessible to a pipeline shader stage when the `stageFlags` member of the `VkDescriptorsetLayoutBinding` structure has the bit for that shader stage set. These are only supported for the fragment stage. See Input Attachment.

• **maxPerStageResources** is the maximum number of resources that can be accessible to a single shader stage in a pipeline layout. Descriptors with a type of `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER`, `VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE`, `VK_DESCRIPTOR_TYPE_STORAGE_IMAGE`, `VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER`, `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER`, `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER`, `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER`, `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC`, or `VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT` count against this limit. Only descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set count against this limit. For the fragment shader stage the framebuffer color attachments also count against this limit.

• **maxDescriptorSetSamplers** is the maximum number of samplers that can be included in a pipeline layout. Descriptors with a type of `VK_DESCRIPTOR_TYPE_SAMPLER` or `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER` count against this limit. Only descriptors in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set count against this limit. See
**Sampler** and **Combined Image Sampler**.

- **maxDescriptorSetUniformBuffers** is the maximum number of uniform buffers that *can* be included in a pipeline layout. Descriptors with a type of **VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER** or **VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC** count against this limit. Only descriptors in descriptor set layouts created without the **VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT** bit set count against this limit. See Uniform Buffer and Dynamic Uniform Buffer.

- **maxDescriptorSetUniformBuffersDynamic** is the maximum number of dynamic uniform buffers that *can* be included in a pipeline layout. Descriptors with a type of **VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC** count against this limit. Only descriptors in descriptor set layouts created without the **VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT** bit set count against this limit. See Dynamic Uniform Buffer.

- **maxDescriptorSetStorageBuffers** is the maximum number of storage buffers that *can* be included in a pipeline layout. Descriptors with a type of **VK_DESCRIPTOR_TYPE_STORAGE_BUFFER** or **VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC** count against this limit. Only descriptors in descriptor set layouts created without the **VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT** bit set count against this limit. See Storage Buffer and Dynamic Storage Buffer.

- **maxDescriptorSetStorageBuffersDynamic** is the maximum number of dynamic storage buffers that *can* be included in a pipeline layout. Descriptors with a type of **VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC** count against this limit. Only descriptors in descriptor set layouts created without the **VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT** bit set count against this limit. See Dynamic Storage Buffer.

- **maxDescriptorSetSampledImages** is the maximum number of sampled images that *can* be included in a pipeline layout. Descriptors with a type of **VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER**, **VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE**, or **VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER** count against this limit. Only descriptors in descriptor set layouts created without the **VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT** bit set count against this limit. See Combined Image Sampler, Sampled Image, and Uniform Texel Buffer.

- **maxDescriptorSetStorageImages** is the maximum number of storage images that *can* be included in a pipeline layout. Descriptors with a type of **VK_DESCRIPTOR_TYPE_STORAGE_IMAGE**, or **VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER** count against this limit. Only descriptors in descriptor set layouts created without the **VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT** bit set count against this limit. See Storage Image, and Storage Texel Buffer.

- **maxDescriptorSetInputAttachments** is the maximum number of input attachments that *can* be included in a pipeline layout. Descriptors with a type of **VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT** count against this limit. Only descriptors in descriptor set layouts created without the **VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT** bit set count against this limit. See Input Attachment.

- **maxVertexInputAttributes** is the maximum number of vertex input attributes that *can* be specified for a graphics pipeline. These are described in the array of **VkVertexInputAttributeDescription** structures that are provided at graphics pipeline creation time via the **pVertexAttributeDescriptions** member of the **VkPipelineVertexInputStateCreateInfo**.
structure. See **Vertex Attributes** and **Vertex Input Description**.

- **maxVertexInputBindings** is the maximum number of vertex buffers that can be specified for providing vertex attributes to a graphics pipeline. These are described in the array of **VkVertexInputBindingDescription** structures that are provided at graphics pipeline creation time via the pVertexBindingDescriptions member of the **VkPipelineVertexInputStateCreateInfo** structure. The binding member of **VkVertexInputBindingDescription** must be less than this limit. See **Vertex Input Description**.

- **maxVertexInputAttributeOffset** is the maximum vertex input attribute offset that can be added to the vertex input binding stride. The offset member of the **VkVertexInputAttributeDescription** structure must be less than or equal to this limit. See **Vertex Input Description**.

- **maxVertexInputBindingStride** is the maximum vertex input binding stride that can be specified in a vertex input binding. The stride member of the **VkVertexInputBindingDescription** structure must be less than or equal to this limit. See **Vertex Input Description**.

- **maxVertexOutputComponents** is the maximum number of components of output variables which can be output by a vertex shader. See **Vertex Shaders**.

- **maxTessellationGenerationLevel** is the maximum tessellation generation level supported by the fixed-function tessellation primitive generator. See **Tessellation**.

- **maxTessellationPatchSize** is the maximum patch size, in vertices, of patches that can be processed by the tessellation control shader and tessellation primitive generator. The patchControlPoints member of the **VkPipelineTessellationStateCreateInfo** structure specified at pipeline creation time and the value provided in the **OutputVertices** execution mode of shader modules must be less than or equal to this limit. See **Tessellation**.

- **maxTessellationControlPerVertexInputComponents** is the maximum number of components of input variables which can be provided as per-vertex inputs to the tessellation control shader stage.

- **maxTessellationControlPerVertexOutputComponents** is the maximum number of components of per-vertex output variables which can be output from the tessellation control shader stage.

- **maxTessellationControlPerPatchOutputComponents** is the maximum number of components of per-patch output variables which can be output from the tessellation control shader stage.

- **maxTessellationControlTotalOutputComponents** is the maximum total number of components of per-vertex and per-patch output variables which can be output from the tessellation control shader stage.

- **maxTessellationEvaluationInputComponents** is the maximum number of components of input variables which can be provided as per-vertex inputs to the tessellation evaluation shader stage.

- **maxTessellationEvaluationOutputComponents** is the maximum number of components of per-vertex output variables which can be output from the tessellation evaluation shader stage.

- **maxGeometryShaderInvocations** is the maximum invocation count supported for instanced geometry shaders. The value provided in the **Invocations** execution mode of shader modules must be less than or equal to this limit. See **Geometry Shading**.

- **maxGeometryInputComponents** is the maximum number of components of input variables which can be provided as inputs to the geometry shader stage.
• **maxGeometryOutputComponents** is the maximum number of components of output variables which can be output from the geometry shader stage.

• **maxGeometryOutputVertices** is the maximum number of vertices which can be emitted by any geometry shader.

• **maxGeometryTotalOutputComponents** is the maximum total number of components of output variables, across all emitted vertices, which can be output from the geometry shader stage.

• **maxFragmentInputComponents** is the maximum number of components of input variables which can be provided as inputs to the fragment shader stage.

• **maxFragmentOutputAttachments** is the maximum number of output attachments which can be written to by the fragment shader stage.

• **maxFragmentDualSrcAttachments** is the maximum number of output attachments which can be written to by the fragment shader stage when blending is enabled and one of the dual source blend modes is in use. See Dual-Source Blending and dualSrcBlend.

• **maxFragmentCombinedOutputResources** is the total number of storage buffers, storage images, and output Location decorated color attachments (described in Fragment Output Interface) which can be used in the fragment shader stage.

• **maxComputeSharedMemorySize** is the maximum total storage size, in bytes, available for variables declared with the Workgroup storage class in shader modules (or with the shared storage qualifier in GLSL) in the compute shader stage.

• **maxComputeWorkGroupCount[3]** is the maximum number of local workgroups that can be dispatched by a single dispatching command. These three values represent the maximum number of local workgroups for the X, Y, and Z dimensions, respectively. The workgroup count parameters to the dispatching commands must be less than or equal to the corresponding limit. See Dispatching Commands.

• **maxComputeWorkGroupInvocations** is the maximum total number of compute shader invocations in a single local workgroup. The product of the X, Y, and Z sizes, as specified by the LocalSize or LocalSizeId execution mode in shader modules or by the object decorated by the WorkgroupSize decoration, must be less than or equal to this limit.

• **maxComputeWorkGroupSize[3]** is the maximum size of a local compute workgroup, per dimension. These three values represent the maximum local workgroup size in the X, Y, and Z dimensions, respectively. The x, y, and z sizes, as specified by the LocalSize or LocalSizeId execution mode or by the object decorated by the WorkgroupSize decoration in shader modules, must be less than or equal to the corresponding limit.

• **subPixelPrecisionBits** is the number of bits of subpixel precision in framebuffer coordinates \(x_f\) and \(y_f\). See Rasterization.

• **subTexelPrecisionBits** is the number of bits of precision in the division along an axis of an image used for minification and magnification filters. \(2^{\text{subTexelPrecisionBits}}\) is the actual number of divisions along each axis of the image represented. Sub-texel values calculated during image sampling will snap to these locations when generating the filtered results.

• **mipmapPrecisionBits** is the number of bits of division that the LOD calculation for mipmap fetching get snapped to when determining the contribution from each mipmap level to the mip filtered results. \(2^{\text{mipmapPrecisionBits}}\) is the actual number of divisions.
• **maxDrawIndexedIndexValue** is the maximum index value that **can** be used for indexed draw calls when using 32-bit indices. This excludes the primitive restart index value of 0xFFFFF. See [fullDrawIndexedUint32].

• **maxDrawIndirectCount** is the maximum draw count that is supported for indirect drawing calls. See [multiDrawIndirect].

• **maxSamplerLodBias** is the maximum absolute sampler LOD bias. The sum of the `mipLodBias` member of the `VkSamplerCreateInfo` structure and the `Bias` operand of image sampling operations in shader modules (or 0 if no `Bias` operand is provided to an image sampling operation) are clamped to the range \([-\text{maxSamplerLodBias},+\text{maxSamplerLodBias}]\). See [samplers-mipLodBias].

• **maxSamplerAnisotropy** is the maximum degree of sampler anisotropy. The maximum degree of anisotropic filtering used for an image sampling operation is the minimum of the `maxAnisotropy` member of the `VkSamplerCreateInfo` structure and this limit. See [samplers-maxAnisotropy].

• **maxViewports** is the maximum number of active viewports. The `viewportCount` member of the `VkPipelineViewportStateCreateInfo` structure that is provided at pipeline creation **must** be less than or equal to this limit.

• **maxViewportDimensions[2]** are the maximum viewport dimensions in the X (width) and Y (height) dimensions, respectively. The maximum viewport dimensions **must** be greater than or equal to the largest image which **can** be created and used as a framebuffer attachment. See Controlling the Viewport.

• **viewportBoundsRange[2]** is the \([\text{minimum}, \text{maximum}]\) range that the corners of a viewport **must** be contained in. This range **must** be at least \([-2 \times \text{size}, 2 \times \text{size} - 1]\), where \(\text{size} = \max(\text{maxViewportDimensions}[0], \text{maxViewportDimensions}[1])\). See Controlling the Viewport.

  **Note**

  The intent of the `viewportBoundsRange` limit is to allow a maximum sized viewport to be arbitrarily shifted relative to the output target as long as at least some portion intersects. This would give a bounds limit of \([-\text{size} + 1, 2 \times \text{size} - 1]\) which would allow all possible non-empty-set intersections of the output target and the viewport. Since these numbers are typically powers of two, picking the signed number range using the smallest possible number of bits ends up with the specified range.

• **viewportSubPixelBits** is the number of bits of subpixel precision for viewport bounds. The subpixel precision that floating-point viewport bounds are interpreted at is given by this limit.

• **minMemoryMapAlignment** is the minimum **required** alignment, in bytes, of host visible memory allocations within the host address space. When mapping a memory allocation with `vkMapMemory`, subtracting `offset` bytes from the returned pointer will always produce an integer multiple of this limit. See Host Access to Device Memory Objects. The value **must** be a power of two.

• **minTexelBufferOffsetAlignment** is the minimum **required** alignment, in bytes, for the `offset` member of the `VkBufferViewCreateInfo` structure for texel buffers. The value **must** be a power of two. If `texelBufferAlignment` is enabled, this limit is equivalent to the maximum of the `uniformTexelBufferOffsetAlignmentBytes` and `storageTexelBufferOffsetAlignmentBytes` members.
of `VkPhysicalDeviceTexelBufferAlignmentProperties`, but smaller alignment is optionally allowed by `storageTexelBufferOffsetSingleTexelAlignment` and `uniformTexelBufferOffsetSingleTexelAlignment`. If `texelBufferAlignment` is not enabled, `VkBufferViewCreateInfo::offset` must be a multiple of this value.

- **minUniformBufferOffsetAlignment** is the minimum **required** alignment, in bytes, for the `offset` member of the `VkDescriptorBufferInfo` structure for uniform buffers. When a descriptor of type `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER` or `VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC` is updated, the `offset` must be an integer multiple of this limit. Similarly, dynamic offsets for uniform buffers must be multiples of this limit. The value **must** be a power of two.

- **minStorageBufferOffsetAlignment** is the minimum **required** alignment, in bytes, for the `offset` member of the `VkDescriptorBufferInfo` structure for storage buffers. When a descriptor of type `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER` or `VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC` is updated, the `offset` must be an integer multiple of this limit. Similarly, dynamic offsets for storage buffers must be multiples of this limit. The value **must** be a power of two.

- **minTexelOffset** is the minimum offset value for the `ConstOffset` image operand of any of the `OpImageSample*` or `OpImageFetch*` image instructions.

- **maxTexelOffset** is the maximum offset value for the `ConstOffset` image operand of any of the `OpImageSample*` or `OpImageFetch*` image instructions.

- **minTexelGatherOffset** is the minimum offset value for the `Offset`, `ConstOffset`, or `ConstOffsets` image operands of any of the `OpImage*Gather` image instructions.

- **maxTexelGatherOffset** is the maximum offset value for the `Offset`, `ConstOffset`, or `ConstOffsets` image operands of any of the `OpImage*Gather` image instructions.

- **minInterpolationOffset** is the base minimum (inclusive) negative offset value for the `Offset` operand of the `InterpolateAtOffset` extended instruction.

- **maxInterpolationOffset** is the base maximum (inclusive) positive offset value for the `Offset` operand of the `InterpolateAtOffset` extended instruction.

- **subPixelInterpolationOffsetBits** is the number of fractional bits that the `x` and `y` offsets to the `InterpolateAtOffset` extended instruction may be rounded to as fixed-point values.

- **maxFramebufferWidth** is the maximum width for a framebuffer. The `width` member of the `VkFramebufferCreateInfo` structure must be less than or equal to this limit.

- **maxFramebufferHeight** is the maximum height for a framebuffer. The `height` member of the `VkFramebufferCreateInfo` structure must be less than or equal to this limit.

- **maxFramebufferLayers** is the maximum layer count for a layered framebuffer. The `layers` member of the `VkFramebufferCreateInfo` structure must be less than or equal to this limit.

- **framebufferColorSampleCounts** is a bitmask of `VkSampleCountFlagBits` indicating the color sample counts that are supported for all framebuffer color attachments with floating- or fixed-point formats. For color attachments with integer formats, see `framebufferIntegerColorSampleCounts`.

- **framebufferDepthSampleCounts** is a bitmask of `VkSampleCountFlagBits` indicating the supported depth sample counts for all framebuffer depth/stencil attachments, when the format includes a depth component.

- **framebufferStencilSampleCounts** is a bitmask of `VkSampleCountFlagBits` indicating the
supported stencil sample counts for all framebuffer depth/stencil attachments, when the format includes a stencil component.

- **framebufferNoAttachmentsSampleCounts** is a bitmask\(^1\) of VkSampleCountFlagBits indicating the supported sample counts for a *subpass which uses no attachments*.

- **maxColorAttachments** is the maximum number of color attachments that can be used by a subpass in a render pass. The *colorAttachmentCount* member of the VkSubpassDescription or VkSubpassDescription2 structure must be less than or equal to this limit.

- **sampledImageColorSampleCounts** is a bitmask\(^1\) of VkSampleCountFlagBits indicating the sample counts supported for all 2D images created with VK_IMAGE_TILING_OPTIMAL, usage containing VK_IMAGE_USAGE_SAMPLED_BIT, and a non-integer color format.

- **sampledImageIntegerSampleCounts** is a bitmask\(^1\) of VkSampleCountFlagBits indicating the sample counts supported for all 2D images created with VK_IMAGE_TILING_OPTIMAL, usage containing VK_IMAGE_USAGE_SAMPLED_BIT, and an integer color format.

- **sampledImageDepthSampleCounts** is a bitmask\(^1\) of VkSampleCountFlagBits indicating the sample counts supported for all 2D images created with VK_IMAGE_TILING_OPTIMAL, usage containing VK_IMAGE_USAGE_SAMPLED_BIT, and a depth format.

- **sampledImageStencilSampleCounts** is a bitmask\(^1\) of VkSampleCountFlagBits indicating the sample counts supported for all 2D images created with VK_IMAGE_TILING_OPTIMAL, usage containing VK_IMAGE_USAGE_SAMPLED_BIT, and a stencil format.

- **storageImageSampleCounts** is a bitmask\(^1\) of VkSampleCountFlagBits indicating the sample counts supported for all 2D images created with VK_IMAGE_TILING_OPTIMAL, and usage containing VK_IMAGE_USAGE_STORAGE_BIT.

- **maxSampleMaskWords** is the maximum number of array elements of a variable decorated with the SampleMask built-in decoration.

- **timestampComputeAndGraphics** specifies support for timestamps on all graphics and compute queues. If this limit is set to VK_TRUE, all queues that advertise the VK_QUEUE_GRAPHICS_BIT or VK_QUEUE_COMPUTE_BIT in the VkQueueFamilyProperties::queueFlags support VkQueueFamilyProperties::timestampValidBits of at least 36. See Timestamp Queries.

- **timestampPeriod** is the number of nanoseconds required for a timestamp query to be incremented by 1. See Timestamp Queries.

- **maxClipDistances** is the maximum number of clip distances that can be used in a single shader stage. The size of any array declared with the ClipDistance built-in decoration in a shader module must be less than or equal to this limit.

- **maxCullDistances** is the maximum number of cull distances that can be used in a single shader stage. The size of any array declared with the CullDistance built-in decoration in a shader module must be less than or equal to this limit.

- **maxCombinedClipAndCullDistances** is the maximum combined number of clip and cull distances that can be used in a single shader stage. The sum of the sizes of any pair of arrays declared with the ClipDistance and CullDistance built-in decoration used by a single shader stage in a shader module must be less than or equal to this limit.

- **discreteQueuePriorities** is the number of discrete priorities that can be assigned to a queue based on the value of each member of VkDeviceQueueCreateInfo::pQueuePriorities. This must
be at least 2, and levels must be spread evenly over the range, with at least one level at 1.0, and another at 0.0. See Queue Priority.

- **pageSizeRange** is the range \([\text{minimum}, \text{maximum}]\) of supported sizes for points. Values written to variables decorated with the PointSize built-in decoration are clamped to this range.

- **lineWidthRange** is the range \([\text{minimum}, \text{maximum}]\) of supported widths for lines. Values specified by the lineWidth member of the VkPipelineRasterizationStateCreateInfo or the lineWidth parameter to vkCmdSetLineWidth are clamped to this range.

- **pageSizeGranularity** is the granularity of supported point sizes. Not all point sizes in the range defined by pageSizeRange are supported. This limit specifies the granularity (or increment) between successive supported point sizes.

- **lineWidthGranularity** is the granularity of supported line widths. Not all line widths in the range defined by lineWidthRange are supported. This limit specifies the granularity (or increment) between successive supported line widths.

- **strictLines** specifies whether lines are rasterized according to the preferred method of rasterization. If set to VK_FALSE, lines may be rasterized under a relaxed set of rules. If set to VK_TRUE, lines are rasterized as per the strict definition. See Basic Line Segment Rasterization.

- **standardSampleLocations** specifies whether rasterization uses the standard sample locations as documented in Multisampling. If set to VK_TRUE, the implementation uses the documented sample locations. If set to VK_FALSE, the implementation may use different sample locations.

- **optimalBufferCopyOffsetAlignment** is the optimal buffer offset alignment in bytes for vkCmdCopyBufferToImage2, vkCmdCopyBufferToImage, vkCmdCopyImageToBuffer2, and vkCmdCopyImageToBuffer. This value is also the optimal host memory offset alignment in bytes for vkCopyMemoryToImageEXT and vkCopyImageToMemoryEXT. The per texel alignment requirements are enforced, but applications should use the optimal alignment for optimal performance and power use. The value must be a power of two.

- **optimalBufferCopyRowPitchAlignment** is the optimal buffer row pitch alignment in bytes for vkCmdCopyBufferToImage2, vkCmdCopyBufferToImage, vkCmdCopyImageToBuffer2, and vkCmdCopyImageToBuffer. This value is also the optimal host memory row pitch alignment in bytes for vkCopyMemoryToImageEXT and vkCopyImageToMemoryEXT. Row pitch is the number of bytes between texels with the same X coordinate in adjacent rows (Y coordinates differ by one). The per texel alignment requirements are enforced, but applications should use the optimal alignment for optimal performance and power use. The value must be a power of two.

- **nonCoherentAtomSize** is the size and alignment in bytes that bounds concurrent access to host-mapped device memory. The value must be a power of two.

1

For all bitmasks of VkSampleCountFlagBits, the sample count limits defined above represent the minimum supported sample counts for each image type. Individual images may support additional sample counts, which are queried using vkGetPhysicalDeviceImageFormatProperties as described in Supported Sample Counts.

Bits which may be set in the sample count limits returned by VkPhysicalDeviceLimits, as well as in other queries and structures representing image sample counts, are:
typedef enum VkSampleCountFlagBits {
    VK_SAMPLE_COUNT_1_BIT = 0x00000001,
    VK_SAMPLE_COUNT_2_BIT = 0x00000002,
    VK_SAMPLE_COUNT_4_BIT = 0x00000004,
    VK_SAMPLE_COUNT_8_BIT = 0x00000008,
    VK_SAMPLE_COUNT_16_BIT = 0x00000010,
    VK_SAMPLE_COUNT_32_BIT = 0x00000020,
    VK_SAMPLE_COUNT_64_BIT = 0x00000040,
} VkSampleCountFlagBits;

• VK_SAMPLE_COUNT_1_BIT specifies an image with one sample per pixel.
• VK_SAMPLE_COUNT_2_BIT specifies an image with 2 samples per pixel.
• VK_SAMPLE_COUNT_4_BIT specifies an image with 4 samples per pixel.
• VK_SAMPLE_COUNT_8_BIT specifies an image with 8 samples per pixel.
• VK_SAMPLE_COUNT_16_BIT specifies an image with 16 samples per pixel.
• VK_SAMPLE_COUNT_32_BIT specifies an image with 32 samples per pixel.
• VK_SAMPLE_COUNT_64_BIT specifies an image with 64 samples per pixel.

typedef VkFlags VkSampleCountFlags;

VkSampleCountFlags is a bitmask type for setting a mask of zero or more VkSampleCountFlagBits.

The VkPhysicalDevicePushDescriptorPropertiesKHR structure is defined as:

typedef struct VkPhysicalDevicePushDescriptorPropertiesKHR {
    VkStructureType sType;
    void* pNext;
    uint32_t maxPushDescriptors;
} VkPhysicalDevicePushDescriptorPropertiesKHR;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• maxPushDescriptors is the maximum number of descriptors that can be used in a descriptor set layout created with VK_DESCRIPTOR_SET_LAYOUT_CREATE_PUSH_DESCRIPTOR_BIT_KHR set.

If the VkPhysicalDevicePushDescriptorPropertiesKHR structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.
The `VkPhysicalDeviceMultiviewProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceMultiviewProperties {
    VkStructureType sType;
    void* pNext;
    uint32_t maxMultiviewViewCount;
    uint32_t maxMultiviewInstanceIndex;
} VkPhysicalDeviceMultiviewProperties;
```

or the equivalent

```c
// Provided by VK_KHR_multiview
typedef VkPhysicalDeviceMultiviewProperties VkPhysicalDeviceMultiviewPropertiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `maxMultiviewViewCount` is one greater than the maximum view index that can be used in a subpass.
- `maxMultiviewInstanceIndex` is the maximum valid value of instance index allowed to be generated by a drawing command recorded within a subpass of a multiview render pass instance.

If the `VkPhysicalDeviceMultiviewProperties` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

The `VkPhysicalDeviceFloatControlsProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceFloatControlsProperties {
    VkStructureType sType;
    void* pNext;
} VkPhysicalDeviceFloatControlsProperties;
```
 VkPhysicalDeviceFloatControlsProperties

or the equivalent

```c
typedef VkPhysicalDeviceFloatControlsProperties
VkPhysicalDeviceFloatControlsPropertiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `denormBehaviorIndependence` is a `VkShaderFloatControlsIndependence` value indicating whether, and how, denorm behavior can be set independently for different bit widths.
- `roundingModeIndependence` is a `VkShaderFloatControlsIndependence` value indicating whether, and how, rounding modes can be set independently for different bit widths.
- `shaderSignedZeroInfNanPreserveFloat16` is a boolean value indicating whether sign of a zero, Nans and ±∞ can be preserved in 16-bit floating-point computations. It also indicates whether the `SignedZeroInfNanPreserve` execution mode can be used for 16-bit floating-point types.
- `shaderSignedZeroInfNanPreserveFloat32` is a boolean value indicating whether sign of a zero, Nans and ±∞ can be preserved in 32-bit floating-point computations. It also indicates whether the `SignedZeroInfNanPreserve` execution mode can be used for 32-bit floating-point types.
- `shaderSignedZeroInfNanPreserveFloat64` is a boolean value indicating whether sign of a zero, Nans and ±∞ can be preserved in 64-bit floating-point computations. It also indicates whether the `SignedZeroInfNanPreserve` execution mode can be used for 64-bit floating-point types.
- `shaderDenormPreserveFloat16` is a boolean value indicating whether denormals can be preserved in 16-bit floating-point computations. It also indicates whether the `DenormPreserve` execution mode can be used for 16-bit floating-point types.
- `shaderDenormPreserveFloat32` is a boolean value indicating whether denormals can be preserved
in 32-bit floating-point computations. It also indicates whether the \texttt{DenormPreserve} execution mode \texttt{can} be used for 32-bit floating-point types.

- \texttt{shaderDenormPreserveFloat64} is a boolean value indicating whether denormals \texttt{can} be preserved in 64-bit floating-point computations. It also indicates whether the \texttt{DenormPreserve} execution mode \texttt{can} be used for 64-bit floating-point types.

- \texttt{shaderDenormFlushToZeroFloat16} is a boolean value indicating whether denormals \texttt{can} be flushed to zero in 16-bit floating-point computations. It also indicates whether the \texttt{DenormFlushToZero} execution mode \texttt{can} be used for 16-bit floating-point types.

- \texttt{shaderDenormFlushToZeroFloat32} is a boolean value indicating whether denormals \texttt{can} be flushed to zero in 32-bit floating-point computations. It also indicates whether the \texttt{DenormFlushToZero} execution mode \texttt{can} be used for 32-bit floating-point types.

- \texttt{shaderDenormFlushToZeroFloat64} is a boolean value indicating whether denormals \texttt{can} be flushed to zero in 64-bit floating-point computations. It also indicates whether the \texttt{DenormFlushToZero} execution mode \texttt{can} be used for 64-bit floating-point types.

- \texttt{shaderRoundingModeRTEFloat16} is a boolean value indicating whether an implementation supports the round-to-nearest-even rounding mode for 16-bit floating-point arithmetic and conversion instructions. It also indicates whether the \texttt{RoundingModeRTE} execution mode \texttt{can} be used for 16-bit floating-point types.

- \texttt{shaderRoundingModeRTEFloat32} is a boolean value indicating whether an implementation supports the round-to-nearest-even rounding mode for 32-bit floating-point arithmetic and conversion instructions. It also indicates whether the \texttt{RoundingModeRTE} execution mode \texttt{can} be used for 32-bit floating-point types.

- \texttt{shaderRoundingModeRTEFloat64} is a boolean value indicating whether an implementation supports the round-to-nearest-even rounding mode for 64-bit floating-point arithmetic and conversion instructions. It also indicates whether the \texttt{RoundingModeRTE} execution mode \texttt{can} be used for 64-bit floating-point types.

- \texttt{shaderRoundingModeRTZFloat16} is a boolean value indicating whether an implementation supports the round-towards-zero rounding mode for 16-bit floating-point arithmetic and conversion instructions. It also indicates whether the \texttt{RoundingModeRTZ} execution mode \texttt{can} be used for 16-bit floating-point types.

- \texttt{shaderRoundingModeRTZFloat32} is a boolean value indicating whether an implementation supports the round-towards-zero rounding mode for 32-bit floating-point arithmetic and conversion instructions. It also indicates whether the \texttt{RoundingModeRTZ} execution mode \texttt{can} be used for 32-bit floating-point types.

- \texttt{shaderRoundingModeRTZFloat64} is a boolean value indicating whether an implementation supports the round-towards-zero rounding mode for 64-bit floating-point arithmetic and conversion instructions. It also indicates whether the \texttt{RoundingModeRTZ} execution mode \texttt{can} be used for 64-bit floating-point types.

If the \texttt{VkPhysicalDeviceFloatControlsProperties} structure is included in the \texttt{pNext} chain of the \texttt{VkPhysicalDeviceProperties2} structure passed to \texttt{vkGetPhysicalDeviceProperties2}, it is filled in with each corresponding implementation-dependent property.
Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceFloatControlsProperties-sType-sType**
  
  *sType* must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FLOAT_CONTROLS_PROPERTIES**

Values which **may** be returned in the *denormBehaviorIndependence* and *roundingModeIndependence* fields of **VkPhysicalDeviceFloatControlsProperties** are:

```c
// Provided by VK_VERSION_1_2
typedef enum VkShaderFloatControlsIndependence {
    VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_32_BIT_ONLY = 0,
    VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_ALL = 1,
    VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_NONE = 2,
    // Provided by VK_KHR_shader_float_controls
    VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_32_BIT_ONLY_KHR =
    VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_32_BIT_ONLY,
    // Provided by VK_KHR_shader_float_controls
    VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_ALL_KHR =
    VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_ALL,
    // Provided by VK_KHR_shader_float_controls
    VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_NONE_KHR =
    VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_NONE,
} VkShaderFloatControlsIndependence;
```

or the equivalent

```c
// Provided by VK_KHR_shader_float_controls
typedef VkShaderFloatControlsIndependence VkShaderFloatControlsIndependenceKHR;
```

- **VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_32_BIT_ONLY** specifies that shader float controls for 32-bit floating point can be set independently; other bit widths must be set identically to each other.
- **VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_ALL** specifies that shader float controls for all bit widths can be set independently.
- **VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_NONE** specifies that shader float controls for all bit widths must be set identically.

The **VkPhysicalDeviceDiscardRectanglePropertiesEXT** structure is defined as:

```c
// Provided by VK_EXT_discard_rectangles
typedef struct VkPhysicalDeviceDiscardRectanglePropertiesEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t maxDiscardRectangles;
} VkPhysicalDeviceDiscardRectanglePropertiesEXT;
```
• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• maxDiscardRectangles is the maximum number of active discard rectangles that can be specified.

If the VkPhysicalDeviceDiscardRectanglePropertiesEXT structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

---

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceDiscardRectanglePropertiesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DISCARD_RECTANGLE_PROPERTIES_EXT

The VkPhysicalDeviceSampleLocationsPropertiesEXT structure is defined as:

```c
// Provided by VK_EXT_sample_locations
typedef struct VkPhysicalDeviceSampleLocationsPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    VkSampleCountFlags sampleLocationSampleCounts;
    VkExtent2D maxSampleLocationGridSize;
    float sampleLocationCoordinateRange[2];
    uint32_t sampleLocationSubPixelBits;
    VkBool32 variableSampleLocations;
} VkPhysicalDeviceSampleLocationsPropertiesEXT;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• sampleLocationSampleCounts is a bitmask of VkSampleCountFlagBits indicating the sample counts supporting custom sample locations.
• maxSampleLocationGridSize is the maximum size of the pixel grid in which sample locations can vary that is supported for all sample counts in sampleLocationSampleCounts.
• sampleLocationCoordinateRange[2] is the range of supported sample location coordinates.
• sampleLocationSubPixelBits is the number of bits of subpixel precision for sample locations.
• variableSampleLocations specifies whether the sample locations used by all pipelines that will be bound to a command buffer during a subpass must match. If set to VK_TRUE, the implementation supports variable sample locations in a subpass. If set to VK_FALSE, then the sample locations must stay constant in each subpass.

If the VkPhysicalDeviceSampleLocationsPropertiesEXT structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.
The **VkPhysicalDeviceExternalMemoryHostPropertiesEXT** structure is defined as:

```c
// Provided by VK_EXT_external_memory_host
typedef struct VkPhysicalDeviceExternalMemoryHostPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    VkDeviceSize minImportedHostPointerAlignment;
} VkPhysicalDeviceExternalMemoryHostPropertiesEXT;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **minImportedHostPointerAlignment** is the minimum **required** alignment, in bytes, for the base address and size of host pointers that **can** be imported to a Vulkan memory object. The value **must** be a power of two.

If the **VkPhysicalDeviceExternalMemoryHostPropertiesEXT** structure is included in the **pNext** chain of the **VkPhysicalDeviceProperties2** structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

The **VkPhysicalDeviceMultiviewPerViewAttributesPropertiesNVX** structure is defined as:

```c
// Provided by VK_NVX_multiview_per_view_attributes
typedef struct VkPhysicalDeviceMultiviewPerViewAttributesPropertiesNVX {
    VkStructureType sType;
    void* pNext;
    VkBool32 perViewPositionAllComponents;
} VkPhysicalDeviceMultiviewPerViewAttributesPropertiesNVX;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **perViewPositionAllComponents** is **VK_TRUE** if the implementation supports per-view position values that differ in components other than the X component.

If the **VkPhysicalDeviceMultiviewPerViewAttributesPropertiesNVX** structure is included in the **pNext** chain of the **VkPhysicalDeviceProperties2** structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.
chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceMultiviewPerViewAttributesPropertiesNVX-sType-sType must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_PER_VIEW_ATTRIBUTES_PROPERTIES_NVX`.

The `VkPhysicalDevicePointClippingProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDevicePointClippingProperties {
    VkStructureType sType;
    void* pNext;
    VkPointClippingBehavior pointClippingBehavior;
} VkPhysicalDevicePointClippingProperties;
```

or the equivalent

```c
// Provided by VK_KHR_maintenance2
typedef VkPhysicalDevicePointClippingProperties
    VkPhysicalDevicePointClippingPropertiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `pointClippingBehavior` is a `VkPointClippingBehavior` value specifying the point clipping behavior supported by the implementation.

If the `VkPhysicalDevicePointClippingProperties` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- VUID-VkPhysicalDevicePointClippingProperties-sType-sType  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_POINT_CLIPPING_PROPERTIES`.

The `VkPhysicalDeviceSubgroupProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceSubgroupProperties {
    VkStructureType sType;
    void* pNext;
} VkPhysicalDeviceSubgroupProperties;
```
```c
uint32_t subgroupSize;
VkShaderStageFlags supportedStages;
VkSubgroupFeatureFlags supportedOperations;
VkBool32 quadOperationsInAllStages;
} VkPhysicalDeviceSubgroupProperties;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `subgroupSize` is the default number of invocations in each subgroup. `subgroupSize` is at least 1 if any of the physical device’s queues support `VK_QUEUE_GRAPHICS_BIT` or `VK_QUEUE_COMPUTE_BIT`. `subgroupSize` is a power-of-two.
- `supportedStages` is a bitfield of `VkShaderStageFlagBits` describing the shader stages that group operations with subgroup scope are supported in. `supportedStages` will have the `VK_SHADER_STAGE_COMPUTE_BIT` bit set if any of the physical device’s queues support `VK_QUEUE_COMPUTE_BIT`.
- `supportedOperations` is a bitmask of `VkSubgroupFeatureFlagBits` specifying the sets of group operations with subgroup scope supported on this device. `supportedOperations` will have the `VK_SUBGROUP_FEATURE_BASIC_BIT` bit set if any of the physical device’s queues support `VK_QUEUE_GRAPHICS_BIT` or `VK_QUEUE_COMPUTE_BIT`.
- `quadOperationsInAllStages` is a boolean specifying whether quad group operations are available in all stages, or are restricted to fragment and compute stages.

If the `VkPhysicalDeviceSubgroupProperties` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

If `supportedOperations` includes `VK_SUBGROUP_FEATURE_QUAD_BIT`, or `shaderSubgroupUniformControlFlow` is enabled, `subgroupSize` must be greater than or equal to 4.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceSubgroupProperties-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBGROUP_PROPERTIES`

Bits which can be set in `VkPhysicalDeviceSubgroupProperties::supportedOperations` and `VkPhysicalDeviceVulkan11Properties::subgroupSupportedOperations` to specify supported group operations with subgroup scope are:

```c
// Provided by VK_VERSION_1_1
typedef enum VkSubgroupFeatureFlagBits {
    VK_SUBGROUP_FEATURE_BASIC_BIT = 0x00000001,
    VK_SUBGROUP_FEATURE_VOTE_BIT = 0x00000002,
    VK_SUBGROUP_FEATURE_ARITHMETIC_BIT = 0x00000004,
    VK_SUBGROUP_FEATURE_BALLOT_BIT = 0x00000008,
    VK_SUBGROUP_FEATURE_SHUFFLE_BIT = 0x00000010,
} VkSubgroupFeatureFlagBits;
```
VK_SUBGROUP_FEATURE_SHUFFLE_RELATIVE_BIT = 0x00000020,
VK_SUBGROUP_FEATURE_CLUSTERED_BIT = 0x00000040,
VK_SUBGROUP_FEATURE_QUAD_BIT = 0x00000080,
// Provided by VK_NV_shader_subgroup_partitioned
VK_SUBGROUP_FEATURE_PARTITIONED_BIT_NV = 0x00000100,
} VkSubgroupFeatureFlagBits;

• VK_SUBGROUP_FEATURE_BASIC_BIT specifies the device will accept SPIR-V shader modules containing the GroupNonUniform capability.
• VK_SUBGROUP_FEATURE_VOTE_BIT specifies the device will accept SPIR-V shader modules containing the GroupNonUniformVote capability.
• VK_SUBGROUP_FEATURE_ARITHMETIC_BIT specifies the device will accept SPIR-V shader modules containing the GroupNonUniformArithmetic capability.
• VK_SUBGROUP_FEATURE_BALLOT_BIT specifies the device will accept SPIR-V shader modules containing the GroupNonUniformBallot capability.
• VK_SUBGROUP_FEATURE_SHUFFLE_BIT specifies the device will accept SPIR-V shader modules containing the GroupNonUniformShuffle capability.
• VK_SUBGROUP_FEATURE_SHUFFLE_RELATIVE_BIT specifies the device will accept SPIR-V shader modules containing the GroupNonUniformShuffleRelative capability.
• VK_SUBGROUP_FEATURE_CLUSTERED_BIT specifies the device will accept SPIR-V shader modules containing the GroupNonUniformClustered capability.
• VK_SUBGROUP_FEATURE_QUAD_BIT specifies the device will accept SPIR-V shader modules containing the GroupNonUniformQuad capability.
• VK_SUBGROUP_FEATURE_PARTITIONED_BIT_NV specifies the device will accept SPIR-V shader modules containing the GroupNonUniformPartitionedNV capability.

// Provided by VK_VERSION_1_1
typedef VkFlags VkSubgroupFeatureFlags;

VkSubgroupFeatureFlags is a bitmask type for setting a mask of zero or more VkSubgroupFeatureFlagBits.

The VkPhysicalDeviceSubgroupSizeControlProperties structure is defined as:

// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceSubgroupSizeControlProperties {
    VkStructureType sType;
    void* pNext;
    uint32_t minSubgroupSize;
    uint32_t maxSubgroupSize;
    uint32_t maxComputeWorkgroupSubgroups;
    VkShaderStageFlags requiredSubgroupSizeStages;
} VkPhysicalDeviceSubgroupSizeControlProperties;
or the equivalent

```c
// Provided by VK_EXT_subgroup_size_control
typedef VkPhysicalDeviceSubgroupSizeControlProperties
VkPhysicalDeviceSubgroupSizeControlPropertiesEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.

- `minSubgroupSize` is the minimum subgroup size supported by this device. `minSubgroupSize` is at least one if any of the physical device’s queues support `VK_QUEUE_GRAPHICS_BIT` or `VK_QUEUE_COMPUTE_BIT`. `minSubgroupSize` is a power-of-two. `minSubgroupSize` is less than or equal to `maxSubgroupSize`. `minSubgroupSize` is less than or equal to `subgroupSize`.

- `maxSubgroupSize` is the maximum subgroup size supported by this device. `maxSubgroupSize` is at least one if any of the physical device’s queues support `VK_QUEUE_GRAPHICS_BIT` or `VK_QUEUE_COMPUTE_BIT`. `maxSubgroupSize` is a power-of-two. `maxSubgroupSize` is greater than or equal to `minSubgroupSize`. `maxSubgroupSize` is greater than or equal to `subgroupSize`.

- `maxComputeWorkgroupSubgroups` is the maximum number of subgroups supported by the implementation within a workgroup.

- `requiredSubgroupSizeStages` is a bitfield of what shader stages support having a required subgroup size specified.

If the `VkPhysicalDeviceSubgroupSizeControlProperties` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

If `VkPhysicalDeviceSubgroupProperties::supportedOperations` includes `VK_SUBGROUP_FEATURE_QUAD_BIT`, `minSubgroupSize` must be greater than or equal to 4.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceSubgroupSizeControlProperties-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBGROUP_SIZE_CONTROL_PROPERTIES`

The `VkPhysicalDeviceBlendOperationAdvancedPropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_blend_operation_advanced
typedef struct VkPhysicalDeviceBlendOperationAdvancedPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t advancedBlendMaxColorAttachments;
    VkBool32 advancedBlendIndependentBlend;
    VkBool32 advancedBlendNonPremultipliedSrcColor;
    VkBool32 advancedBlendNonPremultipliedDstColor;
    VkBool32 advancedBlendCorrelatedOverlap;
} VkPhysicalDeviceBlendOperationAdvancedPropertiesEXT;
```
• **sType** is a VkStructureType value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **advancedBlendMaxColorAttachments** is one greater than the highest color attachment index that can be used in a subpass, for a pipeline that uses an advanced blend operation.

• **advancedBlendIndependentBlend** specifies whether advanced blend operations can vary per-attachment.

• **advancedBlendNonPremultipliedSrcColor** specifies whether the source color can be treated as non-premultiplied. If this is VK_FALSE, then VkPipelineColorBlendAdvancedStateCreateInfoEXT::srcPremultiplied must be VK_TRUE.

• **advancedBlendNonPremultipliedDstColor** specifies whether the destination color can be treated as non-premultiplied. If this is VK_FALSE, then VkPipelineColorBlendAdvancedStateCreateInfoEXT::dstPremultiplied must be VK_TRUE.

• **advancedBlendCorrelatedOverlap** specifies whether the overlap mode can be treated as correlated. If this is VK_FALSE, then VkPipelineColorBlendAdvancedStateCreateInfoEXT::blendOverlap must be VK_BLEND_OVERLAP_UNCORRELATED_EXT.

• **advancedBlendAllOperations** specifies whether all advanced blend operation enums are supported. See the valid usage of VkPipelineColorBlendAttachmentState.

If the VkPhysicalDeviceBlendOperationAdvancedPropertiesEXT structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

---

**Valid Usage (Implicit)**

• VUID-VkPhysicalDeviceBlendOperationAdvancedPropertiesEXT-sType-sType

  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BLEND_OPERATION_ADVANCED_PROPERTIES_EXT

---

The VkPhysicalDeviceVertexAttributeDivisorPropertiesEXT structure is defined as:

```c
// Provided by VK_EXT_vertex_attribute_divisor
typedef struct VkPhysicalDeviceVertexAttributeDivisorPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t maxVertexAttribDivisor;
} VkPhysicalDeviceVertexAttributeDivisorPropertiesEXT;
```

• **sType** is a VkStructureType value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **maxVertexAttribDivisor** is the maximum value of the number of instances that will repeat the
value of vertex attribute data when instanced rendering is enabled.

If the VkPhysicalDeviceVertexAttributeDivisorPropertiesEXT structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceVertexAttributeDivisorPropertiesEXT-sType-sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VERTEX_ATTRIBUTE_DIVISOR_PROPERTIES_EXT

The VkPhysicalDeviceSamplerFilterMinmaxProperties structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceSamplerFilterMinmaxProperties {
    VkStructureType sType;
    void* pNext;
    VkBool32 filterMinmaxSingleComponentFormats;
    VkBool32 filterMinmaxImageComponentMapping;
} VkPhysicalDeviceSamplerFilterMinmaxProperties;
```

or the equivalent

```c
// Provided by VK_EXT_sampler_filter_minmax
typedef VkPhysicalDeviceSamplerFilterMinmaxProperties VkPhysicalDeviceSamplerFilterMinmaxPropertiesEXT;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- filterMinmaxSingleComponentFormats is a boolean value indicating whether a minimum set of required formats support min/max filtering.
- filterMinmaxImageComponentMapping is a boolean value indicating whether the implementation supports non-identity component mapping of the image when doing min/max filtering.

If the VkPhysicalDeviceSamplerFilterMinmaxProperties structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

If filterMinmaxSingleComponentFormats is VK_TRUE, the following formats must support the VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_MINMAX_BIT feature with VK_IMAGE_TILING_OPTIMAL, if they support VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT:

- VK_FORMAT_R8_UNORM
- VK_FORMAT_R8_SNORM
• VK_FORMAT_R16_UNORM
• VK_FORMAT_R16_SNORM
• VK_FORMAT_R16_SFLOAT
• VK_FORMAT_R32_SFLOAT
• VK_FORMAT_D16_UNORM
• VK_FORMAT_X8_D24_UNORM_PACK32
• VK_FORMAT_D32_SFLOAT
• VK_FORMAT_D16_UNORM_S8_UINT
• VK_FORMAT_D24_UNORM_S8_UINT
• VK_FORMAT_D32_SFLOAT_S8_UINT

If the format is a depth/stencil format, this bit only specifies that the depth aspect (not the stencil aspect) of an image of this format supports min/max filtering, and that min/max filtering of the depth aspect is supported when depth compare is disabled in the sampler.

If filterMinmaxImageComponentMapping is VK_FALSE the component mapping of the image view used with min/max filtering must have been created with the r component set to the identity swizzle. Only the r component of the sampled image value is defined and the other component values are undefined. If filterMinmaxImageComponentMapping is VK_TRUE this restriction does not apply and image component mapping works as normal.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceSamplerFilterMinmaxProperties-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SAMPLER_FILTER_MINMAX_PROPERTIES

The VkPhysicalDeviceProtectedMemoryProperties structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceProtectedMemoryProperties {
    VkStructureType           sType;
    void*                     pNext;
    VkBool32                  protectedNoFault;
} VkPhysicalDeviceProtectedMemoryProperties;
```

• sType is a VkStructureType value identifying this structure.

• pNext is NULL or a pointer to a structure extending this structure.

• protectedNoFault specifies how an implementation behaves when an application attempts to write to unprotected memory in a protected queue operation, read from protected memory in an unprotected queue operation, or perform a query in a protected queue operation. If this limit is VK_TRUE, such writes will be discarded or have undefined values written, reads and queries will return undefined values. If this limit is VK_FALSE, applications must not perform these
operations. See Protected Memory Access Rules for more information.

If the VkPhysicalDeviceProtectedMemoryProperties structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceProtectedMemoryProperties-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PROTECTED_MEMORY_PROPERTIES

The VkPhysicalDeviceMaintenance3Properties structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceMaintenance3Properties {
    VkStructureType sType;
    void*  pNext;
    uint32_t maxPerSetDescriptors;
    VkDeviceSize maxMemoryAllocationSize;
} VkPhysicalDeviceMaintenance3Properties;
```

or the equivalent

```c
// Provided by VK_KHR_maintenance3
typedef VkPhysicalDeviceMaintenance3Properties
    VkPhysicalDeviceMaintenance3PropertiesKHR;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• maxPerSetDescriptors is a maximum number of descriptors (summed over all descriptor types) in a single descriptor set that is guaranteed to satisfy any implementation-dependent constraints on the size of a descriptor set itself. Applications can query whether a descriptor set that goes beyond this limit is supported using vkGetDescriptorSetLayoutSupport.
• maxMemoryAllocationSize is the maximum size of a memory allocation that can be created, even if there is more space available in the heap.

If the VkPhysicalDeviceMaintenance3Properties structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceMaintenance3Properties-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_3_PROPERTIES
The `VkPhysicalDeviceMaintenance4Properties` structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceMaintenance4Properties {
    VkStructureType   sType;
    void*             pNext;
    VkDeviceSize      maxBufferSize;
} VkPhysicalDeviceMaintenance4Properties;
```

or the equivalent

```c
// Provided by VK_KHR_maintenance4
typedef VkPhysicalDeviceMaintenance4Properties
    VkPhysicalDeviceMaintenance4PropertiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `maxBufferSize` is the maximum size `VkBuffer` that can be created.

If the `VkPhysicalDeviceMaintenance4Properties` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceMaintenance4Properties-sType-sType
  ```plaintext
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_4_PROPERTIES
  ```

The `VkPhysicalDeviceMaintenance5PropertiesKHR` structure is defined as:

```c
// Provided by VK_KHR_maintenance5
typedef struct VkPhysicalDeviceMaintenance5PropertiesKHR {
    VkStructureType   sType;
    void*             pNext;
    VkBool32          earlyFragmentMultisampleCoverageAfterSampleCounting;
    VkBool32          earlyFragmentSampleMaskTestBeforeSampleCounting;
    VkBool32          depthStencilSwizzleOneSupport;
    VkBool32          polygonModePointSize;
    VkBool32          nonStrictSinglePixelWideLinesUseParallelogram;
    VkBool32          nonStrictWideLinesUseParallelogram;
} VkPhysicalDeviceMaintenance5PropertiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `earlyFragmentMultisampleCoverageAfterSampleCounting` is a boolean value indicating whether the fragment shading and multisample coverage operations are performed after sample counting for fragment shaders with `EarlyFragmentTests` execution mode.

- `earlyFragmentSampleMaskTestBeforeSampleCounting` is a boolean value indicating whether the sample mask test operation is performed before sample counting for fragment shaders using the `EarlyFragmentTests` execution mode.

- `depthStencilSwizzleOneSupport` is a boolean indicating that depth/stencil texturing operations with `VK_COMPONENT_SWIZZLE_ONE` have defined behavior.

- `polygonModePointSize` is a boolean value indicating whether the point size of the final rasterization of polygons with `VK_POLYGON_MODE_POINT` is controlled by `PointSize`.

- `nonStrictSinglePixelWideLinesUseParallelogram` is a boolean value indicating whether non-strict lines with a width of 1.0 are rasterized as parallelograms or using Bresenham’s algorithm.

- `nonStrictWideLinesUseParallelogram` is a boolean value indicating whether non-strict lines with a width greater than 1.0 are rasterized as parallelograms or using Bresenham’s algorithm.

If the `VkPhysicalDeviceMaintenance5PropertiesKHR` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

**Valid Usage (Implicit)**

- `VUID-VkPhysicalDeviceMaintenance5PropertiesKHR-sType-sType` 
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_5_PROPERTIES_KHR`

The `VkPhysicalDeviceMeshShaderPropertiesNV` structure is defined as:

```c
// Provided by VK_NV_mesh_shader
typedef struct VkPhysicalDeviceMeshShaderPropertiesNV {
    VkStructureType sType;
    void* pNext;
    uint32_t maxDrawMeshTasksCount;
    uint32_t maxTaskWorkGroupInvocations;
    uint32_t maxTaskWorkGroupSize[3];
    uint32_t maxTaskTotalMemorySize;
    uint32_t maxTaskOutputCount;
    uint32_t maxMeshWorkGroupInvocations;
    uint32_t maxMeshWorkGroupSize[3];
    uint32_t maxMeshTotalMemorySize;
    uint32_t maxMeshOutputVertices;
    uint32_t maxMeshOutputPrimitives;
    uint32_t maxMeshMultiviewViewCount;
    uint32_t meshOutputPerVertexGranularity;
    uint32_t meshOutputPerPrimitiveGranularity;
} VkPhysicalDeviceMeshShaderPropertiesNV;
```
- **sType** is a `VkStructureType` value identifying this structure.

- **pNext** is NULL or a pointer to a structure extending this structure.

- **maxDrawMeshTasksCount** is the maximum number of local workgroups that can be launched by a single draw mesh tasks command. See Programmable Mesh Shading.

- **maxTaskWorkGroupInvocations** is the maximum total number of task shader invocations in a single local workgroup. The product of the X, Y, and Z sizes, as specified by the `LocalSize` or `LocalSizeId` execution mode in shader modules or by the object decorated by the `WorkgroupSize` decoration, must be less than or equal to this limit.

- **maxTaskWorkGroupSize[3]** is the maximum size of a local task workgroup. These three values represent the maximum local workgroup size in the X, Y, and Z dimensions, respectively. The X, Y, and Z sizes, as specified by the `LocalSize` or `LocalSizeId` execution mode or by the object decorated by the `WorkgroupSize` decoration in shader modules, must be less than or equal to the corresponding limit.

- **maxTaskTotalMemorySize** is the maximum number of bytes that the task shader can use in total for shared and output memory combined.

- **maxTaskOutputCount** is the maximum number of output tasks a single task shader workgroup can emit.

- **maxMeshWorkGroupInvocations** is the maximum total number of mesh shader invocations in a single local workgroup. The product of the X, Y, and Z sizes, as specified by the `LocalSize` or `LocalSizeId` execution mode in shader modules or by the object decorated by the `WorkgroupSize` decoration, must be less than or equal to this limit.

- **maxMeshWorkGroupSize[3]** is the maximum size of a local mesh workgroup. These three values represent the maximum local workgroup size in the X, Y, and Z dimensions, respectively. The X, Y, and Z sizes, as specified by the `LocalSize` or `LocalSizeId` execution mode or by the object decorated by the `WorkgroupSize` decoration in shader modules, must be less than or equal to the corresponding limit.

- **maxMeshTotalMemorySize** is the maximum number of bytes that the mesh shader can use in total for shared and output memory combined.

- **maxMeshOutputVertices** is the maximum number of vertices a mesh shader output can store.

- **maxMeshOutputPrimitives** is the maximum number of primitives a mesh shader output can store.

- **maxMeshMultiviewViewCount** is the maximum number of multiview views a mesh shader can use.

- **meshOutputPerVertexGranularity** is the granularity with which mesh vertex outputs are allocated. The value can be used to compute the memory size used by the mesh shader, which must be less than or equal to **maxMeshTotalMemorySize**.

- **meshOutputPerPrimitiveGranularity** is the granularity with which mesh outputs qualified as per-primitive are allocated. The value can be used to compute the memory size used by the mesh shader, which must be less than or equal to **maxMeshTotalMemorySize**.

If the `VkPhysicalDeviceMeshShaderPropertiesNV` structure is included in the **pNext** chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceMeshShaderPropertiesNV-sType-sType
  
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MESH_SHADER_PROPERTIES_NV

The `VkPhysicalDeviceMeshShaderPropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_mesh_shader
typedef struct VkPhysicalDeviceMeshShaderPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t maxTaskWorkGroupTotalCount;
    uint32_t maxTaskWorkGroupCount[3];
    uint32_t maxTaskWorkGroupInvocations;
    uint32_t maxTaskWorkGroupSize[3];
    uint32_t maxTaskPayloadSize;
    uint32_t maxTaskSharedMemorySize;
    uint32_t maxTaskPayloadAndSharedMemorySize;
    uint32_t maxMeshWorkGroupTotalCount;
    uint32_t maxMeshWorkGroupCount[3];
    uint32_t maxMeshWorkGroupInvocations;
    uint32_t maxMeshWorkGroupSize[3];
    uint32_t maxMeshSharedMemorySize;
    uint32_t maxMeshPayloadAndSharedMemorySize;
    uint32_t maxMeshPayloadAndOutputMemorySize;
    uint32_t maxMeshOutputMemorySize;
    uint32_t maxMeshOutputComponents;
    uint32_t maxMeshOutputVertices;
    uint32_t maxMeshOutputPrimitives;
    uint32_t maxMeshOutputLayers;
    uint32_t maxMeshMultiviewViewCount;
    uint32_t meshOutputPerVertexGranularity;
    uint32_t meshOutputPerPrimitiveGranularity;
    uint32_t maxPreferredTaskWorkGroupInvocations;
    uint32_t maxPreferredMeshWorkGroupInvocations;
    VkBool32 prefersLocalInvocationVertexOutput;
    VkBool32 prefersLocalInvocationPrimitiveOutput;
    VkBool32 prefersCompactVertexOutput;
    VkBool32 prefersCompactPrimitiveOutput;
} VkPhysicalDeviceMeshShaderPropertiesEXT;
```

The members of the `VkPhysicalDeviceMeshShaderPropertiesEXT` structure describe the following implementation-dependent limits:

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `maxTaskWorkGroupTotalCount` is the maximum number of total local workgroups that can be
launched by a single mesh tasks drawing command. See Programmable Mesh Shading.

- **maxTaskWorkGroupCount[3]** is the maximum number of local workgroups that can be launched by a single mesh tasks drawing command. These three values represent the maximum number of local workgroups for the X, Y, and Z dimensions, respectively. The workgroup count parameters to the drawing commands must be less than or equal to the corresponding limit. The product of these dimensions must be less than or equal to **maxTaskWorkGroupTotalCount**.

- **maxTaskWorkGroupInvocations** is the maximum total number of task shader invocations in a single local workgroup. The product of the X, Y, and Z sizes, as specified by the LocalSize or LocalSizeId execution mode in shader modules or by the object decorated by the WorkgroupSize decoration, must be less than or equal to this limit.

- **maxTaskWorkGroupSize[3]** is the maximum size of a local task workgroup, per dimension. These three values represent the maximum local workgroup size in the X, Y, and Z dimensions, respectively. The x, y, and z sizes, as specified by the LocalSize or LocalSizeId execution mode or by the object decorated by the WorkgroupSize decoration in shader modules, must be less than or equal to the corresponding limit.

- **maxTaskPayloadSize** is the maximum total storage size, in bytes, available for variables declared with the TaskPayloadWorkgroupEXT storage class in shader modules in the task shader stage.

- **maxTaskSharedMemorySize** is the maximum total storage size, in bytes, available for variables declared with the Workgroup storage class in shader modules in the task shader stage.

- **maxTaskPayloadAndSharedMemorySize** is the maximum total storage size, in bytes, available for variables that are declared with the TaskPayloadWorkgroupEXT or Workgroup storage class, in shader modules in the task shader stage.

- **maxMeshWorkGroupTotalCount** is the maximum number of local output tasks a single task shader workgroup can emit.

- **maxMeshWorkGroupCount[3]** is the maximum number of local output tasks a single task shader workgroup can emit, per dimension. These three values represent the maximum number of local output tasks for the X, Y, and Z dimensions, respectively. The workgroup count parameters to the OpEmitMeshTasksEXT must be less than or equal to the corresponding limit. The product of these dimensions must be less than or equal to **maxMeshWorkGroupTotalCount**.

- **maxMeshWorkGroupInvocations** is the maximum total number of mesh shader invocations in a single local workgroup. The product of the X, Y, and Z sizes, as specified by the LocalSize or LocalSizeId execution mode in shader modules or by the object decorated by the WorkgroupSize decoration, must be less than or equal to this limit.

- **maxMeshWorkGroupSize[3]** is the maximum size of a local mesh workgroup, per dimension. These three values represent the maximum local workgroup size in the X, Y, and Z dimensions, respectively. The x, y, and z sizes, as specified by the LocalSize or LocalSizeId execution mode or by the object decorated by the WorkgroupSize decoration in shader modules, must be less than or equal to the corresponding limit.

- **maxMeshSharedMemorySize** is the maximum total storage size, in bytes, available for variables declared with the Workgroup storage class in shader modules in the mesh shader stage.

- **maxMeshPayloadAndSharedMemorySize** is the maximum total storage size, in bytes, available for variables that are declared with the TaskPayloadWorkgroupEXT or Workgroup storage class in shader modules in the mesh shader stage.
• **maxMeshOutputMemorySize** is the maximum total storage size, in bytes, available for output variables in shader modules in the mesh shader stage, according to the formula in [Mesh Shader Output](#).

• **maxMeshPayloadAndOutputMemorySize** is the maximum total storage size, in bytes, available for variables that are declared with the `TaskPayloadWorkgroupEXT` storage class, or output variables in shader modules in the mesh shader stage, according to the formula in [Mesh Shader Output](#).

• **maxMeshOutputComponents** is the maximum number of components of output variables which can be output from the mesh shader stage.

• **maxMeshOutputVertices** is the maximum number of vertices which can be emitted by a single mesh shader workgroup.

• **maxMeshOutputPrimitives** is the maximum number of primitives which can be emitted by a single mesh shader workgroup.

• **maxMeshOutputLayers** is one greater than the maximum layer index that can be output from the mesh shader stage.

• **maxMeshMultiviewViewCount** is one greater than the maximum view index that can be used by any mesh shader.

• **meshOutputPerVertexGranularity** is the granularity of vertex allocation. The number of output vertices allocated for the mesh shader stage is padded to a multiple of this number. The value can be used to calculate the required storage size for output variables in shader modules in the mesh shader stage, which must be less than or equal to **maxMeshOutputMemorySize**.

• **meshOutputPerPrimitiveGranularity** is the granularity of primitive allocation. The number of output primitives allocated for the mesh shader stage is padded to a multiple of this number. The value can be used to calculate the required storage size for output variables in shader modules in the mesh shader stage, which must be less than or equal to **maxMeshOutputMemorySize**.

• **maxPreferredTaskWorkGroupInvocations** is the maximum number of task shader invocations in a single workgroup that is preferred by the implementation for optimal performance. The value is guaranteed to be a multiple of a supported subgroup size for the task shader stage.

• **maxPreferredMeshWorkGroupInvocations** is the maximum number of mesh shader invocations in a single workgroup that is preferred by the implementation for optimal performance. The value is guaranteed to be a multiple of a supported subgroup size for the mesh shader stage.

• **prefersLocalInvocationVertexOutput** specifies whether writes to the vertex output array in a mesh shader yield best performance when the array index matches `LocalInvocationIndex`.

• **prefersLocalInvocationPrimitiveOutput** specifies whether writes to the primitive output array in a mesh shader yield best performance when the array index matches `LocalInvocationIndex`.

• **prefersCompactVertexOutput** specifies whether output vertices should be compacted after custom culling in the mesh shader for best performance, otherwise keeping the vertices at their original location may be better.

• **prefersCompactPrimitiveOutput** specifies whether output primitives should be compacted after custom culling in the mesh shader for best performance, otherwise the use of `CullPrimitiveEXT` may be better.

If the `VkPhysicalDeviceMeshShaderPropertiesEXT` structure is included in the **pNext** chain of
VkPhysicalDeviceProperties2, it is filled with the implementation-dependent limits.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceMeshShaderPropertiesEXT-sType-sType

  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MESH_SHADER_PROPERTIES_EXT

The VkPhysicalDeviceDescriptorIndexingProperties structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceDescriptorIndexingProperties {
    VkStructureType sType;
    void* pNext;
    uint32_t maxUpdateAfterBindDescriptorsInAllPools;
    VkBool32 shaderUniformBufferArrayNonUniformIndexingNative;
    VkBool32 shaderSampledImageArrayNonUniformIndexingNative;
    VkBool32 shaderStorageBufferArrayNonUniformIndexingNative;
    VkBool32 shaderStorageImageArrayNonUniformIndexingNative;
    VkBool32 shaderInputAttachmentArrayNonUniformIndexingNative;
    VkBool32 robustBufferAccessUpdateAfterBind;
    VkBool32 quadDivergentImplicitLod;
    uint32_t maxPerStageDescriptorUpdateAfterBindSamplers;
    uint32_t maxPerStageDescriptorUpdateAfterBindUniformBuffers;
    uint32_t maxPerStageDescriptorUpdateAfterBindUniformBuffersDynamic;
    uint32_t maxPerStageDescriptorUpdateAfterBindStorageBuffers;
    uint32_t maxPerStageDescriptorUpdateAfterBindStorageBuffersDynamic;
    uint32_t maxPerStageDescriptorUpdateAfterBindSampledImages;
    uint32_t maxPerStageDescriptorUpdateAfterBindSampledImages;
    uint32_t maxPerStageDescriptorUpdateAfterBindInputAttachments;
    uint32_t maxPerStageUpdateAfterBindResources;
    uint32_t maxDescriptorSetUpdateAfterBindSamplers;
    uint32_t maxDescriptorSetUpdateAfterBindUniformBuffers;
    uint32_t maxDescriptorSetUpdateAfterBindUniformBuffersDynamic;
    uint32_t maxDescriptorSetUpdateAfterBindStorageBuffers;
    uint32_t maxDescriptorSetUpdateAfterBindStorageBuffersDynamic;
    uint32_t maxDescriptorSetUpdateAfterBindSampledImages;
    uint32_t maxDescriptorSetUpdateAfterBindSampledImages;
    uint32_t maxDescriptorSetUpdateAfterBindInputAttachments;
} VkPhysicalDeviceDescriptorIndexingProperties;
```

or the equivalent

```c
// Provided by VK_EXT_descriptor_indexing
typedef VkPhysicalDeviceDescriptorIndexingProperties
    VkPhysicalDeviceDescriptorIndexingPropertiesEXT;
```

- **sType** is a VkStructureType value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
• `maxUpdateAfterBindDescriptorsInAllPools` is the maximum number of descriptors (summed over all descriptor types) that can be created across all pools that are created with the `VK_DESCRIPTOR_POOL_CREATE_UPDATE_AFTER_BIND_BIT` bit set. Pool creation may fail when this limit is exceeded, or when the space this limit represents is unable to satisfy a pool creation due to fragmentation.

• `shaderUniformBufferArrayNonUniformIndexingNative` is a boolean value indicating whether uniform buffer descriptors natively support nonuniform indexing. If this is `VK_FALSE`, then a single dynamic instance of an instruction that nonuniformly indexes an array of uniform buffers may execute multiple times in order to access all the descriptors.

• `shaderSampledImageArrayNonUniformIndexingNative` is a boolean value indicating whether sampler and image descriptors natively support nonuniform indexing. If this is `VK_FALSE`, then a single dynamic instance of an instruction that nonuniformly indexes an array of samplers or images may execute multiple times in order to access all the descriptors.

• `shaderStorageBufferArrayNonUniformIndexingNative` is a boolean value indicating whether storage buffer descriptors natively support nonuniform indexing. If this is `VK_FALSE`, then a single dynamic instance of an instruction that nonuniformly indexes an array of storage buffers may execute multiple times in order to access all the descriptors.

• `shaderStorageImageArrayNonUniformIndexingNative` is a boolean value indicating whether storage image descriptors natively support nonuniform indexing. If this is `VK_FALSE`, then a single dynamic instance of an instruction that nonuniformly indexes an array of storage images may execute multiple times in order to access all the descriptors.

• `shaderInputAttachmentArrayNonUniformIndexingNative` is a boolean value indicating whether input attachment descriptors natively support nonuniform indexing. If this is `VK_FALSE`, then a single dynamic instance of an instruction that nonuniformly indexes an array of input attachments may execute multiple times in order to access all the descriptors.

• `robustBufferAccessUpdateAfterBind` is a boolean value indicating whether `robustBufferAccess` can be enabled on a device simultaneously with `descriptorBindingUniformBufferUpdateAfterBind`, `descriptorBindingStorageBufferUpdateAfterBind`, `descriptorBindingUniformTexelBufferUpdateAfterBind`, and/or `descriptorBindingStorageTexelBufferUpdateAfterBind`. If this is `VK_FALSE`, then either `robustBufferAccess` must be disabled or all of these update-after-bind features must be disabled.

• `quadDivergentImplicitLod` is a boolean value indicating whether implicit LOD calculations for image operations have well-defined results when the image and/or sampler objects used for the instruction are not uniform within a quad. See Derivative Image Operations.

• `maxPerStageDescriptorUpdateAfterBindSamplers` is similar to `maxPerStageDescriptorSamplers` but counts descriptors from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.

• `maxPerStageDescriptorUpdateAfterBindUniformBuffers` is similar to `maxPerStageDescriptorUniformBuffers` but counts descriptors from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.

• `maxPerStageDescriptorUpdateAfterBindStorageBuffers` is similar to `maxPerStageDescriptorStorageBuffers` but counts descriptors from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.
• `maxPerStageDescriptorUpdateAfterBindSampledImages` is similar to `maxPerStageDescriptorSampledImages` but counts descriptors from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.

• `maxPerStageDescriptorUpdateAfterBindStorageImages` is similar to `maxPerStageDescriptorStorageImages` but counts descriptors from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.

• `maxPerStageDescriptorUpdateAfterBindInputAttachments` is similar to `maxPerStageDescriptorInputAttachments` but counts descriptors from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.

• `maxPerStageUpdateAfterBindResources` is similar to `maxPerStageResources` but counts descriptors from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.

• `maxDescriptorSetUpdateAfterBindSamplers` is similar to `maxDescriptorSetSamplers` but counts descriptors from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.

• `maxDescriptorSetUpdateAfterBindUniformBuffers` is similar to `maxDescriptorSetUniformBuffers` but counts descriptors from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set. While an application can allocate dynamic uniform buffer descriptors from a pool created with the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT`, bindings for these descriptors must not be present in any descriptor set layout that includes bindings created with `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT`.

• `maxDescriptorSetUpdateAfterBindStorageBuffers` is similar to `maxDescriptorSetStorageBuffers` but counts descriptors from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.

• `maxDescriptorSetUpdateAfterBindStorageBuffersDynamic` is similar to `maxDescriptorSetStorageBuffersDynamic` but counts descriptors from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set. While an application can allocate dynamic storage buffer descriptors from a pool created with the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT`, bindings for these descriptors must not be present in any descriptor set layout that includes bindings created with `VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT`.

• `maxDescriptorSetUpdateAfterBindSampledImages` is similar to `maxDescriptorSetSampledImages` but counts descriptors from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.

• `maxDescriptorSetUpdateAfterBindStorageImages` is similar to `maxDescriptorSetStorageImages` but counts descriptors from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.

• `maxDescriptorSetUpdateAfterBindInputAttachments` is similar to `maxDescriptorSetInputAttachments` but counts descriptors from descriptor sets created with or without the
VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set.

If the VkPhysicalDeviceDescriptorIndexingProperties structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDescriptorIndexingProperties-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_INDEXING_PROPERTIES

The VkPhysicalDeviceInlineUniformBlockProperties structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceInlineUniformBlockProperties {
    VkStructureType   sType;
    void*             pNext;
    uint32_t          maxInlineUniformBlockSize;
    uint32_t          maxPerStageDescriptorInlineUniformBlocks;
    uint32_t          maxPerStageDescriptorUpdateAfterBindInlineUniformBlocks;
    uint32_t          maxDescriptorSetInlineUniformBlocks;
    uint32_t          maxDescriptorSetUpdateAfterBindInlineUniformBlocks;
} VkPhysicalDeviceInlineUniformBlockProperties;
```

or the equivalent

```c
// Provided by VK_EXT_inline_uniform_block
typedef VkPhysicalDeviceInlineUniformBlockProperties
    VkPhysicalDeviceInlineUniformBlockPropertiesEXT;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- maxInlineUniformBlockSize is the maximum size in bytes of an inline uniform block binding.
- maxPerStageDescriptorInlineUniformBlocks is the maximum number of inline uniform block bindings that can be accessible to a single shader stage in a pipeline layout. Descriptor bindings with a descriptor type of VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK count against this limit. Only descriptor bindings in descriptor set layouts created without the VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set count against this limit.
- maxPerStageDescriptorUpdateAfterBindInlineUniformBlocks is similar to maxPerStageDescriptorInlineUniformBlocks but counts descriptor bindings from descriptor sets created with or without the VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set.
- maxDescriptorSetInlineUniformBlocks is the maximum number of inline uniform block bindings that can be included in descriptor bindings in a pipeline layout across all pipeline shader stages and descriptor set numbers. Descriptor bindings with a descriptor type of
VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK count against this limit. Only descriptor bindings in descriptor set layouts created without the VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set count against this limit.

- maxDescriptorSetUpdateAfterBindInlineUniformBlocks is similar to maxDescriptorSetInlineUniformBlocks but counts descriptor bindings from descriptor sets created with or without the VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT bit set.

If the VkPhysicalDeviceInlineUniformBlockProperties structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceInlineUniformBlockProperties-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INLINE_UNIFORM_BLOCK_PROPERTIES

The VkPhysicalDeviceConservativeRasterizationPropertiesEXT structure is defined as:

```c
// Provided by VK_EXT_conservative_rasterization
typedef struct VkPhysicalDeviceConservativeRasterizationPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    float primitiveOverestimationSize;
    float maxExtraPrimitiveOverestimationSize;
    float extraPrimitiveOverestimationSizeGranularity;
    VkBool32 primitiveUnderestimation;
    VkBool32 conservativePointAndLineRasterization;
    VkBool32 degenerateTrianglesRasterized;
    VkBool32 degenerateLinesRasterized;
    VkBool32 fullyCoveredFragmentShaderInputVariable;
    VkBool32 conservativeRasterizationPostDepthCoverage;
} VkPhysicalDeviceConservativeRasterizationPropertiesEXT;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- primitiveOverestimationSize is the size in pixels the generating primitive is increased at each of its edges during conservative rasterization overestimation mode. Even with a size of 0.0, conservative rasterization overestimation rules still apply and if any part of the pixel rectangle is covered by the generating primitive, fragments are generated for the entire pixel. However implementations may make the pixel coverage area even more conservative by increasing the size of the generating primitive.
- maxExtraPrimitiveOverestimationSize is the maximum size in pixels of extra overestimation the implementation supports in the pipeline state. A value of 0.0 means the implementation does not support any additional overestimation of the generating primitive during conservative rasterization. A value above 0.0 allows the application to further increase the size of the
generating primitive during conservative rasterization overestimation.

- **extraPrimitiveOverestimationSizeGranularity** is the granularity of extra overestimation that can be specified in the pipeline state between 0.0 and `maxExtraPrimitiveOverestimationSize` inclusive. A value of 0.0 means the implementation can use the smallest representable non-zero value in the screen space pixel fixed-point grid.

- **primitiveUnderestimation** is `VK_TRUE` if the implementation supports the `VK_CONSERVATIVE_RASTERIZATION_MODE_UNDERESTIMATE_EXT` conservative rasterization mode in addition to `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`. Otherwise the implementation only supports `VK_CONSERVATIVE_RASTERIZATION_MODE_OVERESTIMATE_EXT`.

- **conservativePointAndLineRasterization** is `VK_TRUE` if the implementation supports conservative rasterization of point and line primitives as well as triangle primitives. Otherwise the implementation only supports triangle primitives.

- **degenerateTrianglesRasterized** is `VK_FALSE` if the implementation culls primitives generated from triangles that become zero area after they are quantized to the fixed-point rasterization pixel grid. **degenerateTrianglesRasterized** is `VK_TRUE` if these primitives are not culled and the provoking vertex attributes and depth value are used for the fragments. The primitive area calculation is done on the primitive generated from the clipped triangle if applicable. Zero area primitives are back-facing and the application can enable backface culling if desired.

- **degenerateLinesRasterized** is `VK_FALSE` if the implementation culls lines that become zero length after they are quantized to the fixed-point rasterization pixel grid. **degenerateLinesRasterized** is `VK_TRUE` if zero length lines are not culled and the provoking vertex attributes and depth value are used for the fragments.

- **fullyCoveredFragmentShaderInputVariable** is `VK_TRUE` if the implementation supports the SPIR-V builtin fragment shader input variable `FullyCoveredEXT` specifying that conservative rasterization is enabled and the fragment area is fully covered by the generating primitive.

- **conservativeRasterizationPostDepthCoverage** is `VK_TRUE` if the implementation supports conservative rasterization with the `PostDepthCoverage` execution mode enabled. Otherwise the `PostDepthCoverage` execution mode must not be used when conservative rasterization is enabled.

If the `VkPhysicalDeviceConservativeRasterizationPropertiesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceConservativeRasterizationPropertiesEXT-sType-sType**

  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CONSERVATIVE_RASTERIZATION_PROPERTIES_EXT`

The `VkPhysicalDeviceFragmentDensityMapPropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_fragment_density_map
typedef struct VkPhysicalDeviceFragmentDensityMapPropertiesEXT {
```
 VkStructureType sType;
 void* pNext;
 VkExtent2D minFragmentDensityTexelSize;
 VkExtent2D maxFragmentDensityTexelSize;
 VkBool32 fragmentDensityInvocations;
} VkPhysicalDeviceFragmentDensityMapPropertiesEXT;

• **sType** is a *VkStructureType* value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.
• **minFragmentDensityTexelSize** is the minimum fragment density texel size.
• **maxFragmentDensityTexelSize** is the maximum fragment density texel size.
• **fragmentDensityInvocations** specifies whether the implementation may invoke additional fragment shader invocations for each covered sample.

If the *VkPhysicalDeviceFragmentDensityMapPropertiesEXT* structure is included in the *pNext* chain of the *VkPhysicalDeviceProperties2* structure passed to *vkGetPhysicalDeviceProperties2*, it is filled in with each corresponding implementation-dependent property.

**Valid Usage (Implicit)**

• VUID-VkPhysicalDeviceFragmentDensityMapPropertiesEXT-sType-sType
  
  *sType* must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_PROPERTIES_EXT

The *VkPhysicalDeviceFragmentDensityMap2PropertiesEXT* structure is defined as:

```c
// Provided by VK_EXT_fragment_density_map2
typedef struct VkPhysicalDeviceFragmentDensityMap2PropertiesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 subsampled Loads;
    VkBool32 subsampledCoarseReconstructionEarlyAccess;
    uint32_t maxSubsampledArrayLayers;
    uint32_t maxDescriptorSetSubsampledSamplers;
} VkPhysicalDeviceFragmentDensityMap2PropertiesEXT;
```

• **sType** is a *VkStructureType* value identifying this structure.
• **pNext** is NULL or a pointer to a structure extending this structure.
• **subsampledLoads** specifies if performing image data read with load operations on subsampled attachments will be resampled to the fragment density of the render pass
• **subsampledCoarseReconstructionEarlyAccess** specifies if performing image data read with samplers created with flags containing VK_SAMPLER_CREATE_SUBSAMPLED_COARSE_RECONSTRUCTION_BIT_EXT in fragment shader will trigger additional reads during VK_PIPELINE_STAGE_VERTEX_SHADER_BIT
• **maxSubsampledArrayLayers** is the maximum number of *VkImageView* array layers for usages
supporting subsampled samplers

- `maxDescriptorSetSubsampledSamplers` is the maximum number of subsampled samplers that can be included in a `VkPipelineLayout`

If the `VkPhysicalDeviceFragmentDensityMap2PropertiesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceFragmentDensityMap2PropertiesEXT-sType-sType` 
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_2_PROPERTIES_EXT`

The `VkPhysicalDeviceFragmentDensityMapOffsetPropertiesQCOM` structure is defined as:

```c
// Provided by VK_QCOM_fragment_density_map_offset
typedef struct VkPhysicalDeviceFragmentDensityMapOffsetPropertiesQCOM {
    VkStructureType sType;
    void* pNext;
    VkExtent2D fragmentDensityOffsetGranularity;
} VkPhysicalDeviceFragmentDensityMapOffsetPropertiesQCOM;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `fragmentDensityOffsetGranularity` is the granularity for fragment density offsets.

If the `VkPhysicalDeviceFragmentDensityMapOffsetPropertiesQCOM` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceFragmentDensityMapOffsetPropertiesQCOM-sType-sType` 
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_OFFSET_PROPERTIES_QCOM`

The `VkPhysicalDeviceShaderCorePropertiesAMD` structure is defined as:

```c
// Provided by VK_AMD_shader_core_properties
typedef struct VkPhysicalDeviceShaderCorePropertiesAMD {
    VkStructureType sType;
    void* pNext;
    uint32_t shaderEngineCount;
    uint32_t shaderArraysPerEngineCount;
    uint32_t computeUnitsPerShaderArray;
}
```

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uint32_t simdPerComputeUnit;
uint32_t wavefrontsPerSimd;
uint32_t wavefrontSize;
uint32_t sgprsPerSimd;
uint32_t minSgprAllocation;
uint32_t maxSgprAllocation;
uint32_t sgprAllocationGranularity;
uint32_t vgprsPerSimd;
uint32_t minVgprAllocation;
uint32_t maxVgprAllocation;
uint32_t vgprAllocationGranularity;
}

VkPhysicalDeviceShaderCorePropertiesAMD;

• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **shaderEngineCount** is an unsigned integer value indicating the number of shader engines found inside the shader core of the physical device.

• **shaderArraysPerEngineCount** is an unsigned integer value indicating the number of shader arrays inside a shader engine. Each shader array has its own scan converter, set of compute units, and a render back end (color and depth attachments). Shader arrays within a shader engine share shader processor input (wave launcher) and shader export (export buffer) units. Currently, a shader engine can have one or two shader arrays.

• **computeUnitsPerShaderArray** is an unsigned integer value indicating the physical number of compute units within a shader array. The active number of compute units in a shader array may be lower. A compute unit houses a set of SIMDs along with a sequencer module and a local data store.

• **simdPerComputeUnit** is an unsigned integer value indicating the number of SIMDs inside a compute unit. Each SIMD processes a single instruction at a time.

• **wavefrontSize** is an unsigned integer value indicating the maximum size of a subgroup.

• **sgprsPerSimd** is an unsigned integer value indicating the number of physical Scalar General-Purpose Registers (SGPRs) per SIMD.

• **minSgprAllocation** is an unsigned integer value indicating the minimum number of SGPRs allocated for a wave.

• **maxSgprAllocation** is an unsigned integer value indicating the maximum number of SGPRs allocated for a wave.

• **sgprAllocationGranularity** is an unsigned integer value indicating the granularity of SGPR allocation for a wave.

• **vgprsPerSimd** is an unsigned integer value indicating the number of physical Vector General-Purpose Registers (VGPRs) per SIMD.

• **minVgprAllocation** is an unsigned integer value indicating the minimum number of VGPRs allocated for a wave.

• **maxVgprAllocation** is an unsigned integer value indicating the maximum number of VGPRs allocated for a wave.
• `vgprAllocationGranularity` is an unsigned integer value indicating the granularity of VGPR allocation for a wave.

If the `VkPhysicalDeviceShaderCorePropertiesAMD` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceShaderCorePropertiesAMD-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CORE_PROPERTIES_AMD`

The `VkPhysicalDeviceShaderCoreProperties2AMD` structure is defined as:

```c
// Provided by VK_AMD_shader_core_properties2
typedef struct VkPhysicalDeviceShaderCoreProperties2AMD {
    VkStructureType sType;
    void* pNext;
    VkShaderCorePropertiesFlagsAMD shaderCoreFeatures;
    uint32_t activeComputeUnitCount;
} VkPhysicalDeviceShaderCoreProperties2AMD;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `shaderCoreFeatures` is a bitmask of `VkShaderCorePropertiesFlagBitsAMD` indicating the set of features supported by the shader core.
- `activeComputeUnitCount` is an unsigned integer value indicating the number of compute units that have been enabled.

If the `VkPhysicalDeviceShaderCoreProperties2AMD` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceShaderCoreProperties2AMD-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CORE_PROPERTIES_2_AMD`

Bits for this type may be defined by future extensions, or new versions of the `VK_AMD_shader_core_properties2` extension. Possible values of the `flags` member of `VkShaderCorePropertiesFlagsAMD` are:

```c
// Provided by VK_AMD_shader_core_properties2
typedef enum VkShaderCorePropertiesFlagBitsAMD {
```

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 VkShaderCorePropertiesFlagBitsAMD is a bitmask type for providing zero or more VkShaderCorePropertiesFlagBitsAMD.

The VkPhysicalDeviceDepthStencilResolveProperties structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceDepthStencilResolveProperties {
    VkStructureType sType;
    void* pNext;
    VkResolveModeFlags supportedDepthResolveModes;
    VkResolveModeFlags supportedStencilResolveModes;
    VkBool32 independentResolveNone;
    VkBool32 independentResolve;
} VkPhysicalDeviceDepthStencilResolveProperties;

or the equivalent

// Provided by VK_KHR_depth_stencil_resolve
typedef VkPhysicalDeviceDepthStencilResolveProperties
    VkPhysicalDeviceDepthStencilResolvePropertiesKHR;
```

- **sType** is a VkStructureType value identifying this structure.

- **pNext** is NULL or a pointer to a structure extending this structure.

- **supportedDepthResolveModes** is a bitmask of VkResolveModeFlagBits indicating the set of supported depth resolve modes. VK_RESOLVE_MODE_SAMPLE_ZERO_BIT must be included in the set but implementations may support additional modes.

- **supportedStencilResolveModes** is a bitmask of VkResolveModeFlagBits indicating the set of supported stencil resolve modes. VK_RESOLVE_MODE_SAMPLE_ZERO_BIT must be included in the set but implementations may support additional modes. VK_RESOLVE_MODE_AVERAGE_BIT must not be included in the set.

- **independentResolveNone** is VK_TRUE if the implementation supports setting the depth and stencil resolve modes to different values when one of those modes is VK_RESOLVE_MODE_NONE. Otherwise the implementation only supports setting both modes to the same value.

- **independentResolve** is VK_TRUE if the implementation supports all combinations of the supported depth and stencil resolve modes, including setting either depth or stencil resolve mode to VK_RESOLVE_MODE_NONE. An implementation that supports independentResolve must also support independentResolveNone.
If the `VkPhysicalDeviceDepthStencilResolveProperties` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceDepthStencilResolveProperties-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_STENCIL_RESOLVE_PROPERTIES`

The `VkPhysicalDevicePerformanceQueryPropertiesKHR` structure is defined as:

```c
// Provided by VK_KHR_performance_query
typedef struct VkPhysicalDevicePerformanceQueryPropertiesKHR {
    VkStructureType           sType;
    void*                     pNext;
    VkBool32                  allowCommandBufferQueryCopies;
} VkPhysicalDevicePerformanceQueryPropertiesKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **allowCommandBufferQueryCopies** is `VK_TRUE` if the performance query pools are allowed to be used with `vkCmdCopyQueryPoolResults`.

If the `VkPhysicalDevicePerformanceQueryPropertiesKHR` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDevicePerformanceQueryPropertiesKHR-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PERFORMANCE_QUERY_PROPERTIES_KHR`

The `VkPhysicalDeviceShadingRateImagePropertiesNV` structure is defined as:

```c
// Provided by VK_NV_shading_rate_image
typedef struct VkPhysicalDeviceShadingRateImagePropertiesNV {
    VkStructureType           sType;
    void*                     pNext;
    VkExtent2D                shadingRateTexelSize;
    uint32_t                  shadingRatePaletteSize;
    uint32_t                  shadingRateMaxCoarseSamples;
} VkPhysicalDeviceShadingRateImagePropertiesNV;
```

- **sType** is a `VkStructureType` value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.

• `shadingRateTexelSize` indicates the width and height of the portion of the framebuffer corresponding to each texel in the shading rate image.

• `shadingRatePaletteSize` indicates the maximum number of palette entries supported for the shading rate image.

• `shadingRateMaxCoarseSamples` specifies the maximum number of coverage samples supported in a single fragment. If the product of the fragment size derived from the base shading rate and the number of coverage samples per pixel exceeds this limit, the final shading rate will be adjusted so that its product does not exceed the limit.

If the `VkPhysicalDeviceShadingRateImagePropertiesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

These properties are related to the shading rate image feature.

**Valid Usage (Implicit)**

- `VUID-VkPhysicalDeviceShadingRateImagePropertiesNV-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADING_RATE_IMAGE_PROPERTIES_NV`

The `VkPhysicalDeviceMemoryDecompressionPropertiesNV` structure is defined as:

```c
// Provided by VK_NV_memory_decompression
typedef struct VkPhysicalDeviceMemoryDecompressionPropertiesNV {
    VkStructureType          sType;
    void*                    pNext;
    VkMemoryDecompressionMethodFlagsNV  decompressionMethods;
    uint64_t                  maxDecompressionIndirectCount;
} VkPhysicalDeviceMemoryDecompressionPropertiesNV;
```

- `sType` is a `VkStructureType` value identifying this structure.

- `pNext` is `NULL` or a pointer to a structure extending this structure.

- `decompressionMethods` is a bitmask of `VkMemoryDecompressionMethodFlagBitsNV` specifying memory decompression methods supported by the implementation.

- `maxDecompressionIndirectCount` specifies the maximum supported count value in the `countBuffer` of `vkCmdDecompressMemoryIndirectCountNV`

If the `VkPhysicalDeviceMemoryDecompressionPropertiesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.
Valid Usage (Implicit)

• VUID-VkPhysicalDeviceMemoryDecompressionPropertiesNV-sType-sType

sType must be Vk_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_DECOMPRESSION_PROPERTIES_NV

The VkPhysicalDeviceTransformFeedbackPropertiesEXT structure is defined as:

```c
// Provided by VK_EXT_transform_feedback
typedef struct VkPhysicalDeviceTransformFeedbackPropertiesEXT {
    VkStructureType      sType;
    void*                 pNext;
    uint32_t              maxTransformFeedbackStreams;
    uint32_t              maxTransformFeedbackBuffers;
    VkDeviceSize          maxTransformFeedbackBufferSize;
    uint32_t              maxTransformFeedbackStreamDataSize;
    uint32_t              maxTransformFeedbackBufferDataSize;
    uint32_t              maxTransformFeedbackBufferDataStride;
    VkBool32              transformFeedbackQueries;
    VkBool32              transformFeedbackStreamsLinesTriangles;
    VkBool32              transformFeedbackRasterizationStreamSelect;
    VkBool32              transformFeedbackDraw;
} VkPhysicalDeviceTransformFeedbackPropertiesEXT;
```

• **sType** is a VkStructureType value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **maxTransformFeedbackStreams** is the maximum number of vertex streams that can be output from geometry shaders declared with the GeometryStreams capability. If the implementation does not support VkPhysicalDeviceTransformFeedbackFeaturesEXT::geometryStreams then maxTransformFeedbackStreams must be set to 1.

• **maxTransformFeedbackBuffers** is the maximum number of transform feedback buffers that can be bound for capturing shader outputs from the last pre-rasterization shader stage.

• **maxTransformFeedbackBufferSize** is the maximum size that can be specified when binding a buffer for transform feedback in vkCmdBindTransformFeedbackBuffersEXT.

• **maxTransformFeedbackStreamDataSize** is the maximum amount of data in bytes for each vertex that captured to one or more transform feedback buffers associated with a specific vertex stream.

• **maxTransformFeedbackBufferDataSize** is the maximum amount of data in bytes for each vertex that can be captured to a specific transform feedback buffer.

• **maxTransformFeedbackBufferDataStride** is the maximum stride between each capture of vertex data to the buffer.

• **transformFeedbackQueries** is VK_TRUE if the implementation supports the VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT query type. transformFeedbackQueries is VK_FALSE if queries of this type cannot be created.
• `transformFeedbackStreamsLinesTriangles` is `VK_TRUE` if the implementation supports the geometry shader `OpExecutionMode` of `OutputLineStrip` and `OutputTriangleStrip` in addition to `OutputPoints` when more than one vertex stream is output. If `transformFeedbackStreamsLinesTriangles` is `VK_FALSE` the implementation only supports an `OpExecutionMode` of `OutputPoints` when more than one vertex stream is output from the geometry shader.

• `transformFeedbackRasterizationStreamSelect` is `VK_TRUE` if the implementation supports the `GeometryStreams` SPIR-V capability and the application can use `VkPipelineRasterizationStateStreamCreateInfoEXT` to modify which vertex stream output is used for rasterization. Otherwise vertex stream `0` must always be used for rasterization.

• `transformFeedbackDraw` is `VK_TRUE` if the implementation supports the `vkCmdDrawIndirectByteCountEXT` function otherwise the function must not be called.

If the `VkPhysicalDeviceTransformFeedbackPropertiesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceTransformFeedbackPropertiesEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TRANSFORM_FEEDBACK_PROPERTIES_EXT`

The `VkPhysicalDeviceCopyMemoryIndirectPropertiesNV` structure is defined as:

```c
// Provided by VK_NV_copy_memory_indirect
typedef struct VkPhysicalDeviceCopyMemoryIndirectPropertiesNV {
    VkStructureType sType;
    void* pNext;
    VkQueueFlags supportedQueues;
} VkPhysicalDeviceCopyMemoryIndirectPropertiesNV;
```

• `sType` is a `VkStructureType` value identifying this structure.

• `pNext` is `NULL` or a pointer to a structure extending this structure.

• `supportedQueues` is a bitmask of `VkQueueFlagBits` indicating the queues on which indirect copy commands are supported.

If the `indirectCopy` feature is supported, `supportedQueues` must return at least one supported queue.

If the `VkPhysicalDeviceCopyMemoryIndirectPropertiesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceCopyMemoryIndirectPropertiesNV-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COPY_MEMORY_INDIRECT_PROPERTIES_NV`
The `VkPhysicalDeviceRayTracingPropertiesNV` structure is defined as:

```c
// Provided by VK_NV_ray_tracing
typedef struct VkPhysicalDeviceRayTracingPropertiesNV {
    VkStructureType sType;
    void* pNext;
    uint32_t shaderGroupHandleSize;
    uint32_t maxRecursionDepth;
    uint32_t maxShaderGroupStride;
    uint32_t shaderGroupBaseAlignment;
    uint64_t maxGeometryCount;
    uint64_t maxInstanceCount;
    uint64_t maxTriangleCount;
    uint32_t maxDescriptorSetAccelerationStructures;
} VkPhysicalDeviceRayTracingPropertiesNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `shaderGroupHandleSize` is the size in bytes of the shader header.
- `maxRecursionDepth` is the maximum number of levels of recursion allowed in a trace command.
- `maxShaderGroupStride` is the maximum stride in bytes allowed between shader groups in the shader binding table.
- `shaderGroupBaseAlignment` is the required alignment in bytes for the base of the shader binding table.
- `maxGeometryCount` is the maximum number of geometries in the bottom level acceleration structure.
- `maxInstanceCount` is the maximum number of instances in the top level acceleration structure.
- `maxTriangleCount` is the maximum number of triangles in all geometries in the bottom level acceleration structure.
- `maxDescriptorSetAccelerationStructures` is the maximum number of acceleration structure descriptors that are allowed in a descriptor set.

Due to the fact that the geometry, instance, and triangle counts are specified at acceleration structure creation as 32-bit values, `maxGeometryCount`, `maxInstanceCount`, and `maxTriangleCount` must not exceed $2^{32}-1$.

If the `VkPhysicalDeviceRayTracingPropertiesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

Limits specified by this structure must match those specified with the same name in `VkPhysicalDeviceAccelerationStructurePropertiesKHR` and `VkPhysicalDeviceRayTracingPipelinePropertiesKHR`. 

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Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceRayTracingPropertiesNV-sType-sType**

  *sType* must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_PROPERTIES_NV`

The `VkPhysicalDeviceAccelerationStructurePropertiesKHR` structure is defined as:

```c
// Provided by VK_KHR_acceleration_structure
typedef struct VkPhysicalDeviceAccelerationStructurePropertiesKHR {
    VkStructureType sType;
    void* pNext;
    uint64_t maxGeometryCount;
    uint64_t maxInstanceCount;
    uint64_t maxPrimitiveCount;
    uint32_t maxPerStageDescriptorAccelerationStructures;
    uint32_t maxPerStageDescriptorUpdateAfterBindAccelerationStructures;
    uint32_t maxDescriptorSetAccelerationStructures;
    uint32_t maxDescriptorSetUpdateAfterBindAccelerationStructures;
    uint32_t minAccelerationStructureScratchOffsetAlignment;
} VkPhysicalDeviceAccelerationStructurePropertiesKHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **maxGeometryCount** is the maximum number of geometries in the bottom level acceleration structure.
- **maxInstanceCount** is the maximum number of instances in the top level acceleration structure.
- **maxPrimitiveCount** is the maximum number of triangles or AABBs in all geometries in the bottom level acceleration structure.
- **maxPerStageDescriptorAccelerationStructures** is the maximum number of acceleration structure bindings that can be accessible to a single shader stage in a pipeline layout. Descriptor bindings with a descriptor type of `VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR` count against this limit. Only descriptor bindings in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set count against this limit.
- **maxPerStageDescriptorUpdateAfterBindAccelerationStructures** is similar to `maxPerStageDescriptorAccelerationStructures` but counts descriptor bindings from descriptor sets created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.
- **maxDescriptorSetAccelerationStructures** is the maximum number of acceleration structure descriptors that can be included in descriptor bindings in a pipeline layout across all pipeline shader stages and descriptor set numbers. Descriptor bindings with a descriptor type of `VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR` count against this limit. Only descriptor bindings in descriptor set layouts created without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set count against this limit.
• `maxDescriptorSetUpdateAfterBindAccelerationStructures` is similar to
`maxDescriptorSetAccelerationStructures` but counts descriptor bindings from descriptor sets
created with or without the `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` bit set.

• `minAccelerationStructureScratchOffsetAlignment` is the minimum required alignment, in bytes,
for scratch data passed in to an acceleration structure build command. The value must be a
power of two.

Due to the fact that the geometry, instance, and primitive counts are specified at acceleration
structure creation as 32-bit values, `maxGeometryCount`, `maxInstanceCount`, and `maxPrimitiveCount` must
not exceed $2^{32}-1$.

If the `VkPhysicalDeviceAccelerationStructurePropertiesKHR` structure is included in the `pNext` chain
of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled
in with each corresponding implementation-dependent property.

Limits specified by this structure must match those specified with the same name in
`VkPhysicalDeviceRayTracingPropertiesNV`.

---

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceAccelerationStructurePropertiesKHR-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ACCELERATION_STRUCTURE_PROPERTIES_KHR`

The `VkPhysicalDeviceRayTracingPipelinePropertiesKHR` structure is defined as:

```c
typedef struct VkPhysicalDeviceRayTracingPipelinePropertiesKHR {
    VkStructureType sType;
    void* pNext;
    uint32_t shaderGroupHandleSize;
    uint32_t maxRayRecursionDepth;
    uint32_t maxShaderGroupStride;
    uint32_t shaderGroupBaseAlignment;
    uint32_t shaderGroupHandleCaptureReplaySize;
    uint32_t maxRayDispatchInvocationCount;
    uint32_t shaderGroupHandleAlignment;
    uint32_t maxRayHitAttributeSize;
} VkPhysicalDeviceRayTracingPipelinePropertiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `shaderGroupHandleSize` is the size in bytes of the shader header.
- `maxRayRecursionDepth` is the maximum number of levels of ray recursion allowed in a trace
  command.
- `maxShaderGroupStride` is the maximum stride in bytes allowed between shader groups in the
shader binding table.

- **shaderGroupBaseAlignment** is the **required** alignment in bytes for the base of the shader binding table.

- **shaderGroupHandleCaptureReplaySize** is the number of bytes for the information required to do capture and replay for shader group handles.

- **maxRayDispatchInvocationCount** is the maximum number of ray generation shader invocations which may be produced by a single `vkCmdTraceRaysIndirectKHR` or `vkCmdTraceRaysKHR` command.

- **shaderGroupHandleAlignment** is the **required** alignment in bytes for each shader binding table entry. The value must be a power of two.

- **maxRayHitAttributeSize** is the maximum size in bytes for a ray attribute structure.

If the `VkPhysicalDeviceRayTracingPipelinePropertiesKHR` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

Limits specified by this structure must match those specified with the same name in `VkPhysicalDeviceRayTracingPropertiesNV`.

---

**Valid Usage (Implicit)**

- **VUID-VkPhysicalDeviceRayTracingPipelinePropertiesKHR-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_PIPELINE_PROPERTIES_KHR`.

The `VkPhysicalDeviceCooperativeMatrixPropertiesNV` structure is defined as:

```c
// Provided by VK_NV_cooperative_matrix
typedef struct VkPhysicalDeviceCooperativeMatrixPropertiesNV {
    VkStructureType sType;
    void* pNext;
    VkShaderStageFlags cooperativeMatrixSupportedStages;
} VkPhysicalDeviceCooperativeMatrixPropertiesNV;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **cooperativeMatrixSupportedStages** is a bitfield of `VkShaderStageFlagBits` describing the shader stages that cooperative matrix instructions are supported in. `cooperativeMatrixSupportedStages` will have the `VK_SHADER_STAGE_COMPUTE_BIT` bit set if any of the physical device’s queues support `VK_QUEUE_COMPUTE_BIT`.

If the `VkPhysicalDeviceCooperativeMatrixPropertiesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceCooperativeMatrixPropertiesNV-sType-sType
  
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COOPERATIVE_MATRIX_PROPERTIES_NV

The VkPhysicalDeviceCooperativeMatrixPropertiesKHR structure is defined as:

```c
// Provided by VK_KHR_cooperative_matrix
typedef struct VkPhysicalDeviceCooperativeMatrixPropertiesKHR {
    VkStructureType       sType;
    void*                  pNext;
    VkShaderStageFlags    cooperativeMatrixSupportedStages;
} VkPhysicalDeviceCooperativeMatrixPropertiesKHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- cooperativeMatrixSupportedStages is a bitfield of VkShaderStageFlagBits describing the shader stages that cooperative matrix instructions are supported in. cooperativeMatrixSupportedStages will have the VK_SHADER_STAGE_COMPUTE_BIT bit set if any of the physical device's queues support VK_QUEUE_COMPUTE_BIT.

If the VkPhysicalDeviceCooperativeMatrixPropertiesKHR structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceCooperativeMatrixPropertiesKHR-sType-sType
  
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COOPERATIVE_MATRIX_PROPERTIES_KHR

The VkPhysicalDeviceShaderSMBuiltinsPropertiesNV structure is defined as:

```c
// Provided by VK_NV_shader_sm_builtins
typedef struct VkPhysicalDeviceShaderSMBuiltinsPropertiesNV {
    VkStructureType       sType;
    void*                  pNext;
    uint32_t               shaderSMCount;
    uint32_t               shaderWarpsPerSM;
} VkPhysicalDeviceShaderSMBuiltinsPropertiesNV;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- shaderSMCount is the number of SMs on the device.
• shaderWarpSPerSM is the maximum number of simultaneously executing warps on an SM.

If the VkPhysicalDeviceShaderSMBuiltinsPropertiesNV structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceShaderSMBuiltinsPropertiesNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICALDEVICE_SHADER_SM_BUILTINS_PROPERTIES_NV

The VkPhysicalDeviceTexelBufferAlignmentProperties structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceTexelBufferAlignmentProperties {
    VkStructureType sType;
    void* pNext;
    VkDeviceSize storageTexelBufferOffsetAlignmentBytes;
    VkBool32 storageTexelBufferOffsetSingleTexelAlignment;
    VkDeviceSize uniformTexelBufferOffsetAlignmentBytes;
    VkBool32 uniformTexelBufferOffsetSingleTexelAlignment;
} VkPhysicalDeviceTexelBufferAlignmentProperties;
```

or the equivalent

```c
// Provided by VK_EXT_texel_buffer_alignment
typedef VkPhysicalDeviceTexelBufferAlignmentProperties
VkPhysicalDeviceTexelBufferAlignmentPropertiesEXT;
```

• sType is a VkStructureType value identifying this structure.

• pNext is NULL or a pointer to a structure extending this structure.

• storageTexelBufferOffsetAlignmentBytes is a byte alignment that is sufficient for a storage texel buffer of any format. The value must be a power of two.

• storageTexelBufferOffsetSingleTexelAlignment indicates whether single texel alignment is sufficient for a storage texel buffer of any format.

• uniformTexelBufferOffsetAlignmentBytes is a byte alignment that is sufficient for a uniform texel buffer of any format. The value must be a power of two.

• uniformTexelBufferOffsetSingleTexelAlignment indicates whether single texel alignment is sufficient for a uniform texel buffer of any format.

If the VkPhysicalDeviceTexelBufferAlignmentProperties structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.
If the single texel alignment property is `VK_FALSE`, then the buffer view's offset **must** be aligned to the corresponding byte alignment value. If the single texel alignment property is `VK_TRUE`, then the buffer view's offset **must** be aligned to the lesser of the corresponding byte alignment value or the size of a single texel, based on `VkBufferViewCreateInfo::format`. If the size of a single texel is a multiple of three bytes, then the size of a single component of the format is used instead.

These limits **must** not advertise a larger alignment than the required maximum minimum value of `VkPhysicalDeviceLimits::minTexelBufferOffsetAlignment`, for any format that supports use as a texel buffer.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceTexelBufferAlignmentProperties-sType-sType**
  
  `sType` **must** be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXEL_BUFFER_ALIGNMENT_PROPERTIES`

---

The `VkPhysicalDeviceTimelineSemaphoreProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDeviceTimelineSemaphoreProperties {
    VkStructureType sType;
    void* pNext;
    uint64_t maxTimelineSemaphoreValueDifference;
} VkPhysicalDeviceTimelineSemaphoreProperties;
```

or the equivalent

```c
// Provided by VK_KHR_timeline_semaphore
typedef VkPhysicalDeviceTimelineSemaphoreProperties
VkPhysicalDeviceTimelineSemaphorePropertiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `maxTimelineSemaphoreValueDifference` indicates the maximum difference allowed by the implementation between the current value of a timeline semaphore and any pending signal or wait operations.

If the `VkPhysicalDeviceTimelineSemaphoreProperties` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceTimelineSemaphoreProperties-sType-sType**
  
  `sType` **must** be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TIMELINE_SEMAPHORE_PROPERTIES`
The `VkPhysicalDeviceLineRasterizationPropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_line_rasterization
typedef struct VkPhysicalDeviceLineRasterizationPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t lineSubPixelPrecisionBits;
} VkPhysicalDeviceLineRasterizationPropertiesEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `lineSubPixelPrecisionBits` is the number of bits of subpixel precision in framebuffer coordinates \( x_f \) and \( y_f \) when rasterizing line segments.

If the `VkPhysicalDeviceLineRasterizationPropertiesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

**Valid Usage (Implicit)**

- VUID-VkPhysicalDeviceLineRasterizationPropertiesEXT-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_LINE_RASTERIZATION_PROPERTIES_EXT`

The `VkPhysicalDeviceRobustness2PropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_robustness2
typedef struct VkPhysicalDeviceRobustness2PropertiesEXT {
    VkStructureType sType;
    void* pNext;
    VkDeviceSize robustStorageBufferAccessSizeAlignment;
    VkDeviceSize robustUniformBufferAccessSizeAlignment;
} VkPhysicalDeviceRobustness2PropertiesEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `robustStorageBufferAccessSizeAlignment` is the number of bytes that the range of a storage buffer descriptor is rounded up to when used for bounds-checking when the `robustBufferAccess2` feature is enabled. This value must be either 1 or 4.
- `robustUniformBufferAccessSizeAlignment` is the number of bytes that the range of a uniform buffer descriptor is rounded up to when used for bounds-checking when the `robustBufferAccess2` feature is enabled. This value must be a power of two in the range \([1, 256]\).

If the `VkPhysicalDeviceRobustness2PropertiesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with
each corresponding implementation-dependent property.

Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceRobustness2PropertiesEXT-sType-sType**
  - `sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ROBUSTNESS_2_PROPERTIES_EXT`

The `VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV` structure is defined as:

```c
// Provided by VK_NV_device_generated_commands
typedef struct VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV {
    VkStructureType sType;
    void* pNext;
    uint32_t maxGraphicsShaderGroupCount;
    uint32_t maxIndirectSequenceCount;
    uint32_t maxIndirectCommandsTokenCount;
    uint32_t maxIndirectCommandsStreamCount;
    uint32_t maxIndirectCommandsTokenOffset;
    uint32_t maxIndirectCommandsStreamStride;
    uint32_t minSequencesCountBufferOffsetAlignment;
    uint32_t minSequencesIndexBufferOffsetAlignment;
    uint32_t minIndirectCommandsBufferOffsetAlignment;
} VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `maxGraphicsShaderGroupCount` is the maximum number of shader groups in `VkGraphicsPipelineShaderGroupsCreateInfoNV`.
- `maxIndirectSequenceCount` is the maximum number of sequences in `VkGeneratedCommandsInfoNV` and in `VkGeneratedCommandsMemoryRequirementsInfoNV`.
- `maxIndirectCommandsTokenCount` is the maximum number of tokens in `VkIndirectCommandsLayoutCreateInfoNV`.
- `maxIndirectCommandsStreamCount` is the maximum number of streams in `VkIndirectCommandsLayoutCreateInfoNV`.
- `maxIndirectCommandsTokenOffset` is the maximum offset in `VkIndirectCommandsLayoutTokenNV`.
- `maxIndirectCommandsStreamStride` is the maximum stream stride in `VkIndirectCommandsLayoutCreateInfoNV`.
- `minSequencesCountBufferOffsetAlignment` is the minimum alignment for memory addresses which can be used in `VkGeneratedCommandsInfoNV`.
- `minSequencesIndexBufferOffsetAlignment` is the minimum alignment for memory addresses which can be used in `VkGeneratedCommandsInfoNV`.
- `minIndirectCommandsBufferOffsetAlignment` is the minimum alignment for memory addresses used in `VkIndirectCommandsStreamNV`, and as preprocess buffer in
VkGeneratedCommandsInfoNV.

If the VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEVICE_GENERATED_COMMANDS_PROPERTIES_NV

The VkPhysicalDevicePortabilitySubsetPropertiesKHR structure is defined as:

```c
typedef struct VkPhysicalDevicePortabilitySubsetPropertiesKHR {
    VkStructureType sType;
    void* pNext;
    uint32_t minVertexInputBindingStrideAlignment;
} VkPhysicalDevicePortabilitySubsetPropertiesKHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- minVertexInputBindingStrideAlignment indicates the minimum alignment for vertex input strides. VkVertexInputBindingDescription::stride must be a multiple of, and at least as large as, this value. The value must be a power of two.

If the VkPhysicalDevicePortabilitySubsetPropertiesKHR structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

Valid Usage (Implicit)

- VUID-VkPhysicalDevicePortabilitySubsetPropertiesKHR-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PORTABILITY_SUBSET_PROPERTIES_KHR

The VkPhysicalDeviceFragmentShadingRatePropertiesKHR structure is defined as:

```c
typedef struct VkPhysicalDeviceFragmentShadingRatePropertiesKHR {
    VkStructureType sType;
    void* pNext;
    VkExtent2D minFragmentShadingRateAttachmentTexelSize;
    VkExtent2D maxFragmentShadingRateAttachmentTexelSize;
    uint32_t maxFragmentShadingRateAttachmentTexelSizeAspectRatio;
} VkPhysicalDeviceFragmentShadingRatePropertiesKHR;
```

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VkBool32 primitiveFragmentShadingRateWithMultipleViewports;
VkBool32 layeredShadingRateAttachments;
VkBool32 fragmentShadingRateNonTrivialCombinerOps;
VkExtent2D maxFragmentSize;
uint32_t maxFragmentSizeAspectRatio;
uint32_t maxFragmentShadingRateCoverageSamples;
VkSampleCountFlagBits maxFragmentShadingRateRasterizationSamples;
VkBool32 fragmentShadingRateWithShaderDepthStencil Writes;
VkBool32 fragmentShadingRateWithSampleMask;
VkBool32 fragmentShadingRateWithShaderSampleMask;
VkBool32 fragmentShadingRateWithConservativeRasterization;
VkBool32 fragmentShadingRateWithFragmentShaderInterlock;
VkBool32 fragmentShadingRateWithCustomSampleLocations;
VkBool32 fragmentShadingRateStrictMultiplyCombiner;

} VkPhysicalDeviceFragmentShadingRatePropertiesKHR;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• minFragmentShadingRateAttachmentTexelSize indicates minimum supported width and height of the portion of the framebuffer corresponding to each texel in a fragment shading rate attachment. Each value must be less than or equal to the values in maxFragmentShadingRateAttachmentTexelSize. Each value must be a power-of-two. It must be (0,0) if the attachmentFragmentShadingRate feature is not supported.
• maxFragmentShadingRateAttachmentTexelSize indicates maximum supported width and height of the portion of the framebuffer corresponding to each texel in a fragment shading rate attachment. Each value must be greater than or equal to the values in minFragmentShadingRateAttachmentTexelSize. Each value must be a power-of-two. It must be (0,0) if the attachmentFragmentShadingRate feature is not supported.
• maxFragmentShadingRateAttachmentTexelSizeAspectRatio indicates the maximum ratio between the width and height of the portion of the framebuffer corresponding to each texel in a fragment shading rate attachment. maxFragmentShadingRateAttachmentTexelSizeAspectRatio must be a power-of-two value, and must be less than or equal to \( \frac{\text{max(}}\frac{\text{maxFragmentShadingRateAttachmentTexelSize.width}}{\text{minFragmentShadingRateAttachmentTexelSize.height}}, \frac{\text{maxFragmentShadingRateAttachmentTexelSize.height}}{\text{minFragmentShadingRateAttachmentTexelSize.width}}\))\). It must be 0 if the attachmentFragmentShadingRate feature is not supported.
• primitiveFragmentShadingRateWithMultipleViewports specifies whether the primitive fragment shading rate can be used when multiple viewports are used. If this value is VK_FALSE, only a single viewport must be used, and applications must not write to the ViewportMaskNV or ViewportIndex built-in when setting PrimitiveShadingRateKHR. It must be VK_FALSE if the shaderOutputViewportIndex feature, the VK_EXT_shader_viewport_index_layer extension, or the geometryShader feature is not supported, or if the primitiveFragmentShadingRate feature is not supported.
• layeredShadingRateAttachments specifies whether a shading rate attachment image view can be created with multiple layers. If this value is VK_FALSE, when creating an image view with a usage
that includes VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR, layerCount must be 1. It must be VK_FALSE if the multiview feature, the shaderOutputViewportIndex feature, the VK_EXT_shader_viewport_index_layer extension, or the geometryShader feature is not supported, or if the attachmentFragmentShadingRate feature is not supported.

- fragmentShadingRateNonTrivialCombinerOps specifies whether
  VkFragmentShadingRateCombinerOpKHR enums other than VK_FRAGMENT_SHADING_RATE_COMBINER_OP_KEEP_KHR or VK_FRAGMENT_SHADING_RATE_COMBINER_OP_REPLACE_KHR can be used. It must be VK_FALSE unless either the primitiveFragmentShadingRate or attachmentFragmentShadingRate feature is supported.

- maxFragmentSize indicates the maximum supported width and height of a fragment. Its width and height members must both be power-of-two values. This limit is purely informational, and is not validated.

- maxFragmentSizeAspectRatio indicates the maximum ratio between the width and height of a fragment. maxFragmentSizeAspectRatio must be a power-of-two value, and must be less than or equal to the maximum of the width and height members of maxFragmentSize. This limit is purely informational, and is not validated.

- maxFragmentShadingRateCoverageSamples specifies the maximum number of coverage samples supported in a single fragment. maxFragmentShadingRateCoverageSamples must be less than or equal to the product of the width and height members of maxFragmentSize, and the sample count reported by maxFragmentShadingRateRasterizationSamples. maxFragmentShadingRateCoverageSamples must be less than or equal to maxSampleMaskWords × 32 if fragmentShadingRateWithShaderSampleMask is supported. This limit is purely informational, and is not validated.

- maxFragmentShadingRateRasterizationSamples is a VkSampleCountFlagBits value specifying the maximum sample rate supported when a fragment covers multiple pixels. This limit is purely informational, and is not validated.

- fragmentShadingRateWithShaderDepthStencilWrites specifies whether the implementation supports writing FragDepth or FragStencilRefEXT from a fragment shader for multi-pixel fragments. If this value is VK_FALSE, writing to those built-ins will clamp the fragment shading rate to (1,1).

- fragmentShadingRateWithSampleMask specifies whether the implementation supports setting valid bits of VkPipelineMultisampleStateCreateInfo::pSampleMask to 0 for multi-pixel fragments. If this value is VK_FALSE, zeroing valid bits in the sample mask will clamp the fragment shading rate to (1,1).

- fragmentShadingRateWithShaderSampleMask specifies whether the implementation supports reading or writing SampleMask for multi-pixel fragments. If this value is VK_FALSE, using that built-in will clamp the fragment shading rate to (1,1).

- fragmentShadingRateWithConservativeRasterization specifies whether conservative rasterization is supported for multi-pixel fragments. It must be VK_FALSE if VK_EXT_conservative_rasterization is not supported. If this value is VK_FALSE, using conservative rasterization will clamp the fragment shading rate to (1,1).

- fragmentShadingRateWithFragmentShaderInterlock specifies whether fragment shader interlock is supported for multi-pixel fragments. It must be VK_FALSE if VK_EXT_fragment_shader_interlock is not supported. If this value is VK_FALSE, using fragment shader interlock will clamp the fragment
shading rate to \((1,1)\).

- **fragmentShadingRateWithCustomSampleLocations** specifies whether custom sample locations are supported for multi-pixel fragments. It **must** be **VK_FALSE** if **VK_EXT_sample_locations** is not supported. If this value is **VK_FALSE**, using custom sample locations will clamp the fragment shading rate to \((1,1)\).

- **fragmentShadingRateStrictMultiplyCombiner** specifies whether **VK_FRAGMENT_SHADING_RATE_COMBINER_OP_MUL_KHR** accurately performs a multiplication or not. Implementations where this value is **VK_FALSE** will instead combine rates with an addition. If **fragmentShadingRateNonTrivialCombinerOps** is **VK_FALSE**, implementations **must** report this as **VK_FALSE**. If **fragmentShadingRateNonTrivialCombinerOps** is **VK_TRUE**, implementations **should** report this as **VK_TRUE**.

**Note**

Multiplication of the combiner rates using the fragment width/height in linear space is equivalent to an addition of those values in log2 space. Some implementations inadvertently implemented an addition in linear space due to unclear requirements originating outside of this specification. This resulted in **fragmentShadingRateStrictMultiplyCombiner** being added. Fortunately, this only affects situations where a rate of 1 in either dimension is combined with another rate of 1. All other combinations result in the exact same result as if multiplication was performed in linear space due to the clamping logic, and the fact that both the sum and product of 2 and 2 are equal. In many cases, this limit will not affect the correct operation of applications.

If the **VkPhysicalDeviceFragmentShadingRatePropertiesKHR** structure is included in the **pNext** chain of the **VkPhysicalDeviceProperties2** structure passed to **vkGetPhysicalDeviceProperties2**, it is filled in with each corresponding implementation-dependent property.

These properties are related to **fragment shading rates**.

**Valid Usage (Implicit)**

- **VUID-VkPhysicalDeviceFragmentShadingRatePropertiesKHR-sType-sType**
  
  **sType** **must** be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADING_RATE_PROPERTIES_KHR**

The **VkPhysicalDeviceFragmentShadingRateEnumsPropertiesNV** structure is defined as:

```c
// Provided by VK_NV_fragment_shading_rateEnums
typedef struct VkPhysicalDeviceFragmentShadingRateEnumsPropertiesNV {
  VkStructureType sType;
  void* pNext;
  VkSampleCountFlagBits maxFragmentShadingRateInvocationCount;
} VkPhysicalDeviceFragmentShadingRateEnumsPropertiesNV;
```

- **sType** is a **VkStructureType** value identifying this structure.
• `pNext` is NULL or a pointer to a structure extending this structure.

• `maxFragmentShadingRateInvocationCount` is a `VkSampleCountFlagBits` value indicating the maximum number of fragment shader invocations per fragment supported in pipeline, primitive, and attachment fragment shading rates.

If the `VkPhysicalDeviceFragmentShadingRateEnumsPropertiesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

These properties are related to fragment shading rates.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceFragmentShadingRateEnumsPropertiesNV-sType-sType must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADING_RATE_ENUMS_PROPERTIES_NV`

• VUID-VkPhysicalDeviceFragmentShadingRateEnumsPropertiesNV-maxFragmentShadingRateInvocationCount-parameter `maxFragmentShadingRateInvocationCount` must be a valid `VkSampleCountFlagBits` value

The `VkPhysicalDeviceCustomBorderColorPropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_custom_border_color
typedef struct VkPhysicalDeviceCustomBorderColorPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t maxCustomBorderColorSamplers;
} VkPhysicalDeviceCustomBorderColorPropertiesEXT;
```

• `maxCustomBorderColorSamplers` indicates the maximum number of samplers with custom border colors which can simultaneously exist on a device.

If the `VkPhysicalDeviceCustomBorderColorPropertiesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceCustomBorderColorPropertiesEXT-sType-sType `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CUSTOM_BORDER_COLOR_PROPERTIES_EXT`

The `VkPhysicalDeviceProvokingVertexPropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_provoking_vertex
typedef struct VkPhysicalDeviceProvokingVertexPropertiesEXT {
```
VkStructureType sType;
void* pNext;
VkBool32 provokingVertexModePerPipeline;
VkBool32 transformFeedbackPreservesTriangleFanProvokingVertex;
} VkPhysicalDeviceProvokingVertexPropertiesEXT;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `provokingVertexModePerPipeline` indicates whether the implementation supports graphics pipelines with different provoking vertex modes within the same render pass instance.
- `transformFeedbackPreservesTriangleFanProvokingVertex` indicates whether the implementation can preserve the provoking vertex order when writing triangle fan vertices to transform feedback.

If the `VkPhysicalDeviceProvokingVertexPropertiesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceProvokingVertexPropertiesEXT-sType-sType`  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PROVOKING_VERTEX_PROPERTIES_EXT`

The `VkPhysicalDeviceDescriptorBufferPropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_descriptor_buffer
typedef struct VkPhysicalDeviceDescriptorBufferPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 combinedImageSamplerDescriptorSingleArray;
    VkBool32 bufferlessPushDescriptors;
    VkBool32 allowSamplerImageViewPostSubmitCreation;
    VkDeviceSize descriptorBufferOffsetAlignment;
    uint32_t maxDescriptorBufferBindings;
    uint32_t maxResourceDescriptorBufferBindings;
    uint32_t maxSamplerDescriptorBufferBindings;
    uint32_t maxEmbeddedImmutableSamplerBindings;
    uint32_t maxEmbeddedImmutableSamplers;
    size_t bufferCaptureReplayDescriptorDataSize;
    size_t imageCaptureReplayDescriptorDataSize;
    size_t imageViewCaptureReplayDescriptorDataSize;
    size_t samplerCaptureReplayDescriptorDataSize;
    size_t accelerationStructureCaptureReplayDescriptorDataSize;
    size_t samplerDescriptorSize;
    size_t combinedImageSamplerDescriptorSize;
    size_t sampledImageDescriptorSize;
    size_t storageImageDescriptorSize;
} VkPhysicalDeviceDescriptorBufferPropertiesEXT;
```
size_t uniformTexelBufferDescriptorSize;
size_t robustUniformTexelBufferDescriptorSize;
size_t storageTexelBufferDescriptorSize;
size_t robustStorageTexelBufferDescriptorSize;
size_t uniformBufferDescriptorSize;
size_t robustUniformBufferDescriptorSize;
size_t storageBufferDescriptorSize;
size_t robustStorageBufferDescriptorSize;
size_t inputAttachmentDescriptorSize;
size_t accelerationStructureDescriptorSize;
VkDeviceSize maxSamplerDescriptorBufferRange;
VkDeviceSize maxResourceDescriptorBufferRange;
VkDeviceSize samplerDescriptorBufferAddressSpaceSize;
VkDeviceSize resourceDescriptorBufferAddressSpaceSize;
VkDeviceSize descriptorBufferAddressSpaceSize;
}


- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `combinedImageSamplerDescriptorSingleArray` indicates that the implementation does not require an array of `VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER` descriptors to be written into a descriptor buffer as an array of image descriptors, immediately followed by an array of sampler descriptors.
- `bufferlessPushDescriptors` indicates that the implementation does not require a buffer created with `VK_BUFFER_USAGE_PUSH_DESCRIPTORS_DESCRIPTOR_BUFFER_BIT_EXT` to be bound when using push descriptors.
- `allowSamplerImageViewPostSubmitCreation` indicates that the implementation does not restrict when the `VkSampler` or `VkImageView` objects used to retrieve descriptor data can be created in relation to command buffer submission. If this value is `VK_FALSE`, then the application must create any `VkSampler` or `VkImageView` objects whose descriptor data is accessed during the execution of a command buffer, before the `vkQueueSubmit` or `vkQueueSubmit2`, call that submits that command buffer.
- `descriptorBufferOffsetAlignment` indicates the required alignment in bytes when setting offsets into the descriptor buffer.
- `maxDescriptorBufferBindings` indicates the maximum sum total number of descriptor buffers and embedded immutable sampler sets that can be bound.
- `maxResourceDescriptorBufferBindings` indicates the maximum number of resource descriptor buffers that can be bound.
- `maxSamplerDescriptorBufferBindings` indicates the maximum number of sampler descriptor buffers that can be bound.
- `maxEmbeddedImmutableSamplerBindings` indicates the maximum number of embedded immutable sampler sets that can be bound.
- `maxEmbeddedImmutableSamplers` indicates the maximum number of unique immutable samplers in descriptor set layouts created with
VK_DESCRIPTOR_SET_LAYOUT_CREATE_EMBEDDED_IMMUTABLE_SAMPLERS_BIT_EXT, and pipeline layouts created from them, which can simultaneously exist on a device.

- bufferCaptureReplayDescriptorDataSize indicates the maximum size in bytes of the opaque data used for capture and replay with buffers.
- imageCaptureReplayDescriptorDataSize indicates the maximum size in bytes of the opaque data used for capture and replay with images.
- imageViewCaptureReplayDescriptorDataSize indicates the maximum size in bytes of the opaque data used for capture and replay with image views.
- samplerCaptureReplayDescriptorDataSize indicates the maximum size in bytes of the opaque data used for capture and replay with samplers.
- accelerationStructureCaptureReplayDescriptorDataSize indicates the maximum size in bytes of the opaque data used for capture and replay with acceleration structures.
- samplerDescriptorSize indicates the size in bytes of a VK_DESCRIPTOR_TYPE_SAMPLER descriptor.
- combinedImageSamplerDescriptorSize indicates the size in bytes of a VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER descriptor.
- sampledImageDescriptorSize indicates the size in bytes of a VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE descriptor.
- storageImageDescriptorSize indicates the size in bytes of a VK_DESCRIPTOR_TYPE_STORAGE_IMAGE descriptor.
- uniformTexelBufferDescriptorSize indicates the size in bytes of a VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER descriptor if the robustBufferAccess feature is not enabled.
- robustUniformTexelBufferDescriptorSize indicates the size in bytes of a VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER descriptor if the robustBufferAccess feature is enabled.
- storageTexelBufferDescriptorSize indicates the size in bytes of a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor if the robustBufferAccess feature is not enabled.
- robustStorageTexelBufferDescriptorSize indicates the size in bytes of a VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER descriptor if the robustBufferAccess feature is enabled.
- uniformBufferDescriptorSize indicates the size in bytes of a VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER descriptor.
- robustUniformBufferDescriptorSize indicates the size in bytes of a VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER descriptor if the robustBufferAccess feature is enabled.
- storageBufferDescriptorSize indicates the size in bytes of a VK_DESCRIPTOR_TYPE_STORAGE_BUFFER descriptor.
- robustStorageBufferDescriptorSize indicates the size in bytes of a VK_DESCRIPTOR_TYPE_STORAGE_BUFFER descriptor if the robustBufferAccess feature is enabled.
- inputAttachmentDescriptorSize indicates the size in bytes of a VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT descriptor.
- accelerationStructureDescriptorSize indicates the size in bytes of a
VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR or VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_NV descriptor.

- `maxSamplerDescriptorBufferRange` indicates the maximum range in bytes from the address of a sampler descriptor buffer binding that is accessible to a shader.
- `maxResourceDescriptorBufferRange` indicates the maximum range in bytes from the address of a resource descriptor buffer binding that is accessible to a shader.
- `samplerDescriptorBufferAddressSpaceSize` indicates the total size in bytes of the address space available for descriptor buffers created with VK_BUFFER_USAGE_SAMPLER_DESCRIPTOR_BUFFER_BIT_EXT.
- `resourceDescriptorBufferAddressSpaceSize` indicates the total size in bytes of the address space available for descriptor buffers created with both VK_BUFFER_USAGE_SAMPLER_DESCRIPTOR_BUFFER_BIT_EXT and VK_BUFFER_USAGE_RESOURCE_DESCRIPTOR_BUFFER_BIT_EXT.
- `descriptorBufferAddressSpaceSize` indicates the total size in bytes of the address space available for descriptor buffers created with both VK_BUFFER_USAGE_SAMPLER_DESCRIPTOR_BUFFER_BIT_EXT and VK_BUFFER_USAGE_RESOURCE_DESCRIPTOR_BUFFER_BIT_EXT.

A descriptor binding with type VK_DESCRIPTOR_TYPE_MUTABLE_VALUE has a descriptor size which is implied by the descriptor types included in the VkMutableDescriptorTypeCreateInfoVALVE::pDescriptorTypes list. The descriptor size is equal to the maximum size of any descriptor type included in the pDescriptorTypes list.

As there is no way to request robust and non-robust descriptors separately, or specify robust/non-robust descriptors in the set layout, if robustBufferAccess is enabled then robust descriptors are always used.

If the VkPhysicalDeviceDescriptorBufferPropertiesEXT structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDescriptorBufferPropertiesEXT-sType-sType
  - sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_BUFFER_PROPERTIES_EXT

The VkPhysicalDeviceDescriptorBufferDensityMapPropertiesEXT structure is defined as:

```c
// Provided by VK_EXT_descriptor_buffer
typedef struct VkPhysicalDeviceDescriptorBufferDensityMapPropertiesEXT {
    VkStructureType      sType;
    void*                 pNext;
    size_t                combinedImageSamplerDensityMapDescriptorSize;
} VkPhysicalDeviceDescriptorBufferDensityMapPropertiesEXT;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
combinedImageSamplerDensityMapDescriptorSize indicates the size in bytes of a VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER descriptor when creating the descriptor with VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT set.

If the VkPhysicalDeviceDescriptorBufferDensityMapPropertiesEXT structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDescriptorBufferDensityMapPropertiesEXT-sType-sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_BUFFER_DENSITY_MAP_PROPERTIES_EXT

The VkPhysicalDeviceHostImageCopyPropertiesEXT structure is defined as:

```c
typedef struct VkPhysicalDeviceHostImageCopyPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t copySrcLayoutCount;
    VkImageLayout* pCopySrcLayouts;
    uint32_t copyDstLayoutCount;
    VkImageLayout* pCopyDstLayouts;
    uint8_t optimalTilingLayoutUUID[VK_UUID_SIZE];
    VkBool32 identicalMemoryTypeRequirements;
} VkPhysicalDeviceHostImageCopyPropertiesEXT;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- copySrcLayoutCount is an integer related to the number of image layouts for host copies from images available or queried, as described below.
- pCopy SrcLayouts is a pointer to an array of VkImageLayout in which supported image layouts for use with host copy operations from images are returned.
- copyDstLayoutCount is an integer related to the number of image layouts for host copies to images available or queried, as described below.
- pCopyDstLayouts is a pointer to an array of VkImageLayout in which supported image layouts for use with host copy operations to images are returned.
- optimalTilingLayoutUUID is an array of VK_UUID_SIZE uint8_t values representing a universally unique identifier for the implementation’s swizzling layout of images created with VK_IMAGE_TILING_OPTIMAL.
- identicalMemoryTypeRequirements indicates that specifying the VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT flag in VkImageCreateInfo::usage does not affect the memory type requirements of the image.
If the `VkPhysicalDeviceHostImageCopyPropertiesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

If `pCopyDstLayouts` is `NULL`, then the number of image layouts that are supported in `VkCopyMemoryToImageInfoEXT::dstImageLayout` and `VkCopyImageToImageInfoEXT::dstImageLayout` is returned in `copyDstLayoutCount`. Otherwise, `copyDstLayoutCount` must be set by the user to the number of elements in the `pCopyDstLayouts` array, and on return the variable is overwritten with the number of values actually written to `pCopyDstLayouts`. If the value of `copyDstLayoutCount` is less than the number of image layouts that are supported, at most `copyDstLayoutCount` values will be written to `pCopyDstLayouts`. The implementation must include the `VK_IMAGE_LAYOUT_GENERAL` image layout in `pCopyDstLayouts`.

If `pCopySrcLayouts` is `NULL`, then the number of image layouts that are supported in `VkCopyImageToMemoryInfoEXT::srcImageLayout` and `VkCopyImageToImageInfoEXT::srcImageLayout` is returned in `copySrcLayoutCount`. Otherwise, `copySrcLayoutCount` must be set by the user to the number of elements in the `pCopySrcLayouts` array, and on return the variable is overwritten with the number of values actually written to `pCopySrcLayouts`. If the value of `copySrcLayoutCount` is less than the number of image layouts that are supported, at most `copySrcLayoutCount` values will be written to `pCopySrcLayouts`. The implementation must include the `VK_IMAGE_LAYOUT_GENERAL` image layout in `pCopySrcLayouts`.

The `optimalTilingLayoutUUID` value can be used to ensure compatible data layouts when using the `VK_HOST_IMAGE_COPY_MEMCPY_EXT` flag in `vkCopyMemoryToImageEXT` and `vkCopyImageToMemoryEXT`.

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceHostImageCopyPropertiesEXT-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_HOST_IMAGE_COPY_PROPERTIES_EXT`

- **VUID-VkPhysicalDeviceHostImageCopyPropertiesEXT-pCopySrcLayouts-parameter**
  
  If `copySrcLayoutCount` is not 0, and `pCopySrcLayouts` is not `NULL`, `pCopySrcLayouts` must be a valid pointer to an array of `copySrcLayoutCount` `VkImageLayout` values

- **VUID-VkPhysicalDeviceHostImageCopyPropertiesEXT-pCopyDstLayouts-parameter**
  
  If `copyDstLayoutCount` is not 0, and `pCopyDstLayouts` is not `NULL`, `pCopyDstLayouts` must be a valid pointer to an array of `copyDstLayoutCount` `VkImageLayout` values

The `VkPhysicalDeviceSubpassShadingPropertiesHUAWEI` structure is defined as:

```c
// Provided by VK_HUAWEI_subpass_shading
typedef struct VkPhysicalDeviceSubpassShadingPropertiesHUAWEI {
  VkStructureType sType;
  void* pNext;
  uint32_t maxSubpassShadingWorkgroupSizeAspectRatio;
} VkPhysicalDeviceSubpassShadingPropertiesHUAWEI;
```
• **sType** is a *VkStructureType* value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **maxSubpassShadingWorkgroupSizeAspectRatio** indicates the maximum ratio between the width and height of the portion of the subpass shading shader workgroup size. **maxSubpassShadingWorkgroupSizeAspectRatio** must be a power-of-two value, and **must** be less than or equal to \(\text{max}(\text{WorkgroupSize.x} / \text{WorkgroupSize.y}, \text{WorkgroupSize.y} / \text{WorkgroupSize.x})\).

If the *VkPhysicalDeviceSubpassShadingPropertiesHUAWEI* structure is included in the **pNext** chain of the *VkPhysicalDeviceProperties2* structure passed to *vkGetPhysicalDeviceProperties2*, it is filled in with each corresponding implementation-dependent property.

---

**Valid Usage (Implicit)**

• VUID-VkPhysicalDeviceSubpassShadingPropertiesHUAWEI-sType-sType
  
  **sType** must be *VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBPASS_SHADING_PROPERTIES_HUAWEI*

---

The *VkPhysicalDeviceMultiDrawPropertiesEXT* structure is defined as:

```c
typedef struct VK_EXT_multi_draw
    VkPhysicalDeviceMultiDrawPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t maxMultiDrawCount;
} VkPhysicalDeviceMultiDrawPropertiesEXT;
```

The members of the *VkPhysicalDeviceMultiDrawPropertiesEXT* structure describe the following features:

• **maxMultiDrawCount** indicates the maximum number of draw calls which **can** be batched into a single multidraw.

If the *VkPhysicalDeviceMultiDrawPropertiesEXT* structure is included in the **pNext** chain of the *VkPhysicalDeviceProperties2* structure passed to *vkGetPhysicalDeviceProperties2*, it is filled in with each corresponding implementation-dependent property.

---

**Valid Usage (Implicit)**

• VUID-VkPhysicalDeviceMultiDrawPropertiesEXT-sType-sType
  
  **sType** must be *VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTI_DRAW_PROPERTIES_EXT*

---

The *VkPhysicalDeviceGraphicsPipelineLibraryPropertiesEXT* structure is defined as:

```c
// Provided by VK_EXT_graphics_pipeline_library
typedef struct VK_EXT_graphics_pipeline_library
    VkPhysicalDeviceGraphicsPipelineLibraryPropertiesEXT {
    VkStructureType sType;
```
`void* pNext;`  
`VkBool32 graphicsPipelineLibraryFastLinking;`  
`VkBool32 graphicsPipelineLibraryIndependentInterpolationDecoration;`  
`} VkPhysicalDeviceGraphicsPipelineLibraryPropertiesEXT;`

- `graphicsPipelineLibraryFastLinking` indicates whether fast linking of graphics pipelines is supported. If it is `VK_TRUE`, creating a graphics pipeline entirely from pipeline libraries without `VK_PIPELINE_CREATE_LINK_TIME_OPTIMIZATION_BIT_EXT` is comparable in cost to recording a command in a command buffer.

- `graphicsPipelineLibraryIndependentInterpolationDecoration` indicates whether `NoPerspective` and `Flat` interpolation decorations in the last vertex processing stage and the fragment shader are required to match when using graphics pipeline libraries. If it is `VK_TRUE`, the interpolation decorations do not need to match. If it is `VK_FALSE`, these decorations must either be present in both stages or neither stage in order for a given interface variable to match.

If the `VkPhysicalDeviceGraphicsPipelineLibraryPropertiesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceGraphicsPipelineLibraryPropertiesEXT-sType-sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GRAPHICS_PIPELINE_LIBRARY_PROPERTIES_EXT`

The `VkPhysicalDeviceFragmentShaderBarycentricPropertiesKHR` structure is defined as:

```c
// Provided by VK_KHR_fragment_shader_barycentric
typedef struct VkPhysicalDeviceFragmentShaderBarycentricPropertiesKHR {
    VkStructureType sType;
    void* pNext;
    VkBool32 triStripVertexOrderIndependentOfProvokingVertex;
} VkPhysicalDeviceFragmentShaderBarycentricPropertiesKHR;
```

- When the `providing vertex mode` is `VK_PROVOKING_VERTEX_MODE_LAST_VERTEX_EXT`, and the primitive order is odd in a triangle strip, the ordering of vertices is defined in `last vertex table`. `triStripVertexOrderIndependentOfProvokingVertex` equal to `VK_TRUE` indicates that the implementation ignores this and uses the vertex order defined by `VK_PROVOKING_VERTEX_MODE_FIRST_VERTEX_EXT` instead.

If the `VkPhysicalDeviceFragmentShaderBarycentricPropertiesKHR` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.
The `VkPhysicalDeviceShaderModuleIdentifierPropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_shader_module_identifier
typedef struct VkPhysicalDeviceShaderModuleIdentifierPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    uint8_t shaderModuleIdentifierAlgorithmUUID[VK_UUID_SIZE];
} VkPhysicalDeviceShaderModuleIdentifierPropertiesEXT;
```

The members of the `VkPhysicalDeviceShaderModuleIdentifierPropertiesEXT` structure describe the following:

- `shaderModuleIdentifierAlgorithmUUID` is an array of `VK_UUID_SIZE` `uint8_t` values which uniquely represents the algorithm used to compute an identifier in `vkGetShaderModuleIdentifierEXT` and `vkGetShaderModuleCreateInfoIdentifierEXT`. Implementations should not change this value in different driver versions if the algorithm used to compute an identifier is the same.

**Note**

The algorithm UUID may be the same in different ICDs if the algorithms are guaranteed to produce the same results. This may happen in driver stacks which support different kinds of hardware with shared code.

Khronos’ conformance testing cannot guarantee that `shaderModuleIdentifierAlgorithmUUID` values are actually unique, so implementors should make their own best efforts to ensure that their UUID is unlikely to conflict with other implementations which may use a different algorithm. In particular, hard-coded values which easily conflict, such as all-0 bits, should never be used. Hard-coded values are acceptable if best effort is ensured that the value will not accidentally conflict.

If the `VkPhysicalDeviceShaderModuleIdentifierPropertiesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.
The `VkPhysicalDevicePipelineRobustnessPropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_pipeline_robustness
typedef struct VkPhysicalDevicePipelineRobustnessPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    VkPipelineRobustnessBufferBehaviorEXT defaultRobustnessStorageBuffers;
    VkPipelineRobustnessBufferBehaviorEXT defaultRobustnessUniformBuffers;
    VkPipelineRobustnessBufferBehaviorEXT defaultRobustnessVertexInputs;
    VkPipelineRobustnessImageBehaviorEXT defaultRobustnessImages;
} VkPhysicalDevicePipelineRobustnessPropertiesEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **defaultRobustnessStorageBuffers** describes the behaviour of out of bounds accesses made to storage buffers when no robustness features are enabled.
- **defaultRobustnessUniformBuffers** describes the behaviour of out of bounds accesses made to uniform buffers when no robustness features are enabled.
- **defaultRobustnessVertexInputs** describes the behaviour of out of bounds accesses made to vertex input attributes when no robustness features are enabled.
- **defaultRobustnessImages** describes the behaviour of out of bounds accesses made to images when no robustness features are enabled.

Some implementations of Vulkan may be able to guarantee that certain types of accesses are always performed with robustness even when the Vulkan API's robustness features are not explicitly enabled.

Even when an implementation reports that accesses to a given resource type are robust by default, it remains invalid to make an out of bounds access without requesting the appropriate robustness feature.

If the `VkPhysicalDevicePipelineRobustnessPropertiesEXT` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

**Valid Usage (Implicit)**

- **VUID-VkPhysicalDevicePipelineRobustnessPropertiesEXT-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_ROBUSTNESS_PROPERTIES_EXT`

The `VkPhysicalDeviceExtendedDynamicState3PropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_extended_dynamic_state3
typedef struct VkPhysicalDeviceExtendedDynamicState3PropertiesEXT {
    VkStructureType  sType;
    ...
} VkPhysicalDeviceExtendedDynamicState3PropertiesEXT;
```
void* pNext;
VkBool32 dynamicPrimitiveTopologyUnrestricted;
} VkPhysicalDeviceExtendedDynamicState3PropertiesEXT;

• dynamicPrimitiveTopologyUnrestricted indicates that the implementation allows
vkCmdSetPrimitiveTopology to use a different primitive topology class to the one specified in the
active graphics pipeline.

If the VkPhysicalDeviceExtendedDynamicState3PropertiesEXT structure is included in the pNext chain
of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled
in with each corresponding implementation-dependent property.

Valid Usage (Implicit)

• VUID-VkPhysicalDeviceExtendedDynamicState3PropertiesEXT-sType-sType
sType must be
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTENDED_DYNAMIC_STATE_3_PROPERTIES_EXT

The VkPhysicalDeviceOpticalFlowPropertiesNV structure is defined as:

// Provided by VK_NV_optical_flow
typedef struct VkPhysicalDeviceOpticalFlowPropertiesNV {
    VkStructureType sType;
    void* pNext;
    VkOpticalFlowGridSizeFlagsNV supportedOutputGridSizes;
    VkOpticalFlowGridSizeFlagsNV supportedHintGridSizes;
    VkBool32 hintSupported;
    VkBool32 costSupported;
    VkBool32 bidirectionalFlowSupported;
    VkBool32 globalFlowSupported;
    uint32_t minWidth;
    uint32_t minHeight;
    uint32_t maxWidth;
    uint32_t maxHeight;
    uint32_t maxNumRegionsOfInterest;
} VkPhysicalDeviceOpticalFlowPropertiesNV;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• supportedOutputGridSizes are the supported VkOpticalFlowGridSizeFlagsNV which can be
specified in VkOpticalFlowSessionCreateInfoNV::outputGridSize.
• supportedHintGridSizes are the supported VkOpticalFlowGridSizeFlagsNV which can be
specified in VkOpticalFlowSessionCreateInfoNV::hintGridSize.
• hintSupported is a boolean describing whether using hint flow vector map is supported in an
optical flow session.
• **costSupported** is a boolean describing whether cost map generation is supported in an optical flow session.

• **bidirectionalFlowSupported** is a boolean describing whether bi-directional flow generation is supported in an optical flow session.

• **globalFlowSupported** is a boolean describing whether global flow vector map generation is supported in an optical flow session.

• **minWidth** is the minimum width in pixels for images used in an optical flow session.

• **minHeight** is the minimum height in pixels for images used in an optical flow session.

• **maxWidth** is the maximum width in pixels for images used in an optical flow session.

• **maxHeight** is the maximum height in pixels for images used in an optical flow session.

• **maxNumRegionsOfInterest** is the maximum number of regions of interest which can be used in an optical flow session. If this **maxNumRegionsOfInterest** is 0, regions of interest are not supported in an optical flow session.

If the **VkPhysicalDeviceOpticalFlowPropertiesNV** structure is included in the **pNext** chain of the **VkPhysicalDeviceProperties2** structure passed to **vkGetPhysicalDeviceProperties2**, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

• VUID-VkPhysicalDeviceOpticalFlowPropertiesNV-sType-sType
  
  **sType** must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_OPTICAL_FLOW_PROPERTIES_NV**

The **VkPhysicalDeviceOpacityMicromapPropertiesEXT** structure is defined as:

```c
// Provided by VK_EXT_opacity_micromap
typedef struct VkPhysicalDeviceOpacityMicromapPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t maxOpacity2StateSubdivisionLevel;
    uint32_t maxOpacity4StateSubdivisionLevel;
} VkPhysicalDeviceOpacityMicromapPropertiesEXT;
```

• **sType** is a **VkStructureType** value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **maxOpacity2StateSubdivisionLevel** is the maximum allowed **subdivisionLevel** when **format** is **VK_OPACITY_MICROMAP_FORMAT_2_STATE_EXT**

• **maxOpacity4StateSubdivisionLevel** is the maximum allowed **subdivisionLevel** when **format** is **VK_OPACITY_MICROMAP_FORMAT_4_STATE_EXT**

If the **VkPhysicalDeviceOpacityMicromapPropertiesEXT** structure is included in the **pNext** chain of the **VkPhysicalDeviceProperties2** structure passed to **vkGetPhysicalDeviceProperties2**, it is filled in with each corresponding implementation-dependent property.
The **VkPhysicalDeviceOpacityMicromapPropertiesEXT** structure is defined as:

```c
typedef struct VkPhysicalDeviceOpacityMicromapPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t maxOpacityMicromapSubdivisionLevel;
} VkPhysicalDeviceOpacityMicromapPropertiesEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **maxOpacityMicromapSubdivisionLevel** is the maximum allowed subdivision level for opacity micromaps.

If the **VkPhysicalDeviceOpacityMicromapPropertiesEXT** structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

---

The **VkPhysicalDeviceDisplacementMicromapPropertiesNV** structure is defined as:

```c
// Provided by VK_NV_displacement_micromap
typedef struct VkPhysicalDeviceDisplacementMicromapPropertiesNV {
    VkStructureType sType;
    void* pNext;
    uint32_t maxDisplacementMicromapSubdivisionLevel;
} VkPhysicalDeviceDisplacementMicromapPropertiesNV;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **maxDisplacementMicromapSubdivisionLevel** is the maximum allowed subdivision level for displacement micromaps.

If the **VkPhysicalDeviceDisplacementMicromapPropertiesNV** structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

---

The **VkPhysicalDeviceShaderCoreBuiltinsPropertiesARM** structure is defined as:

```c
// Provided by VK_ARM_shader_core_builtins
typedef struct VkPhysicalDeviceShaderCoreBuiltinsPropertiesARM {
    VkStructureType sType;
    void* pNext;
    uint64_t shaderCoreMask;
    uint32_t shaderCoreCount;
    uint32_t shaderWarpsPerCore;
} VkPhysicalDeviceShaderCoreBuiltinsPropertiesARM;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **shaderCoreMask** is a bitfield where each bit set represents the presence of a shader core whose ID is the bit position. The highest ID for any shader core on the device is the position of the most
significant bit set.

• **shaderCoreCount** is the number of shader cores on the device.

• **shaderWarpSPerCore** is the maximum number of simultaneously executing warps on a shader core.

If the **VkPhysicalDeviceShaderCoreBuiltinsPropertiesARM** structure is included in the **pNext** chain of the **VkPhysicalDeviceProperties2** structure passed to **vkGetPhysicalDeviceProperties2**, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

• VUID-VkPhysicalDeviceShaderCoreBuiltinsPropertiesARM-sType-sType

  
  sType must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CORE_BUILTINS_PROPERTIES_ARM**

Values which **may** be returned in the **rayTracingInvocationReorderReorderingHint** field of **VkPhysicalDeviceRayTracingInvocationReorderPropertiesNV** are:

```c
// Provided by VK_NV_ray_tracing_invocation_reorder
typedef enum VkRayTracingInvocationReorderModeNV {
    VK_RAY_TRACING_INVOCATION_REORDER_MODE_NONE_NV = 0,
    VK_RAY_TRACING_INVOCATION_REORDER_MODE_REORDER_NV = 1,
} VkRayTracingInvocationReorderModeNV;
```

- **VK_RAY_TRACING_INVOCATION_REORDER_MODE_NONE_NV** indicates that the implementation is likely to not reorder at reorder calls.
- **VK_RAY_TRACING_INVOCATION_REORDER_MODE_REORDER_NV** indicates that the implementation is likely to reorder at reorder calls.

The **VkPhysicalDeviceRayTracingInvocationReorderPropertiesNV** structure is defined as:

```c
// Provided by VK_NV_ray_tracing_invocation_reorder
typedef struct VkPhysicalDeviceRayTracingInvocationReorderPropertiesNV {
    VkStructureType sType;
    void* pNext;
    VkRayTracingInvocationReorderModeNV rayTracingInvocationReorderReorderingHint;
} VkPhysicalDeviceRayTracingInvocationReorderPropertiesNV;
```

- **rayTracingInvocationReorderReorderingHint** is a hint indicating if the implementation will actually reorder at the reorder calls.

**Note**

Because the extension changes how hits are managed there is a compatibility reason to expose the extension even when an implementation does not have sorting active.
If the `VkPhysicalDeviceRayTracingInvocationReorderPropertiesNV` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceRayTracingInvocationReorderPropertiesNV-sType-sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_INVOCATION_REORDER_PROPERTIES_NV`

The `VkPhysicalDeviceClusterCullingShaderPropertiesHUAWEI` structure is defined as:

```c
// Provided by VK_HUAWEI_cluster_culling_shader
typedef struct VkPhysicalDeviceClusterCullingShaderPropertiesHUAWEI {
    VkStructureType sType;
    void* pNext;
    uint32_t maxWorkGroupCount[3];
    uint32_t maxWorkGroupSize[3];
    uint32_t maxOutputClusterCount;
    VkDeviceSize indirectBufferOffsetAlignment;
} VkPhysicalDeviceClusterCullingShaderPropertiesHUAWEI;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `maxWorkGroupCount[3]` is the maximum number of local workgroups that can be launched by a single command. These three value represent the maximum local workgroup count in the X, Y and Z dimensions, respectively. In the current implementation, the values of Y and Z are both implicitly set as one. `groupCountX` of DrawCluster command must be less than or equal to `maxWorkGroupCount[0]`.
- `maxWorkGroupSize[3]` is the maximum size of a local workgroup. These three value represent the maximum local workgroup size in the X, Y and Z dimensions, respectively. The x, y and z sizes, as specified by the `LocalSize` or `LocalSizeId` execution mode or by the object decorated by the `WorkgroupSize` decoration in shader modules, must be less than or equal to the corresponding limit. In the current implementation, the maximum workgroup size of the X dimension is 32, the others are 1.
- `maxOutputClusterCount` is the maximum number of output cluster a single cluster culling shader workgroup can emit.
- `indirectBufferOffsetAlignment` indicates the alignment for cluster drawing command buffer stride. `vkCmdDrawClusterIndirectHUAWEI::offset` must be a multiple of this value.

If the `VkPhysicalDeviceClusterCullingShaderPropertiesHUAWEI` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.
The `VkPhysicalDeviceShaderCorePropertiesARM` structure is defined as:

```c
// Provided by VK_ARM_shader_core_properties
typedef struct VkPhysicalDeviceShaderCorePropertiesARM {
    VkStructureType   sType;
    void*             pNext;
    uint32_t          pixelRate;
    uint32_t          texelRate;
    uint32_t          fmaRate;
} VkPhysicalDeviceShaderCorePropertiesARM;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `pixelRate` is an unsigned integer value indicating the maximum number of pixels output per clock per shader core.
- `texelRate` is an unsigned integer value indicating the maximum number of texels per clock per shader core.
- `fmaRate` is an unsigned integer value indicating the maximum number of single-precision fused multiply-add operations per clock per shader core.

If a throughput rate cannot be determined on the physical device, the value 0 will be returned for that rate.

If the `VkPhysicalDeviceShaderCorePropertiesARM` structure is included in the `pNext` chain of the `VkPhysicalDeviceProperties2` structure passed to `vkGetPhysicalDeviceProperties2`, it is filled in with each corresponding implementation-dependent property.

The `VkPhysicalDeviceShaderObjectPropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_shader_object
typedef struct VkPhysicalDeviceShaderObjectPropertiesEXT {
    VkStructureType   sType;
    void*             pNext;
} VkPhysicalDeviceShaderObjectPropertiesEXT;
```


```c
uint8_t shaderBinaryUUID[VK_UUID_SIZE];
uint32_t shaderBinaryVersion;
}
```

• **sType** is a **VkStructureType** value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **shaderBinaryUUID** is an array of **VK_UUID_SIZE** uint8_t values representing a universally unique identifier for one or more implementations whose shader binaries are guaranteed to be compatible with each other.

• **shaderBinaryVersion** is an unsigned integer incremented to represent backwards compatible differences between implementations with the same **shaderBinaryUUID**.

The purpose and usage of the values of this structure are described in greater detail in [Binary Shader Compatibility](#).

If the **VkPhysicalDeviceShaderObjectPropertiesEXT** structure is included in the **pNext** chain of the **VkPhysicalDeviceProperties2** structure passed to **vkGetPhysicalDeviceProperties2**, it is filled in with each corresponding implementation-dependent property.

---

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceShaderObjectPropertiesEXT-sType-sType
  - **sType** must be **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_OBJECT_PROPERTIES_EXT**

The **VkPhysicalDeviceShaderEnqueuePropertiesAMDX** structure is defined as:

```c
// Provided by VK_AMDX_shader_enqueue
typedef struct VkPhysicalDeviceShaderEnqueuePropertiesAMDX {
    VkStructureType sType;
    void* pNext;
    uint32_t maxExecutionGraphDepth;
    uint32_t maxExecutionGraphShaderOutputNodes;
    uint32_t maxExecutionGraphShaderPayloadSize;
    uint32_t maxExecutionGraphShaderPayloadCount;
    uint32_t executionGraphDispatchAddressAlignment;
} VkPhysicalDeviceShaderEnqueuePropertiesAMDX;
```

The members of the **VkPhysicalDeviceShaderEnqueuePropertiesAMDX** structure describe the following limits:

• **sType** is a **VkStructureType** value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **maxExecutionGraphDepth** defines the maximum node chain depth in the graph. The dispatched node is at depth 1 and the node enqueued by it is at depth 2, and so on. If a node enqueues itself, each recursive enqueue increases the depth by 1 as well.
• **maxExecutionGraphShaderOutputNodes** specifies the maximum number of unique nodes that can be dispatched from a single shader, and must be at least 256.

• **maxExecutionGraphShaderPayloadSize** specifies the maximum total size of payload declarations in a shader. For any payload declarations that share resources, indicated by NodeSharesPayloadLimitsWithAMDX decorations, the maximum size of each set of shared payload declarations is taken. The sum of each shared set's maximum size and the size of each unshared payload is counted against this limit.

• **maxExecutionGraphShaderPayloadCount** specifies the maximum number of output payloads that can be initialized in a single workgroup.

• **executionGraphDispatchAddressAlignment** specifies the alignment of non-scratch VkDeviceAddress arguments consumed by graph dispatch commands.

If the VkPhysicalDeviceShaderEnqueuePropertiesAMDX structure is included in the pNext chain of the VkPhysicalDeviceProperties2 structure passed to vkGetPhysicalDeviceProperties2, it is filled in with each corresponding implementation-dependent property.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceShaderEnqueuePropertiesAMDX-sType-sType

  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ENQUEUE_PROPERTIES_AMDX

### 47.1. Limit Requirements

The following table specifies the **required** minimum/maximum for all Vulkan graphics implementations. Where a limit corresponds to a fine-grained device feature which is **optional**, the feature name is listed with two **required** limits, one when the feature is supported and one when it is not supported. If an implementation supports a feature, the limits reported are the same whether or not the feature is enabled.

**Table 56. Required Limit Types**

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<thead>
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<th>Type</th>
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<th>Feature</th>
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</thead>
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Table 57. Required Limits

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| maxPerStageDescriptorUpdateAfterBindUniformBuffers        | 0^9               | 12^9            | min        |
| maxPerStageDescriptorUpdateAfterBindStorageBuffers        | 0^9               | 500000^9        | min        |
| maxPerStageDescriptorUpdateAfterBindSampledImages         | 0^9               | 500000^9        | min        |
| maxPerStageDescriptorUpdateAfterBindStorageImages         | 0^9               | 500000^9        | min        |
| maxPerStageDescriptorUpdateAfterBindInputAttachments      | 0^9               | 4^9             | min        |
| maxPerStageUpdateAfterBindResources                       | 0^9               | 500000^9        | min        |
| maxDescriptorSetUpdateAfterBindSamplers                   | 0^9               | 500000^9        | min        |
| maxDescriptorSetUpdateAfterBindUniformBuffers             | 0^9               | 72^8^9          | min, n ×
PerStage  |
<p>| maxDescriptorSetUpdateAfterBindUniformBuffersDynamic      | 0^9               | 8^9             | min        |
| maxDescriptorSetUpdateAfterBindStorageBuffers             | 0^9               | 500000^9        | min        |
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| maxDescriptorSetUpdateAfterBindInputAttachments           | 0^9               | 4^9             | min        |
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| maxPerStageDescriptorInlineUniformBlocks                   | -                 | 4               | min        |
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<td><code>maxOutputClusterCount</code></td>
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<td><code>indirectBufferOffsetAlignment</code></td>
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<td>-</td>
<td>implementation-dependent</td>
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<td><code>maxExecutionGraphDepth</code></td>
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<tr>
<td><code>maxExecutionGraphShaderOutputNodes</code></td>
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<td>min</td>
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<tr>
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</tr>
<tr>
<td><code>maxExecutionGraphShaderPayloadCount</code></td>
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<td>min</td>
</tr>
<tr>
<td><code>executionGraphDispatchAddressAlignment</code></td>
<td>-</td>
<td>4</td>
<td>max</td>
</tr>
</tbody>
</table>

1

The **Limit Type** column specifies the limit is either the minimum limit all implementations must support, the maximum limit all implementations must support, or the exact value all implementations must support. For bitmasks a minimum limit is the least bits all implementations must set, but they may have additional bits set beyond this minimum.

2

The `maxPerStageResources` must be at least the smallest of the following:

- the sum of the `maxPerStageDescriptorUniformBuffers`, `maxPerStageDescriptorStorageBuffers`, `maxPerStageDescriptorSampledImages`, `maxPerStageDescriptorStorageImages`, `maxPerStageDescriptorInputAttachments`, `maxColorAttachments` limits, or
It **may** not be possible to reach this limit in every stage.

See `maxViewportDimensions` for the **required** relationship to other limits.

See `viewportBoundsRange` for the **required** relationship to other limits.

The values `minInterpolationOffset` and `maxInterpolationOffset` describe the closed interval of supported interpolation offsets: `[minInterpolationOffset, maxInterpolationOffset]`. The ULP is determined by `subPixelInterpolationOffsetBits`. If `subPixelInterpolationOffsetBits` is 4, this provides increments of \((1/2^4) = 0.0625\), and thus the range of supported interpolation offsets would be \([-0.5, 0.4375]\).

The point size ULP is determined by `pointSizeGranularity`. If the `pointSizeGranularity` is 0.125, the range of supported point sizes **must** be at least \([1.0, 63.875]\).

The line width ULP is determined by `lineWidthGranularity`. If the `lineWidthGranularity` is 0.0625, the range of supported line widths **must** be at least \([1.0, 7.9375]\).

The minimum `maxDescriptorSet*` limit is \(n\) times the corresponding `specification` minimum `maxPerStageDescriptor*` limit, where \(n\) is the number of shader stages supported by the `VkPhysicalDevice`. If all shader stages are supported, \(n = 6\) (vertex, tessellation control, tessellation evaluation, geometry, fragment, compute).

The `UpdateAfterBind` descriptor limits **must** each be greater than or equal to the corresponding `non-UpdateAfterBind` limit.

If the `VK_KHR_portability_subset` extension is enabled, the required minimum value of `maxVertexInputBindings` is 8.

`maxResourceDescriptorSize` is defined as the maximum value of `storageImageDescriptorSize`, `sampledImageDescriptorSize`, `robustUniformTexelBufferDescriptorSize`, `robustStorageTexelBufferDescriptorSize`, `robustUniformBufferDescriptorSize`, `robustStorageBufferDescriptorSize`, `inputAttachmentDescriptorSize`, and `accelerationStructureDescriptorSize`. 
47.2. Additional Multisampling Capabilities

To query additional multisampling capabilities which may be supported for a specific sample count, beyond the minimum capabilities described for Limits above, call:

```c
// Provided by VK_EXT_sample_locations
void vkGetPhysicalDeviceMultisamplePropertiesEXT(
    VkPhysicalDevice physicalDevice,
    VkSampleCountFlagBits samples,     
    VkMultisamplePropertiesEXT* pMultisampleProperties);
```

- `physicalDevice` is the physical device from which to query the additional multisampling capabilities.
- `samples` is a `VkSampleCountFlagBits` value specifying the sample count to query capabilities for.
- `pMultisampleProperties` is a pointer to a `VkMultisamplePropertiesEXT` structure in which information about additional multisampling capabilities specific to the sample count is returned.

### Valid Usage (Implicit)

- `VUID-vkGetPhysicalDeviceMultisamplePropertiesEXT-physicalDevice-parameter` physicalDevice must be a valid `VkPhysicalDevice` handle
- `VUID-vkGetPhysicalDeviceMultisamplePropertiesEXT-samples-parameter` samples must be a valid `VkSampleCountFlagBits` value
- `VUID-vkGetPhysicalDeviceMultisamplePropertiesEXT-pMultisampleProperties-parameter` pMultisampleProperties must be a valid pointer to a `VkMultisamplePropertiesEXT` structure

The `VkMultisamplePropertiesEXT` structure is defined as:

```c
// Provided by VK_EXT_sample_locations
typedef struct VkMultisamplePropertiesEXT {
    VkStructureType sType;
    void* pNext;
    VkExtent2D maxSampleLocationGridSize;
} VkMultisamplePropertiesEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `maxSampleLocationGridSize` is the maximum size of the pixel grid in which sample locations can vary.
Valid Usage (Implicit)

- VUID-VkMultisamplePropertiesEXT-sType-sType
  
  sType must be VK_STRUCTURE_TYPE_MULTISAMPLE_PROPERTIES_EXT

- VUID-VkMultisamplePropertiesEXT-pNext-pNext
  
  pNext must be NULL

If the sample count for which additional multisampling capabilities are requested using `vkGetPhysicalDeviceMultisamplePropertiesEXT` is set in `sampleLocationSampleCounts` the width and height members of `VkMultisamplePropertiesEXT::maxSampleLocationGridSize` must be greater than or equal to the corresponding members of `maxSampleLocationGridSize`, respectively, otherwise both members must be 0.

### 47.3. Profile Limits

#### 47.3.1. Roadmap 2022

Implementations that claim support for the Roadmap 2022 profile must satisfy the following additional limit requirements:

<table>
<thead>
<tr>
<th>Limit</th>
<th>Supported Limit</th>
<th>Limit Type</th>
</tr>
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<tbody>
<tr>
<td>maxImageDimension1D</td>
<td>8192</td>
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</tr>
<tr>
<td>maxImageDimension2D</td>
<td>8192</td>
<td>min</td>
</tr>
<tr>
<td>maxImageDimensionCube</td>
<td>8192</td>
<td>min</td>
</tr>
<tr>
<td>maxImageArrayLayers</td>
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</tr>
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<td>maxUniformBufferRange</td>
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</tr>
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<td>bufferImageGranularity</td>
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<td>min</td>
</tr>
<tr>
<td>maxPerStageDescriptorUniformBuffers</td>
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<td>min</td>
</tr>
<tr>
<td>maxPerStageDescriptorStorageBuffers</td>
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<tr>
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</tr>
<tr>
<td>maxDescriptorSetStorageImages</td>
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<tr>
<td>maxFragmentCombinedOutputResources</td>
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<tr>
<td>Limit</td>
<td>Supported Limit</td>
<td>Limit Type</td>
</tr>
<tr>
<td>--------------------------------------------------</td>
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<td>------------</td>
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<td>maxComputeWorkGroupInvocations</td>
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</tr>
<tr>
<td>maxComputeWorkGroupSize</td>
<td>(256,256,64)</td>
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<td>.mipmapPrecisionBits</td>
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<tr>
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<td>VK_SUBGROUP_FEATURE_BASIC_BIT, VK_SUBGROUP_FEATURE_VOTE_BIT, VK_SUBGROUP_FEATURE_ARITHMETIC_BIT, VK_SUBGROUP_FEATURE_BALLOT_BIT, VK_SUBGROUP_FEATURE_S Huffe_BIT, VK_SUBGROUP_FEATURE_S Huffle_Relative_BIT, VK_SUBGROUP_FEATURE_QUAD_BIT</td>
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<td>shaderSignedZeroInfNanPreserveFloat32</td>
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</tr>
<tr>
<td>maxPerStageDescriptorUpdateAfterBindInputAttachments</td>
<td>7</td>
<td>min</td>
</tr>
</tbody>
</table>
Chapter 48. Formats

Supported buffer and image formats may vary across implementations. A minimum set of format features are guaranteed, but others must be explicitly queried before use to ensure they are supported by the implementation.

The features for the set of formats (VkFormat) supported by the implementation are queried individually using the vkGetPhysicalDeviceFormatProperties command.

48.1. Format Definition

The following image formats can be passed to, and may be returned from Vulkan commands. The memory required to store each format is discussed with that format, and also summarized in the Representation and Texel Block Size section and the Compatible formats table.

```c
// Provided by VK_VERSION_1_0
typedef enum VkFormat { 
    VK_FORMAT_UNDEFINED = 0,
    VK_FORMAT_R4G4_UNORM_PACK8 = 1,
    VK_FORMAT_R4G4B4A4_UNORM_PACK16 = 2,
    VK_FORMAT_B4G4R4A4_UNORM_PACK16 = 3,
    VK_FORMAT_R5G6B5_UNORM_PACK16 = 4,
    VK_FORMAT_B5G6R5_UNORM_PACK16 = 5,
    VK_FORMAT_R5G5B5A1_UNORM_PACK16 = 6,
    VK_FORMAT_B5G5R5A1_UNORM_PACK16 = 7,
    VK_FORMAT_A1R5G5B5_UNORM_PACK16 = 8,
    VK_FORMAT_R8_UNORM = 9,
    VK_FORMAT_R8_SNORM = 10,
    VK_FORMAT_R8_USCALED = 11,
    VK_FORMAT_R8_SSCALED = 12,
    VK_FORMAT_R8_UINT = 13,
    VK_FORMAT_R8_SINT = 14,
    VK_FORMAT_R8_SRGB = 15,
    VK_FORMAT_R8G8_UNORM = 16,
    VK_FORMAT_R8G8_SNORM = 17,
    VK_FORMAT_R8G8_USCALED = 18,
    VK_FORMAT_R8G8_SSCALED = 19,
    VK_FORMAT_R8G8_UINT = 20,
    VK_FORMAT_R8G8_SINT = 21,
    VK_FORMAT_R8G8_SRGB = 22,
    VK_FORMAT_R8G8B8_UNORM = 23,
    VK_FORMAT_R8G8B8_SNORM = 24,
    VK_FORMAT_R8G8B8_USCALED = 25,
    VK_FORMAT_R8G8B8_SSCALED = 26,
    VK_FORMAT_R8G8B8_UINT = 27,
    VK_FORMAT_R8G8B8_SINT = 28,
    VK_FORMAT_R8G8B8_SRGB = 29,
    VK_FORMAT_B8G8R8_UNORM = 30,
    VK_FORMAT_B8G8R8_SNORM = 31,
};```

VK_FORMAT_B8G8R8_USCALED = 32,
VK_FORMAT_B8G8R8_SSCALED = 33,
VK_FORMAT_B8G8R8_UINT = 34,
VK_FORMAT_B8G8R8_SINT = 35,
VK_FORMAT_B8G8R8_SRGB = 36,
VK_FORMAT_R8G8B8A8_UNORM = 37,
VK_FORMAT_R8G8B8A8_SNORM = 38,
VK_FORMAT_R8G8B8A8_USCALED = 39,
VK_FORMAT_R8G8B8A8_SSCALED = 40,
VK_FORMAT_R8G8B8A8_UINT = 41,
VK_FORMAT_R8G8B8A8_SINT = 42,
VK_FORMAT_R8G8B8A8_SRGB = 43,
VK_FORMAT_B8G8R8A8_UNORM = 44,
VK_FORMAT_B8G8R8A8_SNORM = 45,
VK_FORMAT_B8G8R8A8_USCALED = 46,
VK_FORMAT_B8G8R8A8_SSCALED = 47,
VK_FORMAT_B8G8R8A8_UINT = 48,
VK_FORMAT_B8G8R8A8_SINT = 49,
VK_FORMAT_B8G8R8A8_SRGB = 50,
VK_FORMAT_A8B8G8R8_UNORM_PACK32 = 51,
VK_FORMAT_A8B8G8R8_SNORM_PACK32 = 52,
VK_FORMAT_A8B8G8R8_USCALED_PACK32 = 53,
VK_FORMAT_A8B8G8R8_SSCALED_PACK32 = 54,
VK_FORMAT_A8B8G8R8_UINT_PACK32 = 55,
VK_FORMAT_A8B8G8R8_SINT_PACK32 = 56,
VK_FORMAT_A8B8G8R8_SRGB_PACK32 = 57,
VK_FORMAT_A2R10G10B10_UNORM_PACK32 = 58,
VK_FORMAT_A2R10G10B10_SNORM_PACK32 = 59,
VK_FORMAT_A2R10G10B10_USCALED_PACK32 = 60,
VK_FORMAT_A2R10G10B10_SSCALED_PACK32 = 61,
VK_FORMAT_A2R10G10B10_UINT_PACK32 = 62,
VK_FORMAT_A2R10G10B10_SINT_PACK32 = 63,
VK_FORMAT_A2B10G10R10_UNORM_PACK32 = 64,
VK_FORMAT_A2B10G10R10_SNORM_PACK32 = 65,
VK_FORMAT_A2B10G10R10_USCALED_PACK32 = 66,
VK_FORMAT_A2B10G10R10_SSCALED_PACK32 = 67,
VK_FORMAT_A2B10G10R10_UINT_PACK32 = 68,
VK_FORMAT_A2B10G10R10_SINT_PACK32 = 69,
VK_FORMAT_R16_UNORM = 70,
VK_FORMAT_R16_SNORM = 71,
VK_FORMAT_R16_USCALED = 72,
VK_FORMAT_R16_SSCALED = 73,
VK_FORMAT_R16_UINT = 74,
VK_FORMAT_R16_SINT = 75,
VK_FORMAT_R16_SFLOAT = 76,
VK_FORMAT_R16G16_UNORM = 77,
VK_FORMAT_R16G16_SNORM = 78,
VK_FORMAT_R16G16_USCALED = 79,
VK_FORMAT_R16G16_SSCALED = 80,
VK_FORMAT_R16G16_SFLOAT = 83,
VK_FORMAT_R16G16B16_UNORM = 84,
VK_FORMAT_R16G16B16_SNORM = 85,
VK_FORMAT_R16G16B16_USCALED = 86,
VK_FORMAT_R16G16B16_SSCALED = 87,
VK_FORMAT_R16G16B16_UINT = 88,
VK_FORMAT_R16G16B16_SINT = 89,
VK_FORMAT_R16G16B16_SFLOAT = 90,
VK_FORMAT_R16G16B16A16_UNORM = 91,
VK_FORMAT_R16G16B16A16_SNORM = 92,
VK_FORMAT_R16G16B16A16_USCALED = 93,
VK_FORMAT_R16G16B16A16_SSCALED = 94,
VK_FORMAT_R16G16B16A16_UINT = 95,
VK_FORMAT_R16G16B16A16_SINT = 96,
VK_FORMAT_R16G16B16A16_SFLOAT = 97,
VK_FORMAT_R32_UINT = 98,
VK_FORMAT_R32_SINT = 99,
VK_FORMAT_R32_SFLOAT = 100,
VK_FORMAT_R32G32_UINT = 101,
VK_FORMAT_R32G32_SINT = 102,
VK_FORMAT_R32G32_SFLOAT = 103,
VK_FORMAT_R32G32B32_UINT = 104,
VK_FORMAT_R32G32B32_SINT = 105,
VK_FORMAT_R32G32B32_SFLOAT = 106,
VK_FORMAT_R32G32B32A32_UINT = 107,
VK_FORMAT_R32G32B32A32_SINT = 108,
VK_FORMAT_R32G32B32A32_SFLOAT = 109,
VK_FORMAT_R64_UINT = 110,
VK_FORMAT_R64_SINT = 111,
VK_FORMAT_R64_SFLOAT = 112,
VK_FORMAT_R64G64_UINT = 113,
VK_FORMAT_R64G64_SINT = 114,
VK_FORMAT_R64G64_SFLOAT = 115,
VK_FORMAT_R64G64B64_UINT = 116,
VK_FORMAT_R64G64B64_SINT = 117,
VK_FORMAT_R64G64B64_SFLOAT = 118,
VK_FORMAT_R64G64B64A64_UINT = 119,
VK_FORMAT_R64G64B64A64_SINT = 120,
VK_FORMAT_R64G64B64A64_SFLOAT = 121,
VK_FORMAT_B10G11R11_UFLOAT_PACK32 = 122,
VK_FORMAT_E5B9G9R9_UFLOAT_PACK32 = 123,
VK_FORMAT_D16_UNORM = 124,
VK_FORMAT_X8_D24_UNORM_PACK32 = 125,
VK_FORMAT_D32_SFLOAT = 126,
VK_FORMAT_S8_UINT = 127,
VK_FORMAT_D16_UNORM_S8_UINT = 128,
VK_FORMAT_D24_UNORM_S8_UINT = 129,
VK_FORMAT_D32_SFLOAT_S8_UINT = 130,
VK_FORMAT_BC1_RGB_UNORM_BLOCK = 131,
VK_FORMAT_BC1_RGB_SRGB_BLOCK = 132,
VK_FORMAT_BC1_RGBA_UNORM_BLOCK = 133,
VK_FORMAT_BC1_RGBA_SRGB_BLOCK = 134,
VK_FORMAT_BC2_UNORM_BLOCK = 135,
VK_FORMAT_BC2_SRGB_BLOCK = 136,
VK_FORMAT_BC3_UNORM_BLOCK = 137,
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VK_FORMAT_BC4_UNORM_BLOCK = 139,
VK_FORMAT_BC4_SNORM_BLOCK = 140,
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VK_FORMAT_BC5_SNORM_BLOCK = 142,
VK_FORMAT_BC6H_UFLOAT_BLOCK = 143,
VK_FORMAT_BC6H_SFLOAT_BLOCK = 144,
VK_FORMAT_BC7_UNORM_BLOCK = 145,
VK_FORMAT_BC7_SRGB_BLOCK = 146,
VK_FORMAT_ETC2_R8G8B8_UNORM_BLOCK = 147,
VK_FORMAT_ETC2_R8G8B8_SRGB_BLOCK = 148,
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VK_FORMAT_EAC_R11_SNORM_BLOCK = 154,
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VK_FORMAT_ASTC_4x4_SRGB_BLOCK = 158,
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VK_FORMAT_G12X4_B12X4R12X4_2PLANE_420_UNORM_3PACK16 = 1000156023,
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<th>Video Format</th>
<th>Value</th>
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<td>VK_FORMAT_G16B16G16R16_422_UNORM</td>
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VK_FORMAT_ASTC_10x10_SFLOAT_BLOCK = 1000066011,
// Provided by VK_VERSION_1_3
VK_FORMAT_ASTC_12x10_SFLOAT_BLOCK = 1000066012,
// Provided by VK_VERSION_1_3
VK_FORMAT_ASTC_12x12_SFLOAT_BLOCK = 1000066013,
// Provided by VK_IMG_format_pvrtc
VK_FORMAT_PVRTC1_2BPP_UNORM_BLOCK_IMG = 1000054000,
// Provided by VK_IMG_format_pvrtc
VK_FORMAT_PVRTC1_4BPP_UNORM_BLOCK_IMG = 1000054001,
// Provided by VK_IMG_format_pvrtc
VK_FORMAT_PVRTC2_2BPP_UNORM_BLOCK_IMG = 1000054002,
// Provided by VK_IMG_format_pvrtc
VK_FORMAT_PVRTC2_4BPP_UNORM_BLOCK_IMG = 1000054003,
// Provided by VK_IMG_format_pvrtc
VK_FORMAT_PVRTC1_2BPP_SRGB_BLOCK_IMG = 1000054004,
// Provided by VK_IMG_format_pvrtc
VK_FORMAT_PVRTC1_4BPP_SRGB_BLOCK_IMG = 1000054005,
// Provided by VK_IMG_format_pvrtc
VK_FORMAT_PVRTC2_2BPP_SRGB_BLOCK_IMG = 1000054006,
// Provided by VK_IMG_format_pvrtc
VK_FORMAT_PVRTC2_4BPP_SRGB_BLOCK_IMG = 1000054007,
// Provided by VK_NV_optical_flow
VK_FORMAT_R16G16_S10_5_NV = 1000464000,
// Provided by VK_KHR_maintenance5
VK_FORMAT_A1B5G5R5_UNORM_PACK16_KHR = 1000470000
// Provided by VK_KHR_maintenance5
VK_FORMAT_A8_UNORM_KHR = 1000470001,
// Provided by VK_EXT_texture_compression_astc_hdr
VK_FORMAT_ASTC_4x4_SFLOAT_BLOCK_EXT = VK_FORMAT_ASTC_4x4_SFLOAT_BLOCK,
// Provided by VK_EXT_texture_compression_astc_hdr
VK_FORMAT_ASTC_5x4_SFLOAT_BLOCK_EXT = VK_FORMAT_ASTC_5x4_SFLOAT_BLOCK,
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// Provided by VK_EXT_texture_compression_astc_hdr
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// Provided by VK_EXT_texture_compression_astc_hdr
VK_FORMAT_ASTC_8x6_SFLOAT_BLOCK_EXT = VK_FORMAT_ASTC_8x6_SFLOAT_BLOCK,
// Provided by VK_EXT_texture_compression_astc_hdr
VK_FORMAT_ASTC_8x8_SFLOAT_BLOCK_EXT = VK_FORMAT_ASTC_8x8_SFLOAT_BLOCK,
Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_R12X4G12X4B12X4A12X4_UNORM_4PACK16_KHR = VK_FORMAT_R12X4G12X4B12X4A12X4_UNORM_4PACK16,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G12X4B12X4G12X4R12X4_422_UNORM_4PACK16_KHR = VK_FORMAT_G12X4B12X4G12X4R12X4_422_UNORM_4PACK16,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_B12X4G12X4R12X4_422_UNORM_4PACK16_KHR = VK_FORMAT_B12X4G12X4R12X4_422_UNORM_4PACK16,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_420_UNORM_3PACK16_KHR = VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_420_UNORM_3PACK16,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G12X4_B12X4R12X4_2PLANE_420_UNORM_3PACK16_KHR = VK_FORMAT_G12X4_B12X4R12X4_2PLANE_420_UNORM_3PACK16,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_422_UNORM_3PACK16_KHR = VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_422_UNORM_3PACK16,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G12X4_B12X4R12X4_2PLANE_422_UNORM_3PACK16_KHR = VK_FORMAT_G12X4_B12X4R12X4_2PLANE_422_UNORM_3PACK16,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_444_UNORM_3PACK16_KHR = VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_444_UNORM_3PACK16,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G16B16G16R16_422_UNORM_KHR = VK_FORMAT_G16B16G16R16_422_UNORM_KHR = VK_FORMAT_G16B16G16R16_422_UNORM_KHR,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_B16G16R16G16_422_UNORM_KHR = VK_FORMAT_B16G16R16G16_422_UNORM_KHR = VK_FORMAT_B16G16R16G16_422_UNORM_KHR,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G16_B16_R16_3PLANE_420_UNORM_KHR = VK_FORMAT_G16_B16_R16_3PLANE_420_UNORM_KHR = VK_FORMAT_G16_B16_R16_3PLANE_420_UNORM_KHR,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G16_B16R16_2PLANE_420_UNORM_KHR = VK_FORMAT_G16_B16R16_2PLANE_420_UNORM_KHR = VK_FORMAT_G16_B16R16_2PLANE_420_UNORM_KHR,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G16_B16_R16_3PLANE_422_UNORM_KHR = VK_FORMAT_G16_B16_R16_3PLANE_422_UNORM_KHR = VK_FORMAT_G16_B16_R16_3PLANE_422_UNORM_KHR,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G16_B16R16_2PLANE_422_UNORM_KHR = VK_FORMAT_G16_B16R16_2PLANE_422_UNORM_KHR = VK_FORMAT_G16_B16R16_2PLANE_422_UNORM_KHR,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G16_B16_R16_3PLANE_444_UNORM_KHR = VK_FORMAT_G16_B16_R16_3PLANE_444_UNORM_KHR = VK_FORMAT_G16_B16_R16_3PLANE_444_UNORM_KHR,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G16_B16R16_2PLANE_444_UNORM_KHR = VK_FORMAT_G16_B16R16_2PLANE_444_UNORM_KHR = VK_FORMAT_G16_B16R16_2PLANE_444_UNORM_KHR,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G10X6_B10X6R10X6_2PLANE_444_UNORM_3PACK16_KHR = VK_FORMAT_G10X6_B10X6R10X6_2PLANE_444_UNORM_3PACK16_KHR = VK_FORMAT_G10X6_B10X6R10X6_2PLANE_444_UNORM_3PACK16_KHR,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G12X4_B12X4R12X4_2PLANE_444_UNORM_3PACK16_KHR = VK_FORMAT_G12X4_B12X4R12X4_2PLANE_444_UNORM_3PACK16_KHR = VK_FORMAT_G12X4_B12X4R12X4_2PLANE_444_UNORM_3PACK16_KHR,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_G16_B16R16_2PLANE_444_UNORM_KHR = VK_FORMAT_G16_B16R16_2PLANE_444_UNORM_KHR = VK_FORMAT_G16_B16R16_2PLANE_444_UNORM_KHR,
**VK_FORMAT_UNDEFINED** specifies that the format is not specified.

**VK_FORMAT_R4G4_UNORM_PACK8** specifies a two-component, 8-bit packed unsigned normalized format that has a 4-bit R component in bits 4..7, and a 4-bit G component in bits 0..3.

**VK_FORMAT_R4G4B4A4_UNORM_PACK16** specifies a four-component, 16-bit packed unsigned normalized format that has a 4-bit R component in bits 12..15, a 4-bit G component in bits 8..11, a 4-bit B component in bits 4..7, and a 4-bit A component in bits 0..3.

**VK_FORMAT_B4G4R4A4_UNORM_PACK16** specifies a four-component, 16-bit packed unsigned normalized format that has a 4-bit B component in bits 12..15, a 4-bit G component in bits 8..11, a 4-bit R component in bits 4..7, and a 4-bit A component in bits 0..3.

**VK_FORMAT_A4R4G4B4_UNORM_PACK16** specifies a four-component, 16-bit packed unsigned normalized format that has a 4-bit A component in bits 12..15, a 4-bit R component in bits 8..11, a 4-bit G component in bits 4..7, and a 4-bit B component in bits 0..3.

**VK_FORMAT_A4B4G4R4_UNORM_PACK16** specifies a four-component, 16-bit packed unsigned normalized format that has a 4-bit A component in bits 12..15, a 4-bit B component in bits 8..11, a 4-bit G component in bits 4..7, and a 4-bit R component in bits 0..3.

**VK_FORMAT_R5G6B5_UNORM_PACK16** specifies a three-component, 16-bit packed unsigned normalized format that has a 5-bit R component in bits 11..15, a 6-bit G component in bits 5..10, and a 5-bit B component in bits 0..4.

**VK_FORMAT_B5G6R5_UNORM_PACK16** specifies a three-component, 16-bit packed unsigned normalized format that has a 5-bit B component in bits 11..15, a 6-bit G component in bits 5..10, and a 5-bit R component in bits 0..4.

**VK_FORMAT_R5G5B5A1_UNORM_PACK16** specifies a four-component, 16-bit packed unsigned normalized format that has a 5-bit R component in bits 11..15, a 5-bit G component in bits 6..10, a 5-bit B component in bits 1..5, and a 1-bit A component in bit 0.

**VK_FORMAT_B5G5R5A1_UNORM_PACK16** specifies a four-component, 16-bit packed unsigned normalized format that has a 5-bit B component in bits 11..15, a 5-bit G component in bits 6..10, a 5-bit R component in bits 1..5, and a 1-bit A component in bit 0.

**VK_FORMAT_A1R5G5B5_UNORM_PACK16** specifies a four-component, 16-bit packed unsigned normalized format that has a 1-bit A component in bit 15, a 5-bit R component in bits 10..14, a 5-bit G component in bits 5..9, and a 5-bit B component in bits 0..4.

**VK_FORMAT_A1B5G5R5_UNORM_PACK16_KHR** specifies a four-component, 16-bit packed unsigned normalized format that has a 1-bit A component in bit 15, a 5-bit B component in bits 10..14, a 5-bit G component in bits 5..9, and a 5-bit R component in bits 0..4.

**VK_FORMAT_A8_UNORM_KHR** specifies a one-component, 8-bit unsigned normalized format that has a single 8-bit A component.

**VK_FORMAT_R8_UNORM** specifies a one-component, 8-bit unsigned normalized format that has a
single 8-bit R component.

- **VK_FORMAT_R8_SNORM** specifies a one-component, 8-bit signed normalized format that has a single 8-bit R component.

- **VK_FORMAT_R8_USCALED** specifies a one-component, 8-bit unsigned scaled integer format that has a single 8-bit R component.

- **VK_FORMAT_R8_SSCALED** specifies a one-component, 8-bit signed scaled integer format that has a single 8-bit R component.

- **VK_FORMAT_R8_UINT** specifies a one-component, 8-bit unsigned integer format that has a single 8-bit R component.

- **VK_FORMAT_R8_SINT** specifies a one-component, 8-bit signed integer format that has a single 8-bit R component.

- **VK_FORMAT_R8_SRGB** specifies a one-component, 8-bit unsigned normalized format that has a single 8-bit R component stored with sRGB nonlinear encoding.

- **VK_FORMAT_R8G8_UNORM** specifies a two-component, 16-bit unsigned normalized format that has an 8-bit R component in byte 0, and an 8-bit G component in byte 1.

- **VK_FORMAT_R8G8_SNORM** specifies a two-component, 16-bit signed normalized format that has an 8-bit R component in byte 0, and an 8-bit G component in byte 1.

- **VK_FORMAT_R8G8_USCALED** specifies a two-component, 16-bit unsigned scaled integer format that has an 8-bit R component in byte 0, and an 8-bit G component in byte 1.

- **VK_FORMAT_R8G8_SSCALED** specifies a two-component, 16-bit signed scaled integer format that has an 8-bit R component in byte 0, and an 8-bit G component in byte 1.

- **VK_FORMAT_R8G8_UINT** specifies a two-component, 16-bit unsigned integer format that has an 8-bit R component in byte 0, and an 8-bit G component in byte 1.

- **VK_FORMAT_R8G8_SINT** specifies a two-component, 16-bit signed integer format that has an 8-bit R component in byte 0, and an 8-bit G component in byte 1.

- **VK_FORMAT_R8G8_SRGB** specifies a two-component, 16-bit unsigned normalized format that has an 8-bit R component stored with sRGB nonlinear encoding in byte 0, and an 8-bit G component in byte 1.

- **VK_FORMAT_R8G8B8_UNORM** specifies a three-component, 24-bit unsigned normalized format that has an 8-bit R component in byte 0, an 8-bit G component in byte 1, and an 8-bit B component in byte 2.

- **VK_FORMAT_R8G8B8_SNORM** specifies a three-component, 24-bit signed normalized format that has an 8-bit R component in byte 0, an 8-bit G component in byte 1, and an 8-bit B component in byte 2.

- **VK_FORMAT_R8G8B8_USCALED** specifies a three-component, 24-bit unsigned scaled format that has an 8-bit R component in byte 0, an 8-bit G component in byte 1, and an 8-bit B component in byte 2.

- **VK_FORMAT_R8G8B8_SSCALED** specifies a three-component, 24-bit signed scaled format that has an 8-bit R component in byte 0, an 8-bit G component in byte 1, and an 8-bit B component in byte 2.

- **VK_FORMAT_R8G8B8_UINT** specifies a three-component, 24-bit unsigned integer format that has an 8-bit R component in byte 0, an 8-bit G component in byte 1, and an 8-bit B component in byte 2.
• **VK_FORMAT_R8G8B8_SINT** specifies a three-component, 24-bit signed integer format that has an 8-bit R component in byte 0, an 8-bit G component in byte 1, and an 8-bit B component in byte 2.

• **VK_FORMAT_R8G8B8_SRGB** specifies a three-component, 24-bit unsigned normalized format that has an 8-bit R component stored with sRGB nonlinear encoding in byte 0, an 8-bit G component stored with sRGB nonlinear encoding in byte 1, and an 8-bit B component stored with sRGB nonlinear encoding in byte 2.

• **VK_FORMAT_B8G8R8_UNORM** specifies a three-component, 24-bit unsigned normalized format that has an 8-bit B component in byte 0, an 8-bit G component in byte 1, and an 8-bit R component in byte 2.

• **VK_FORMAT_B8G8R8_SNORM** specifies a three-component, 24-bit signed normalized format that has an 8-bit B component in byte 0, an 8-bit G component in byte 1, and an 8-bit R component in byte 2.

• **VK_FORMAT_B8G8R8_USCALED** specifies a three-component, 24-bit unsigned scaled format that has an 8-bit B component in byte 0, an 8-bit G component in byte 1, and an 8-bit R component in byte 2.

• **VK_FORMAT_B8G8R8_SSCALED** specifies a three-component, 24-bit signed scaled format that has an 8-bit B component in byte 0, an 8-bit G component in byte 1, and an 8-bit R component in byte 2.

• **VK_FORMAT_B8G8R8_UINT** specifies a three-component, 24-bit unsigned integer format that has an 8-bit B component in byte 0, an 8-bit G component in byte 1, and an 8-bit R component in byte 2.

• **VK_FORMAT_B8G8R8_SINT** specifies a three-component, 24-bit signed integer format that has an 8-bit B component in byte 0, an 8-bit G component in byte 1, and an 8-bit R component in byte 2.

• **VK_FORMAT_B8G8R8_SRGB** specifies a three-component, 24-bit unsigned normalized format that has an 8-bit B component stored with sRGB nonlinear encoding in byte 0, an 8-bit G component stored with sRGB nonlinear encoding in byte 1, and an 8-bit R component stored with sRGB nonlinear encoding in byte 2.

• **VK_FORMAT_R8G8B8A8_UNORM** specifies a four-component, 32-bit unsigned normalized format that has an 8-bit R component in byte 0, an 8-bit G component in byte 1, an 8-bit B component in byte 2, and an 8-bit A component in byte 3.

• **VK_FORMAT_R8G8B8A8_SNORM** specifies a four-component, 32-bit signed normalized format that has an 8-bit R component in byte 0, an 8-bit G component in byte 1, an 8-bit B component in byte 2, and an 8-bit A component in byte 3.

• **VK_FORMAT_R8G8B8A8_USCALED** specifies a four-component, 32-bit unsigned scaled format that has an 8-bit R component in byte 0, an 8-bit G component in byte 1, an 8-bit B component in byte 2, and an 8-bit A component in byte 3.

• **VK_FORMAT_R8G8B8A8_SSCALED** specifies a four-component, 32-bit signed scaled format that has an 8-bit R component in byte 0, an 8-bit G component in byte 1, an 8-bit B component in byte 2, and an 8-bit A component in byte 3.

• **VK_FORMAT_R8G8B8A8_UINT** specifies a four-component, 32-bit unsigned integer format that has an 8-bit R component in byte 0, an 8-bit G component in byte 1, an 8-bit B component in byte 2, and an 8-bit A component in byte 3.

• **VK_FORMAT_R8G8B8A8_SINT** specifies a four-component, 32-bit signed integer format that has an 8-bit R component in byte 0, an 8-bit G component in byte 1, an 8-bit B component in byte 2, and an 8-bit A component in byte 3.
• **VK_FORMAT_R8G8B8A8_SRGB** specifies a four-component, 32-bit unsigned normalized format that has an 8-bit R component stored with sRGB nonlinear encoding in byte 0, an 8-bit G component stored with sRGB nonlinear encoding in byte 1, an 8-bit B component stored with sRGB nonlinear encoding in byte 2, and an 8-bit A component in byte 3.

• **VK_FORMAT_B8G8R8A8_UNORM** specifies a four-component, 32-bit unsigned normalized format that has an 8-bit B component in byte 0, an 8-bit G component in byte 1, an 8-bit R component in byte 2, and an 8-bit A component in byte 3.

• **VK_FORMAT_B8G8R8A8_SNORM** specifies a four-component, 32-bit signed normalized format that has an 8-bit B component in byte 0, an 8-bit G component in byte 1, an 8-bit R component in byte 2, and an 8-bit A component in byte 3.

• **VK_FORMAT_B8G8R8A8_USCALED** specifies a four-component, 32-bit unsigned scaled format that has an 8-bit B component in byte 0, an 8-bit G component in byte 1, an 8-bit R component in byte 2, and an 8-bit A component in byte 3.

• **VK_FORMAT_B8G8R8A8_SSCALED** specifies a four-component, 32-bit signed scaled format that has an 8-bit B component in byte 0, an 8-bit G component in byte 1, an 8-bit R component in byte 2, and an 8-bit A component in byte 3.

• **VK_FORMAT_B8G8R8A8_UINT** specifies a four-component, 32-bit unsigned integer format that has an 8-bit B component in byte 0, an 8-bit G component in byte 1, an 8-bit R component in byte 2, and an 8-bit A component in byte 3.

• **VK_FORMAT_B8G8R8A8_SINT** specifies a four-component, 32-bit signed integer format that has an 8-bit B component in byte 0, an 8-bit G component in byte 1, an 8-bit R component in byte 2, and an 8-bit A component in byte 3.

• **VK_FORMAT_B8G8R8A8_SRGB** specifies a four-component, 32-bit unsigned normalized format that has an 8-bit B component stored with sRGB nonlinear encoding in byte 0, an 8-bit G component stored with sRGB nonlinear encoding in byte 1, an 8-bit R component stored with sRGB nonlinear encoding in byte 2, and an 8-bit A component in byte 3.

• **VK_FORMAT_A8B8G8R8_UNORM_PACK32** specifies a four-component, 32-bit packed unsigned normalized format that has an 8-bit A component in bits 24..31, an 8-bit B component in bits 16..23, an 8-bit G component in bits 8..15, and an 8-bit R component in bits 0..7.

• **VK_FORMAT_A8B8G8R8_SNORM_PACK32** specifies a four-component, 32-bit packed signed normalized format that has an 8-bit A component in bits 24..31, an 8-bit B component in bits 16..23, an 8-bit G component in bits 8..15, and an 8-bit R component in bits 0..7.

• **VK_FORMAT_A8B8G8R8_USCALED_PACK32** specifies a four-component, 32-bit packed unsigned scaled integer format that has an 8-bit A component in bits 24..31, an 8-bit B component in bits 16..23, an 8-bit G component in bits 8..15, and an 8-bit R component in bits 0..7.

• **VK_FORMAT_A8B8G8R8_SSCALED_PACK32** specifies a four-component, 32-bit packed signed scaled integer format that has an 8-bit A component in bits 24..31, an 8-bit B component in bits 16..23, an 8-bit G component in bits 8..15, and an 8-bit R component in bits 0..7.

• **VK_FORMAT_A8B8G8R8_UINT_PACK32** specifies a four-component, 32-bit packed unsigned integer format that has an 8-bit A component in bits 24..31, an 8-bit B component in bits 16..23, an 8-bit G component in bits 8..15, and an 8-bit R component in bits 0..7.

• **VK_FORMAT_A8B8G8R8_SINT_PACK32** specifies a four-component, 32-bit packed signed integer format that has an 8-bit A component in bits 24..31, an 8-bit B component in bits 16..23, an 8-bit G component in bits 8..15, and an 8-bit R component in bits 0..7.
component in bits 8..15, and an 8-bit R component in bits 0..7.

- **VK_FORMAT_A8B8G8R8_SRGB_PACK32** specifies a four-component, 32-bit packed unsigned normalized format that has an 8-bit A component in bits 24..31, an 8-bit B component stored with sRGB nonlinear encoding in bits 16..23, an 8-bit G component stored with sRGB nonlinear encoding in bits 8..15, and an 8-bit R component stored with sRGB nonlinear encoding in bits 0..7.

- **VK_FORMAT_A2R10G10B10_UNORM_PACK32** specifies a four-component, 32-bit packed unsigned normalized format that has a 2-bit A component in bits 30..31, a 10-bit R component in bits 20..29, a 10-bit G component in bits 10..19, and a 10-bit B component in bits 0..9.

- **VK_FORMAT_A2R10G10B10_SNORM_PACK32** specifies a four-component, 32-bit packed signed normalized format that has a 2-bit A component in bits 30..31, a 10-bit R component in bits 20..29, a 10-bit G component in bits 10..19, and a 10-bit B component in bits 0..9.

- **VK_FORMAT_A2R10G10B10_USCALED_PACK32** specifies a four-component, 32-bit packed unsigned scaled integer format that has a 2-bit A component in bits 30..31, a 10-bit R component in bits 20..29, a 10-bit G component in bits 10..19, and a 10-bit B component in bits 0..9.

- **VK_FORMAT_A2R10G10B10_SSCALED_PACK32** specifies a four-component, 32-bit packed signed scaled integer format that has a 2-bit A component in bits 30..31, a 10-bit R component in bits 20..29, a 10-bit G component in bits 10..19, and a 10-bit B component in bits 0..9.

- **VK_FORMAT_A2R10G10B10_UINT_PACK32** specifies a four-component, 32-bit packed unsigned integer format that has a 2-bit A component in bits 30..31, a 10-bit R component in bits 20..29, a 10-bit G component in bits 10..19, and a 10-bit B component in bits 0..9.

- **VK_FORMAT_A2R10G10B10_SINT_PACK32** specifies a four-component, 32-bit packed signed integer format that has a 2-bit A component in bits 30..31, a 10-bit R component in bits 20..29, a 10-bit G component in bits 10..19, and a 10-bit B component in bits 0..9.

- **VK_FORMAT_A2B10G10R10_UNORM_PACK32** specifies a four-component, 32-bit packed unsigned normalized format that has a 2-bit A component in bits 30..31, a 10-bit B component in bits 20..29, a 10-bit G component in bits 10..19, and a 10-bit R component in bits 0..9.

- **VK_FORMAT_A2B10G10R10_SNORM_PACK32** specifies a four-component, 32-bit packed signed normalized format that has a 2-bit A component in bits 30..31, a 10-bit B component in bits 20..29, a 10-bit G component in bits 10..19, and a 10-bit R component in bits 0..9.

- **VK_FORMAT_A2B10G10R10_USCALED_PACK32** specifies a four-component, 32-bit packed unsigned scaled integer format that has a 2-bit A component in bits 30..31, a 10-bit B component in bits 20..29, a 10-bit G component in bits 10..19, and a 10-bit R component in bits 0..9.

- **VK_FORMAT_A2B10G10R10_SSCALED_PACK32** specifies a four-component, 32-bit packed signed scaled integer format that has a 2-bit A component in bits 30..31, a 10-bit B component in bits 20..29, a 10-bit G component in bits 10..19, and a 10-bit R component in bits 0..9.

- **VK_FORMAT_A2B10G10R10_UINT_PACK32** specifies a four-component, 32-bit packed unsigned integer format that has a 2-bit A component in bits 30..31, a 10-bit B component in bits 20..29, a 10-bit G component in bits 10..19, and a 10-bit R component in bits 0..9.

- **VK_FORMAT_A2B10G10R10_SINT_PACK32** specifies a four-component, 32-bit packed signed integer format that has a 2-bit A component in bits 30..31, a 10-bit B component in bits 20..29, a 10-bit G component in bits 10..19, and a 10-bit R component in bits 0..9.

- **VK_FORMAT_R16_UNORM** specifies a one-component, 16-bit unsigned normalized format that has a
single 16-bit R component.

- **VK_FORMAT_R16_SNORM** specifies a one-component, 16-bit signed normalized format that has a single 16-bit R component.

- **VK_FORMAT_R16_USCALED** specifies a one-component, 16-bit unsigned scaled integer format that has a single 16-bit R component.

- **VK_FORMAT_R16_SSCALED** specifies a one-component, 16-bit signed scaled integer format that has a single 16-bit R component.

- **VK_FORMAT_R16_UINT** specifies a one-component, 16-bit unsigned integer format that has a single 16-bit R component.

- **VK_FORMAT_R16_SINT** specifies a one-component, 16-bit signed integer format that has a single 16-bit R component.

- **VK_FORMAT_R16_SFLOAT** specifies a one-component, 16-bit signed floating-point format that has a single 16-bit R component.

- **VK_FORMAT_R16G16_UNORM** specifies a two-component, 32-bit unsigned normalized format that has a 16-bit R component in bytes 0..1, and a 16-bit G component in bytes 2..3.

- **VK_FORMAT_R16G16_SNORM** specifies a two-component, 32-bit signed normalized format that has a 16-bit R component in bytes 0..1, and a 16-bit G component in bytes 2..3.

- **VK_FORMAT_R16G16_USCALED** specifies a two-component, 32-bit unsigned scaled integer format that has a 16-bit R component in bytes 0..1, and a 16-bit G component in bytes 2..3.

- **VK_FORMAT_R16G16_SSCALED** specifies a two-component, 32-bit signed scaled integer format that has a 16-bit R component in bytes 0..1, and a 16-bit G component in bytes 2..3.

- **VK_FORMAT_R16G16_UINT** specifies a two-component, 32-bit unsigned integer format that has a 16-bit R component in bytes 0..1, and a 16-bit G component in bytes 2..3.

- **VK_FORMAT_R16G16_SINT** specifies a two-component, 32-bit signed integer format that has a 16-bit R component in bytes 0..1, and a 16-bit G component in bytes 2..3.

- **VK_FORMAT_R16G16_SFLOAT** specifies a two-component, 32-bit signed floating-point format that has a 16-bit R component in bytes 0..1, and a 16-bit G component in bytes 2..3.

- **VK_FORMAT_R16G16B16_UNORM** specifies a three-component, 48-bit unsigned normalized format that has a 16-bit R component in bytes 0..1, a 16-bit G component in bytes 2..3, and a 16-bit B component in bytes 4..5.

- **VK_FORMAT_R16G16B16_SNORM** specifies a three-component, 48-bit signed normalized format that has a 16-bit R component in bytes 0..1, a 16-bit G component in bytes 2..3, and a 16-bit B component in bytes 4..5.

- **VK_FORMAT_R16G16B16_USCALED** specifies a three-component, 48-bit unsigned scaled integer format that has a 16-bit R component in bytes 0..1, a 16-bit G component in bytes 2..3, and a 16-bit B component in bytes 4..5.

- **VK_FORMAT_R16G16B16_SSCALED** specifies a three-component, 48-bit signed scaled integer format that has a 16-bit R component in bytes 0..1, a 16-bit G component in bytes 2..3, and a 16-bit B component in bytes 4..5.

- **VK_FORMAT_R16G16B16_UINT** specifies a three-component, 48-bit unsigned integer format that has a 16-bit R component in bytes 0..1, a 16-bit G component in bytes 2..3, and a 16-bit B component in
• **VK_FORMAT_R16G16B16_SINT** specifies a three-component, 48-bit signed integer format that has a 16-bit R component in bytes 0..1, a 16-bit G component in bytes 2..3, and a 16-bit B component in bytes 4..5.

• **VK_FORMAT_R16G16B16_SFLOAT** specifies a three-component, 48-bit signed floating-point format that has a 16-bit R component in bytes 0..1, a 16-bit G component in bytes 2..3, and a 16-bit B component in bytes 4..5.

• **VK_FORMAT_R16G16B16A16_UNORM** specifies a four-component, 64-bit unsigned normalized format that has a 16-bit R component in bytes 0..1, a 16-bit G component in bytes 2..3, a 16-bit B component in bytes 4..5, and a 16-bit A component in bytes 6..7.

• **VK_FORMAT_R16G16B16A16_SFLOAT** specifies a four-component, 64-bit signed floating-point format that has a 16-bit R component in bytes 0..1, a 16-bit G component in bytes 2..3, a 16-bit B component in bytes 4..5, and a 16-bit A component in bytes 6..7.

• **VK_FORMAT_R16G16B16A16_UINT** specifies a four-component, 64-bit unsigned integer format that has a 16-bit R component in bytes 0..1, a 16-bit G component in bytes 2..3, a 16-bit B component in bytes 4..5, and a 16-bit A component in bytes 6..7.

• **VK_FORMAT_R16G16B16A16_SINT** specifies a four-component, 64-bit signed integer format that has a 16-bit R component in bytes 0..1, a 16-bit G component in bytes 2..3, a 16-bit B component in bytes 4..5, and a 16-bit A component in bytes 6..7.

• **VK_FORMAT_R32_UINT** specifies a one-component, 32-bit unsigned integer format that has a single 32-bit R component.

• **VK_FORMAT_R32_SINT** specifies a one-component, 32-bit signed integer format that has a single 32-bit R component.

• **VK_FORMAT_R32_SFLOAT** specifies a one-component, 32-bit signed floating-point format that has a single 32-bit R component.

• **VK_FORMAT_R32G32_UINT** specifies a two-component, 64-bit unsigned integer format that has a 32-bit R component in bytes 0..3, and a 32-bit G component in bytes 4..7.

• **VK_FORMAT_R32G32_SINT** specifies a two-component, 64-bit signed integer format that has a 32-bit R component in bytes 0..3, and a 32-bit G component in bytes 4..7.

• **VK_FORMAT_R32G32_SFLOAT** specifies a two-component, 64-bit signed floating-point format that has a 32-bit R component in bytes 0..3, and a 32-bit G component in bytes 4..7.

• **VK_FORMAT_R32G32B32_UINT** specifies a three-component, 96-bit unsigned integer format that has a
32-bit R component in bytes 0..3, a 32-bit G component in bytes 4..7, and a 32-bit B component in bytes 8..11.

- **VK_FORMAT_R32G32B32_SINT** specifies a three-component, 96-bit signed integer format that has a 32-bit R component in bytes 0..3, a 32-bit G component in bytes 4..7, and a 32-bit B component in bytes 8..11.

- **VK_FORMAT_R32G32B32_SFLOAT** specifies a three-component, 96-bit signed floating-point format that has a 32-bit R component in bytes 0..3, a 32-bit G component in bytes 4..7, and a 32-bit B component in bytes 8..11.

- **VK_FORMAT_R32G32B32A32_UINT** specifies a four-component, 128-bit unsigned integer format that has a 32-bit R component in bytes 0..3, a 32-bit G component in bytes 4..7, a 32-bit B component in bytes 8..11, and a 32-bit A component in bytes 12..15.

- **VK_FORMAT_R32G32B32A32_SINT** specifies a four-component, 128-bit signed integer format that has a 32-bit R component in bytes 0..3, a 32-bit G component in bytes 4..7, a 32-bit B component in bytes 8..11, and a 32-bit A component in bytes 12..15.

- **VK_FORMAT_R32G32B32A32_SFLOAT** specifies a four-component, 128-bit signed floating-point format that has a 32-bit R component in bytes 0..3, a 32-bit G component in bytes 4..7, a 32-bit B component in bytes 8..11, and a 32-bit A component in bytes 12..15.

- **VK_FORMAT_R64_UINT** specifies a one-component, 64-bit unsigned integer format that has a single 64-bit R component.

- **VK_FORMAT_R64_SINT** specifies a one-component, 64-bit signed integer format that has a single 64-bit R component.

- **VK_FORMAT_R64_SFLOAT** specifies a one-component, 64-bit signed floating-point format that has a single 64-bit R component.

- **VK_FORMAT_R64G64_UINT** specifies a two-component, 128-bit unsigned integer format that has a 64-bit R component in bytes 0..7, and a 64-bit G component in bytes 8..15.

- **VK_FORMAT_R64G64_SINT** specifies a two-component, 128-bit signed integer format that has a 64-bit R component in bytes 0..7, and a 64-bit G component in bytes 8..15.

- **VK_FORMAT_R64G64_SFLOAT** specifies a two-component, 128-bit signed floating-point format that has a 64-bit R component in bytes 0..7, and a 64-bit G component in bytes 8..15.

- **VK_FORMAT_R64G64B64_UINT** specifies a three-component, 192-bit unsigned integer format that has a 64-bit R component in bytes 0..7, a 64-bit G component in bytes 8..15, and a 64-bit B component in bytes 16..23.

- **VK_FORMAT_R64G64B64_SINT** specifies a three-component, 192-bit signed integer format that has a 64-bit R component in bytes 0..7, a 64-bit G component in bytes 8..15, and a 64-bit B component in bytes 16..23.

- **VK_FORMAT_R64G64B64_SFLOAT** specifies a three-component, 192-bit signed floating-point format that has a 64-bit R component in bytes 0..7, a 64-bit G component in bytes 8..15, and a 64-bit B component in bytes 16..23.

- **VK_FORMAT_R64G64B64A64_UINT** specifies a four-component, 256-bit unsigned integer format that has a 64-bit R component in bytes 0..7, a 64-bit G component in bytes 8..15, a 64-bit B component in bytes 16..23, and a 64-bit A component in bytes 24..31.
• **VK_FORMAT_R64G64B64A64_SINT** specifies a four-component, 256-bit signed integer format that has a 64-bit R component in bytes 0..7, a 64-bit G component in bytes 8..15, a 64-bit B component in bytes 16..23, and a 64-bit A component in bytes 24..31.

• **VK_FORMAT_R64G64B64A64_SFLOAT** specifies a four-component, 256-bit signed floating-point format that has a 64-bit R component in bytes 0..7, a 64-bit G component in bytes 8..15, a 64-bit B component in bytes 16..23, and a 64-bit A component in bytes 24..31.

• **VK_FORMAT_B10G11R11_UFLOAT_PACK32** specifies a three-component, 32-bit packed unsigned floating-point format that has a 10-bit B component in bits 22..31, an 11-bit G component in bits 11..21, an 11-bit R component in bits 0..10. See [Unsigned 10-Bit Floating-Point Numbers](#) and [Unsigned 11-Bit Floating-Point Numbers](#).

• **VK_FORMAT_E5B9G9R9_UFLOAT_PACK32** specifies a three-component, 32-bit packed unsigned floating-point format that has a 5-bit shared exponent in bits 27..31, a 9-bit B component mantissa in bits 18..26, a 9-bit G component mantissa in bits 9..17, and a 9-bit R component mantissa in bits 0..8.

• **VK_FORMAT_D16_UNORM** specifies a one-component, 16-bit unsigned normalized format that has a single 16-bit depth component.

• **VK_FORMAT_X8_D24_UNORM_PACK32** specifies a two-component, 32-bit format that has 24 unsigned normalized bits in the depth component and, optionally, 8 bits that are unused.

• **VK_FORMAT_D32_SFLOAT** specifies a one-component, 32-bit signed floating-point format that has 32 bits in the depth component.

• **VK_FORMAT_S8_UINT** specifies a one-component, 8-bit unsigned integer format that has 8 bits in the stencil component.

• **VK_FORMAT_D16_UNORM_S8_UINT** specifies a two-component, 24-bit format that has 16 unsigned normalized bits in the depth component and 8 unsigned integer bits in the stencil component.

• **VK_FORMAT_D24_UNORM_S8_UINT** specifies a two-component, 32-bit packed format that has 8 unsigned integer bits in the stencil component, and 24 unsigned normalized bits in the depth component.

• **VK_FORMAT_D32_SFLOAT_S8_UINT** specifies a two-component format that has 32 signed float bits in the depth component and 8 unsigned integer bits in the stencil component. There are optionally 24 bits that are unused.

• **VK_FORMAT_BC1_RGB_UNORM_BLOCK** specifies a three-component, block-compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGB texel data. This format has no alpha and is considered opaque.

• **VK_FORMAT_BC1_RGB_SRGB_BLOCK** specifies a three-component, block-compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGB texel data with sRGB nonlinear encoding. This format has no alpha and is considered opaque.

• **VK_FORMAT_BC1_RGBA_UNORM_BLOCK** specifies a four-component, block-compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGB texel data, and provides 1 bit of alpha.

• **VK_FORMAT_BC1_RGBA_SRGB_BLOCK** specifies a four-component, block-compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGB texel data with sRGB nonlinear encoding, and provides 1 bit of alpha.

• **VK_FORMAT_BC2_UNORM_BLOCK** specifies a four-component, block-compressed format where each
128-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGBA texel data with the first 64 bits encoding alpha values followed by 64 bits encoding RGB values.

- **VK_FORMAT_BC2_SRGB_BLOCK** specifies a four-component, block-compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGBA texel data with the first 64 bits encoding alpha values followed by 64 bits encoding RGB values with sRGB nonlinear encoding.

- **VK_FORMAT_BC3_UNORM_BLOCK** specifies a four-component, block-compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGBA texel data with the first 64 bits encoding alpha values followed by 64 bits encoding RGB values.

- **VK_FORMAT_BC3_SRGB_BLOCK** specifies a four-component, block-compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGBA texel data with the first 64 bits encoding alpha values followed by 64 bits encoding RGB values with sRGB nonlinear encoding.

- **VK_FORMAT_BC4_UNORM_BLOCK** specifies a one-component, block-compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized red texel data.

- **VK_FORMAT_BC4_SNORM_BLOCK** specifies a one-component, block-compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of signed normalized red texel data.

- **VK_FORMAT_BC5_UNORM_BLOCK** specifies a two-component, block-compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RG texel data with the first 64 bits encoding red values followed by 64 bits encoding green values.

- **VK_FORMAT_BC5_SNORM_BLOCK** specifies a two-component, block-compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of signed normalized RG texel data with the first 64 bits encoding red values followed by 64 bits encoding green values.

- **VK_FORMAT_BC6H_UFLOAT_BLOCK** specifies a three-component, block-compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of unsigned floating-point RGB texel data.

- **VK_FORMAT_BC6H_SFLOAT_BLOCK** specifies a three-component, block-compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of signed floating-point RGB texel data.

- **VK_FORMAT_BC7_UNORM_BLOCK** specifies a four-component, block-compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGBA texel data.

- **VK_FORMAT_BC7_SRGB_BLOCK** specifies a four-component, block-compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

- **VK_FORMAT_ETC2_R8G8B8_UNORM_BLOCK** specifies a three-component, ETC2 compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGB texel data. This format has no alpha and is considered opaque.

- **VK_FORMAT_ETC2_R8G8B8_SRGB_BLOCK** specifies a three-component, ETC2 compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGB texel data with sRGB nonlinear encoding. This format has no alpha and is considered opaque.

- **VK_FORMAT_ETC2_R8G8B8A1_UNORM_BLOCK** specifies a four-component, ETC2 compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGB
• **VK_FORMAT_ETC2_R8G8B8A1_SRGB_BLOCK** specifies a four-component, ETC2 compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGB texel data with sRGB nonlinear encoding, and provides 1 bit of alpha.

• **VK_FORMAT_ETC2_R8G8B8A8_UNORM_BLOCK** specifies a four-component, ETC2 compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGBA texel data with the first 64 bits encoding alpha values followed by 64 bits encoding RGB values.

• **VK_FORMAT_ETC2_R8G8B8A8_SRGB_BLOCK** specifies a four-component, ETC2 compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGBA texel data with the first 64 bits encoding alpha values followed by 64 bits encoding RGB values with sRGB nonlinear encoding applied.

• **VK_FORMAT_EAC_R11_UNORM_BLOCK** specifies a one-component, ETC2 compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized red texel data.

• **VK_FORMAT_EAC_R11_SNORM_BLOCK** specifies a one-component, ETC2 compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of signed normalized red texel data.

• **VK_FORMAT_EAC_R11G11_UNORM_BLOCK** specifies a two-component, ETC2 compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RG texel data with the first 64 bits encoding red values followed by 64 bits encoding green values.

• **VK_FORMAT_EAC_R11G11_SNORM_BLOCK** specifies a two-component, ETC2 compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of signed normalized RG texel data with the first 64 bits encoding red values followed by 64 bits encoding green values.

• **VK_FORMAT_ASTC_4x4_UNORM_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGBA texel data.

• **VK_FORMAT_ASTC_4x4_SRGB_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

• **VK_FORMAT_ASTC_4x4_SFLOAT_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 4×4 rectangle of signed floating-point RGBA texel data.

• **VK_FORMAT_ASTC_5x4_UNORM_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 5×4 rectangle of unsigned normalized RGBA texel data.

• **VK_FORMAT_ASTC_5x4_SRGB_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 5×4 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

• **VK_FORMAT_ASTC_5x4_SFLOAT_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 5×4 rectangle of signed floating-point RGBA texel data.

• **VK_FORMAT_ASTC_5x5_UNORM_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 5×5 rectangle of unsigned normalized RGBA texel data.
• **VK_FORMAT_ASTC_5x5_SRGB_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 5×5 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

• **VK_FORMAT_ASTC_5x5_SFLOAT_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 5×5 rectangle of signed floating-point RGBA texel data.

• **VK_FORMAT_ASTC_6x5_UNORM_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 6×5 rectangle of unsigned normalized RGBA texel data.

• **VK_FORMAT_ASTC_6x5_SRGB_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 6×5 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

• **VK_FORMAT_ASTC_6x5_SFLOAT_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 6×5 rectangle of signed floating-point RGBA texel data.

• **VK_FORMAT_ASTC_6x6_UNORM_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 6×6 rectangle of unsigned normalized RGBA texel data.

• **VK_FORMAT_ASTC_6x6_SRGB_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 6×6 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

• **VK_FORMAT_ASTC_6x6_SFLOAT_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 6×6 rectangle of signed floating-point RGBA texel data.

• **VK_FORMAT_ASTC_8x5_UNORM_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes an 8×5 rectangle of unsigned normalized RGBA texel data.

• **VK_FORMAT_ASTC_8x5_SRGB_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes an 8×5 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

• **VK_FORMAT_ASTC_8x5_SFLOAT_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 8×5 rectangle of signed floating-point RGBA texel data.

• **VK_FORMAT_ASTC_8x6_UNORM_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes an 8×6 rectangle of unsigned normalized RGBA texel data.

• **VK_FORMAT_ASTC_8x6_SRGB_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes an 8×6 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

• **VK_FORMAT_ASTC_8x6_SFLOAT_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 8×6 rectangle of signed floating-point RGBA texel data.
- **VK_FORMAT_ASTC_8x8_UNORM_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes an 8×8 rectangle of unsigned normalized RGBA texel data.

- **VK_FORMAT_ASTC_8x8_SRGB_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes an 8×8 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

- **VK_FORMAT_ASTC_8x8_SFLOAT_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 8×8 rectangle of signed floating-point RGBA texel data.

- **VK_FORMAT_ASTC_10x5_UNORM_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 10×5 rectangle of unsigned normalized RGBA texel data.

- **VK_FORMAT_ASTC_10x5_SRGB_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 10×5 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

- **VK_FORMAT_ASTC_10x5_SFLOAT_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 10×5 rectangle of signed floating-point RGBA texel data.

- **VK_FORMAT_ASTC_10x6_UNORM_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 10×6 rectangle of unsigned normalized RGBA texel data.

- **VK_FORMAT_ASTC_10x6_SRGB_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 10×6 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

- **VK_FORMAT_ASTC_10x6_SFLOAT_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 10×6 rectangle of signed floating-point RGBA texel data.

- **VK_FORMAT_ASTC_10x8_UNORM_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 10×8 rectangle of unsigned normalized RGBA texel data.

- **VK_FORMAT_ASTC_10x8_SRGB_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 10×8 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

- **VK_FORMAT_ASTC_10x8_SFLOAT_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 10×8 rectangle of signed floating-point RGBA texel data.

- **VK_FORMAT_ASTC_10x10_UNORM_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 10×10 rectangle of unsigned normalized RGBA texel data.

- **VK_FORMAT_ASTC_10x10_SRGB_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 10×10 rectangle of unsigned normalized RGBA texel data.
texel data with sRGB nonlinear encoding applied to the RGB components.

- **VK_FORMAT_ASTC_10x10_SFLOAT_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 10×10 rectangle of signed floating-point RGBA texel data.

- **VK_FORMAT_ASTC_12x10_UNORM_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 12×10 rectangle of unsigned normalized RGBA texel data.

- **VK_FORMAT_ASTC_12x10_SRGB_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 12×10 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

- **VK_FORMAT_ASTC_12x10_SFLOAT_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 12×10 rectangle of signed floating-point RGBA texel data.

- **VK_FORMAT_ASTC_12x12_UNORM_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 12×12 rectangle of unsigned normalized RGBA texel data.

- **VK_FORMAT_ASTC_12x12_SRGB_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 12×12 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

- **VK_FORMAT_ASTC_12x12_SFLOAT_BLOCK** specifies a four-component, ASTC compressed format where each 128-bit compressed texel block encodes a 12×12 rectangle of signed floating-point RGBA texel data.

- **VK_FORMAT_G8B8G8R8_422_UNORM** specifies a four-component, 32-bit format containing a pair of G components, an R component, and a B component, collectively encoding a 2×1 rectangle of unsigned normalized RGB texel data. One G value is present at each i coordinate, with the B and R values shared across both G values and thus recorded at half the horizontal resolution of the image. This format has an 8-bit B component in byte 0, an 8-bit G component for the even i coordinate in byte 1, an 8-bit G component for the odd i coordinate in byte 2, and an 8-bit R component in byte 3. This format only supports images with a width that is a multiple of two. For the purposes of the constraints on copy extents, this format is treated as a compressed format with a 2×1 compressed texel block.

- **VK_FORMAT_B8G8R8G8_422_UNORM** specifies a four-component, 32-bit format containing a pair of G components, an R component, and a B component, collectively encoding a 2×1 rectangle of unsigned normalized RGB texel data. One G value is present at each i coordinate, with the B and R values shared across both G values and thus recorded at half the horizontal resolution of the image. This format has an 8-bit G component in plane 0, an 8-bit B component in plane 1, and an 8-bit R component in plane 2. The horizontal and vertical dimensions of the R and B planes are halved relative to the image dimensions, and each R and B component is shared with the G components for which

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\[ i_G \times 0.5 = i_B = i_R \] and \[ j_G \times 0.5 = j_B = j_R. \] The location of each plane when this image is in linear layout can be determined via \texttt{vkGetImageSubresourceLayout}, using \texttt{VK_IMAGE_ASPECT_PLANE_0_BIT} for the G plane, \texttt{VK_IMAGE_ASPECT_PLANE_1_BIT} for the B plane, and \texttt{VK_IMAGE_ASPECT_PLANE_2_BIT} for the R plane. This format only supports images with a width and height that is a multiple of two.

- \texttt{VK_FORMAT_G8_B8R8_2PLANE_420_UNORM} specifies an unsigned normalized \textit{multi-planar format} that has an 8-bit G component in plane 0, and a two-component, 16-bit BR plane 1 consisting of an 8-bit B component in byte 0 and an 8-bit R component in byte 1. The horizontal and vertical dimensions of the BR plane are halved relative to the image dimensions, and each R and B value is shared with the G components for which \[ l_G \times 0.5 = i_B = i_R \] and \[ j_G \times 0.5 = j_B = j_R. \] The location of each plane when this image is in linear layout can be determined via \texttt{vkGetImageSubresourceLayout}, using \texttt{VK_IMAGE_ASPECT_PLANE_0_BIT} for the G plane, and \texttt{VK_IMAGE_ASPECT_PLANE_1_BIT} for the BR plane. This format only supports images with a width and height that is a multiple of two.

- \texttt{VK_FORMAT_G8_B8_R8_3PLANE_422_UNORM} specifies an unsigned normalized \textit{multi-planar format} that has an 8-bit G component in plane 0, an 8-bit B component in plane 1, and an 8-bit R component in plane 2. The horizontal dimension of the R and B plane is halved relative to the image dimensions, and each R and B value is shared with the G components for which \[ l_G \times 0.5 = i_B = i_R. \] The location of each plane when this image is in linear layout can be determined via \texttt{vkGetImageSubresourceLayout}, using \texttt{VK_IMAGE_ASPECT_PLANE_0_BIT} for the G plane, \texttt{VK_IMAGE_ASPECT_PLANE_1_BIT} for the B plane, and \texttt{VK_IMAGE_ASPECT_PLANE_2_BIT} for the R plane. This format only supports images with a width that is a multiple of two.

- \texttt{VK_FORMAT_G8_B8R8_2PLANE_422_UNORM} specifies an unsigned normalized \textit{multi-planar format} that has an 8-bit G component in plane 0, and a two-component, 16-bit BR plane 1 consisting of an 8-bit B component in byte 0 and an 8-bit R component in byte 1. The horizontal dimension of the BR plane is halved relative to the image dimensions, and each R and B value is shared with the G components for which \[ l_G \times 0.5 = i_B = i_R. \] The location of each plane when this image is in linear layout can be determined via \texttt{vkGetImageSubresourceLayout}, using \texttt{VK_IMAGE_ASPECT_PLANE_0_BIT} for the G plane, and \texttt{VK_IMAGE_ASPECT_PLANE_1_BIT} for the BR plane. This format only supports images with a width that is a multiple of two.

- \texttt{VK_FORMAT_G8_B8_R8_3PLANE_444_UNORM} specifies an unsigned normalized \textit{multi-planar format} that has an 8-bit G component in plane 0, an 8-bit B component in plane 1, and an 8-bit R component in plane 2. Each plane has the same dimensions and each R, G and B component contributes to a single texel. The location of each plane when this image is in linear layout can be determined via \texttt{vkGetImageSubresourceLayout}, using \texttt{VK_IMAGE_ASPECT_PLANE_0_BIT} for the G plane, \texttt{VK_IMAGE_ASPECT_PLANE_1_BIT} for the B plane, and \texttt{VK_IMAGE_ASPECT_PLANE_2_BIT} for the R plane.

- \texttt{VK_FORMAT_R10X6_UNORM_PACK16} specifies a one-component, 16-bit unsigned normalized format that has a single 10-bit R component in the top 10 bits of a 16-bit word, with the bottom 6 bits unused.

- \texttt{VK_FORMAT_R10X6G10X6_UNORM_2PACK16} specifies a two-component, 32-bit unsigned normalized format that has a 10-bit R component in the top 10 bits of the word in bytes 0..1, and a 10-bit G component in the top 10 bits of the word in bytes 2..3, with the bottom 6 bits of each word unused.

- \texttt{VK_FORMAT_R10X6G10X6B10X6A10X6_UNORM_4PACK16} specifies a four-component, 64-bit unsigned normalized format that has a 10-bit R component in the top 10 bits of the word in bytes 0..1, a
10-bit G component in the top 10 bits of the word in bytes 2..3, a 10-bit B component in the top 10 bits of the word in bytes 4..5, and a 10-bit A component in the top 10 bits of the word in bytes 6..7, with the bottom 6 bits of each word unused.

- **VK_FORMAT_G10X6B10X6G10X6R10X6_422_UNORM_4PACK16** specifies a four-component, 64-bit format containing a pair of G components, an R component, and a B component, collectively encoding a 2×1 rectangle of unsigned normalized RGB texel data. One G value is present at each i coordinate, with the B and R values shared across both G values and thus recorded at half the horizontal resolution of the image. This format has a 10-bit G component for the even i coordinate in the top 10 bits of the word in bytes 0..1, a 10-bit B component in the top 10 bits of the word in bytes 2..3, a 10-bit G component for the odd i coordinate in the top 10 bits of the word in bytes 4..5, and a 10-bit R component in the top 10 bits of the word in bytes 6..7, with the bottom 6 bits of each word unused. This format only supports images with a width that is a multiple of two. For the purposes of the constraints on copy extents, this format is treated as a compressed format with a 2×1 compressed texel block.

- **VK_FORMAT_B10X6G10X6R10X6G10X6_422_UNORM_4PACK16** specifies a four-component, 64-bit format containing a pair of G components, an R component, and a B component, collectively encoding a 2×1 rectangle of unsigned normalized RGB texel data. One G value is present at each i coordinate, with the B and R values shared across both G values and thus recorded at half the horizontal resolution of the image. This format has a 10-bit B component in the top 10 bits of the word in bytes 0..1, a 10-bit G component for the even i coordinate in the top 10 bits of the word in bytes 2..3, a 10-bit R component in the top 10 bits of the word in bytes 4..5, and a 10-bit G component for the odd i coordinate in the top 10 bits of the word in bytes 6..7, with the bottom 6 bits of each word unused. This format only supports images with a width that is a multiple of two. For the purposes of the constraints on copy extents, this format is treated as a compressed format with a 2×1 compressed texel block.

- **VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_420_UNORM_3PACK16** specifies an unsigned normalized multi-planar format that has a 10-bit G component in the top 10 bits of each 16-bit word of plane 0, a 10-bit B component in the top 10 bits of each 16-bit word of plane 1, and a 10-bit R component in the top 10 bits of each 16-bit word of plane 2, with the bottom 6 bits of each word unused. The horizontal and vertical dimensions of the R and B planes are halved relative to the image dimensions, and each R and B component is shared with the G components for which \(|i_G \times 0.5| = i_B = i_R\) and \(|j_G \times 0.5| = j_B = j_R\). The location of each plane when this image is in linear layout can be determined via `vkGetImageSubresourceLayout`, using `VK_IMAGE_ASPECT_PLANE_0_BIT` for the G plane, `VK_IMAGE_ASPECT_PLANE_1_BIT` for the B plane, and `VK_IMAGE_ASPECT_PLANE_2_BIT` for the R plane. This format only supports images with a width and height that is a multiple of two.

- **VK_FORMAT_G10X6_B10X6R10X6_2PLANE_420_UNORM_3PACK16** specifies an unsigned normalized multi-planar format that has a 10-bit G component in the top 10 bits of each 16-bit word of plane 0, and a two-component, 32-bit BR plane 1 consisting of a 10-bit B component in the top 10 bits of the word in bytes 0..1, and a 10-bit R component in the top 10 bits of the word in bytes 2..3, with the bottom 6 bits of each word unused. The horizontal and vertical dimensions of the BR plane are halved relative to the image dimensions, and each R and B value is shared with the G components for which \(|i_G \times 0.5| = i_B = i_R\) and \(|j_G \times 0.5| = j_B = j_R\). The location of each plane when this image is in linear layout can be determined via `vkGetImageSubresourceLayout`, using `VK_IMAGE_ASPECT_PLANE_0_BIT` for the G plane, and `VK_IMAGE_ASPECT_PLANE_1_BIT` for the BR plane. This format only supports images with a width and height that is a multiple of two.
VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_422_UNORM_3PACK16 specifies an unsigned normalized multi-planar format that has a 10-bit G component in the top 10 bits of each 16-bit word of plane 0, a 10-bit B component in the top 10 bits of each 16-bit word of plane 1, and a 10-bit R component in the top 10 bits of each 16-bit word of plane 2, with the bottom 6 bits of each word unused. The horizontal dimension of the R and B plane is halved relative to the image dimensions, and each R and B value is shared with the G components for which $|i_G \times 0.5| = i_B = i_R$. The location of each plane when this image is in linear layout can be determined via vkGetImageSubresourceLayout, using VK_IMAGE_ASPECT_PLANE_0_BIT for the G plane, VK_IMAGE_ASPECT_PLANE_1_BIT for the B plane, and VK_IMAGE_ASPECT_PLANE_2_BIT for the R plane. This format only supports images with a width that is a multiple of two.

VK_FORMAT_G10X6_B10X6R10X6_2PLANE_422_UNORM_3PACK16 specifies an unsigned normalized multi-planar format that has a 10-bit G component in the top 10 bits of each 16-bit word of plane 0, and a two-component, 32-bit BR plane 1 consisting of a 10-bit B component in the top 10 bits of the word in bytes 0..1, and a 10-bit R component in the top 10 bits of the word in bytes 2..3, with the bottom 6 bits of each word unused. The horizontal dimension of the BR plane is halved relative to the image dimensions, and each R and B value is shared with the G components for which $|i_G \times 0.5| = i_B = i_R$. The location of each plane when this image is in linear layout can be determined via vkGetImageSubresourceLayout, using VK_IMAGE_ASPECT_PLANE_0_BIT for the G plane, and VK_IMAGE_ASPECT_PLANE_1_BIT for the BR plane. This format only supports images with a width that is a multiple of two.

VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_444_UNORM_3PACK16 specifies an unsigned normalized multi-planar format that has a 10-bit G component in the top 10 bits of each 16-bit word of plane 0, a 10-bit B component in the top 10 bits of each 16-bit word of plane 1, and a 10-bit R component in the top 10 bits of each 16-bit word of plane 2, with the bottom 6 bits of each word unused. Each plane has the same dimensions and each R, G and B component contributes to a single texel. The location of each plane when this image is in linear layout can be determined via vkGetImageSubresourceLayout, using VK_IMAGE_ASPECT_PLANE_0_BIT for the G plane, VK_IMAGE_ASPECT_PLANE_1_BIT for the B plane, and VK_IMAGE_ASPECT_PLANE_2_BIT for the R plane.

VK_FORMAT_R12X4_UNORM_PACK16 specifies a one-component, 16-bit unsigned normalized format that has a single 12-bit R component in the top 12 bits of a 16-bit word, with the bottom 4 bits unused.

VK_FORMAT_R12X4G12X4_UNORM_2PACK16 specifies a two-component, 32-bit unsigned normalized format that has a 12-bit R component in the top 12 bits of the word in bytes 0..1, and a 12-bit G component in the top 12 bits of the word in bytes 2..3, with the bottom 4 bits of each word unused.

VK_FORMAT_R12X4G12X4B12X4A12X4_UNORM_4PACK16 specifies a four-component, 64-bit unsigned normalized format that has a 12-bit R component in the top 12 bits of the word in bytes 0..1, a 12-bit G component in the top 12 bits of the word in bytes 2..3, a 12-bit B component in the top 12 bits of the word in bytes 4..5, and a 12-bit A component in the top 12 bits of the word in bytes 6..7, with the bottom 4 bits of each word unused.

VK_FORMAT_G12X4B12X4G12X4R12X4_422_UNORM_4PACK16 specifies a four-component, 64-bit format containing a pair of G components, an R component, and a B component, collectively encoding a $2 \times 1$ rectangle of unsigned normalized RGB texel data. One G value is present at each $i$ coordinate, with the B and R values shared across both G values and thus recorded at half the horizontal resolution of the image. This format has a 12-bit G component for the even $i$
coordinate in the top 12 bits of the word in bytes 0..1, a 12-bit B component in the top 12 bits of the word in bytes 2..3, a 12-bit G component for the odd \( i \) coordinate in the top 12 bits of the word in bytes 4..5, and a 12-bit R component in the top 12 bits of the word in bytes 6..7, with the bottom 4 bits of each word unused. This format only supports images with a width that is a multiple of two. For the purposes of the constraints on copy extents, this format is treated as a compressed format with a 2\( \times \)1 compressed texel block.

- **VK_FORMAT_B12X4G12X4R12X4G12X4_422_UNORM_4PACK16** specifies a four-component, 64-bit format containing a pair of G components, an R component, and a B component, collectively encoding a 2\( \times \)1 rectangle of unsigned normalized RGB texel data. One G value is present at each \( i \) coordinate, with the B and R values shared across both G values and thus recorded at half the horizontal resolution of the image. This format has a 12-bit B component in the top 12 bits of the word in bytes 0..1, a 12-bit G component for the even \( i \) coordinate in the top 12 bits of the word in bytes 2..3, a 12-bit R component in the top 12 bits of the word in bytes 4..5, and a 12-bit G component for the odd \( i \) coordinate in the top 12 bits of the word in bytes 6..7, with the bottom 4 bits of each word unused. This format only supports images with a width that is a multiple of two. For the purposes of the constraints on copy extents, this format is treated as a compressed format with a 2\( \times \)1 compressed texel block.

- **VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_420_UNORM_3PACK16** specifies an unsigned normalized multiplanar format that has a 12-bit G component in the top 12 bits of each 16-bit word of plane 0, a 12-bit B component in the top 12 bits of each 16-bit word of plane 1, and a 12-bit R component in the top 12 bits of each 16-bit word of plane 2, with the bottom 4 bits of each word unused. The horizontal and vertical dimensions of the R and B planes are halved relative to the image dimensions, and each R and B component is shared with the G components for which \( \lfloor i_G \times 0.5 \rfloor = i_B = i_R \) and \( \lfloor j_G \times 0.5 \rfloor = j_B = j_R \). The location of each plane when this image is in linear layout can be determined via `vkGetImageSubresourceLayout`, using `VK_IMAGE_ASPECT_PLANE_0_BIT` for the G plane, `VK_IMAGE_ASPECT_PLANE_1_BIT` for the B plane, and `VK_IMAGE_ASPECT_PLANE_2_BIT` for the R plane. This format only supports images with a width and height that is a multiple of two.

- **VK_FORMAT_B12X4G12X4R12X4_3PLANE_422_UNORM_3PACK16** specifies an unsigned normalized multiplanar format that has a 12-bit G component in the top 12 bits of each 16-bit word of plane 0, a 12-bit B component in the top 12 bits of each 16-bit word of plane 1, and a 12-bit R component in the top 12 bits of each 16-bit word of plane 2, with the bottom 4 bits of each word unused. The horizontal dimension of the R and B plane is halved relative to the image dimensions, and each R and B value is shared with the G components for which \( \lfloor i_G \times 0.5 \rfloor = i_B = i_R \). The location of each plane when this image is in linear layout can be determined via `vkGetImageSubresourceLayout`, using `VK_IMAGE_ASPECT_PLANE_0_BIT` for the G plane, `VK_IMAGE_ASPECT_PLANE_1_BIT` for the B plane, and `VK_IMAGE_ASPECT_PLANE_2_BIT` for the R plane. This format only supports images with a width and height that is a multiple of two.

- **VK_FORMAT_G12X4_B12X4_R12X4_2PLANE_420_UNORM_3PACK16** specifies an unsigned normalized multiplanar format that has a 12-bit G component in the top 12 bits of each 16-bit word of plane 0, and a two-component, 32-bit BR plane 1 consisting of a 12-bit B component in the top 12 bits of the word in bytes 0..1, and a 12-bit R component in the top 12 bits of the word in bytes 2..3, with the bottom 4 bits of each word unused. The horizontal and vertical dimensions of the BR plane are halved relative to the image dimensions, and each R and B value is shared with the G components for which \( \lfloor i_G \times 0.5 \rfloor = i_B = i_R \) and \( \lfloor j_G \times 0.5 \rfloor = j_B = j_R \). The location of each plane when this image is in linear layout can be determined via `vkGetImageSubresourceLayout`, using `VK_IMAGE_ASPECT_PLANE_0_BIT` for the G plane, and `VK_IMAGE_ASPECT_PLANE_1_BIT` for the BR plane. This format only supports images with a width and height that is a multiple of two.
and VK_IMAGE_ASPECT_PLANE_2_BIT for the R plane. This format only supports images with a width that is a multiple of two.

- **VK_FORMAT_G12X4_B12X4R12X4_2PLANE_422_UNORM_3PACK16** specifies an unsigned normalized multi-planar format that has a 12-bit G component in the top 12 bits of each 16-bit word of plane 0, and a two-component, 32-bit BR plane 1 consisting of a 12-bit B component in the top 12 bits of the word in bytes 0..1, and a 12-bit R component in the top 12 bits of the word in bytes 2..3, with the bottom 4 bits of each word unused. The horizontal dimension of the BR plane is halved relative to the image dimensions, and each R and B value is shared with the G components for which \(|i_G \times 0.5| = i_B = i_R\). The location of each plane when this image is in linear layout can be determined via vkGetImageSubresourceLayout, using VK_IMAGE_ASPECT_PLANE_0_BIT for the G plane, and VK_IMAGE_ASPECT_PLANE_1_BIT for the BR plane. This format only supports images with a width that is a multiple of two.

- **VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_444_UNORM_3PACK16** specifies an unsigned normalized multi-planar format that has a 12-bit G component in the top 12 bits of each 16-bit word of plane 0, a 12-bit B component in the top 12 bits of each 16-bit word of plane 1, and a 12-bit R component in the top 12 bits of each 16-bit word of plane 2, with the bottom 4 bits of each word unused. Each plane has the same dimensions and each R, G and B component contributes to a single texel. The location of each plane when this image is in linear layout can be determined via vkGetImageSubresourceLayout, using VK_IMAGE_ASPECT_PLANE_0_BIT for the G plane, VK_IMAGE_ASPECT_PLANE_1_BIT for the B plane, and VK_IMAGE_ASPECT_PLANE_2_BIT for the R plane.

- **VK_FORMAT_G16B16G16R16_422_UNORM** specifies a four-component, 64-bit format containing a pair of G components, an R component, and a B component, collectively encoding a 2×1 rectangle of unsigned normalized RGB texel data. One G value is present at each i coordinate, with the B and R values shared across both G values and thus recorded at half the horizontal resolution of the image. This format has a 16-bit G component for the even i coordinate in the word in bytes 0..1, a 16-bit B component in the word in bytes 2..3, a 16-bit G component for the odd i coordinate in the word in bytes 4..5, and a 16-bit R component in the word in bytes 6..7. This format only supports images with a width that is a multiple of two. For the purposes of the constraints on copy extents, this format is treated as a compressed format with a 2×1 compressed texel block.

- **VK_FORMAT_B16G16R16G16_422_UNORM** specifies a four-component, 64-bit format containing a pair of G components, an R component, and a B component, collectively encoding a 2×1 rectangle of unsigned normalized RGB texel data. One G value is present at each i coordinate, with the B and R values shared across both G values and thus recorded at half the horizontal resolution of the image. This format has a 16-bit B component in the word in bytes 0..1, a 16-bit G component for the even i coordinate in the word in bytes 2..3, a 16-bit R component in the word in bytes 4..5, and a 16-bit G component for the odd i coordinate in the word in bytes 6..7. This format only supports images with a width that is a multiple of two. For the purposes of the constraints on copy extents, this format is treated as a compressed format with a 2×1 compressed texel block.

- **VK_FORMAT_G16_B16_R16_3PLANE_420_UNORM** specifies an unsigned normalized multi-planar format that has a 16-bit G component in each 16-bit word of plane 0, a 16-bit B component in each 16-bit word of plane 1, and a 16-bit R component in each 16-bit word of plane 2. The horizontal and vertical dimensions of the R and B planes are halved relative to the image dimensions, and each R and B component is shared with the G components for which \(|i_G \times 0.5| = i_B = i_R\) and \(|j_G \times 0.5| = j_B = j_R\). The location of each plane when this image is in linear layout can be determined via vkGetImageSubresourceLayout, using VK_IMAGE_ASPECT_PLANE_0_BIT for the G plane, VK_IMAGE_ASPECT_PLANE_1_BIT for the B plane, and VK_IMAGE_ASPECT_PLANE_2_BIT for the R plane.
plane. This format only supports images with a width and height that is a multiple of two.

- **VK_FORMAT_G16_B16R16_2PLANE_420_UNORM** specifies an unsigned normalized multi-planar format that has a 16-bit G component in each 16-bit word of plane 0, and a two-component, 32-bit BR plane 1 consisting of a 16-bit B component in the word in bytes 0..1, and a 16-bit R component in the word in bytes 2..3. The horizontal and vertical dimensions of the BR plane are halved relative to the image dimensions, and each R and B value is shared with the G components for which \( i_G \times 0.5 = i_B = i_R \). The location of each plane when this image is in linear layout can be determined via `vkGetImageSubresourceLayout`, using `VK_IMAGE_ASPECT_PLANE_0_BIT` for the G plane, and `VK_IMAGE_ASPECT_PLANE_1_BIT` for the BR plane. This format only supports images with a width and height that is a multiple of two.

- **VK_FORMAT_G16_B16_R16_3PLANE_422_UNORM** specifies an unsigned normalized multi-planar format that has a 16-bit G component in each 16-bit word of plane 0, a 16-bit B component in each 16-bit word of plane 1, and a 16-bit R component in each 16-bit word of plane 2. The horizontal dimension of the R and B plane is halved relative to the image dimensions, and each R and B value is shared with the G components for which \( i_G \times 0.5 = i_B = i_R \). The location of each plane when this image is in linear layout can be determined via `vkGetImageSubresourceLayout`, using `VK_IMAGE_ASPECT_PLANE_0_BIT` for the G plane, `VK_IMAGE_ASPECT_PLANE_1_BIT` for the B plane, and `VK_IMAGE_ASPECT_PLANE_2_BIT` for the R plane. This format only supports images with a width that is a multiple of two.

- **VK_FORMAT_G16_B16R16_2PLANE_422_UNORM** specifies an unsigned normalized multi-planar format that has a 16-bit G component in each 16-bit word of plane 0, and a two-component, 32-bit BR plane 1 consisting of a 16-bit B component in the word in bytes 0..1, and a 16-bit R component in the word in bytes 2..3. The horizontal dimension of the BR plane is halved relative to the image dimensions, and each R and B value is shared with the G components for which \( i_G \times 0.5 = i_B = i_R \). The location of each plane when this image is in linear layout can be determined via `vkGetImageSubresourceLayout`, using `VK_IMAGE_ASPECT_PLANE_0_BIT` for the G plane, and `VK_IMAGE_ASPECT_PLANE_1_BIT` for the BR plane. This format only supports images with a width that is a multiple of two.

- **VK_FORMAT_G16_B16_R16_3PLANE_444_UNORM** specifies an unsigned normalized multi-planar format that has a 16-bit G component in each 16-bit word of plane 0, a 16-bit B component in each 16-bit word of plane 1, and a 16-bit R component in each 16-bit word of plane 2. Each plane has the same dimensions and each R, G and B component contributes to a single texel. The location of each plane when this image is in linear layout can be determined via `vkGetImageSubresourceLayout`, using `VK_IMAGE_ASPECT_PLANE_0_BIT` for the G plane, `VK_IMAGE_ASPECT_PLANE_1_BIT` for the B plane, and `VK_IMAGE_ASPECT_PLANE_2_BIT` for the R plane.

- **VK_FORMAT_G8_B8R8_2PLANE_444_UNORM** specifies an unsigned normalized multi-planar format that has an 8-bit G component in plane 0, and a two-component, 16-bit BR plane 1 consisting of an 8-bit B component in byte 0 and an 8-bit R component in byte 1. Both planes have the same dimensions and each R, G and B component contributes to a single texel. The location of each plane when this image is in linear layout can be determined via `vkGetImageSubresourceLayout`, using `VK_IMAGE_ASPECT_PLANE_0_BIT` for the G plane, `VK_IMAGE_ASPECT_PLANE_1_BIT` for the BR plane.

- **VK_FORMAT_G10X6_B10X6R10X6_2PLANE_444_UNORM_3PACK16** specifies an unsigned normalized multi-planar format that has a 10-bit G component in the top 10 bits of each 16-bit word of plane 0, and a two-component, 32-bit BR plane 1 consisting of a 10-bit B component in the top 10 bits of
the word in bytes 0..1, and a 10-bit R component in the top 10 bits of the word in bytes 2..3, the bottom 6 bits of each word unused. Both planes have the same dimensions and each R, G and B component contributes to a single texel. The location of each plane when this image is in linear layout can be determined via \texttt{vkGetImageSubresourceLayout}, using \texttt{VK_IMAGE_ASPECT_PLANE_0_BIT} for the G plane, and \texttt{VK_IMAGE_ASPECT_PLANE_1_BIT} for the BR plane.

- \texttt{VK_FORMAT_G12X4_B12X4R12X4_2PLANE_444_UNORM_3PACK16} specifies an unsigned normalized multi-planar format that has a 12-bit G component in the top 12 bits of each 16-bit word of plane 0, and a two-component, 32-bit BR plane 1 consisting of a 12-bit B component in the top 12 bits of the word in bytes 0..1, and a 12-bit R component in the top 12 bits of the word in bytes 2..3, the bottom 4 bits of each word unused. Both planes have the same dimensions and each R, G and B component contributes to a single texel. The location of each plane when this image is in linear layout can be determined via \texttt{vkGetImageSubresourceLayout}, using \texttt{VK_IMAGE_ASPECT_PLANE_0_BIT} for the G plane, and \texttt{VK_IMAGE_ASPECT_PLANE_1_BIT} for the BR plane.

- \texttt{VK_FORMAT_G16_B16R16_2PLANE_444_UNORM} specifies an unsigned normalized multi-planar format that has a 16-bit G component in each 16-bit word of plane 0, and a two-component, 32-bit BR plane 1 consisting of a 16-bit B component in the word in bytes 0..1, and a 16-bit R component in the word in bytes 2..3. Both planes have the same dimensions and each R, G and B component contributes to a single texel. The location of each plane when this image is in linear layout can be determined via \texttt{vkGetImageSubresourceLayout}, using \texttt{VK_IMAGE_ASPECT_PLANE_0_BIT} for the G plane, and \texttt{VK_IMAGE_ASPECT_PLANE_1_BIT} for the BR plane.

- \texttt{VK_FORMAT_PVRTC1_2BPP_UNORM_BLOCK_IMG} specifies a four-component, PVRTC compressed format where each 64-bit compressed texel block encodes an 8×4 rectangle of unsigned normalized RGBA texel data.

- \texttt{VK_FORMAT_PVRTC1_4BPP_UNORM_BLOCK_IMG} specifies a four-component, PVRTC compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGBA texel data.

- \texttt{VK_FORMAT_PVRTC2_2BPP_UNORM_BLOCK_IMG} specifies a four-component, PVRTC compressed format where each 64-bit compressed texel block encodes an 8×4 rectangle of unsigned normalized RGBA texel data.

- \texttt{VK_FORMAT_PVRTC2_4BPP_UNORM_BLOCK_IMG} specifies a four-component, PVRTC compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGBA texel data.

- \texttt{VK_FORMAT_PVRTC1_2BPP_SRGB_BLOCK_IMG} specifies a four-component, PVRTC compressed format where each 64-bit compressed texel block encodes an 8×4 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

- \texttt{VK_FORMAT_PVRTC1_4BPP_SRGB_BLOCK_IMG} specifies a four-component, PVRTC compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

- \texttt{VK_FORMAT_PVRTC2_2BPP_SRGB_BLOCK_IMG} specifies a four-component, PVRTC compressed format where each 64-bit compressed texel block encodes an 8×4 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.

- \texttt{VK_FORMAT_PVRTC2_4BPP_SRGB_BLOCK_IMG} specifies a four-component, PVRTC compressed format where each 64-bit compressed texel block encodes a 4×4 rectangle of unsigned normalized RGBA texel data with sRGB nonlinear encoding applied to the RGB components.
• **VK_FORMAT_R16G16_S10_5_NV** specifies a two-component, fixed-point format where most significant bit specifies the sign bit, next 10 bits specify the integer value and last 5 bits represent the fractional value.

### 48.1.1. Compatible formats of planes of multi-planar formats

Individual planes of multi-planar formats are size-compatible with single-plane color formats if they occupy the same number of bits per texel block, and are compatible with those formats if they have the same block extent.

In the following table, individual planes of a *multi-planar* format are compatible with the format listed against the relevant plane index for that multi-planar format, and any format compatible with the listed single-plane format according to Format Compatibility Classes. These planes are also size-compatible with any format that is size-compatible with the listed single-plane format.

**Table 58. Plane Format Compatibility Table**

<table>
<thead>
<tr>
<th>Plane</th>
<th>Compatible format for plane</th>
<th>Width relative to the width ( w ) of the plane with the largest dimensions</th>
<th>Height relative to the height ( h ) of the plane with the largest dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_FORMAT_G8_B8_R8_3PLANE_420_UNORM</td>
<td>VK_FORMAT_R8_UNORM</td>
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</tr>
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<td>( h ) /2</td>
</tr>
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<td>( w ) /2</td>
<td>( h ) /2</td>
</tr>
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<td>( h )</td>
</tr>
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<td>( h ) /2</td>
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<td>( h )</td>
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<td>Plane</td>
<td>Compatible format for plane</td>
<td>Width relative to the width $w$ of the plane with the largest dimensions</td>
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<td>( w )</td>
<td>( h )</td>
</tr>
</tbody>
</table>
48.1.2. Multi-planar format image aspect

When using `VkImageAspectFlagBits` to select a plane of a multi-planar format, the following are the valid options:

- Two planes
  - `VK_IMAGE_ASPECT_PLANE_0_BIT`
  - `VK_IMAGE_ASPECT_PLANE_1_BIT`

- Three planes
  - `VK_IMAGE_ASPECT_PLANE_0_BIT`
  - `VK_IMAGE_ASPECT_PLANE_1_BIT`
  - `VK_IMAGE_ASPECT_PLANE_2_BIT`

48.1.3. Packed Formats

For the purposes of address alignment when accessing buffer memory containing vertex attribute or texel data, the following formats are considered packed - components of the texels or attributes are stored in bitfields packed into one or more 8-, 16-, or 32-bit fundamental data type.

- Packed into 8-bit data types:
  - `VK_FORMAT_R4G4_UNORM_PACK8`

- Packed into 16-bit data types:
  - `VK_FORMAT_R4G4B4A4_UNORM_PACK16`
  - `VK_FORMAT_B4G4R4A4_UNORM_PACK16`
  - `VK_FORMAT_R5G6B5_UNORM_PACK16`
  - `VK_FORMAT_B5G6R5_UNORM_PACK16`
  - `VK_FORMAT_R5G5B5A1_UNORM_PACK16`
  - `VK_FORMAT_B5G5R5A1_UNORM_PACK16`
  - `VK_FORMAT_A1R5G5B5_UNORM_PACK16`
  - `VK_FORMAT_A1B5G5R5_UNORM_PACK16_KHR`
  - `VK_FORMAT_R10X6_UNORM_PACK16`
  - `VK_FORMAT_R10X6G10X6_UNORM_2PACK16`
  - `VK_FORMAT_R10X6G10X6B10X6A10X6_UNORM_4PACK16`
  - `VK_FORMAT_G10X6B10X6G10X6R10X6_422_UNORM_4PACK16`
  - `VK_FORMAT_B10X6G10X6R10X6G10X6_422_UNORM_4PACK16`
  - `VK_FORMAT_G10X6B10X6_R10X6_3PLANE_420_UNORM_3PACK16`
  - `VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_420_UNORM_3PACK16`
  - `VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_422_UNORM_3PACK16`
  - `VK_FORMAT_G10X6_B10X6R10X6_2PLANE_422_UNORM_3PACK16`
- VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_444_UNORM_3PACK16
- VK_FORMAT_R12X4_UNORM_PACK16
- VK_FORMAT_R12X4G12X4_UNORM_2PACK16
- VK_FORMAT_R12X4G12X4B12X4A12X4_UNORM_4PACK16
- VK_FORMAT_G12X4B12X4G12X4R12X4_422_UNORM_4PACK16
- VK_FORMAT_B12X4G12X4R12X4_422_UNORM_4PACK16
- VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_420_UNORM_3PACK16
- VK_FORMAT_G12X4_B12X4R12X4_2PLANE_420_UNORM_3PACK16
- VK_FORMAT_G12X4_B12X4R12X4_2PLANE_422_UNORM_3PACK16
- VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_444_UNORM_3PACK16
- VK_FORMAT_G10X6_B10X6R10X6_2PLANE_444_UNORM_3PACK16
- VK_FORMAT_G12X4_B12X4R12X4_2PLANE_444_UNORM_3PACK16

- Packed into 32-bit data types:
  - VK_FORMAT_A8B8G8R8_UNORM_PACK32
  - VK_FORMAT_A8B8G8R8_SNORM_PACK32
  - VK_FORMAT_A8B8G8R8_USCALED_PACK32
  - VK_FORMAT_A8B8G8R8_SSCALED_PACK32
  - VK_FORMAT_A8B8G8R8_UINT_PACK32
  - VK_FORMAT_A8B8G8R8_SINT_PACK32
  - VK_FORMAT_A8B8G8R8_SRGB_PACK32
  - VK_FORMAT_A2R10G10B10_UNORM_PACK32
  - VK_FORMAT_A2R10G10B10_SNORM_PACK32
  - VK_FORMAT_A2R10G10B10_USCALED_PACK32
  - VK_FORMAT_A2R10G10B10_SSCALED_PACK32
  - VK_FORMAT_A2R10G10B10_UINT_PACK32
  - VK_FORMAT_A2R10G10B10_SINT_PACK32
48.1.4. Identification of Formats

A “format” is represented by a single enum value. The name of a format is usually built up by using the following pattern:

\[ \text{VK_FORMAT}_{\text{component-format|compression-scheme}}_{\text{numeric-format}} \]

The component-format indicates either the size of the R, G, B, and A components (if they are present) in the case of a color format, or the size of the depth (D) and stencil (S) components (if they are present) in the case of a depth/stencil format (see below). An X indicates a component that is unused, but may be present for padding.
<table>
<thead>
<tr>
<th>Numeric format</th>
<th>Type-Declaration instructions</th>
<th>Numeric type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNORM</td>
<td>OpTypeFloat</td>
<td>floating-point</td>
<td>The components are unsigned normalized values in the range [0,1]</td>
</tr>
<tr>
<td>SNORM</td>
<td>OpTypeFloat</td>
<td>floating-point</td>
<td>The components are signed normalized values in the range [-1,1]</td>
</tr>
<tr>
<td>USCALED</td>
<td>OpTypeFloat</td>
<td>floating-point</td>
<td>The components are unsigned integer values that get converted to floating-point in the range [0,2\textsuperscript{n}-1]</td>
</tr>
<tr>
<td>SSCALED</td>
<td>OpTypeFloat</td>
<td>floating-point</td>
<td>The components are signed integer values that get converted to floating-point in the range [-2\textsuperscript{n-1},2\textsuperscript{n-1}-1]</td>
</tr>
<tr>
<td>UINT</td>
<td>OpTypeInt</td>
<td>unsigned integer</td>
<td>The components are unsigned integer values in the range [0,2\textsuperscript{n}-1]</td>
</tr>
<tr>
<td>SINT</td>
<td>OpTypeInt</td>
<td>signed integer</td>
<td>The components are signed integer values in the range [-2\textsuperscript{n-1},2\textsuperscript{n-1}-1]</td>
</tr>
<tr>
<td>UFLOAT</td>
<td>OpTypeFloat</td>
<td>floating-point</td>
<td>The components are unsigned floating-point numbers (used by packed, shared exponent, and some compressed formats)</td>
</tr>
<tr>
<td>SFLOAT</td>
<td>OpTypeFloat</td>
<td>floating-point</td>
<td>The components are signed floating-point numbers</td>
</tr>
<tr>
<td>SRGB</td>
<td>OpTypeFloat</td>
<td>floating-point</td>
<td>The R, G, and B components are unsigned normalized values that represent values using sRGB nonlinear encoding, while the A component (if one exists) is a regular unsigned normalized value</td>
</tr>
</tbody>
</table>

n is the number of bits in the component.

The suffix \_PACKnn indicates that the format is packed into an underlying type with nn bits. The suffix \_mPACKnn is a short-hand that indicates that the format has m groups of components (which may or may not be stored in separate planes) that are each packed into an underlying type with nn bits.

The suffix \_BLOCK indicates that the format is a block-compressed format, with the representation of multiple pixels encoded interdependently within a region.

<table>
<thead>
<tr>
<th>Compression scheme</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC</td>
<td>Block Compression. See Block-Compressed Image Formats.</td>
</tr>
<tr>
<td>ETC2</td>
<td>Ericsson Texture Compression. See ETC Compressed Image Formats.</td>
</tr>
<tr>
<td>EAC</td>
<td>ETC2 Alpha Compression. See ETC Compressed Image Formats.</td>
</tr>
<tr>
<td>Compression scheme</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>ASTC</td>
<td>Adaptive Scalable Texture Compression (LDR Profile). See <a href="#">ASTC Compressed Image Formats</a>.</td>
</tr>
</tbody>
</table>

For multi-planar images, the components in separate planes are separated by underscores, and the number of planes is indicated by the addition of a `_2PLANE` or `_3PLANE` suffix. Similarly, the separate aspects of depth-stencil formats are separated by underscores, although these are not considered separate planes. Formats are suffixed by `_422` to indicate that planes other than the first are reduced in size by a factor of two horizontally or that the R and B values appear at half the horizontal frequency of the G values, `_420` to indicate that planes other than the first are reduced in size by a factor of two both horizontally and vertically, and `_444` for consistency to indicate that all three planes of a three-planar image are the same size.

**Note**
No common format has a single plane containing both R and B components but does not store these components at reduced horizontal resolution.

### 48.1.5. Representation and Texel Block Size

Color formats must be represented in memory in exactly the form indicated by the format's name. This means that promoting one format to another with more bits per component and/or additional components must not occur for color formats. Depth/stencil formats have more relaxed requirements as discussed below.

Each format has a texel block size, the number of bytes used to store one texel block (a single addressable element of an uncompressed image, or a single compressed block of a compressed image). The texel block size for each format is shown in the [Compatible formats](#) table.

The representation of non-packed formats is that the first component specified in the name of the format is in the lowest memory addresses and the last component specified is in the highest memory addresses. See [Byte mappings for non-packed/compressed color formats](#). The in-memory ordering of bytes within a component is determined by the host endianness.

**Table 61. Byte mappings for non-packed/compressed color formats**

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>→ Byte</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><code>VK_FORMAT_R8_*</code></td>
</tr>
<tr>
<td>R</td>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><code>VK_FORMAT_R8G8_*</code></td>
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<tr>
<td>R</td>
<td>G</td>
<td>B</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td><code>VK_FORMAT_R8G8B8_*</code></td>
</tr>
<tr>
<td>B</td>
<td>G</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td><code>VK_FORMAT_B8G8R8_*</code></td>
</tr>
<tr>
<td>R</td>
<td>G</td>
<td>B</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td><code>VK_FORMAT_R8G8B8A8_*</code></td>
</tr>
<tr>
<td>B</td>
<td>G</td>
<td>R</td>
<td>A</td>
<td></td>
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<td></td>
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<td><code>VK_FORMAT_B8G8R8A8_*</code></td>
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<td></td>
<td></td>
<td></td>
<td><code>VK_FORMAT_A8_UNORM_KHR</code></td>
</tr>
<tr>
<td>G</td>
<td>B</td>
<td>G</td>
<td>R</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td><code>VK_FORMAT_G8B8G8R8_422_UNORM</code></td>
</tr>
</tbody>
</table>
Packed formats store multiple components within one underlying type. The bit representation is that the first component specified in the name of the format is in the most-significant bits and the last component specified is in the least-significant bits of the underlying type. The in-memory ordering of bytes comprising the underlying type is determined by the host endianness.

Table 62. Bit mappings for packed 8-bit formats

<table>
<thead>
<tr>
<th>Bit</th>
<th>VK_FORMAT_R4G4_UNORM_PACK8</th>
</tr>
</thead>
<tbody>
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<td>7</td>
<td>6</td>
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<tr>
<td>R</td>
<td>G</td>
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</table>

Table 63. Bit mappings for packed 16-bit formats

<table>
<thead>
<tr>
<th>Bit</th>
<th>VK_FORMAT_R4G4B4A4_UNORM_PACK16</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>R</td>
<td>G</td>
</tr>
</tbody>
</table>

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Table 64. Bit mappings for packed 32-bit formats

<table>
<thead>
<tr>
<th>Bit</th>
<th>B</th>
<th>G</th>
<th>R</th>
<th>A</th>
</tr>
</thead>
<tbody>
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<td>3210</td>
<td>3210</td>
<td>3210</td>
<td></td>
</tr>
<tr>
<td><strong>VK_FORMAT_A4R4G4B4_UNORM_PACK16</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>R</td>
<td>G</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>3210</td>
<td>3210</td>
<td>3210</td>
<td>3210</td>
<td></td>
</tr>
<tr>
<td><strong>VK_FORMAT_A4R4G4B4R4_UNORM_PACK16</strong></td>
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<td></td>
</tr>
<tr>
<td>A</td>
<td>B</td>
<td>G</td>
<td>R</td>
<td></td>
</tr>
<tr>
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<td>3210</td>
<td>3210</td>
<td>3210</td>
<td></td>
</tr>
<tr>
<td><strong>VK_FORMAT_R5G6B5_UNORM_PACK16</strong></td>
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</tr>
<tr>
<td>R</td>
<td>G</td>
<td>B</td>
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<td>43210</td>
<td>43210</td>
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<td></td>
</tr>
<tr>
<td><strong>VK_FORMAT_B5G6R5_UNORM_PACK16</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>G</td>
<td>R</td>
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<tr>
<td>43210</td>
<td>43210</td>
<td>43210</td>
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</tr>
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<tr>
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</tr>
<tr>
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</tr>
<tr>
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<td>A</td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>VK_FORMAT_A1B5G5R5_UNORM_PACK16_KHR</strong></td>
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</tr>
<tr>
<td>A</td>
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<td>R</td>
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</tr>
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<td>043210</td>
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<td></td>
</tr>
<tr>
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</tr>
<tr>
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</tr>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td></td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**VK_FORMAT_A8B8G8R8_*_PACK32**
### 48.1.6. Depth/Stencil Formats

Depth/stencil formats are considered opaque and need not be stored in the exact number of bits per texel or component ordering indicated by the format enum. However, implementations must not substitute a different depth or stencil precision than is described in the format (e.g. D16 must not be implemented as D24 or D32).

### 48.1.7. Format Compatibility Classes

Uncompressed color formats are compatible with each other if they occupy the same number of bits per texel block as long as neither or both are alpha formats (e.g., VK_FORMAT_A8_UNORM_KHR). Compressed color formats are compatible with each other if the only difference between them is the numeric format of the uncompressed pixels. Each depth/stencil format is only compatible with itself. In the following table, all the formats in the same row are compatible. Each format has a defined texel block extent specifying how many texels each texel block represents in each dimension.

*Table 65. Compatible Formats*
<table>
<thead>
<tr>
<th>Class, Texel Block Size, Texel Block Extent, # Texels/Block</th>
<th>Formats</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-bit</td>
<td>VK_FORMAT_R4G4_UNORM_PACK8, VK_FORMAT_R8_UNORM, VK_FORMAT_R8_SNORM,</td>
</tr>
<tr>
<td>Block size 1 byte</td>
<td>VK_FORMAT_R8_USCALED, VK_FORMAT_R8_SSCALED, VK_FORMAT_R8_UINT,</td>
</tr>
<tr>
<td>1x1x1 block extent</td>
<td>VK_FORMAT_R8_SINT, VK_FORMAT_R8_SR8G8</td>
</tr>
<tr>
<td>1 texel/block</td>
<td></td>
</tr>
<tr>
<td>16-bit</td>
<td>VK_FORMAT_A1B5G5R5_UNORM_PACK16_KHR, VK_FORMAT_R10X6_UNORM_PACK16,</td>
</tr>
<tr>
<td>Block size 2 byte</td>
<td>VK_FORMAT_R12X4_UNORM_PACK16, VK_FORMAT_A4R4G4B4_UNORM_PACK16,</td>
</tr>
<tr>
<td>1x1x1 block extent</td>
<td>VK_FORMAT_A4B4G4R4_UNORM_PACK16, VK_FORMAT_R4G4B4A4_UNORM_PACK16,</td>
</tr>
<tr>
<td>1 texel/block</td>
<td>VK_FORMAT_B4G4R4A4_UNORM_PACK16, VK_FORMAT_R5G6B5_UNORM_PACK16,</td>
</tr>
<tr>
<td></td>
<td>VK_FORMAT_B5G6R5_UNORM_PACK16, VK_FORMAT_R5G5B5A1_UNORM_PACK16,</td>
</tr>
<tr>
<td></td>
<td>VK_FORMAT_B5G5R5A1_UNORM_PACK16, VK_FORMAT_A1R5G5B5_UNORM_PACK16,</td>
</tr>
<tr>
<td></td>
<td>VK_FORMAT_R8G8_UNORM, VK_FORMAT_R8G8_SNORM, VK_FORMAT_R8G8_USCALED,</td>
</tr>
<tr>
<td></td>
<td>VK_FORMAT_R8G8_SSCALED, VK_FORMAT_R8G8_UINT, VK_FORMAT_R8G8_SINT,</td>
</tr>
<tr>
<td></td>
<td>VK_FORMAT_R8G8_SR8G8, VK_FORMAT_R8G8_R16_UNORM, VK_FORMAT_R16_SNORM,</td>
</tr>
<tr>
<td></td>
<td>VK_FORMAT_R16_USCALED, VK_FORMAT_R16_SSCALED, VK_FORMAT_R16_UINT,</td>
</tr>
<tr>
<td></td>
<td>VK_FORMAT_R16_SINT, VK_FORMAT_R16_SR8G8</td>
</tr>
<tr>
<td>8-bit alpha</td>
<td>VK_FORMAT_A8_UNORM_KHR</td>
</tr>
<tr>
<td>Block size 1 byte</td>
<td></td>
</tr>
<tr>
<td>1x1x1 block extent</td>
<td></td>
</tr>
<tr>
<td>1 texel/block</td>
<td></td>
</tr>
<tr>
<td>Class, Texel Block Size, Texel Block Extent, # Texels/Block</td>
<td>Formats</td>
</tr>
<tr>
<td>-------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>24-bit Block size 3 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_R8G8B8_UNORM, VK_FORMAT_R8G8B8_SNORM, VK_FORMAT_R8G8B8_USCALED, VK_FORMAT_R8G8B8_SSCALED, VK_FORMAT_R8G8B8_UINT, VK_FORMAT_R8G8B8_SINT, VK_FORMAT_R8G8B8_SRGB, VK_FORMAT_B8G8R8_UNORM, VK_FORMAT_B8G8R8_SNORM, VK_FORMAT_B8G8R8_USCALED, VK_FORMAT_B8G8R8_SSCALED, VK_FORMAT_B8G8R8_UINT, VK_FORMAT_B8G8R8_SINT, VK_FORMAT_B8G8R8_SRGB</td>
</tr>
<tr>
<td>Class, Texel Block Size, Texel Block Extent, # Texels/Block</td>
<td>Formats</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>32-bit Block size 4 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_R10X6G10X6_UNORM_2PACK16, VK_FORMAT_R12X4G12X4_UNORM_2PACK16, VK_FORMAT_R16G16_S10_5_NV, VK_FORMAT_R8G8B8A8_UNORM, VK_FORMAT_R8G8B8A8_SNORM, VK_FORMAT_R8G8B8A8_USCALED, VK_FORMAT_R8G8B8A8_SSCALED, VK_FORMAT_R8G8B8A8_UINT, VK_FORMAT_R8G8B8A8_SINT, VK_FORMAT_R8G8B8A8_SRGB, VK_FORMAT_B8G8R8A8_UNORM, VK_FORMAT_B8G8R8A8_SNORM, VK_FORMAT_B8G8R8A8_USCALED, VK_FORMAT_B8G8R8A8_SSCALED, VK_FORMAT_B8G8R8A8_UINT, VK_FORMAT_B8G8R8A8_SINT, VK_FORMAT_B8G8R8A8_SRGB, VK_FORMAT_A8B8G8R8_UNORM_PACK32, VK_FORMAT_A8B8G8R8_SNORM_PACK32, VK_FORMAT_A8B8G8R8_USCALED_PACK32, VK_FORMAT_A8B8G8R8_SSCALED_PACK32, VK_FORMAT_A8B8G8R8_UINT_PACK32, VK_FORMAT_A8B8G8R8_SINT_PACK32, VK_FORMAT_A8B8G8R8_SRGB_PACK32, VK_FORMAT_A2R10G10B10_UNORM_PACK32, VK_FORMAT_A2R10G10B10_SNORM_PACK32, VK_FORMAT_A2R10G10B10_USCALED_PACK32, VK_FORMAT_A2R10G10B10_SSCALED_PACK32, VK_FORMAT_A2R10G10B10_UINT_PACK32, VK_FORMAT_A2R10G10B10_SINT_PACK32, VK_FORMAT_A2B10G10R10_UNORM_PACK32, VK_FORMAT_A2B10G10R10_SNORM_PACK32, VK_FORMAT_A2B10G10R10_USCALED_PACK32, VK_FORMAT_A2B10G10R10_SSCALED_PACK32, VK_FORMAT_A2B10G10R10_UINT_PACK32, VK_FORMAT_A2B10G10R10_SINT_PACK32, VK_FORMAT_R16G16_UNORM, VK_FORMAT_R16G16_SNORM, VK_FORMAT_R16G16_USCALED, VK_FORMAT_R16G16_SSCALED, VK_FORMAT_R16G16_UINT, VK_FORMAT_R16G16_SINT, VK_FORMAT_R16G16_SFLOAT, VK_FORMAT_R32_UINT, VK_FORMAT_R32_SINT, VK_FORMAT_R32_SFLOAT, VK_FORMAT_B10G11R11_UFLOAT_PACK32, VK_FORMAT_E5B9G9R9_UFLOAT_PACK32</td>
</tr>
<tr>
<td>Class, Texel Block Size, Texel Block Extent, # Texels/Block</td>
<td>Formats</td>
</tr>
<tr>
<td>------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>48-bit Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_R16G16B16_UINT, VK_FORMAT_R16G16B16_SNORM, VK_FORMAT_R16G16B16_USCALED, VK_FORMAT_R16G16B16_SSCALED, VK_FORMAT_R16G16B16_UINT, VK_FORMAT_R16G16B16_SINT, VK_FORMAT_R16G16B16_SFLOAT</td>
</tr>
<tr>
<td>96-bit Block size 12 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_R32G32B32_UINT, VK_FORMAT_R32G32B32_SINT, VK_FORMAT_R32G32B32_SFLOAT</td>
</tr>
<tr>
<td>128-bit Block size 16 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_R32G32B32A32_UINT, VK_FORMAT_R32G32B32A32_SINT, VK_FORMAT_R32G32B32A32_SFLOAT, VK_FORMAT_R64G64_UINT, VK_FORMAT_R64G64_SINT, VK_FORMAT_R64G64_SFLOAT</td>
</tr>
<tr>
<td>192-bit Block size 24 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_R64G64B64_UINT, VK_FORMAT_R64G64B64_SINT, VK_FORMAT_R64G64B64_SFLOAT</td>
</tr>
<tr>
<td>256-bit Block size 32 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_R64G64B64A64_UINT, VK_FORMAT_R64G64B64A64_SINT, VK_FORMAT_R64G64B64A64_SFLOAT</td>
</tr>
<tr>
<td>Class, Texel Block Size, Texel Block Extent, # Texels/Block</td>
<td>Formats</td>
</tr>
<tr>
<td>-------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>D16 Block size 2 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_D16_UNORM</td>
</tr>
<tr>
<td>D24 Block size 4 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_X8_D24_UNORM_PACK32</td>
</tr>
<tr>
<td>D32 Block size 4 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_D32_SFLOAT</td>
</tr>
<tr>
<td>S8 Block size 1 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_S8_UINT</td>
</tr>
<tr>
<td>D16S8 Block size 3 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_D16_UNORM_S8_UINT</td>
</tr>
<tr>
<td>D24S8 Block size 4 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_D24_UNORM_S8_UINT</td>
</tr>
<tr>
<td>D32S8 Block size 5 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_D32_SFLOAT_S8_UINT</td>
</tr>
<tr>
<td>BC1_RGB Block size 8 byte 4x4x1 block extent 16 texel/block</td>
<td>VK_FORMAT_BC1_RGB_UNORM_BLOCK, VK_FORMAT_BC1_RGB_SRGB_BLOCK</td>
</tr>
<tr>
<td>BC1_RGBA Block size 8 byte 4x4x1 block extent 16 texel/block</td>
<td>VK_FORMAT_BC1_RGBA_UNORM_BLOCK, VK_FORMAT_BC1_RGBA_SRGB_BLOCK</td>
</tr>
<tr>
<td>BC2 Block size 16 byte 4x4x1 block extent 16 texel/block</td>
<td>VK_FORMAT_BC2_UNORM_BLOCK, VK_FORMAT_BC2_SRGB_BLOCK</td>
</tr>
<tr>
<td>Class, Texel Block Size, Texel Block Extent, # Texels/Block</td>
<td>Formats</td>
</tr>
<tr>
<td>------------------------------------------------------------</td>
<td>----------------------------------------------</td>
</tr>
<tr>
<td>BC3 Block size 16 byte 4x4x1 block extent 16 texel/block</td>
<td>VK_FORMAT_BC3_UNORM_BLOCK,</td>
</tr>
<tr>
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<td>VK_FORMAT_BC3_SRGB_BLOCK</td>
</tr>
<tr>
<td>BC4 Block size 8 byte 4x4x1 block extent 16 texel/block</td>
<td>VK_FORMAT_BC4_UNORM_BLOCK,</td>
</tr>
<tr>
<td></td>
<td>VK_FORMAT_BC4_SNORM_BLOCK</td>
</tr>
<tr>
<td>BC5 Block size 16 byte 4x4x1 block extent 16 texel/block</td>
<td>VK_FORMAT_BC5_UNORM_BLOCK,</td>
</tr>
<tr>
<td></td>
<td>VK_FORMAT_BC5_SNORM_BLOCK</td>
</tr>
<tr>
<td>BC6H Block size 16 byte 4x4x1 block extent 16 texel/block</td>
<td>VK_FORMAT_BC6H_UFLOAT_BLOCK,</td>
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<tr>
<td></td>
<td>VK_FORMAT_BC6H_SFLOAT_BLOCK</td>
</tr>
<tr>
<td>BC7 Block size 16 byte 4x4x1 block extent 16 texel/block</td>
<td>VK_FORMAT_BC7_UNORM_BLOCK,</td>
</tr>
<tr>
<td></td>
<td>VK_FORMAT_BC7_SRGB_BLOCK</td>
</tr>
<tr>
<td>ETC2_RGB Block size 8 byte 4x4x1 block extent 16 texel/block</td>
<td>VK_FORMAT_ETC2_R8G8B8_UNORM_BLOCK,</td>
</tr>
<tr>
<td></td>
<td>VK_FORMAT_ETC2_R8G8B8_SRGB_BLOCK</td>
</tr>
<tr>
<td>ETC2_RGBA Block size 8 byte 4x4x1 block extent 16 texel/block</td>
<td>VK_FORMAT_ETC2_R8G8B8A1_UNORM_BLOCK,</td>
</tr>
<tr>
<td></td>
<td>VK_FORMAT_ETC2_R8G8B8A1_SRGB_BLOCK</td>
</tr>
<tr>
<td>ETC2_EAC_RGBA Block size 16 byte 4x4x1 block extent 16 texel/block</td>
<td>VK_FORMAT_ETC2_R8G8B8A8_UNORM_BLOCK,</td>
</tr>
<tr>
<td></td>
<td>VK_FORMAT_ETC2_R8G8B8A8_SRGB_BLOCK</td>
</tr>
<tr>
<td>EAC_R Block size 8 byte 4x4x1 block extent 16 texel/block</td>
<td>VK_FORMAT_EAC_R11_UNORM_BLOCK,</td>
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<tr>
<td></td>
<td>VK_FORMAT_EAC_R11_SNORM_BLOCK</td>
</tr>
<tr>
<td>EAC_RG Block size 16 byte 4x4x1 block extent 16 texel/block</td>
<td>VK_FORMAT_EAC_R11G11_UNORM_BLOCK,</td>
</tr>
<tr>
<td></td>
<td>VK_FORMAT_EAC_R11G11_SNORM_BLOCK</td>
</tr>
<tr>
<td>Class, Texel Block Size, Texel Block Extent, # Texels/Block</td>
<td>Formats</td>
</tr>
<tr>
<td>-------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>ASTC_4x4 Block size 16 byte 4x4x1 block extent 16 texel/block</td>
<td>VK_FORMAT_ASTC_4x4_SFLOAT_BLOCK, VK_FORMAT_ASTC_4x4_UNORM_BLOCK, VK_FORMAT_ASTC_4x4_SRGB_BLOCK</td>
</tr>
<tr>
<td>ASTC_5x4 Block size 16 byte 5x4x1 block extent 20 texel/block</td>
<td>VK_FORMAT_ASTC_5x4_SFLOAT_BLOCK, VK_FORMAT_ASTC_5x4_UNORM_BLOCK, VK_FORMAT_ASTC_5x4_SRGB_BLOCK</td>
</tr>
<tr>
<td>ASTC_5x5 Block size 16 byte 5x5x1 block extent 25 texel/block</td>
<td>VK_FORMAT_ASTC_5x5_SFLOAT_BLOCK, VK_FORMAT_ASTC_5x5_UNORM_BLOCK, VK_FORMAT_ASTC_5x5_SRGB_BLOCK</td>
</tr>
<tr>
<td>ASTC_6x5 Block size 16 byte 6x5x1 block extent 30 texel/block</td>
<td>VK_FORMAT_ASTC_6x5_SFLOAT_BLOCK, VK_FORMAT_ASTC_6x5_UNORM_BLOCK, VK_FORMAT_ASTC_6x5_SRGB_BLOCK</td>
</tr>
<tr>
<td>ASTC_6x6 Block size 16 byte 6x6x1 block extent 36 texel/block</td>
<td>VK_FORMAT_ASTC_6x6_SFLOAT_BLOCK, VK_FORMAT_ASTC_6x6_UNORM_BLOCK, VK_FORMAT_ASTC_6x6_SRGB_BLOCK</td>
</tr>
<tr>
<td>ASTC_8x5 Block size 16 byte 8x5x1 block extent 40 texel/block</td>
<td>VK_FORMAT_ASTC_8x5_SFLOAT_BLOCK, VK_FORMAT_ASTC_8x5_UNORM_BLOCK, VK_FORMAT_ASTC_8x5_SRGB_BLOCK</td>
</tr>
<tr>
<td>ASTC_8x6 Block size 16 byte 8x6x1 block extent 48 texel/block</td>
<td>VK_FORMAT_ASTC_8x6_SFLOAT_BLOCK, VK_FORMAT_ASTC_8x6_UNORM_BLOCK, VK_FORMAT_ASTC_8x6_SRGB_BLOCK</td>
</tr>
<tr>
<td>ASTC_8x8 Block size 16 byte 8x8x1 block extent 64 texel/block</td>
<td>VK_FORMAT_ASTC_8x8_SFLOAT_BLOCK, VK_FORMAT_ASTC_8x8_UNORM_BLOCK, VK_FORMAT_ASTC_8x8_SRGB_BLOCK</td>
</tr>
<tr>
<td>ASTC_10x5 Block size 16 byte 10x5x1 block extent 50 texel/block</td>
<td>VK_FORMAT_ASTC_10x5_SFLOAT_BLOCK, VK_FORMAT_ASTC_10x5_UNORM_BLOCK, VK_FORMAT_ASTC_10x5_SRGB_BLOCK</td>
</tr>
<tr>
<td>ASTC_10x6 Block size 16 byte 10x6x1 block extent 60 texel/block</td>
<td>VK_FORMAT_ASTC_10x6_SFLOAT_BLOCK, VK_FORMAT_ASTC_10x6_UNORM_BLOCK, VK_FORMAT_ASTC_10x6_SRGB_BLOCK</td>
</tr>
<tr>
<td>Class, Texel Block Size, Texel Block Extent, # Texels/Block</td>
<td>Formats</td>
</tr>
<tr>
<td>-------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>ASTC_10x8 Block size 16 byte 10x8x1 block extent 80 texel/block</td>
<td>VK_FORMAT_ASTC_10x8_SFLOAT_BLOCK, VK_FORMAT_ASTC_10x8_UNORM_BLOCK, VK_FORMAT_ASTC_10x8_SRGB_BLOCK</td>
</tr>
<tr>
<td>ASTC_10x10 Block size 16 byte 10x10x1 block extent 100 texel/block</td>
<td>VK_FORMAT_ASTC_10x10_SFLOAT_BLOCK, VK_FORMAT_ASTC_10x10_UNORM_BLOCK, VK_FORMAT_ASTC_10x10_SRGB_BLOCK</td>
</tr>
<tr>
<td>ASTC_12x10 Block size 16 byte 12x10x1 block extent 120 texel/block</td>
<td>VK_FORMAT_ASTC_12x10_SFLOAT_BLOCK, VK_FORMAT_ASTC_12x10_UNORM_BLOCK, VK_FORMAT_ASTC_12x10_SRGB_BLOCK</td>
</tr>
<tr>
<td>ASTC_12x12 Block size 16 byte 12x12x1 block extent 144 texel/block</td>
<td>VK_FORMAT_ASTC_12x12_SFLOAT_BLOCK, VK_FORMAT_ASTC_12x12_UNORM_BLOCK, VK_FORMAT_ASTC_12x12_SRGB_BLOCK</td>
</tr>
<tr>
<td>32-bit G8B8G8R8 Block size 4 byte 2x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G8B8G8R8_422_UNORM</td>
</tr>
<tr>
<td>32-bit B8G8R8G8 Block size 4 byte 2x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_B8G8R8G8_422_UNORM</td>
</tr>
<tr>
<td>8-bit 3-plane 420 Block size 3 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G8_B8_R8_3PLANE_420_UNORM</td>
</tr>
<tr>
<td>8-bit 2-plane 420 Block size 3 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G8_B8R8_2PLANE_420_UNORM</td>
</tr>
<tr>
<td>8-bit 3-plane 422 Block size 3 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G8_B8_R8_3PLANE_422_UNORM</td>
</tr>
<tr>
<td>8-bit 2-plane 422 Block size 3 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G8_B8R8_2PLANE_422_UNORM</td>
</tr>
<tr>
<td>Class, Texel Block Size, Texel Block Extent, # Texels/Block</td>
<td>Formats</td>
</tr>
<tr>
<td>-------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>8-bit 3-plane 444 Block size 3 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G8_B8_R8_3PLANE_444_UNORM</td>
</tr>
<tr>
<td>64-bit R10G10B10A10 Block size 8 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_R10X6G10X6B10X6A10X6_UNORM_4PACK16</td>
</tr>
<tr>
<td>64-bit G10B10G10R10 Block size 8 byte 2x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G10X6B10X6G10X6R10X6_422_UNORM_4PACK16</td>
</tr>
<tr>
<td>64-bit B10G10R10G10 Block size 8 byte 2x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_B10X6G10X6R10X6G10X6_422_UNORM_4PACK16</td>
</tr>
<tr>
<td>10-bit 3-plane 420 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_420_UNORM_3PACK16</td>
</tr>
<tr>
<td>10-bit 2-plane 420 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G10X6_B10X6R10X6_2PLANE_420_UNORM_3PACK16</td>
</tr>
<tr>
<td>10-bit 3-plane 422 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_422_UNORM_3PACK16</td>
</tr>
<tr>
<td>10-bit 2-plane 422 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G10X6_B10X6R10X6_2PLANE_422_UNORM_3PACK16</td>
</tr>
<tr>
<td>10-bit 3-plane 444 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_444_UNORM_3PACK16</td>
</tr>
<tr>
<td>64-bit R12G12B12A12 Block size 8 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_R12X4G12X4B12X4A12X4_UNORM_4PACK16</td>
</tr>
<tr>
<td>Class, Texel Block Size, Texel Block Extent, # Texels/Block</td>
<td>Formats</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>64-bit G12B12G12R12 Block size 8 byte 2x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G12X4B12X4G12X4R12X4_422_UNORM_4PACK16</td>
</tr>
<tr>
<td>64-bit B12G12R12G12 Block size 8 byte 2x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_B12X4G12X4R12X4_422_UNORM_4PACK16</td>
</tr>
<tr>
<td>12-bit 3-plane 420 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_420_UNORM_3PACK16</td>
</tr>
<tr>
<td>12-bit 2-plane 420 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G12X4_B12X4_R12X4_2PLANE_420_UNORM_3PACK16</td>
</tr>
<tr>
<td>12-bit 3-plane 422 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_422_UNORM_3PACK16</td>
</tr>
<tr>
<td>12-bit 2-plane 422 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G12X4_B12X4_R12X4_2PLANE_422_UNORM_3PACK16</td>
</tr>
<tr>
<td>12-bit 3-plane 444 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_444_UNORM_3PACK16</td>
</tr>
<tr>
<td>64-bit G16B16G16R16 Block size 8 byte 2x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G16B16G16R16_422_UNORM</td>
</tr>
<tr>
<td>64-bit B16G16R16G16 Block size 8 byte 2x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_B16G16R16G16_422_UNORM</td>
</tr>
<tr>
<td>16-bit 3-plane 420 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G16_B16_R16_3PLANE_420_UNORM</td>
</tr>
<tr>
<td>Class, Texel Block Size, Texel Block Extent, # Texels/Block</td>
<td>Formats</td>
</tr>
<tr>
<td>-------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>16-bit 2-plane 420 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G16_B16R16_2PLANE_420_UNORM</td>
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<tr>
<td>16-bit 3-plane 422 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G16_B16_R16_3PLANE_422_UNORM</td>
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<tr>
<td>16-bit 2-plane 422 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G16_B16R16_2PLANE_422_UNORM</td>
</tr>
<tr>
<td>16-bit 3-plane 444 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G16_B16_R16_3PLANE_444_UNORM</td>
</tr>
<tr>
<td>PVRTC1_2BPP Block size 8 byte 8x4x1 block extent 1 texel/block</td>
<td>VK_FORMAT_PVRTC1_2BPP_UNORM_BLOCK_IMG, VK_FORMAT_PVRTC1_2BPP_SRGB_BLOCK_IMG</td>
</tr>
<tr>
<td>PVRTC1_4BPP Block size 8 byte 4x4x1 block extent 1 texel/block</td>
<td>VK_FORMAT_PVRTC1_4BPP_UNORM_BLOCK_IMG, VK_FORMAT_PVRTC1_4BPP_SRGB_BLOCK_IMG</td>
</tr>
<tr>
<td>PVRTC2_2BPP Block size 8 byte 8x4x1 block extent 1 texel/block</td>
<td>VK_FORMAT_PVRTC2_2BPP_UNORM_BLOCK_IMG, VK_FORMAT_PVRTC2_2BPP_SRGB_BLOCK_IMG</td>
</tr>
<tr>
<td>PVRTC2_4BPP Block size 8 byte 4x4x1 block extent 1 texel/block</td>
<td>VK_FORMAT_PVRTC2_4BPP_UNORM_BLOCK_IMG, VK_FORMAT_PVRTC2_4BPP_SRGB_BLOCK_IMG</td>
</tr>
<tr>
<td>8-bit 2-plane 444 Block size 3 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G8_B8R8_2PLANE_444_UNORM</td>
</tr>
<tr>
<td>10-bit 2-plane 444 Block size 6 byte 1x1x1 block extent 1 texel/block</td>
<td>VK_FORMAT_G10X6_B10X6R10X6_2PLANE_444_UNORM_3PACK16</td>
</tr>
</tbody>
</table>
### Size Compatibility

Color formats with the same texel block size are considered *size-compatible* as long as neither or both are alpha formats (e.g., `VK_FORMAT_A8_UNORM_KHR`). If two size-compatible formats have different block extents (i.e. for compressed formats), then an image with size $A \times B \times C$ in one format with a block extent of $a \times b \times c$ can be represented as an image with size $X \times Y \times Z$ in the other format with block extent $x \times y \times z$ at the ratio between the block extents for each format, where

$$\lceil \frac{A}{a} \rceil = \lceil \frac{X}{x} \rceil$$

$$\lceil \frac{B}{b} \rceil = \lceil \frac{Y}{y} \rceil$$

$$\lceil \frac{C}{c} \rceil = \lceil \frac{Z}{z} \rceil$$

**Note**

For example, a 7x3 image in the `VK_FORMAT_ASTC_8x5_UNORM_BLOCK` format can be represented as a 1x1 `VK_FORMAT_R64G64_UINT` image.

Images created with the `VK_IMAGE_CREATE_BLOCK_TEXEL_VIEW_COMPATIBLE_BIT` flag can have size-compatible views created from them to enable access via different size-compatible formats. Image views created in this way will be sized to match the expectations of the block extents noted above.

Copy operations are able to copy between size-compatible formats in different resources to enable manipulation of data in different formats. The extent used in these copy operations always matches the source image, and is resized to the expectations of the block extents noted above for the destination image.

### 48.2. Format Properties

To query supported format features which are properties of the physical device, call:
void vkGetPhysicalDeviceFormatProperties(
    VkPhysicalDevice physicalDevice,
    VkFormat format,
    VkFormatProperties* pFormatProperties);

- physicalDevice is the physical device from which to query the format properties.
- format is the format whose properties are queried.
- pFormatProperties is a pointer to a VkFormatProperties structure in which physical device properties for format are returned.

Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceFormatProperties-physicalDevice-parameter physicalDevice must be a valid VkPhysicalDevice handle
- VUID-vkGetPhysicalDeviceFormatProperties-format-parameter format must be a valid VkFormat value
- VUID-vkGetPhysicalDeviceFormatProperties-pFormatProperties-parameter pFormatProperties must be a valid pointer to a VkFormatProperties structure

The VkFormatProperties structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkFormatProperties {
    VkFormatFeatureFlags linearTilingFeatures;
    VkFormatFeatureFlags optimalTilingFeatures;
    VkFormatFeatureFlags bufferFeatures;
} VkFormatProperties;
```

- linearTilingFeatures is a bitmask of VkFormatFeatureFlagBits specifying features supported by images created with a tiling parameter of VK_IMAGE_TILING_LINEAR.
- optimalTilingFeatures is a bitmask of VkFormatFeatureFlagBits specifying features supported by images created with a tiling parameter of VK_IMAGE_TILING_OPTIMAL.
- bufferFeatures is a bitmask of VkFormatFeatureFlagBits specifying features supported by buffers.

Note

If no format feature flags are supported, the format itself is not supported, and images of that format cannot be created.

If format is a block-compressed format, then bufferFeatures must not support any features for the format.
If `format` is not a multi-plane format then `linearTilingFeatures` and `optimalTilingFeatures` must not contain `VK_FORMAT_FEATURE_DISJOINT_BIT`.

Bits which can be set in the `VkFormatProperties` features `linearTilingFeatures`, `optimalTilingFeatures`, `VkDrmFormatModifierPropertiesEXT::drmFormatModifierTilingFeatures`, and `bufferFeatures` are:

```c
// Provided by VK_VERSION_1_0
typedef enum VkFormatFeatureFlagBits {
    VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT = 0x00000001,
    VK_FORMAT_FEATURE_STORAGE_IMAGE_BIT = 0x00000002,
    VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT = 0x00000004,
    VK_FORMAT_FEATURE_UNIFORM_TEXEL_BUFFER_BIT = 0x00000008,
    VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_BIT = 0x00000010,
    VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT = 0x00000020,
    VK_FORMAT_FEATURE_VERTEX_BUFFER_BIT = 0x00000040,
    VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT = 0x00000080,
    VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT = 0x00000100,
    VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT = 0x00000200,
    VK_FORMAT_FEATURE_BLIT_SRC_BIT = 0x00000400,
    VK_FORMAT_FEATURE_BLIT_DST_BIT = 0x00000800,
    VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT = 0x00001000,

    // Provided by VK_VERSION_1_1
    VK_FORMAT_FEATURE_TRANSFER_SRC_BIT = 0x00004000,
    // Provided by VK_VERSION_1_1
    VK_FORMAT_FEATURE_TRANSFER_DST_BIT = 0x00008000,
    // Provided by VK_VERSION_1_1
    VK_FORMAT_FEATURE_MIDPOINT_CHROMA_SAMPLES_BIT = 0x00020000,
    // Provided by VK_VERSION_1_1
    VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_LINEAR_FILTER_BIT = 0x00040000,
    // Provided by VK_VERSION_1_1
    VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_SEPARATE_RECONSTRUCTION_FILTER_BIT = 0x00080000,
    // Provided by VK_VERSION_1_1
    VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_BIT = 0x00100000,
    // Provided by VK_VERSION_1_1
    VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_FORCEABLE_BIT = 0x00200000,
    // Provided by VK_VERSION_1_2
    VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_MINMAX_BIT = 0x00010000,

    // Provided by VK_KHR_video_decode_queue
    VK_FORMAT_FEATURE_VIDEO_DECODE_OUTPUT_BIT_KHR = 0x02000000,

    // Provided by VK_KHR_surface
    VK_FORMAT_FEATURE_VIDEO_CODEC_KHR = 0x00000000
};
```
Provided by VK_KHR_video_decode_queue

VK_FORMAT_FEATURE_VIDEO_DECODE_DPB_BIT_KHR = 0x04000000,

Provided by VK_KHR_acceleration_structure

VK_FORMAT_FEATURE_ACCELERATION_STRUCTURE_VERTEX_BUFFER_BIT_KHR = 0x20000000,

Provided by VK_EXT_filter_cubic

VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT = 0x00002000,

Provided by VK_KHR_fragment_density_map

VK_FORMAT_FEATURE_FRAGMENT_DENSITY_MAP_BIT_EXT = 0x01000000,

Provided by VK_KHR_fragment_shading_rate

VK_FORMAT_FEATURE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR = 0x40000000,

#ifdef VK_ENABLE_BETA_EXTENSIONS
Provided by VK_KHR_video_encode_queue

VK_FORMAT_FEATURE_VIDEO_ENCODE_INPUT_BIT_KHR = 0x08000000,
#endif

#ifdef VK_ENABLE_BETA_EXTENSIONS
Provided by VK_KHR_video_encode_queue

VK_FORMAT_FEATURE_VIDEO_ENCODE_DPB_BIT_KHR = 0x10000000,
#endif

Provided by VK_IMG_filter_cubic

VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_IMG = VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT,

Provided by VK_KHR_maintenance1

VK_FORMAT_FEATURE_TRANSFER_SRC_BIT_KHR = VK_FORMAT_FEATURE_TRANSFER_SRC_BIT,

Provided by VK_KHR_maintenance1

VK_FORMAT_FEATURE_TRANSFER_DST_BIT_KHR = VK_FORMAT_FEATURE_TRANSFER_DST_BIT,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_LINEAR_FILTER_BIT_KHR = VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_LINEAR_FILTER_BIT,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_SEPARATE_RECONSTRUCTION_FILTER_BIT_KHR = VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_SEPARATE_RECONSTRUCTION_FILTER_BIT,

Provided by VK_KHR_sampler_ycbcr_conversion

VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_FORCEABLE_BIT_KHR = VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_FORCEABLE_BIT,
VK_FORMAT_FEATURE_DISJOINT_BIT_KHR = VK_FORMAT_FEATURE_DISJOINT_BIT,
                            // Provided by VK_KHR_sampler_ycbcr_conversion
VK_FORMAT_FEATURE_COSITED_CHROMA_SAMPLES_BIT_KHR =
VK_FORMAT_FEATURE_COSITED_CHROMA_SAMPLES_BIT,
} VkFormatFeatureFlagBits;

These values all have the same meaning as the equivalently named values for VkFormatFeatureFlags2 and may be set in linearTilingFeatures, optimalTilingFeatures, and VkDrmFormatModifierPropertiesEXT::drmFormatModifierTilingFeatures, specifying that the features are supported by images or image views or sampler Y′C_bC_r conversion objects created with the queried vkGetPhysicalDeviceFormatProperties::format:

- **VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT** specifies that an image view can be sampled from.
- **VK_FORMAT_FEATURE_STORAGE_IMAGE_BIT** specifies that an image view can be used as a storage image.
- **VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT** specifies that an image view can be used as storage image that supports atomic operations.
- **VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT** specifies that an image view can be used as a framebuffer color attachment and as an input attachment.
- **VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT** specifies that an image view can be used as a framebuffer color attachment that supports blending.
- **VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT** specifies that an image view can be used as a framebuffer depth/stencil attachment and as an input attachment.
- **VK_FORMAT_FEATURE_BLIT_SRC_BIT** specifies that an image can be used as srcImage for the vkCmdBlitImage2 and vkCmdBlitImage commands.
- **VK_FORMAT_FEATURE_BLIT_DST_BIT** specifies that an image can be used as dstImage for the vkCmdBlitImage2 and vkCmdBlitImage commands.
- **VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT** specifies that if VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT is also set, an image view can be used with a sampler that has either of magFilter or minFilter set to VK_FILTER_LINEAR, ormousemove set to VK_SAMPLER_MIPMAP_MODE_LINEAR. If VK_FORMAT_FEATURE_BLIT_SRC_BIT is also set, an image can be used as the srcImage to vkCmdBlitImage2 and vkCmdBlitImage with a filter of VK_FILTER_LINEAR. This bit must only be exposed for formats that also support the VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT or VK_FORMAT_FEATURE_BLIT_SRC_BIT.

If the format being queried is a depth/stencil format, this bit only specifies that the depth aspect (not the stencil aspect) of an image of this format supports linear filtering, and that linear filtering of the depth aspect is supported whether depth compare is enabled in the sampler or not. Where depth comparison is supported it may be linear filtered whether this bit is present or not, but where this bit is not present the filtered value may be computed in an implementation-dependent manner which differs from the normal rules of linear filtering. The resulting value must be in the range [0,1] and should be proportional to, or a weighted average of, the number of comparison passes or failures.

- **VK_FORMAT_FEATURE_TRANSFER_SRC_BIT** specifies that an image can be used as a source image for
copy commands. If the application apiVersion is Vulkan 1.0 and VK_KHR_maintenance1 is not supported, VK_FORMAT_FEATURE_TRANSFER_SRC_BIT is implied to be set when the format feature flag is not 0.

- VK_FORMAT_FEATURE_TRANSFER_DST_BIT specifies that an image can be used as a destination image for copy commands and clear commands. If the application apiVersion is Vulkan 1.0 and VK_KHR_maintenance1 is not supported, VK_FORMAT_FEATURE_TRANSFER_DST_BIT is implied to be set when the format feature flag is not 0.

- VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_MINMAX_BIT specifies VkImage can be used as a sampled image with a min or max VkSamplerReductionMode. This bit must only be exposed for formats that also support the VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT.

- VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT specifies that VkImage can be used with a sampler that has either of magFilter or minFilter set to VK_FILTER_CUBIC_EXT, or be the source image for a blit with filter set to VK_FILTER_CUBIC_EXT. This bit must only be exposed for formats that also support the VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT. If the format being queried is a depth/stencil format, this only specifies that the depth aspect is cubic filterable.

- VK_FORMAT_FEATURE_MIDPOINT_CHROMA_SAMPLES_BIT specifies that an application can define a sampler Y’C\_B\_C\_R conversion using this format as a source, and that an image of this format can be used with a VkSamplerYcbcrConversionCreateInfo xChromaOffset and/or yChromaOffset of VK_CHROMA_LOCATION_MIDPOINT. Otherwise both xChromaOffset and yChromaOffset must be VK_CHROMA_LOCATION_COSITED_EVEN. If a format does not incorporate chroma downsampling (it is not a “422” or “420” format) but the implementation supports sampler Y’C\_B\_C\_R conversion for this format, the implementation must set VK_FORMAT_FEATURE_MIDPOINT_CHROMA_SAMPLES_BIT.

- VK_FORMAT_FEATURE_COSITED_CHROMA_SAMPLES_BIT specifies that an application can define a sampler Y’C\_B\_C\_R conversion using this format as a source, and that an image of this format can be used with a VkSamplerYcbcrConversionCreateInfo xChromaOffset and/or yChromaOffset of VK_CHROMA_LOCATION_COSITED_EVEN. Otherwise both xChromaOffset and yChromaOffset must be VK_CHROMA_LOCATION_MIDPOINT. If neither VK_FORMAT_FEATURE_COSITED_CHROMA_SAMPLES_BIT nor VK_FORMAT_FEATURE_MIDPOINT_CHROMA_SAMPLES_BIT is set, the application must not define a sampler Y’C\_B\_C\_R conversion using this format as a source.

- VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_LINEAR_FILTER_BIT specifies that an application can define a sampler Y’C\_B\_C\_R conversion using this format as a source with chromaFilter set to VK_FILTER_LINEAR.

- VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_SEPARATE_RECONSTRUCTION_FILTER_BIT specifies that the format can have different chroma, min, and mag filters.

- VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_BIT specifies that reconstruction is explicit, as described in Chroma Reconstruction. If this bit is not present, reconstruction is implicit by default.

- VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_FORCEABLE_BIT specifies that reconstruction can be forcibly made explicit by setting VkSamplerYcbcrConversionCreateInfo::forceExplicitReconstruction to VK_TRUE. If the format being queried supports VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_BIT it must also support VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_FORCEABLE_BIT.
...can have the `VK_IMAGE_CREATE_DISJOINT_BIT` set during image creation. An implementation must not set `VK_FORMAT_FEATURE_DISJOINT_BIT` for single-plane formats.

- `VK_FORMAT_FEATURE_FRAGMENT_DENSITY_MAP_BIT_EXT` specifies that an image view can be used as a fragment density map attachment.

- `VK_FORMAT_FEATURE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR` specifies that an image view can be used as a fragment shading rate attachment. An implementation must not set this feature for formats with a numeric format other than `UINT`, or set it as a buffer feature.

- `VK_FORMAT_FEATURE_VIDEO_DECODE_OUTPUT_BIT_KHR` specifies that an image view with this format can be used as a decode output picture in video decode operations.

- `VK_FORMAT_FEATURE_VIDEO_DECODE_DPB_BIT_KHR` specifies that an image view with this format can be used as an output reconstructed picture or an input reference picture in video decode operations.

- `VK_FORMAT_FEATURE_VIDEO_ENCODE_INPUT_BIT_KHR` specifies that an image view with this format can be used as an encode input picture in video encode operations.

- `VK_FORMAT_FEATURE_VIDEO_ENCODE_DPB_BIT_KHR` specifies that an image view with this format can be used as an output reconstructed picture or an input reference picture in video encode operations.

**Note**

Specific video profiles may have additional restrictions on the format and other image creation parameters corresponding to image views used by video coding operations that can be enumerated using the `vkGetPhysicalDeviceVideoFormatPropertiesKHR` command.

The following bits may be set in `bufferFeatures`, specifying that the features are supported by buffers or buffer views created with the queried `vkGetPhysicalDeviceFormatProperties::format`:

- `VK_FORMAT_FEATURE_UNIFORM_TEXEL_BUFFER_BIT` specifies that the format can be used to create a buffer view that can be bound to a `VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER` descriptor.

- `VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_BIT` specifies that the format can be used to create a buffer view that can be bound to a `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER` descriptor.

- `VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT` specifies that atomic operations are supported on `VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER` with this format.

- `VK_FORMAT_FEATURE_VERTEX_BUFFER_BIT` specifies that the format can be used as a vertex attribute format (`VkVertexInputAttributeDescription::format`).

- `VK_FORMAT_FEATURE_ACCELERATION_STRUCTURE_VERTEX_BUFFER_BIT_KHR` specifies that the format can be used as the vertex format when creating an acceleration structure (`VkAccelerationStructureGeometryTrianglesDataKHR::vertexFormat`). This format can also be used as the vertex format in host memory when doing host acceleration structure builds.

**Note**
VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT and VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT are only intended to be advertised for single-component formats, since SPIR-V atomic operations require a scalar type.

// Provided by VK_VERSION_1_0
typedef VkFlags VkFormatFeatureFlags;

VkFormatFeatureFlags is a bitmask type for setting a mask of zero or more VkFormatFeatureFlagBits.

To query supported format features which are properties of the physical device, call:

// Provided by VK_VERSION_1_1
void vkGetPhysicalDeviceFormatProperties2(
    VkPhysicalDevice physicalDevice,
    VkFormat format,
    VkFormatProperties2* pFormatProperties);

or the equivalent command

// Provided by VK_KHR_get_physical_device_properties2
void vkGetPhysicalDeviceFormatProperties2KHR(
    VkPhysicalDevice physicalDevice,
    VkFormat format,
    VkFormatProperties2* pFormatProperties);

- physicalDevice is the physical device from which to query the format properties.
- format is the format whose properties are queried.
- pFormatProperties is a pointer to a VkFormatProperties2 structure in which physical device properties for format are returned.

vkGetPhysicalDeviceFormatProperties2 behaves similarly to vkGetPhysicalDeviceFormatProperties, with the ability to return extended information in a pNext chain of output structures.

Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceFormatProperties2-physicalDevice-parameter physicalDevice must be a valid VkPhysicalDevice handle
- VUID-vkGetPhysicalDeviceFormatProperties2-format-parameter format must be a valid VkFormat value
- VUID-vkGetPhysicalDeviceFormatProperties2-pFormatProperties-parameter pFormatProperties must be a valid pointer to a VkFormatProperties2 structure
The `VkFormatProperties2` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkFormatProperties2 {
    VkStructureType sType;
    void* pNext;
    VkFormatProperties formatProperties;
} VkFormatProperties2;
```

or the equivalent

```c
// Provided by VK_KHR_get_physical_device_properties2
typedef VkFormatProperties2 VkFormatProperties2KHR;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **formatProperties** is a `VkFormatProperties` structure describing features supported by the requested format.

### Valid Usage (Implicit)

- **VUID-VkFormatProperties2-sType-sType**
  The `sType` value of each struct in the `pNext` chain must be unique

To obtain the list of Linux DRM format modifiers compatible with a `VkFormat`, add a `VkDrmFormatModifierPropertiesListEXT` structure to the `pNext` chain of `VkFormatProperties2`.

The `VkDrmFormatModifierPropertiesListEXT` structure is defined as:

```c
// Provided by VK_EXT_image_drm_format_modifier
typedef struct VkDrmFormatModifierPropertiesListEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t drmFormatModifierCount;
    VkDrmFormatModifierPropertiesEXT* pDrmFormatModifierProperties;
} VkDrmFormatModifierPropertiesListEXT;
```
• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **drmFormatModifierCount** is an inout parameter related to the number of modifiers compatible with the `format`, as described below.

• **pDrmFormatModifierProperties** is either `NULL` or a pointer to an array of `VkDrmFormatModifierPropertiesEXT` structures.

If `pDrmFormatModifierProperties` is `NULL`, then the function returns in `drmFormatModifierCount` the number of modifiers compatible with the queried `format`. Otherwise, the application **must** set `drmFormatModifierCount` to the length of the array `pDrmFormatModifierProperties`; the function will write at most `drmFormatModifierCount` elements to the array, and will return in `drmFormatModifierCount` the number of elements written.

Among the elements in array `pDrmFormatModifierProperties`, each returned `drmFormatModifier` must be unique.

### Valid Usage (Implicit)

- VUID-VkDrmFormatModifierPropertiesListEXT-sType-sType

  `sType` **must** be `VK_STRUCTURE_TYPE_DRM_FORMAT_MODIFIER_PROPERTIES_LIST_EXT`

The `VkDrmFormatModifierPropertiesEXT` structure describes properties of a `VkFormat` when that format is combined with a Linux DRM format modifier. These properties, like those of `VkFormatProperties2`, are independent of any particular image.

The `VkDrmFormatModifierPropertiesEXT` structure is defined as:

```c
typedef struct VkDrmFormatModifierPropertiesEXT {
    uint64_t drmFormatModifier;
    uint32_t drmFormatModifierPlaneCount;
    VkFormatFeatureFlags drmFormatModifierTilingFeatures;
} VkDrmFormatModifierPropertiesEXT;
```

- **drmFormatModifier** is a *Linux DRM format modifier.*

- **drmFormatModifierPlaneCount** is the number of *memory planes* in any image created with `format` and `drmFormatModifier`. An image's *memory planecount* is distinct from its *format planecount*, as explained below.

- **drmFormatModifierTilingFeatures** is a bitmask of `VkFormatFeatureFlagBits` that are supported by any image created with `format` and `drmFormatModifier`.

  The returned `drmFormatModifierTilingFeatures` **must** contain at least one bit.

  The implementation **must** not return `DRM_FORMAT_MOD_INVALID` in `drmFormatModifier`.

An image's *memory planecount* (as returned by `drmFormatModifierPlaneCount`) is distinct from its
format planecount (in the sense of multi-planar Y’CbCr formats). In VkImageAspectFlags, each
VK_IMAGE_ASPECT_MEMORY_PLANE_i_BIT_EXT represents a memory plane and each
VK_IMAGE_ASPECT_PLANE_i_BIT a format plane.

An image's set of format planes is an ordered partition of the image's content into separable groups
of format components. The ordered partition is encoded in the name of each VkFormat. For
example, VK_FORMAT_G8_B8R8_2PLANE_420_UNORM contains two format planes; the first plane contains
the green component and the second plane contains the blue component and red component. If the
format name does not contain PLANE, then the format contains a single plane; for example,
VK_FORMAT_R8G8B8A8_UNORM. Some commands, such as vkCmdCopyBufferToImage, do not operate on
all format components in the image, but instead operate only on the format planes explicitly chosen
by the application and operate on each format plane independently.

An image's set of memory planes is an ordered partition of the image's memory rather than the
image's content. Each memory plane is a contiguous range of memory. The union of an image's
memory planes is not necessarily contiguous.

If an image is linear, then the partition is the same for memory planes and for format planes.
Therefore, if the returned drmFormatModifier is DRM_FORMAT_MOD_LINEAR, then
drmFormatModifierPlaneCount must equal the format planecount, and
drmFormatModifierTilingFeatures must be identical to the VkFormatProperties2
::linearTilingFeatures returned in the same pNext chain.

If an image is non-linear, then the partition of the image's memory into memory planes is
implementation-specific and may be unrelated to the partition of the image's content into
format planes. For example, consider an image whose format is VK_FORMAT_G8_B8R8_3PLANE_420_UNORM,
tiling is VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT, whose
drmFormatModifier is not DRM_FORMAT_MOD_LINEAR, and flags lacks VK_IMAGE_CREATE_DISJOINT_BIT. The image has 3 format
planes, and commands such vkCmdCopyBufferToImage act on each format plane independently as
if the data of each format plane were separable from the data of the other planes. In a
straightforward implementation, the implementation may store the image's content in 3 adjacent
memory planes where each memory plane corresponds exactly to a format plane. However, the
implementation may also store the image's content in a single memory plane where all format
components are combined using an implementation-private block-compressed format; or the
implementation may store the image's content in a collection of 7 adjacent memory planes using an
implementation-private sharding technique. Because the image is non-linear and non-disjoint, the
implementation has much freedom when choosing the image's placement in memory.

The memory planecount applies to function parameters and structures only when the API specifies
an explicit requirement on drmFormatModifierPlaneCount. In all other cases, the memory planecount
is ignored.

The list of Linux DRM format modifiers compatible with a VkFormat can be obtained by adding a
VkDrmFormatModifierPropertiesList2EXT structure to the pNext chain of VkFormatProperties2.

The VkDrmFormatModifierPropertiesList2EXT structure is defined as:

```c
typedef struct VkDrmFormatModifierPropertiesList2EXT {
```
VkStructureType
void*
sType;
pNext;
drmFormatModifierCount;
pDrmFormatModifierProperties;
} VkDrmFormatModifierPropertiesList2EXT;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• drmFormatModifierCount is an inout parameter related to the number of modifiers compatible
  with the format, as described below.
• pDrmFormatModifierProperties is either NULL or a pointer to an array of
  VkDrmFormatModifierProperties2EXT structures.

If pDrmFormatModifierProperties is NULL, the number of modifiers compatible with the queried format
is returned in drmFormatModifierCount. Otherwise, the application must set drmFormatModifierCount
to the length of the array pDrmFormatModifierProperties; the function will write at most
drmFormatModifierCount elements to the array, and will return in drmFormatModifierCount the number
of elements written.

Among the elements in array pDrmFormatModifierProperties, each returned drmFormatModifier must
be unique.

Among the elements in array pDrmFormatModifierProperties, the bits reported in
drmFormatModifierTilingFeatures must include the bits reported in the corresponding element of
VkDrmFormatModifierPropertiesListEXT::pDrmFormatModifierProperties.

Valid Usage (Implicit)

• VUID-VkDrmFormatModifierPropertiesList2EXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_DRM_FORMAT_MODIFIER_PROPERTIES_LIST_2_EXT

The VkDrmFormatModifierProperties2EXT structure describes properties of a VkFormat when that
format is combined with a Linux DRM format modifier. These properties, like those of
VkFormatProperties2, are independent of any particular image.

The VkDrmFormatModifierPropertiesEXT structure is defined as:

// Provided by VK_KHR_format_feature_flags2 with VK_EXT_image_drm_format_modifier
typedef struct VkDrmFormatModifierProperties2EXT {
  uint64_t drmFormatModifier;
  uint32_t drmFormatModifierPlaneCount;
  VkFormatFeatureFlags2 drmFormatModifierTilingFeatures;
} VkDrmFormatModifierProperties2EXT;

• drmFormatModifier is a Linux DRM format modifier.
• drmFormatModifierPlaneCount is the number of memory planes in any image created with format
and drmFormatModifier. An image’s memory planecount is distinct from its format planecount, as explained below.

- drmFormatModifierTilingFeatures is a bitmask of VkFormatFeatureFlagBits2 that are supported by any image created with format and drmFormatModifier.

To query supported format extended features which are properties of the physical device, add VkFormatProperties3 structure to the pNext chain of VkFormatProperties2.

The VkFormatProperties3 structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkFormatProperties3 {
    VkStructureType               sType;
    void*                         pNext;
    VkFormatFeatureFlags2         linearTilingFeatures;
    VkFormatFeatureFlags2         optimalTilingFeatures;
    VkFormatFeatureFlags2         bufferFeatures;
} VkFormatProperties3;
```

or the equivalent

```c
// Provided by VK_KHR_format_feature_flags2
typedef VkFormatProperties3 VkFormatProperties3KHR;
```

- linearTilingFeatures is a bitmask of VkFormatFeatureFlagBits2 specifying features supported by images created with a tiling parameter of VK_IMAGE_TILING_LINEAR.

- optimalTilingFeatures is a bitmask of VkFormatFeatureFlagBits2 specifying features supported by images created with a tiling parameter of VK_IMAGE_TILING_OPTIMAL.

- bufferFeatures is a bitmask of VkFormatFeatureFlagBits2 specifying features supported by buffers.

The bits reported in linearTilingFeatures, optimalTilingFeatures and bufferFeatures must include the bits reported in the corresponding fields of VkFormatProperties2::formatProperties.

**Valid Usage (Implicit)**

- VUID-VkFormatProperties3-sType-sType
  
sType must be VK_STRUCTURE_TYPE_FORMAT_PROPERTIES_3

Bits which can be set in the VkFormatProperties3 features linearTilingFeatures, optimalTilingFeatures, and bufferFeatures are:

```c
// Provided by VK_VERSION_1_3
// Flag bits for VkFormatFeatureFlagBits2
typedef VkFlags64 VkFormatFeatureFlagBits2;
```
<table>
<thead>
<tr>
<th>VK Format Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_BIT</td>
<td>0x00000001ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_BIT_KHR</td>
<td>0x00000001ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_STORAGE_IMAGE_BIT</td>
<td>0x00000002ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_STORAGE_IMAGE_BIT_KHR</td>
<td>0x00000002ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_STORAGE_IMAGE_ATOMIC_BIT</td>
<td>0x00000004ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_STORAGE_IMAGE_ATOMIC_BIT_KHR</td>
<td>0x00000004ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_UNIFORM_TEXEL_BUFFER_BIT</td>
<td>0x00000008ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_UNIFORM_TEXEL_BUFFER_BIT_KHR</td>
<td>0x00000008ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_STORAGE_TEXEL_BUFFER_BIT</td>
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</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_STORAGE_TEXEL_BUFFER_BIT_KHR</td>
<td>0x00000010ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_STORAGE_TEXEL_BUFFER_ATOMIC_BIT</td>
<td>0x00000020ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_STORAGE_TEXEL_BUFFER_ATOMIC_BIT_KHR</td>
<td>0x00000020ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_VERTEX_BUFFER_BIT</td>
<td>0x00000040ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_VERTEX_BUFFER_BIT_KHR</td>
<td>0x00000040ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_COLOR_ATTACHMENT_BIT</td>
<td>0x00000080ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_COLOR_ATTACHMENT_BIT_KHR</td>
<td>0x00000080ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_COLOR_ATTACHMENT_BLEND_BIT</td>
<td>0x00000100ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_COLOR_ATTACHMENT_BLEND_BIT_KHR</td>
<td>0x00000100ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_DEPTH_STENCIL_ATTACHMENT_BIT</td>
<td>0x00000200ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_DEPTH_STENCIL_ATTACHMENT_BIT_KHR</td>
<td>0x00000200ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_BLIT_SRC_BIT</td>
<td>0x00000400ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_BLIT_SRC_BIT_KHR</td>
<td>0x00000400ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_BLIT_DST_BIT</td>
<td>0x00000800ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_BLIT_DST_BIT_KHR</td>
<td>0x00000800ULL</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_FILTER_LINEAR_BIT</td>
<td>0x00001000ULL</td>
</tr>
</tbody>
</table>
VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_FILTER_LINEAR_BIT_KHR = 0x00001000ULL;
static const VkFormatFeatureFlagBits2
VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_FILTER_CUBIC_BIT = 0x00002000ULL;
static const VkFormatFeatureFlagBits2
VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT = 0x00002000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_TRANSFER_SRC_BIT = 0x00004000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_TRANSFER_SRC_BIT_KHR = 0x00004000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_TRANSFER_DST_BIT = 0x00008000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_TRANSFER_DST_BIT_KHR = 0x00008000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_FILTER_MINMAX_BIT = 0x00010000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_FILTER_MINMAX_BIT_KHR = 0x00010000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_MIDPOINT_CHROMA_SAMPLES_BIT = 0x00020000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_MIDPOINT_CHROMA_SAMPLES_BIT_KHR = 0x00020000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_YCBCR_CONVERSION_LINEAR_FILTER_BIT = 0x00040000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_YCBCR_CONVERSION_LINEAR_FILTER_BIT_KHR = 0x00040000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_YCBCR_CONVERSION_SEPARATE_RECONSTRUCTION_FILTER_BIT = 0x00080000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_YCBCR_CONVERSION_SEPARATE_RECONSTRUCTION_FILTER_BIT_KHR = 0x00080000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_BIT = 0x00100000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_BIT_KHR = 0x00100000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_FORC_EABLE_BIT = 0x00200000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_FORC_EABLE_BIT_KHR = 0x00200000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_DISJOINT_BIT = 0x00400000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_DISJOINT_BIT_KHR = 0x00400000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_COSITED_CHROMA_SAMPLES_BIT = 0x00800000ULL;
VK_FORMAT_FEATURE_2_COSITED_CHROMA_SAMPLES_BIT_KHR = 0x00800000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT = 0x80000000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT_KHR = 0x100000000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT = 0x200000000ULL;
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT_KHR = 0x200000000ULL;
// Provided by VK_KHR_format_feature_flags2 with VK_KHR_video_decode_queue
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_VIDEO_DECODE_OUTPUT_BIT_KHR = 0x02000000ULL;
// Provided by VK_KHR_format_feature_flags2 with VK_KHR_video_decode_queue
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_VIDEO_DECODE_DPB_BIT_KHR = 0x04000000ULL;
// Provided by VK_KHR_acceleration_structure with VK_KHR_format_feature_flags2
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_ACCELERATION_STRUCTURE_VERTEX_BUFFER_BIT_KHR = 0x20000000ULL;
// Provided by VK_KHR_format_feature_flags2 with VK_EXT_fragment_density_map
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_FRAGMENT_DENSITY_MAP_BIT_EXT = 0x01000000ULL;
// Provided by VK_KHR_format_feature_flags2 with VK_KHR_fragment_shading_rate
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR = 0x40000000ULL;
// Provided by VK_EXT_host_image_copy
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_HOST_IMAGE_TRANSFER_BIT_EXT = 0x400000000000ULL;
#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_format_feature_flags2 with VK_KHR_video_encode_queue
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_VIDEO_ENCODE_INPUT_BIT_KHR = 0x08000000ULL;
#endif
#ifdef VK_ENABLE_BETA_EXTENSIONS
// Provided by VK_KHR_format_feature_flags2 with VK_KHR_video_encode_queue
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_VIDEO_ENCODE_DPB_BIT_KHR = 0x10000000ULL;
#endif
// Provided by VK_KHR_format_feature_flags2 with VK_NV_linear_color_attachment
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV = 0x4000000000ULL;
// Provided by VK_KHR_format_feature_flags2 with VK_QCOM_image_processing
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM = 0x4000000000ULL;
// Provided by VK_KHR_format_feature_flags2 with VK_QCOM_image_processing
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM = 0x8000000000ULL;
// Provided by VK_KHR_format_feature_flags2 with VK_QCOM_image_processing
```c
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM = 0x1000000000ULL;
// Provided by VK_KHR_format_feature_flags2 with VK_QCOM_image_processing
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM = 0x2000000000ULL;
// Provided by VK_NV_optical_flow
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_OPTICAL_FLOW_IMAGE_BIT_NV = 0x10000000000ULL;
// Provided by VK_NV_optical_flow
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_OPTICAL_FLOW_VECTOR_BIT_NV = 0x20000000000ULL;
// Provided by VK_NV_optical_flow
static const VkFormatFeatureFlagBits2 VK_FORMAT_FEATURE_2_OPTICAL_FLOW_COST_BIT_NV = 0x40000000000ULL;
```

or the equivalent

```c
// Provided by VK_KHR_format_feature_flags2
typedef VkFormatFeatureFlagBits2 VkFormatFeatureFlagBits2KHR;
```

The following bits may be set in `linearTilingFeatures` and `optimalTilingFeatures`, specifying that the features are supported by images or image views or sampler Y’C_b,C_r conversion objects created with the queried `vkGetPhysicalDeviceFormatProperties2::format`:

- `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_BIT` specifies that an image view can be sampled from.
- `VK_FORMAT_FEATURE_2_STORAGE_IMAGE_BIT` specifies that an image view can be used as a storage image.
- `VK_FORMAT_FEATURE_2_STORAGE_IMAGE_ATOMIC_BIT` specifies that an image view can be used as storage image that supports atomic operations.
- `VK_FORMAT_FEATURE_2_COLOR_ATTACHMENT_BIT` specifies that an image view can be used as a framebuffer color attachment and as an input attachment.
- `VK_FORMAT_FEATURE_2_COLOR_ATTACHMENT_BLEND_BIT` specifies that an image view can be used as a framebuffer color attachment that supports blending.
- `VK_FORMAT_FEATURE_2_DEPTH_STENCIL_ATTACHMENT_BIT` specifies that an image view can be used as a framebuffer depth/stencil attachment and as an input attachment.
- `VK_FORMAT_FEATURE_2_BLIT_SRC_BIT` specifies that an image can be used as the srcImage for `vkCmdBlitImage2` and `vkCmdBlitImage`.
- `VK_FORMAT_FEATURE_2_BLIT_DST_BIT` specifies that an image can be used as the dstImage for `vkCmdBlitImage2` and `vkCmdBlitImage`.
- `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_FILTER_LINEAR_BIT` specifies that if `VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_BIT` is also set, an image view can be used with a sampler that has either of `magFilter` or `minFilter` set to `VK_FILTER_LINEAR`, or `mipmapMode` set to `VK_SAMPLER_MIPMAP_MODE_LINEAR`. If `VK_FORMAT_FEATURE_2_BLIT_SRC_BIT` is also set, an image can be used as the srcImage for `vkCmdBlitImage2` and `vkCmdBlitImage` with a filter of `VK_FILTER_LINEAR`.

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This bit must only be exposed for formats that also support the
VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_BIT or VK_FORMAT_FEATURE_2_BLIT_SRC_BIT.

If the format being queried is a depth/stencil format, this bit only specifies that the depth aspect
(not the stencil aspect) of an image of this format supports linear filtering. Where depth
comparison is supported it may be linear filtered whether this bit is present or not, but where
this bit is not present the filtered value may be computed in an implementation-dependent
manner which differs from the normal rules of linear filtering. The resulting value must be in
the range [0,1] and should be proportional to, or a weighted average of, the number of
comparison passes or failures.

- VK_FORMAT_FEATURE_2_TRANSFER_SRC_BIT specifies that an image can be used as a source image for
copy commands.
- VK_FORMAT_FEATURE_2_TRANSFER_DST_BIT specifies that an image can be used as a destination
image for copy commands and clear commands.
- VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_FILTER_MINMAX_BIT specifies VkImage can be used as a
sampled image with a min or max VkSamplerReductionMode. This bit must only be exposed for
formats that also support the VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_BIT.
- VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_FILTER_CUBIC_BIT specifies that VkImage can be used with a
sampler that has either of magFilter or minFilter set to VK_FILTER_CUBIC_EXT, or be the source
image for a blit with filter set to VK_FILTER_CUBIC_EXT. This bit must only be exposed for
formats that also support the VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_BIT. If the format being
queried is a depth/stencil format, this only specifies that the depth aspect is cubic filterable.
- VK_FORMAT_FEATURE_2_MIDPOINT_CHROMA_SAMPLES_BIT specifies that an application can define a
sampler Y’C₈C₉ conversion using this format as a source, and that an image of this format can be
used with a VkSamplerYcbcrConversionCreateInfo xChromaOffset and/or yChromaOffset of
VK_CHROMA_LOCATION_MIDPOINT. Otherwise both xChromaOffset and yChromaOffset must be
VK_CHROMA_LOCATION_COSITED_EVEN. If a format does not incorporate chroma downsampling (it is
not a “422” or “420” format) but the implementation supports sampler Y’C₈C₉ conversion for this
format, the implementation must set VK_FORMAT_FEATURE_2_MIDPOINT_CHROMA_SAMPLES_BIT.
- VK_FORMAT_FEATURE_2_COSITED_CHROMA_SAMPLES_BIT specifies that an application can define a
sampler Y’C₈C₉ conversion using this format as a source, and that an image of this format can be
used with a VkSamplerYcbcrConversionCreateInfo xChromaOffset and/or yChromaOffset of
VK_CHROMA_LOCATION_COSITED_EVEN. If neither VK_FORMAT_FEATURE_2_COSITED_CHROMA_SAMPLES_BIT
nor VK_FORMAT_FEATURE_2_MIDPOINT_CHROMA_SAMPLES_BIT is set, the application must not define a
sampler Y’C₈C₉ conversion using this format as a source.
- VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_YCBCR_CONVERSION_LINEAR_FILTER_BIT specifies that an
application can define a sampler Y’C₈C₉ conversion using this format as a source with
chromaFilter set to VK_FILTER_LINEAR.
- VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_YCBCR_CONVERSION_SEPARATE_RECONSTRUCTION_FILTER_BIT
specifies that the format can have different chroma, min, and mag filters.
- VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_BIT
specifies that reconstruction is explicit, as described in Chroma Reconstruction. If this bit is not
present, reconstruction is implicit by default.
- **VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_YCBR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_FORCEABLE_BIT** specifies that reconstruction can be forcibly made explicit by setting `VkSamplerYcbcrConversionCreateInfo::forceExplicitReconstruction` to `VK_TRUE`. If the format being queried supports VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_YCBR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_BIT it must also support VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_YCBR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_FORCEABLE_BIT.

- **VK_FORMAT_FEATURE_2_DISJOINT_BIT** specifies that a multi-planar image can have the VK_IMAGE_CREATE_DISJOINT_BIT set during image creation. An implementation must not set VK_FORMAT_FEATURE_2_DISJOINT_BIT for single-plane formats.

- **VK_FORMAT_FEATURE_2_FRAGMENT_DENSITY_MAP_BIT_EXT** specifies that an image view can be used as a fragment density map attachment.

- **VK_FORMAT_FEATURE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR** specifies that an image view can be used as a fragment shading rate attachment. An implementation must not set this feature for formats with a numeric format other than `UINT`, or set it as a buffer feature.

- **VK_FORMAT_FEATURE_2_VIDEO_DECODE_OUTPUT_BIT_KHR** specifies that an image view with this format can be used as a decode output picture in video decode operations.

- **VK_FORMAT_FEATURE_2_VIDEO_DECODE_DPB_BIT_KHR** specifies that an image view with this format can be used as an output reconstructed picture or an input reference picture in video decode operations.

- **VK_FORMAT_FEATURE_2_VIDEO_ENCODE_INPUT_BIT_KHR** specifies that an image view with this format can be used as an encode input picture in video encode operations.

- **VK_FORMAT_FEATURE_2_VIDEO_ENCODE_DPB_BIT_KHR** specifies that an image view with this format can be used as an output reconstructed picture or an input reference picture in video encode operations.

- **VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT** specifies that image views or buffer views created with this format can be used as storage images or storage texel buffers respectively for read operations without specifying a format.

- **VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT** specifies that image views or buffer views created with this format can be used as storage images or storage texel buffers respectively for write operations without specifying a format.

- **VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT** specifies that image views created with this format can be used for depth comparison performed by `OpImage*Dref*` instructions.

- **VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV** specifies that the format is supported as a renderable Linear Color Attachment. This bit will be set for renderable color formats in the `linearTilingFeatures`. This must not be set in the `optimalTilingFeatures` or `bufferFeatures`...
members.

- **VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM** specifies that image views created with this format can be used as the weight image input to weight image sampling operations.
- **VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM** specifies that image views created with this format can be sampled in weight image sampling operations.
- **VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM** specifies that image views created with this format can be used in block matching operations.
- **VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM** specifies that image views created with this format can be sampled in box filter sampling operations.
- **VK_FORMAT_FEATURE_2_HOST_IMAGE_TRANSFER_BIT_EXT** specifies that an image can be created with **VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT**.

The following bits may be set in `bufferFeatures`, specifying that the features are supported by buffers or buffer views created with the queried `vkGetPhysicalDeviceFormatProperties2::format`:

- **VK_FORMAT_FEATURE_2_UNIFORM_TEXEL_BUFFER_BIT** specifies that the format can be used to create a buffer view that can be bound to a **VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER** descriptor.
- **VK_FORMAT_FEATURE_2_STORAGE_TEXEL_BUFFER_BIT** specifies that the format can be used to create a buffer view that can be bound to a **VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER** descriptor.
- **VK_FORMAT_FEATURE_2_STORAGE_TEXEL_BUFFER_ATOMIC_BIT** specifies that atomic operations are supported on **VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER** with this format.
- **VK_FORMAT_FEATURE_2_VERTEX_BUFFER_BIT** specifies that the format can be used as a vertex attribute format (**VkVertexInputAttributeDescription::format**).
- **VK_FORMAT_FEATURE_2_ACCELERATION_STRUCTURE_VERTEX_BUFFER_BIT_KHR** specifies that the format can be used as the vertex format when creating an acceleration structure (**VkAccelerationStructureGeometryTrianglesDataKHR::vertexFormat**). This format can also be used as the vertex format in host memory when doing host acceleration structure builds.
- **VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT** specifies that buffer views created with this format can be used as storage texel buffers for read operations without specifying a format.
- **VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT** specifies that buffer views created with this format can be used as storage texel buffers for write operations without specifying a format.
- **VK_FORMAT_FEATURE_2_OPTICAL_FLOW_IMAGE_BIT_NV** specifies that an image view with this format can be used as an input or reference to optical flow operations.
- **VK_FORMAT_FEATURE_2_OPTICAL_FLOW_VECTOR_BIT_NV** specifies that an image view with this format can be used as a flow vector map (either as hint, output or global flow) for optical flow operations.
- **VK_FORMAT_FEATURE_2_OPTICAL_FLOW_COST_BIT_NV** specifies that an image view with this format can be used as an output cost map for optical flow operations.

```c
// Provided by VK_VERSION_1_3
typedef VkFlags64 VkFormatFeatureFlags2;
```
or the equivalent

```c
// Provided by VK_KHR_format_feature_flags2
typedef VkFormatFeatureFlags2 VkFormatFeatureFlags2KHR;
```

`VkFormatFeatureFlags2` is a bitmask type for setting a mask of zero or more `VkFormatFeatureFlagBits2`.

To query the performance characteristics of a subpass resolve operation for an attachment with a `VkFormat`, add a `VkSubpassResolvePerformanceQueryEXT` structure to the `pNext` chain of `VkFormatProperties2`.

The `VkSubpassResolvePerformanceQueryEXT` structure is defined as:

```c
// Provided by VK_EXT_multisampled_render_to_single_sampled
typedef struct VkSubpassResolvePerformanceQueryEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 optimal;
} VkSubpassResolvePerformanceQueryEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `optimal` specifies that a subpass resolve operation is optimally performed.

If `optimal` is `VK_FALSE` for a `VkFormat`, using a subpass resolve operation on a multisampled attachment with this format can incur additional costs, including additional memory bandwidth usage and a higher memory footprint. If an attachment with such a format is used in a multisampled-render-to-single-sampled subpass, the additional memory and memory bandwidth usage can nullify the benefits of using the `VK_EXT_multisampled_render_to_single_sampled` extension.

### Valid Usage (Implicit)

- VUID-VkSubpassResolvePerformanceQueryEXT-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_SUBPASS_RESOLVE_PERFORMANCE_QUERY_EXT`

### 48.2.1. Potential Format Features

Some valid usage conditions depend on the format features supported by a `VkImage` whose `VkImageTiling` is unknown. In such cases the exact `VkFormatFeatureFlagBits` supported by the `VkImage` cannot be determined, so the valid usage conditions are expressed in terms of the potential format features of the `VkImage` format.

The potential format features of a `VkFormat` are defined as follows:

- The union of `VkFormatFeatureFlagBits` and `VkFormatFeatureFlagBits2`, supported when the
48.3. Required Format Support

Implementations must support at least the following set of features on the listed formats. For images, these features must be supported for every VkImageType (including arrayed and cube variants) unless otherwise noted. These features are supported on existing formats without needing to advertise an extension or needing to explicitly enable them. Support for additional functionality beyond the requirements listed here is queried using the vkGetPhysicalDeviceFormatProperties command.

Note
Unless otherwise excluded below, the required formats are supported for all VkImageCreateFlags values as long as those flag values are otherwise allowed.

The following tables show which feature bits must be supported for each format. Formats that are required to support VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT must also support VK_FORMAT_FEATURE_TRANSFER_SRC_BIT and VK_FORMAT_FEATURE_TRANSFER_DST_BIT.

Table 66. Key for format feature tables

| □ | This feature must be supported on the named format |
| † | This feature must be supported on at least some of the named formats, with more information in the table where the symbol appears |
| ‡ | This feature must be supported with some caveats or preconditions, with more information in the table where the symbol appears |

Table 67. Feature bits in optimalTilingFeatures

- VK_FORMAT_FEATURE_TRANSFER_SRC_BIT
- VK_FORMAT_FEATURE_TRANSFER_DST_BIT
- VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT
- VK_FORMAT_FEATURE_BLIT_SRC_BIT
- VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT
- VK_FORMAT_FEATURE_STORAGE_IMAGE_BIT
- VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT
- VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT
<table>
<thead>
<tr>
<th>Feature Bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_FORMAT_FEATURE_BLIT_DST_BIT</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_MINMAX_BIT</td>
</tr>
</tbody>
</table>

Table 68. Feature bits in bufferFeatures

<table>
<thead>
<tr>
<th>Feature Bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_FORMAT_FEATURE_VERTEX_BUFFER_BIT</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_UNIFORM_TEXEL_BUFFER_BIT</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_BIT</td>
</tr>
<tr>
<td>VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT</td>
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### Table 69. Mandatory format support: sub-byte components

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Format features marked † **must** be supported for `optimalTilingFeatures` if the `VkPhysicalDevice` supports the `VkPhysicalDevice4444FormatsFeaturesEXT::formatA4R4G4B4` feature.

Format features marked ‡ **must** be supported for `optimalTilingFeatures` if the `VkPhysicalDevice` supports the `VkPhysicalDevice4444FormatsFeaturesEXT::formatA4B4G4R4` feature.
Table 70. Mandatory format support: 1-3 byte-sized components

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Format features marked with ‡ must be supported for optimalTilingFeatures if the VkPhysicalDevice supports the shaderStorageImageExtendedFormats feature.
Table 71. Mandatory format support: 4 byte-sized components

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Table 72. Mandatory format support: 10- and 12-bit components

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Format features marked with ‡ must be supported for optimalTilingFeatures if the VkPhysicalDevice supports the shaderStorageImageExtendedFormats feature.
Table 73. Mandatory format support: 16-bit components

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Format features marked with ‡ must be supported for optimalTilingFeatures if the VkPhysicalDevice supports the shaderStorageImageExtendedFormats feature.
Table 74. Mandatory format support: 32-bit components

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Format features marked with † must be supported for optimalTilingFeatures if the VkPhysicalDevice supports the shaderImageFloat32Atomics or the shaderImageFloat32AtomicAdd or the shaderImageFloat32AtomicMinMax feature.
Table 75. Mandatory format support: 64-bit/uneven components

| Format features marked with ‡ must be supported for optimalTilingFeatures if the VkPhysicalDevice supports the shaderStorageImageExtendedFormats feature.
| If the shaderImageInt64Atomics feature is supported, VK_FORMAT_FEATURE_STORAGE_IMAGE_BIT and VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT must be advertised in optimalTilingFeatures for both VK_FORMAT_R64_UINT and VK_FORMAT_R64_SINT. |
Table 76. Mandatory format support: depth/stencil with `VkImageType VK_IMAGE_TYPE_2D`

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**feature** must be supported for at least one of `VK_FORMAT_X8_D24_UNORM_PACK32` and `VK_FORMAT_D32_SFLOAT`, and **must** be supported for at least one of `VK_FORMAT_D24_UNORM_S8_UINT` and `VK_FORMAT_D32_SFLOAT_S8_UINT`.

**bufferFeatures** must not support any features for these formats.
Table 77. Mandatory format support: BC compressed formats with \texttt{VkImageType VK\_IMAGE\_TYPE\_2D} and \texttt{VK\_IMAGE\_TYPE\_3D}

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<tr>
<th>Format</th>
<th>VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT</th>
<th>VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT</th>
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The \texttt{VK\_FORMAT\_FEATURE\_SAMPLED\_IMAGE\_BIT}, \texttt{VK\_FORMAT\_FEATURE\_BLIT\_SRC\_BIT} and \texttt{VK\_FORMAT\_FEATURE\_SAMPLED\_IMAGE\_FILTER\_LINEAR\_BIT} features must be supported in \texttt{optimalTilingFeatures} for all the formats in at least one of: this table, \texttt{Mandatory format support: ETC2 and EAC compressed formats with VkImageType VK\_IMAGE\_TYPE\_2D}, or \texttt{Mandatory format support: ASTC LDR compressed formats with VkImageType VK\_IMAGE\_TYPE\_2D}. 
Table 78. Mandatory format support: ETC2 and EAC compressed formats with VkImageType

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<tr>
<th>Format</th>
<th>VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_ATOMIC_BIT</th>
<th>VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_BIT</th>
<th>VK_FORMAT_FEATURE_UNIFORM_TEXEL_BUFFER_BIT</th>
<th>VK_FORMAT_FEATURE_VERTEX_BUFFER_BIT</th>
<th>VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT</th>
<th>VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BLEND_BIT</th>
<th>VK_FORMAT_FEATURE_BLIT_DST_BIT</th>
<th>VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT</th>
<th>VK_FORMAT_FEATURE_STORAGE_IMAGE_ATOMIC_BIT</th>
<th>VK_FORMAT_FEATURE_STORAGE_IMAGE_BIT</th>
<th>VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT</th>
<th>VK_FORMAT_FEATURE_BLIT_SRC_BIT</th>
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The `VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT`, `VK_FORMAT_FEATURE_BLIT_SRC_BIT` and `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT` features must be supported in `optimalTilingFeatures` for all the formats in at least one of: this table, Mandatory format support: BC compressed formats with VkImageType VK_IMAGE_TYPE_2D and VK_IMAGE_TYPE_3D, or Mandatory format support: ASTC LDR compressed formats with VkImageType VK_IMAGE_TYPE_2D.
Table 79. Mandatory format support: ASTC LDR compressed formats with VkImageType VK_IMAGE_TYPE_2D

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### Mandatory format support:

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The `VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT`, `VK_FORMAT_FEATURE_BLIT_SRC_BIT` and `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_LINEAR_BIT` features **must** be supported in `optimalTilingFeatures` for all the formats in at least one of: this table. **Mandatory format support:** BC compressed formats with `VkImageType` `VK_IMAGE_TYPE_2D` and `VK_IMAGE_TYPE_3D`, or **Mandatory format support:** ETC2 and EAC compressed formats with `VkImageType` `VK_IMAGE_TYPE_2D`.

If cubic filtering is supported, `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT` **must** be supported for the following image view types:

- `VK_IMAGE_VIEW_TYPE_2D`
- `VK_IMAGE_VIEW_TYPE_2D_ARRAY`

for the following formats:

- `VK_FORMAT_R4G4_UNORM_PACK8`
- `VK_FORMAT_R4G4B4A4_UNORM_PACK16`
- `VK_FORMAT_B4G4R4A4_UNORM_PACK16`
- `VK_FORMAT_R5G6B5_UNORM_PACK16`
- `VK_FORMAT_B5G6R5_UNORM_PACK16`
- `VK_FORMAT_R5G5B5A1_UNORM_PACK16`
- `VK_FORMAT_B5G5R5A1_UNORM_PACK16`
- `VK_FORMAT_A1R5G5B5_UNORM_PACK16`
- `VK_FORMAT_R8_UNORM`
- `VK_FORMAT_R8_SNORM`
- `VK_FORMAT_R8_SRGB`
- `VK_FORMAT_R8G8_UNORM`
- `VK_FORMAT_R8G8_SNORM`
- `VK_FORMAT_R8G8_SRGB`
- `VK_FORMAT_R8B8_UNORM`
- `VK_FORMAT_R8B8_SNORM`
- `VK_FORMAT_R8B8_SRGB`
- `VK_FORMAT_B8G8R8_UNORM`
If ETC compressed formats are supported, `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT` must be supported for the following image view types:

- `VK_IMAGE_VIEW_TYPE_2D`
- `VK_IMAGE_VIEW_TYPE_2D_ARRAY`

for the following additional formats:

- `VK_FORMAT_ETC2_R8G8B8_UNORM_BLOCK`
- `VK_FORMAT_ETC2_R8G8B8_SRGB_BLOCK`
- `VK_FORMAT_ETC2_R8G8B8A1_UNORM_BLOCK`
- `VK_FORMAT_ETC2_R8G8B8A1_SRGB_BLOCK`
- `VK_FORMAT_ETC2_R8G8B8A8_UNORM_BLOCK`
- `VK_FORMAT_ETC2_R8G8B8A8_SRGB_BLOCK`

If cubic filtering is supported for any other formats, the following image view types must be supported for those formats:

- `VK_IMAGE_VIEW_TYPE_2D`
- `VK_IMAGE_VIEW_TYPE_2D_ARRAY`

To be used with `VkImageView` with `subresourceRange.aspectMask` equal to `VK_IMAGE_ASPECT_COLOR_BIT`, sampler $Y'C_bC_r$ conversion must be enabled for the following formats:
Table 80. Formats requiring sampler Y’C_nC_m conversion for VK_IMAGE_ASPECT_COLOR_BIT image views

<table>
<thead>
<tr>
<th>Format</th>
<th>Planes</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_FORMAT_G8B8G8R8_422_UNORM</td>
<td>1</td>
</tr>
<tr>
<td>VK_FORMAT_B8G8R8G8_422_UNORM</td>
<td>1</td>
</tr>
<tr>
<td>VK_FORMAT_G8_B8_R8_3PLANE_420_UNORM</td>
<td>3</td>
</tr>
<tr>
<td>VK_FORMAT_G8_B8R8_2PLANE_420_UNORM</td>
<td>2</td>
</tr>
<tr>
<td>VK_FORMAT_G8_B8_R8_3PLANE_422_UNORM</td>
<td>3</td>
</tr>
<tr>
<td>VK_FORMAT_G8_B8R8_2PLANE_422_UNORM</td>
<td>2</td>
</tr>
<tr>
<td>VK_FORMAT_G8_B8_3PLANE_444_UNORM</td>
<td>3</td>
</tr>
<tr>
<td>VK_FORMAT_R10X6G10X6B10X6A10X6_4PACK16 ‡</td>
<td>1</td>
</tr>
<tr>
<td>VK_FORMAT_G10X6B10X6G10X6R10X6_422_UNORM_4PACK16</td>
<td>1</td>
</tr>
<tr>
<td>VK_FORMAT_B10X6G10X6B10X6R10X6_422_UNORM_4PACK16</td>
<td>1</td>
</tr>
<tr>
<td>VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_420_UNORM_3PACK16</td>
<td>3</td>
</tr>
<tr>
<td>VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_422_UNORM_3PACK16</td>
<td>3</td>
</tr>
<tr>
<td>VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_444_UNORM_3PACK16</td>
<td>3</td>
</tr>
<tr>
<td>VK_FORMAT_R12X4G12X4B12X4A12X4_UNORM_4PACK16</td>
<td>1</td>
</tr>
<tr>
<td>VK_FORMAT_G12X4B12X4G12X4R12X4_422_UNORM_4PACK16</td>
<td>1</td>
</tr>
<tr>
<td>VK_FORMAT_B12X4G12X4R12X4_422_UNORM_4PACK16</td>
<td>1</td>
</tr>
<tr>
<td>VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_420_UNORM_3PACK16</td>
<td>3</td>
</tr>
<tr>
<td>VK_FORMAT_G12X4_B12X4_R12X4_2PLANE_420_UNORM_3PACK16</td>
<td>2</td>
</tr>
<tr>
<td>VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_422_UNORM_3PACK16</td>
<td>3</td>
</tr>
<tr>
<td>VK_FORMAT_G12X4_B12X4_R12X4_2PLANE_422_UNORM_3PACK16</td>
<td>2</td>
</tr>
<tr>
<td>VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_444_UNORM_3PACK16</td>
<td>3</td>
</tr>
<tr>
<td>Format</td>
<td>Count</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>VK_FORMAT_G16B16G16R16_422_UNORM</td>
<td>1</td>
</tr>
<tr>
<td>VK_FORMAT_B16G16R16G16_422_UNORM</td>
<td>1</td>
</tr>
<tr>
<td>VK_FORMAT_G16_B16_R16_3PLANE_420_UNORM</td>
<td>3</td>
</tr>
<tr>
<td>VK_FORMAT_G16_B16R16_2PLANE_420_UNORM</td>
<td>2</td>
</tr>
<tr>
<td>VK_FORMAT_G16_B16_R16_3PLANE_422_UNORM</td>
<td>3</td>
</tr>
<tr>
<td>VK_FORMAT_G16_B16R16_2PLANE_422_UNORM</td>
<td>2</td>
</tr>
<tr>
<td>VK_FORMAT_G16_B16_R16_3PLANE_444_UNORM</td>
<td>3</td>
</tr>
<tr>
<td>VK_FORMAT_G16_B16R16_2PLANE_444_UNORM</td>
<td>2</td>
</tr>
<tr>
<td>VK_FORMAT_G8_B8R8_2PLANE_444_UNORM</td>
<td>2</td>
</tr>
<tr>
<td>VK_FORMAT_G10X6_B10X6R10X6_2PLANE_444_UNORM_3PACK16</td>
<td>2</td>
</tr>
<tr>
<td>VK_FORMAT_G12X4_B12X4R12X4_2PLANE_444_UNORM_3PACK16</td>
<td>2</td>
</tr>
<tr>
<td>VK_FORMAT_G16_B16R16_2PLANE_444_UNORM</td>
<td>2</td>
</tr>
</tbody>
</table>

Format features marked † must be supported for optimalTilingFeatures with VkImageType VK_IMAGE_TYPE_2D if the VkPhysicalDevice supports the VkPhysicalDeviceSamplerYcbcrConversionFeatures feature.

Formats marked ‡ do not require a sampler Y’C_bC_r conversion for VK_IMAGE_ASPECT_COLOR_BIT image views if the VkPhysicalDeviceRGBA10X6FormatsFeaturesEXT::formatRgba10x6WithoutYCbCrSampler feature is enabled.

Implementations are not required to support the VK_IMAGE_CREATE_SPARSE_BINDING_BIT, VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT, or VK_IMAGE_CREATE_SPARSE_ALIASED_BIT VkImageCreateFlags for the above formats that require sampler Y’C_bC_r conversion. To determine whether the implementation supports sparse image creation flags with these formats use vkGetPhysicalDeviceImageFormatProperties or vkGetPhysicalDeviceImageFormatProperties2.

**VK_FORMAT_FEATURE_FRAGMENT_DENSITY_MAP_BIT_EXT must** be supported for the following formats if the fragmentDensityMap feature is enabled:

- VK_FORMAT_R8G8_UNORM

**VK_FORMAT_FEATURE_ACCELERATION_STRUCTURE_VERTEX_BUFFER_BIT_KHR must** be supported in bufferFeatures for the following formats if the accelerationStructure feature is supported:

- VK_FORMAT_R32G32_SFLOAT
- VK_FORMAT_R32G32B32_SFLOAT
- VK_FORMAT_R16G16_SFLOAT
- VK_FORMAT_R16G16B16A16_SFLOAT
- VK_FORMAT_R16G16_SNORM
- VK_FORMAT_R16G16B16A16_SNORM

**VK_FORMAT_FEATURE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR must** be supported for the following formats if the attachmentFragmentShadingRate feature is supported:

- VK_FORMAT_R8_UINT
If `VK_EXT_host_image_copy` is supported and `VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT` is supported in `optimalTilingFeatures` or `linearTilingFeatures` for a color format, `VK_FORMAT_FEATURE_2_HOST_IMAGE_TRANSFER_BIT_EXT` must also be supported in `optimalTilingFeatures` or `linearTilingFeatures` respectively.

### 48.3.1. Formats without shader storage format

The device-level features for using a storage image or a storage texel buffer with an image format of `Unknown`, `shaderStorageImageReadWithoutFormat` and `shaderStorageImageWriteWithoutFormat`, only apply to the following formats:

- `VK_FORMAT_R8G8B8A8_UNORM`
- `VK_FORMAT_R8G8B8A8_SNORM`
- `VK_FORMAT_R8G8B8A8_UINT`
- `VK_FORMAT_R8G8B8A8_SINT`
- `VK_FORMAT_R32_UINT`
- `VK_FORMAT_R32_SINT`
- `VK_FORMAT_R32_SFLOAT`
- `VK_FORMAT_R32G32_UINT`
- `VK_FORMAT_R32G32_SINT`
- `VK_FORMAT_R32G32_SFLOAT`
- `VK_FORMAT_R32G32B32A32_UINT`
- `VK_FORMAT_R32G32B32A32_SINT`
- `VK_FORMAT_R32G32B32A32_SFLOAT`
- `VK_FORMAT_R16G16B16A16_UINT`
- `VK_FORMAT_R16G16B16A16_SINT`
- `VK_FORMAT_R16G16B16A16_SFLOAT`
- `VK_FORMAT_R16G16_SNORM`
- `VK_FORMAT_B10G11R11_UFLOAT_PACK32`
- `VK_FORMAT_R16_SFLOAT`
- `VK_FORMAT_R16G16B16A16_UNORM`
- `VK_FORMAT_A2B10G10R10_UNORM_PACK32`
- `VK_FORMAT_R16G16_UNORM`
- `VK_FORMAT_R8G8_UNORM`
- `VK_FORMAT_R16_UNORM`
- `VK_FORMAT_R8_UNORM`
- `VK_FORMAT_R16G16B16A16_SNORM`
- `VK_FORMAT_R16G16_SNORM`
• VK_FORMAT_R8G8_SNORM
• VK_FORMAT_R16_SNORM
• VK_FORMAT_R8_SNORM
• VK_FORMAT_R16G16_SINT
• VK_FORMAT_R8G8_SINT
• VK_FORMAT_R16_SINT
• VK_FORMAT_R8_SINT
• VK_FORMAT_A2B10G10R10_UINT_PACK32
• VK_FORMAT_R16G16_UINT
• VK_FORMAT_R8G8_UINT
• VK_FORMAT_R16_UINT
• VK_FORMAT_R8_UINT
• VK_FORMAT_A8_UNORM_KHR

Note
This list of formats is the union of required storage formats from Required Format Support section and formats listed in shaderStorageImageExtendedFormats.

An implementation that supports VK_FORMAT_FEATURE_STORAGE_IMAGE_BIT for any format from the given list of formats and supports shaderStorageImageReadWithoutFormat must support VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT for that same format if Vulkan 1.3 or the VK_KHR_format_feature_flags2 extension is supported.

An implementation that supports VK_FORMAT_FEATURE_STORAGE_IMAGE_BIT for any format from the given list of formats and supports shaderStorageImageWriteWithoutFormat must support VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT for that same format if Vulkan 1.3 or the VK_KHR_format_feature_flags2 extension is supported.

48.3.2. Depth comparison format support

If Vulkan 1.3 or the VK_KHR_format_feature_flags2 extension is supported, a depth/stencil format with a depth component supporting VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT must support VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT.

48.3.3. Format feature dependent usage flags

Certain resource usage flags depend on support for the corresponding format feature flag for the format in question. The following tables list the VkBufferUsageFlagBits and VkImageUsageFlagBits that have such dependencies, and the format feature flags they depend on. Additional restrictions, including, but not limited to, further required format feature flags specific to the particular use of the resource may apply, as described in the respective sections of this specification.

Table 81. Format feature dependent buffer usage flags
<table>
<thead>
<tr>
<th>Buffer usage flag</th>
<th>Required format feature flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_BUFFER_USAGE_UNIFORM_TEXEL_BUFFER_BIT</td>
<td>VK_FORMAT_FEATURE_UNIFORM_TEXEL_BUFFER_BIT</td>
</tr>
<tr>
<td>VK_BUFFER_USAGE_STORAGE_TEXEL_BUFFER_BIT</td>
<td>VK_FORMAT_FEATURE_STORAGE_TEXEL_BUFFER_BIT</td>
</tr>
<tr>
<td>VK_BUFFER_USAGE_VERTEX_BUFFER_BIT</td>
<td>VK_FORMAT_FEATURE_VERTEX_BUFFER_BIT</td>
</tr>
</tbody>
</table>

Table 82. Format feature dependent image usage flags

<table>
<thead>
<tr>
<th>Image usage flag</th>
<th>Required format feature flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_IMAGE_USAGE_SAMPLED_BIT</td>
<td>VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT</td>
</tr>
<tr>
<td>VK_IMAGE_USAGE_STORAGE_BIT</td>
<td>VK_FORMAT_FEATURE_STORAGE_IMAGE_BIT</td>
</tr>
<tr>
<td>VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT</td>
<td>VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT</td>
</tr>
<tr>
<td>VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT</td>
<td>VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT</td>
</tr>
<tr>
<td>VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT</td>
<td>VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT or VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT</td>
</tr>
<tr>
<td>VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR</td>
<td>VK_FORMAT_FEATURE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR</td>
</tr>
<tr>
<td>VK_IMAGE_USAGE_VIDEO DECODE_DST_BIT_KHR</td>
<td>VK_FORMAT_FEATURE_VIDEO DECODE OUTPUT_BIT_KHR</td>
</tr>
<tr>
<td>VK_IMAGE_USAGE_VIDEO DECODE DPB_BIT_KHR</td>
<td>VK_FORMAT_FEATURE_VIDEO DECODE DPB_BIT_KHR</td>
</tr>
<tr>
<td>VK_IMAGE_USAGE_VIDEO_ENCODE_SRC_BIT_KHR</td>
<td>VK_FORMAT_FEATURE_VIDEO_ENCODE INPUT_BIT_KHR</td>
</tr>
<tr>
<td>VK_IMAGE_USAGE_VIDEO_ENCODE DPB_BIT_KHR</td>
<td>VK_FORMAT_FEATURE_VIDEO_ENCODE DPB_BIT_KHR</td>
</tr>
</tbody>
</table>
Chapter 49. Additional Capabilities

This chapter describes additional capabilities beyond the minimum capabilities described in the Limits and Formats chapters, including:

- Additional Image Capabilities
- Additional Buffer Capabilities
- Optional Semaphore Capabilities
- Optional Fence Capabilities
- Timestamp Calibration Capabilities

49.1. Additional Image Capabilities

Additional image capabilities, such as larger dimensions or additional sample counts for certain image types, or additional capabilities for linear tiling format images, are described in this section.

To query additional capabilities specific to image types, call:

```c
// Provided by VK_VERSION_1_0
VkResult vkGetPhysicalDeviceImageFormatProperties(
    VkPhysicalDevice physicalDevice,
    VkFormat format,
    VkImageType type,
    VkImageTiling tiling,
    VkImageUsageFlags usage,
    VkImageCreateFlags flags,
    VkImageFormatProperties* pImageFormatProperties);
```

- `physicalDevice` is the physical device from which to query the image capabilities.
- `format` is a `VkFormat` value specifying the image format, corresponding to `VkImageCreateInfo::format`.
- `type` is a `VkImageType` value specifying the image type, corresponding to `VkImageCreateInfo::imageType`.
- `tiling` is a `VkImageTiling` value specifying the image tiling, corresponding to `VkImageCreateInfo::tiling`.
- `usage` is a bitmask of `VkImageUsageFlagBits` specifying the intended usage of the image, corresponding to `VkImageCreateInfo::usage`.
- `flags` is a bitmask of `VkImageCreateFlagBits` specifying additional parameters of the image, corresponding to `VkImageCreateInfo::flags`.
- `pImageFormatProperties` is a pointer to a `VkImageFormatProperties` structure in which capabilities are returned.

The `format`, `type`, `tiling`, `usage`, and `flags` parameters correspond to parameters that would be
consumed by `vkCreateImage` (as members of `VkImageCreateInfo`).

If `format` is not a supported image format, or if the combination of `format`, `type`, `tiling`, `usage`, and `flags` is not supported for images, then `vkGetPhysicalDeviceImageFormatProperties` returns `VK_ERROR_FORMAT_NOT_SUPPORTED`.

The limitations on an image format that are reported by `vkGetPhysicalDeviceImageFormatProperties` have the following property: if `usage1` and `usage2` of type `VkImageUsageFlags` are such that the bits set in `usage1` are a subset of the bits set in `usage2`, and `flags1` and `flags2` of type `VkImageCreateFlags` are such that the bits set in `flags1` are a subset of the bits set in `flags2`, then the limitations for `usage1` and `flags1` must be no more strict than the limitations for `usage2` and `flags2`, for all values of `format`, `type`, and `tiling`.

If `VK_EXT_host_image_copy` is supported, `usage` includes `VK_IMAGE_USAGE_SAMPLED_BIT`, and `flags` does not include either of `VK_IMAGE_CREATE_SPARSE_BINDING_BIT`, `VK_IMAGE_CREATE_SPARSE_RESIDENCY_BIT`, or `VK_IMAGE_CREATE_SPARSE_ALIASED_BIT`, then the result of calls to `vkGetPhysicalDeviceImageFormatProperties` with identical parameters except for the inclusion of `VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT` in `usage` must be identical.

### Valid Usage

- **VUID-vkGetPhysicalDeviceImageFormatProperties-tiling-02248**
  - `tiling` must not be `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`. (Use `vkGetPhysicalDeviceImageFormatProperties2` instead)

### Valid Usage (Implicit)

- **VUID-vkGetPhysicalDeviceImageFormatProperties-physicalDevice-parameter**
  - `physicalDevice` must be a valid `VkPhysicalDevice` handle

- **VUID-vkGetPhysicalDeviceImageFormatProperties-format-parameter**
  - `format` must be a valid `VkFormat` value

- **VUID-vkGetPhysicalDeviceImageFormatProperties-type-parameter**
  - `type` must be a valid `VkImageType` value

- **VUID-vkGetPhysicalDeviceImageFormatProperties-tiling-parameter**
  - `tiling` must be a valid `VkImageTiling` value

- **VUID-vkGetPhysicalDeviceImageFormatProperties-usage-parameter**
  - `usage` must be a valid combination of `VkImageUsageFlagBits` values

- **VUID-vkGetPhysicalDeviceImageFormatProperties-usage-requiredbitmap**
  - `usage` must not be 0

- **VUID-vkGetPhysicalDeviceImageFormatProperties-flags-parameter**
  - `flags` must be a valid combination of `VkImageCreateFlagBits` values

- **VUID-vkGetPhysicalDeviceImageFormatProperties-pImageFormatProperties-parameter**
  - `pImageFormatProperties` must be a valid pointer to a `VkImageFormatProperties` structure
### Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_FORMAT_NOT_SUPPORTED

The `VkImageFormatProperties` structure is defined as:

```c
// Provided by VK_VERSION_1_0
typedef struct VkImageFormatProperties {
    VkExtent3D maxExtent;
    uint32_t maxMipLevels;
    uint32_t maxArrayLayers;
    VkSampleCountFlags sampleCounts;
    VkDeviceSize maxResourceSize;
} VkImageFormatProperties;
```

- `maxExtent` are the maximum image dimensions. See the Allowed Extent Values section below for how these values are constrained by `type`.

- `maxMipLevels` is the maximum number of mipmap levels. `maxMipLevels` **must** be equal to the number of levels in the complete mipmap chain based on the `maxExtent.width`, `maxExtent.height`, and `maxExtent.depth`, except when one of the following conditions is true, in which case it **may** instead be 1:
  - `vkGetPhysicalDeviceImageFormatProperties::tiling` was VK_IMAGE_TILING_LINEAR
  - `VkPhysicalDeviceImageFormatInfo2::tiling` was VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT
  - the `VkPhysicalDeviceImageFormatInfo2::pNext` chain included a `VkPhysicalDeviceExternalImageFormatInfo` structure with a handle type included in the `handleTypes` member for which mipmap image support is not required
  - image `format` is one of the formats that require a sampler Y’CbCr conversion
  - `flags` contains VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT

- `maxArrayLayers` is the maximum number of array layers. `maxArrayLayers` **must** be no less than `VkPhysicalDeviceLimits::maxImageArrayLayers`, except when one of the following conditions is true, in which case it **may** instead be 1:
  - `tiling` is VK_IMAGE_TILING_LINEAR
  - `tiling` is VK_IMAGE_TILING_OPTIMAL and `type` is VK_IMAGE_TYPE_3D
  - `format` is one of the formats that require a sampler Y’CbCr conversion

- If `tiling` is VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT, then `maxArrayLayers` **must** not be 0.
• **sampleCounts** is a bitmask of **VkSampleCountFlagBits** specifying all the supported sample counts for this image as described below.

• **maxResourceSize** is an upper bound on the total image size in bytes, inclusive of all image subresources. Implementations **may** have an address space limit on total size of a resource, which is advertised by this property. **maxResourceSize** **must** be at least $2^{31}$.

**Note**
There is no mechanism to query the size of an image before creating it, to compare that size against **maxResourceSize**. If an application attempts to create an image that exceeds this limit, the creation will fail and **vkCreateImage** will return **VK_ERROR_OUT_OF_DEVICE_MEMORY**. While the advertised limit **must** be at least $2^{31}$, it **may** not be possible to create an image that approaches that size, particularly for **VK_IMAGE_TYPE_1D**.

If the combination of parameters to **vkGetPhysicalDeviceImageFormatProperties** is not supported by the implementation for use in **vkCreateImage**, then all members of **VkImageFormatProperties** will be filled with zero.

**Note**
Filling **VkImageFormatProperties** with zero for unsupported formats is an exception to the usual rule that output structures have undefined contents on error. This exception was unintentional, but is preserved for backwards compatibility.

To determine the image capabilities compatible with an external memory handle type, call:

```c
// Provided by VK_NV_external_memory_capabilities
VkResult vkGetPhysicalDeviceExternalImageFormatPropertiesNV(  
    VkPhysicalDevice physicalDevice,  
    VkFormat format,  
    VkImageType type,  
    VkImageTiling tiling,  
    VkImageUsageFlags usage,  
    VkImageCreateFlags flags,  
    VkExternalMemoryHandleTypeFlagsNV externalHandleType,  
    VkExternalImageFormatPropertiesNV* pExternalImageFormatProperties);
```

• **physicalDevice** is the physical device from which to query the image capabilities

• **format** is the image format, corresponding to **VkImageCreateInfo::format**.

• **type** is the image type, corresponding to **VkImageCreateInfo::imageType**.

• **tiling** is the image tiling, corresponding to **VkImageCreateInfo::tiling**.

• **usage** is the intended usage of the image, corresponding to **VkImageCreateInfo::usage**.

• **flags** is a bitmask describing additional parameters of the image, corresponding to **VkImageCreateInfo::flags**.

• **externalHandleType** is either one of the bits from **VkExternalMemoryHandleTypeFlagBitsNV**, or
• **pExternalImageFormatProperties** is a pointer to a **VkExternalImageFormatPropertiesNV** structure in which capabilities are returned.

If **externalHandleType** is 0, **pExternalImageFormatProperties->imageFormatProperties** will return the same values as a call to **vkGetPhysicalDeviceImageFormatProperties**, and the other members of **pExternalImageFormatProperties** will all be 0. Otherwise, they are filled in as described for **VkExternalImageFormatPropertiesNV**.

---

**Valid Usage**

- VUID-vkGetPhysicalDeviceExternalImageFormatPropertiesNV-externalHandleType-07721
  externalHandleType **must** not have more than one bit set

---

**Valid Usage (Implicit)**

- VUID-vkGetPhysicalDeviceExternalImageFormatPropertiesNV-physicalDevice-parameter
  physicalDevice **must** be a valid **VkPhysicalDevice** handle

- VUID-vkGetPhysicalDeviceExternalImageFormatPropertiesNV-format-parameter
  format **must** be a valid **VkFormat** value

- VUID-vkGetPhysicalDeviceExternalImageFormatPropertiesNV-type-parameter
  type **must** be a valid **VkImageType** value

- VUID-vkGetPhysicalDeviceExternalImageFormatPropertiesNV-tiling-parameter
  tiling **must** be a valid **VkImageTiling** value

- VUID-vkGetPhysicalDeviceExternalImageFormatPropertiesNV-usage-parameter
  usage **must** be a valid combination of **VkImageUsageFlagBits** values

- VUID-vkGetPhysicalDeviceExternalImageFormatPropertiesNV-usage-requiredbitmask
  usage **must not** be 0

- VUID-vkGetPhysicalDeviceExternalImageFormatPropertiesNV-flags-parameter
  flags **must** be a valid combination of **VkImageCreateFlagBits** values

- VUID-vkGetPhysicalDeviceExternalImageFormatPropertiesNV-externalHandleType-parameter
  externalHandleType **must** be a valid combination of **VkExternalMemoryHandleTypeFlagBitsNV** values

  pExternalImageFormatProperties **must** be a valid pointer to a **VkExternalImageFormatPropertiesNV** structure
Return Codes

Success
• VK_SUCCESS

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY
• VK_ERROR_FORMAT_NOT_SUPPORTED

The VkExternalImageFormatPropertiesNV structure is defined as:

```c
// Provided by VK_NV_external_memory_capabilities
typedef struct VkExternalImageFormatPropertiesNV {
    VkImageFormatProperties imageFormatProperties;
    VkExternalMemoryFeatureFlagsNV externalMemoryFeatures;
    VkExternalMemoryHandleTypeFlagsNV exportFromImportedHandleTypes;
    VkExternalMemoryHandleTypeFlagsNV compatibleHandleTypes;
} VkExternalImageFormatPropertiesNV;
```

• `imageFormatProperties` will be filled in as when calling `vkGetPhysicalDeviceImageFormatProperties`, but the values returned may vary depending on the external handle type requested.

• `externalMemoryFeatures` is a bitmask of `VkExternalMemoryFeatureFlagBitsNV`, indicating properties of the external memory handle type (`vkGetPhysicalDeviceExternalImageFormatPropertiesNV::externalHandleType`) being queried, or 0 if the external memory handle type is 0.

• `exportFromImportedHandleTypes` is a bitmask of `VkExternalMemoryHandleTypeFlagBitsNV` containing a bit set for every external handle type that may be used to create memory from which the handles of the type specified in `vkGetPhysicalDeviceExternalImageFormatPropertiesNV::externalHandleType` can be exported, or 0 if the external memory handle type is 0.

• `compatibleHandleTypes` is a bitmask of `VkExternalMemoryHandleTypeFlagBitsNV` containing a bit set for every external handle type that may be specified simultaneously with the handle type specified by `vkGetPhysicalDeviceExternalImageFormatPropertiesNV::externalHandleType` when calling `vkAllocateMemory`, or 0 if the external memory handle type is 0. `compatibleHandleTypes` will always contain `vkGetPhysicalDeviceExternalImageFormatPropertiesNV::externalHandleType`

Bits which can be set in `VkExternalImageFormatPropertiesNV::externalMemoryFeatures`, indicating properties of the external memory handle type, are:

```c
// Provided by VK_NV_external_memory_capabilities
typedef enum VkExternalMemoryFeatureFlagBitsNV {
    VK_EXTERNAL_MEMORY_FEATURE_DEDICATED_ONLY_BIT_NV = 0x00000001,
};
```
• **VK_EXTERNAL_MEMORY_FEATURE_DEDICATED_ONLY_BIT_NV** specifies that external memory of the specified type must be created as a dedicated allocation when used in the manner specified.

• **VK_EXTERNAL_MEMORY_FEATURE_EXPORTABLE_BIT_NV** specifies that the implementation supports exporting handles of the specified type.

• **VK_EXTERNAL_MEMORY_FEATURE_IMPORTABLE_BIT_NV** specifies that the implementation supports importing handles of the specified type.

```
// Provided by VK_NV_external_memory_capabilities
typedef VkFlags VkExternalMemoryFeatureFlagsNV;
```

`VkExternalMemoryFeatureFlagsNV` is a bitmask type for setting a mask of zero or more `VkExternalMemoryFeatureFlagBitsNV`.

To query additional capabilities specific to image types, call:

```
// Provided by VK_VERSION_1_1
VkResult vkGetPhysicalDeviceImageFormatProperties2(
    VkPhysicalDevice physicalDevice,
    const VkPhysicalDeviceImageFormatInfo2* pImageFormatInfo,
    VkImageFormatProperties2* pImageFormatProperties);
```

or the equivalent command

```
// Provided by VK_KHR_get_physical_device_properties2
VkResult vkGetPhysicalDeviceImageFormatProperties2KHR(
    VkPhysicalDevice physicalDevice,
    const VkPhysicalDeviceImageFormatInfo2* pImageFormatInfo,
    VkImageFormatProperties2* pImageFormatProperties);
```

• **physicalDevice** is the physical device from which to query the image capabilities.

• **pImageFormatInfo** is a pointer to a `VkPhysicalDeviceImageFormatInfo2` structure describing the parameters that would be consumed by `vkCreateImage`.

• **pImageFormatProperties** is a pointer to a `VkImageFormatProperties2` structure in which capabilities are returned.

`vkGetPhysicalDeviceImageFormatProperties2` behaves similarly to `vkGetPhysicalDeviceImageFormatProperties`, with the ability to return extended information in a `pNext` chain of output structures.

If the `pNext` chain of `pImageFormatInfo` includes a `VkVideoProfileListInfoKHR` structure with a `profileCount` member greater than 0, then this command returns format capabilities specific to
image types used in conjunction with the specified video profiles. In this case, this command will return one of the video-profile-specific error codes if any of the profiles specified via VkVideoProfileListInfoKHR::pProfiles are not supported. Furthermore, if VkPhysicalDeviceImageFormatInfo2::usage includes any image usage flag not supported by the specified video profiles, then this command returns VK_ERROR_IMAGE_USAGE_NOT_SUPPORTED_KHR.

**Valid Usage**

- VUID-vkGetPhysicalDeviceImageFormatProperties2-pNext-01868
  If the pNext chain of pImageFormatProperties includes a VkAndroidHardwareBufferUsageANDROID structure, the pNext chain of pImageFormatInfo must include a VkPhysicalDeviceExternalImageFormatInfo structure with handleType set to VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID

- VUID-vkGetPhysicalDeviceImageFormatProperties2-pNext-09004
  If the pNext chain of pImageFormatProperties includes a VkHostImageCopyDevicePerformanceQueryEXT structure, pImageFormatInfo->usage must contain VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT

**Valid Usage (Implicit)**

- VUID-vkGetPhysicalDeviceImageFormatProperties2-physicalDevice-parameter
  physicalDevice must be a valid VkPhysicalDevice handle

- VUID-vkGetPhysicalDeviceImageFormatProperties2-pImageFormatInfo-parameter
  pImageFormatInfo must be a valid pointer to a valid VkPhysicalDeviceImageFormatInfo2 structure

  pImageFormatProperties must be a valid pointer to a VkImageFormatProperties2 structure

**Return Codes**

**Success**

- VK_SUCCESS

**Failure**

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY
- VK_ERROR_FORMAT_NOT_SUPPORTED
- VK_ERROR_VIDEO_PROFILE_OPERATION_NOT_SUPPORTED_KHR
- VK_ERROR_VIDEO_PROFILE_FORMAT_NOT_SUPPORTED_KHR
- VK_ERROR_VIDEO_PICTURE_LAYOUT_NOT_SUPPORTED_KHR
- VK_ERROR_VIDEO_PROFILE_CODEC_NOT_SUPPORTED_KHR

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The `VkPhysicalDeviceImageFormatInfo2` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceImageFormatInfo2 {
    VkStructureType    sType;
    const void*        pNext;
    VkFormat           format;
    VkImageType        type;
    VkImageTiling      tiling;
    VkImageUsageFlags  usage;
    VkImageCreateFlags flags;
} VkPhysicalDeviceImageFormatInfo2;
```

or the equivalent

```c
// Provided by VK_KHR_get_physical_device_properties2
typedef VkPhysicalDeviceImageFormatInfo2 VkPhysicalDeviceImageFormatInfo2KHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure. The `pNext` chain of `VkPhysicalDeviceImageFormatInfo2` is used to provide additional image parameters to `vkGetPhysicalDeviceImageFormatProperties2`.
- `format` is a `VkFormat` value indicating the image format, corresponding to `VkImageCreateInfo::format`.
- `type` is a `VkImageType` value indicating the image type, corresponding to `VkImageCreateInfo::imageType`.
- `tiling` is a `VkImageTiling` value indicating the image tiling, corresponding to `VkImageCreateInfo::tiling`.
- `usage` is a bitmask of `VkImageUsageFlagBits` indicating the intended usage of the image, corresponding to `VkImageCreateInfo::usage`.
- `flags` is a bitmask of `VkImageCreateFlagBits` indicating additional parameters of the image, corresponding to `VkImageCreateInfo::flags`.

The members of `VkPhysicalDeviceImageFormatInfo2` correspond to the arguments to `vkGetPhysicalDeviceImageFormatProperties`, with `sType` and `pNext` added for extensibility.

### Valid Usage

- **VUID-VkPhysicalDeviceImageFormatInfo2-tiling-02249**
  - `tiling` must be `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT` if and only if the `pNext` chain includes `VkPhysicalDeviceImageDrmFormatModifierInfoEXT`.

- **VUID-VkPhysicalDeviceImageFormatInfo2-tiling-02313**
  - If `tiling` is `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT` and `flags` contains `VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT`, then the `pNext` chain must include a
Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceImageFormatInfo2-sType-sType**
  
  The `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_FORMAT_INFO_2`.

- **VUID-VkPhysicalDeviceImageFormatInfo2-pNext-pNext**
  
  Each `pNext` member of any structure (including this one) in the `pNext` chain must be either `NULL` or a pointer to a valid instance of `VkImageCompressionControlEXT`, `VkImageFormatListCreateInfo`, `VkImageStencilUsageCreateInfo`, `VkOpticalFlowImageFormatInfoNV`, `VkPhysicalDeviceExternalImageFormatInfo`, `VkPhysicalDeviceImageDrmFormatModifierInfoEXT`, `VkPhysicalDeviceImageViewImageFormatInfoEXT`, or `VkVideoProfileListInfoKHR`.

- **VUID-VkPhysicalDeviceImageFormatInfo2-sType-unique**
  
  The `sType` value of each struct in the `pNext` chain must be unique.

- **VUID-VkPhysicalDeviceImageFormatInfo2-format-parameter**
  
  The `format` must be a valid `VkFormat` value.

- **VUID-VkPhysicalDeviceImageFormatInfo2-type-parameter**
  
  The `type` must be a valid `VkImageType` value.

- **VUID-VkPhysicalDeviceImageFormatInfo2-tiling-parameter**
  
  The `tiling` must be a valid `VkImageTiling` value.

- **VUID-VkPhysicalDeviceImageFormatInfo2-usage-parameter**
  
  The `usage` must be a valid combination of `VkImageUsageFlagBits` values.

- **VUID-VkPhysicalDeviceImageFormatInfo2-usage-requiredbitmask**
  
  The `usage` must not be `0`.

- **VUID-VkPhysicalDeviceImageFormatInfo2-flags-parameter**
  
  The `flags` must be a valid combination of `VkImageCreateFlagBits` values.

The `VkImageFormatProperties2` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkImageFormatProperties2 {
    VkStructureType sType;
    void* pNext;
    VkImageFormatProperties imageFormatProperties;
} VkImageFormatProperties2;
```

or the equivalent

```c
// Provided by VK_KHR_get_physical_device_properties2
typedef VkImageFormatProperties2 VkImageFormatProperties2KHR;
```
• **sType** is a *VkStructureType* value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure. The *pNext* chain of *VkImageFormatProperties2* is used to allow the specification of additional capabilities to be returned from *vkGetPhysicalDeviceImageFormatProperties2*.

• **imageFormatProperties** is a *VkImageFormatProperties* structure in which capabilities are returned.

If the combination of parameters to *vkGetPhysicalDeviceImageFormatProperties2* is not supported by the implementation for use in *vkCreateImage*, then all members of **imageFormatProperties** will be filled with zero.

**Note**

Filling **imageFormatProperties** with zero for unsupported formats is an exception to the usual rule that output structures have undefined contents on error. This exception was unintentional, but is preserved for backwards compatibility. This exception only applies to **imageFormatProperties**, not **sType**, **pNext**, or any structures chained from **pNext**.

### Valid Usage (Implicit)

- **VUID-VkImageFormatProperties2-sType-sType**
  
  **sType** must be **VK_STRUCTURE_TYPE_IMAGE_FORMAT_PROPERTIES_2**

- **VUID-VkImageFormatProperties2-pNext-pNext**
  
  Each **pNext** member of any structure (including this one) in the **pNext** chain must be either **NULL** or a pointer to a valid instance of *VkAndroidHardwareBufferUsageANDROID*, *VkExternalImageFormatProperties*, *VkFilterCubicImageViewImageFormatPropertiesEXT*, *VkHostImageCopyDevicePerformanceQueryEXT*, *VkImageCompressionPropertiesEXT*, *VkSamplerYcbcrConversionImageFormatProperties*, or *VkTextureLODGatherFormatPropertiesAMD*

- **VUID-VkImageFormatProperties2-sType-unique**
  
  The **sType** value of each struct in the **pNext** chain must be unique

To determine if texture gather functions that take explicit LOD and/or bias argument values can be used with a given image format, add a *VkTextureLODGatherFormatPropertiesAMD* structure to the **pNext** chain of the *VkImageFormatProperties2* structure in a call to *vkGetPhysicalDeviceImageFormatProperties2*.

The *VkTextureLODGatherFormatPropertiesAMD* structure is defined as:

```c
// Provided by VK_AMD_texture_gather_bias_lod
typedef struct VkTextureLODGatherFormatPropertiesAMD {
    VkStructureType sType;
    void* pNext;
    VkBool32 supportsTextureGatherLODBiasAMD;
};
```
• **sType** is a VkStructureType value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **supportsTextureGatherLODBiasAMD** tells if the image format can be used with texture gather bias/LOD functions, as introduced by the VK_AMD_texture_gather_bias_lod extension. This field is set by the implementation. User-specified value is ignored.

### Valid Usage (Implicit)

• VUID-VkTextureLODGatherFormatPropertiesAMD-sType-sType

  **sType** must be VK_STRUCTURE_TYPE_TEXTURE_LOD_GATHER_FORMAT_PROPERTIES_AMD

To determine the image capabilities compatible with an external memory handle type, add a VkPhysicalDeviceExternalImageFormatInfo structure to the **pNext** chain of the VkPhysicalDeviceImageFormatInfo2 structure and a VkExternalImageFormatProperties structure to the **pNext** chain of the VkImageFormatProperties2 structure.

The VkPhysicalDeviceExternalImageFormatInfo structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceExternalImageFormatInfo {
    VkStructureType      sType;
    const void*          pNext;
    VkExternalMemoryHandleTypeFlagBits handleType;
} VkPhysicalDeviceExternalImageFormatInfo;
```

or the equivalent

```c
// Provided by VK_KHR_external_memory_capabilities
typedef VkPhysicalDeviceExternalImageFormatInfo
VkPhysicalDeviceExternalImageFormatInfoKHR;
```

• **sType** is a VkStructureType value identifying this structure.

• **pNext** is NULL or a pointer to a structure extending this structure.

• **handleType** is a VkExternalMemoryHandleTypeFlagBits value specifying the memory handle type that will be used with the memory associated with the image.

If **handleType** is 0, **vkGetPhysicalDeviceImageFormatProperties2** will behave as if VkPhysicalDeviceExternalImageFormatInfo was not present, and **VkExternalImageFormatProperties** will be ignored.

If **handleType** is not compatible with the **format**, **type**, **tiling**, **usage**, and **flags** specified in VkPhysicalDeviceImageFormatInfo2, then **vkGetPhysicalDeviceImageFormatProperties2** returns
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceExternalImageFormatInfo-sType-sType
  
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_IMAGE_FORMAT_INFO`

- VUID-VkPhysicalDeviceExternalImageFormatInfo-handleType-parameter
  
  If `handleType` is not 0, `handleType` must be a valid `VkExternalMemoryHandleTypeFlagBits` value

Possible values of `VkPhysicalDeviceExternalImageFormatInfo::handleType`, specifying an external memory handle type, are:

```
// Provided by VK_VERSION_1_1
typedef enum VkExternalMemoryHandleTypeFlagBits {
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT = 0x00000001,
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT = 0x00000002,
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT = 0x00000004,
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_BIT = 0x00000008,
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_KMT_BIT = 0x00000010,
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_HEAP_BIT = 0x00000020,
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_RESOURCE_BIT = 0x00000040,
    // Provided by VK_EXT_external_memory_dma_buf
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_DMA_BUF_BIT_EXT = 0x00000200,
    // Provided by VK_ANDROID_external_memory_android_hardware_buffer
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID = 0x00000400,
    // Provided by VK_EXT_external_memory_host
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_ALLOCATION_BIT_EXT = 0x00000080,
    // Provided by VK_EXT_external_memory_host
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_MAPPED_FOREIGN_MEMORY_BIT_EXT = 0x00000100,
    // Provided by VK_FUCHSIA_external_memory
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_ZIRCON_VMO_BIT_FUCHSIA = 0x00000800,
    // Provided by VK_KHR_external_memory_capabilities
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT_KHR = VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT,
    // Provided by VK_KHR_external_memory_capabilities
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT_KHR = VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT,
    // Provided by VK_KHR_external_memory_capabilities
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT_KHR = VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT,
    // Provided by VK_KHR_external_memory_capabilities
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT_KHR = VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT,
    // Provided by VK_KHR_external_memory_capabilities
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT_KHR = VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT,
    // Provided by VK_KHR_external_memory_capabilities
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT_KHR = VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT,
    // Provided by VK_KHR_external_memory_capabilities
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT_KHR = VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT,
};
```
or the equivalent

```c
// Provided by VK_KHR_external_memory_capabilities
typedef VkExternalMemoryHandleTypeFlagBits VkExternalMemoryHandleTypeFlagBitsKHR;
```

- **VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT** specifies a POSIX file descriptor handle that has only limited valid usage outside of Vulkan and other compatible APIs. It **must** be compatible with the POSIX system calls `dup`, `dup2`, `close`, and the non-standard system call `dup3`. Additionally, it **must** be transportable over a socket using an `SCM_RIGHTS` control message. It owns a reference to the underlying memory resource represented by its Vulkan memory object.

- **VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT** specifies an NT handle that has only limited valid usage outside of Vulkan and other compatible APIs. It **must** be compatible with the functions `DuplicateHandle`, `CloseHandle`, `CompareObjectHandles`, `GetHandleInformation`, and `SetHandleInformation`. It owns a reference to the underlying memory resource represented by its Vulkan memory object.

- **VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT** specifies a global share handle that has only limited valid usage outside of Vulkan and other compatible APIs. It is not compatible with any native APIs. It does not own a reference to the underlying memory resource represented by its Vulkan memory object, and will therefore become invalid when all Vulkan memory objects associated with it are destroyed.

- **VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_BIT** specifies an NT handle returned by `IDXGIResource1::CreateSharedHandle` referring to a Direct3D 10 or 11 texture resource. It owns a reference to the memory used by the Direct3D resource.

- **VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_KMT_BIT** specifies a global share handle returned by `IDXGIResource::GetSharedHandle` referring to a Direct3D 10 or 11 texture resource. It does not own a reference to the underlying Direct3D resource, and will therefore become invalid when all Vulkan memory objects and Direct3D resources associated with it are destroyed.

- **VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_HEAP_BIT** specifies an NT handle returned by `ID3D12Device::CreateSharedHandle` referring to a Direct3D 12 heap resource. It owns a reference to the resources used by the Direct3D heap.

- **VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_RESOURCE_BIT** specifies an NT handle returned by `ID3D12Device::CreateSharedHandle` referring to a Direct3D 12 committed resource. It owns a reference to the memory used by the Direct3D resource.
• `VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_ALLOCATION_BIT_EXT` specifies a host pointer returned by a host memory allocation command. It does not own a reference to the underlying memory resource, and will therefore become invalid if the host memory is freed.

• `VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_MAPPED_FOREIGN_MEMORY_BIT_EXT` specifies a host pointer to *host mapped foreign memory*. It does not own a reference to the underlying memory resource, and will therefore become invalid if the foreign memory is unmapped or otherwise becomes no longer available.

• `VK_EXTERNAL_MEMORY_HANDLE_TYPE_DMA_BUF_BIT_EXT` is a file descriptor for a Linux dma_buf. It owns a reference to the underlying memory resource represented by its Vulkan memory object.

• `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID` specifies an `AHardwareBuffer` object defined by the Android NDK. See *Android Hardware Buffers* for more details of this handle type.

• `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ZIRCON_VMO_BIT_FUCHSIA` is a Zircon handle to a virtual memory object.

• `VK_EXTERNAL_MEMORY_HANDLE_TYPE_RDMA_ADDRESS_BIT_NV` is a handle to an allocation accessible by remote devices. It owns a reference to the underlying memory resource represented by its Vulkan memory object.

• `VK_EXTERNAL_MEMORY_HANDLE_TYPE_SCREEN_BUFFER_BIT_QNX` specifies a `_screen_buffer` object defined by the QNX SDP. See *QNX Screen Buffer* for more details of this handle type.
Some external memory handle types can only be shared within the same underlying physical device and/or the same driver version, as defined in the following table:

Table 83. External memory handle types compatibility

<table>
<thead>
<tr>
<th>Handle type</th>
<th>VkPhysicalDeviceIDProperties::driverUUID</th>
<th>VkPhysicalDeviceIDProperties::deviceUUID</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT</td>
<td>Must match</td>
<td>Must match</td>
</tr>
<tr>
<td>VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT</td>
<td>Must match</td>
<td>Must match</td>
</tr>
<tr>
<td>VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT</td>
<td>Must match</td>
<td>Must match</td>
</tr>
<tr>
<td>VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_BIT</td>
<td>Must match</td>
<td>Must match</td>
</tr>
<tr>
<td>VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_KMT_BIT</td>
<td>Must match</td>
<td>Must match</td>
</tr>
<tr>
<td>VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_HEAP_BIT</td>
<td>Must match</td>
<td>Must match</td>
</tr>
<tr>
<td>VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_RESOURCE_BIT</td>
<td>Must match</td>
<td>Must match</td>
</tr>
<tr>
<td>VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_ALLOCATION_BIT_EXT</td>
<td>No restriction</td>
<td>No restriction</td>
</tr>
<tr>
<td>VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_MAPPED_FOREIGN_MEMORY_BIT_EXT</td>
<td>No restriction</td>
<td>No restriction</td>
</tr>
<tr>
<td>VK_EXTERNAL_MEMORY_HANDLE_TYPE_DMA_BUF_BIT_EXT</td>
<td>No restriction</td>
<td>No restriction</td>
</tr>
<tr>
<td>VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID</td>
<td>No restriction</td>
<td>No restriction</td>
</tr>
<tr>
<td>VK_EXTERNAL_MEMORY_HANDLE_TYPE_ZIRCON_VMO_BIT_FUCHSIA</td>
<td>No restriction</td>
<td>No restriction</td>
</tr>
<tr>
<td>VK_EXTERNAL_MEMORY_HANDLE_TYPE_RDMA_ADDRESS_BIT_NV</td>
<td>No restriction</td>
<td>No restriction</td>
</tr>
<tr>
<td>VK_EXTERNAL_MEMORY_HANDLE_TYPE_SCREEN_BUFFER_BIT_QNX</td>
<td>No restriction</td>
<td>No restriction</td>
</tr>
</tbody>
</table>

Note

The above table does not restrict the drivers and devices with which VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_ALLOCATION_BIT_EXT and VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_MAPPED_FOREIGN_MEMORY_BIT_EXT may be shared, as these handle types inherently mean memory that does not come from the same device, as they import memory from the host or a foreign device, respectively.

Note

Even though the above table does not restrict the drivers and devices with which
VK_EXTERNAL_MEMORY_HANDLE_TYPE_DMA_BUF_BIT_EXT may be shared, query mechanisms exist in the Vulkan API that prevent the import of incompatible dma-bufs (such as vkGetMemoryFdPropertiesKHR) and that prevent incompatible usage of dma-bufs (such as VkPhysicalDeviceExternalBufferInfo and VkPhysicalDeviceExternalImageFormatInfo).

// Provided by VK_VERSION_1_1
typedef VkFlags VkExternalMemoryHandleTypeFlags;

or the equivalent

// Provided by VK_KHR_external_memory_capabilities
typedef VkExternalMemoryHandleTypeFlags VkExternalMemoryHandleTypeFlagsKHR;

VkExternalMemoryHandleTypeFlags is a bitmask type for setting a mask of zero or more VkExternalMemoryHandleTypeFlagBits.

The VkExternalImageFormatProperties structure is defined as:

// Provided by VK_VERSION_1_1
typedef struct VkExternalImageFormatProperties {
    VkStructureType sType;
    void* pNext;
    VkExternalMemoryProperties externalMemoryProperties;
} VkExternalImageFormatProperties;

or the equivalent

// Provided by VK_KHR_external_memory_capabilities
typedef VkExternalImageFormatProperties VkExternalImageFormatPropertiesKHR;

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• externalMemoryProperties is a VkExternalMemoryProperties structure specifying various capabilities of the external handle type when used with the specified image creation parameters.

Valid Usage (Implicit)

• VUID-VkExternalImageFormatProperties-sType-sType
  sType must be VK_STRUCTURE_TYPE_EXTERNAL_IMAGE_FORMAT_PROPERTIES

The VkExternalMemoryProperties structure is defined as:
typedef struct VkExternalMemoryProperties {
    VkExternalMemoryFeatureFlags externalMemoryFeatures;
    VkExternalMemoryHandleTypeFlags exportFromImportedHandleTypes;
    VkExternalMemoryHandleTypeFlags compatibleHandleTypes;
} VkExternalMemoryProperties;

or the equivalent

typedef VkExternalMemoryProperties VkExternalMemoryPropertiesKHR;

- `externalMemoryFeatures` is a bitmask of `VkExternalMemoryFeatureFlagBits` specifying the features of `handleType`.
- `exportFromImportedHandleTypes` is a bitmask of `VkExternalMemoryHandleTypeFlagBits` specifying which types of imported handle `handleType` can be exported from.
- `compatibleHandleTypes` is a bitmask of `VkExternalMemoryHandleTypeFlagBits` specifying handle types which can be specified at the same time as `handleType` when creating an image compatible with external memory.

`compatibleHandleTypes` must include at least `handleType`. Inclusion of a handle type in `compatibleHandleTypes` does not imply the values returned in `VkImageFormatProperties2` will be the same when `VkPhysicalDeviceExternalImageFormatInfo::handleType` is set to that type. The application is responsible for querying the capabilities of all handle types intended for concurrent use in a single image and intersecting them to obtain the compatible set of capabilities.

Bits which may be set in `VkExternalMemoryProperties::externalMemoryFeatures`, specifying features of an external memory handle type, are:

```c
typedef enum VK_VERSION_1_1
typedef enum VkExternalMemoryFeatureFlagBits {
    VK_EXTERNAL_MEMORY_FEATURE_DEDICATED_ONLY_BIT = 0x00000001,
    VK_EXTERNAL_MEMORY_FEATURE_EXPORTABLE_BIT = 0x00000002,
    VK_EXTERNAL_MEMORY_FEATURE_IMPORTABLE_BIT = 0x00000004,
    // Provided by VK_KHR_external_memory_capabilities
    VK_EXTERNAL_MEMORY_FEATURE_DEDICATED_ONLY_BIT_KHR =
    VK_EXTERNAL_MEMORY_FEATURE_EXPORTABLE_BIT_KHR =
    VK_EXTERNAL_MEMORY_FEATURE_IMPORTABLE_BIT_KHR =
    // Provided by VK_KHR_external_memory_capabilities
} VkExternalMemoryFeatureFlagBits;
```

or the equivalent
VK_EXTERNAL_MEMORY_FEATURE_DEDICATED_ONLY_BIT specifies that images or buffers created with the specified parameters and handle type must use the mechanisms defined by VkMemoryDedicatedRequirements and VkMemoryDedicatedAllocateInfo to create (or import) a dedicated allocation for the image or buffer.

VK_EXTERNAL_MEMORY_FEATURE_EXPORTABLE_BIT specifies that handles of this type can be exported from Vulkan memory objects.

VK_EXTERNAL_MEMORY_FEATURE_IMPORTABLE_BIT specifies that handles of this type can be imported as Vulkan memory objects.

Because their semantics in external APIs roughly align with that of an image or buffer with a dedicated allocation in Vulkan, implementations are required to report VK_EXTERNAL_MEMORY_FEATURE_DEDICATED_ONLY_BIT for the following external handle types:

- VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_BIT
- VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_KMT_BIT
- VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_RESOURCE_BIT
- VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID for images only
- VK_EXTERNAL_MEMORY_HANDLE_TYPE_SCREEN_BUFFER_BIT_QNX for images only

Implementations must not report VK_EXTERNAL_MEMORY_FEATURE_DEDICATED_ONLY_BIT for buffers with external handle type VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID.

Implementations must not report VK_EXTERNAL_MEMORY_FEATURE_DEDICATED_ONLY_BIT for buffers with external handle type VK_EXTERNAL_MEMORY_HANDLE_TYPE_SCREEN_BUFFER_BIT_QNX. Implementations must not report VK_EXTERNAL_MEMORY_FEATURE_DEDICATED_ONLY_BIT for images or buffers with external handle type VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_ALLOCATION_BIT_EXT, or VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_MAPPED_FOREIGN_MEMORY_BIT_EXT.

VkExternalMemoryFeatureFlags is a bitmask type for setting a mask of zero or more VkExternalMemoryFeatureFlagBits.

To query the image capabilities that are compatible with a Linux DRM format modifier, set VkPhysicalDeviceImageFormatInfo2::tiling to VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT and add a VkPhysicalDeviceImageDrmFormatModifierInfoEXT structure to the pNext chain of
The **VkPhysicalDeviceImageDrmFormatModifierInfoEXT** structure is defined as:

```c
// Provided by VK_EXT_image_drm_format_modifier
typedef struct VkPhysicalDeviceImageDrmFormatModifierInfoEXT {
    VkStructureType sType;
    const void* pNext;
    uint64_t drmFormatModifier;
    VkSharingMode sharingMode;
    uint32_t queueFamilyIndexCount;
    const uint32_t* pQueueFamilyIndices;
} VkPhysicalDeviceImageDrmFormatModifierInfoEXT;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **drmFormatModifier** is the image's **Linux DRM format modifier**, corresponding to `VkImageDrmFormatModifierExplicitCreateInfoEXT::modifier` or to `VkImageDrmFormatModifierListCreateInfoEXT::pModifiers`.
- **sharingMode** specifies how the image will be accessed by multiple queue families.
- **queueFamilyIndexCount** is the number of entries in the **pQueueFamilyIndices** array.
- **pQueueFamilyIndices** is a pointer to an array of queue families that will access the image. It is ignored if **sharingMode** is not **VK_SHARING_MODE_CONCURRENT**.

If the **drmFormatModifier** is incompatible with the parameters specified in **VkPhysicalDeviceImageFormatInfo2** and its **pNext** chain, then **vkGetPhysicalDeviceImageFormatProperties2** returns **VK_ERROR_FORMAT_NOT_SUPPORTED**. The implementation must support the query of any **drmFormatModifier**, including unknown and invalid modifier values.

### Valid Usage

- **VUID-VkPhysicalDeviceImageDrmFormatModifierInfoEXT-sharingMode-02314**
  If **sharingMode** is **VK_SHARING_MODE_CONCURRENT**, then **pQueueFamilyIndices** must be a valid pointer to an array of **queueFamilyIndexCount uint32_t** values

- **VUID-VkPhysicalDeviceImageDrmFormatModifierInfoEXT-sharingMode-02315**
  If **sharingMode** is **VK_SHARING_MODE_CONCURRENT**, then **queueFamilyIndexCount** must be greater than 1

- **VUID-VkPhysicalDeviceImageDrmFormatModifierInfoEXT-sharingMode-02316**
  If **sharingMode** is **VK_SHARING_MODE_CONCURRENT**, each element of **pQueueFamilyIndices** must be unique and must be less than the **pQueueFamilyPropertyCount** returned by **vkGetPhysicalDeviceQueueFamilyProperties2** for the **physicalDevice** that was used to create device
Valid Usage (Implicit)

- VUID-VkPhysicalDeviceImageDrmFormatModifierInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_DRM_FORMAT_MODIFIER_INFO_EXT

- VUID-VkPhysicalDeviceImageDrmFormatModifierInfoEXT-sharingMode-parameter
  sharingMode must be a valid VkSharingMode value

To determine the number of combined image samplers required to support a multi-planar format, add VkSamplerYcbcrConversionImageFormatProperties to the pNext chain of the VkImageFormatProperties2 structure in a call to vkGetPhysicalDeviceImageFormatProperties2.

The VkSamplerYcbcrConversionImageFormatProperties structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkSamplerYcbcrConversionImageFormatProperties {
    VkStructureType sType;
    void* pNext;
    uint32_t combinedImageSamplerDescriptorCount;
} VkSamplerYcbcrConversionImageFormatProperties;
```

or the equivalent

```c
// Provided by VK_KHR_sampler_ycbcr_conversion
typedef VkSamplerYcbcrConversionImageFormatProperties
VkSamplerYcbcrConversionImageFormatPropertiesKHR;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- combinedImageSamplerDescriptorCount is the number of combined image sampler descriptors that the implementation uses to access the format.

Valid Usage (Implicit)

- VUID-VkSamplerYcbcrConversionImageFormatProperties-sType-sType
  sType must be VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_IMAGE_FORMAT_PROPERTIES

combinedImageSamplerDescriptorCount is a number between 1 and the number of planes in the format. A descriptor set layout binding with immutable Y’C\textsubscript{b}C\textsubscript{r} conversion samplers will have a maximum combinedImageSamplerDescriptorCount which is the maximum across all formats supported by its samplers of the combinedImageSamplerDescriptorCount for each format. Descriptor sets with that layout will internally use that maximum combinedImageSamplerDescriptorCount descriptors for each descriptor in the binding. This expanded number of descriptors will be consumed from the descriptor pool when a descriptor set is allocated, and counts towards the
maxDescriptorSetSamplers, maxDescriptorSetSampledImages, maxPerStageDescriptorSamplers, and maxPerStageDescriptorSampledImages limits.

**Note**

All descriptors in a binding use the same maximum combinedImageSamplerDescriptorCount descriptors to allow implementations to use a uniform stride for dynamic indexing of the descriptors in the binding.

For example, consider a descriptor set layout binding with two descriptors and immutable samplers for multi-planar formats that have VkSamplerYcbcrConversionImageFormatProperties::combinedImageSamplerDescriptorCount values of 2 and 3 respectively. There are two descriptors in the binding and the maximum combinedImageSamplerDescriptorCount is 3, so descriptor sets with this layout consume 6 descriptors from the descriptor pool. To create a descriptor pool that allows allocating four descriptor sets with this layout, descriptorCount must be at least 24.

To obtain optimal Android hardware buffer usage flags for specific image creation parameters, add a VkAndroidHardwareBufferUsageANDROID structure to the pNext chain of a VkImageFormatProperties2 structure passed to vkGetPhysicalDeviceImageFormatProperties2. This structure is defined as:

```c
// Provided by VK_ANDROID_external_memory_android_hardware_buffer
typedef struct VkAndroidHardwareBufferUsageANDROID {
    VkStructureType sType;
    void* pNext;
    uint64_t androidHardwareBufferUsage;
} VkAndroidHardwareBufferUsageANDROID;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- androidHardwareBufferUsage returns the Android hardware buffer usage flags.

The androidHardwareBufferUsage field must include Android hardware buffer usage flags listed in the AHardwareBuffer Usage Equivalence table when the corresponding Vulkan image usage or image creation flags are included in the usage or flags fields of VkPhysicalDeviceImageFormatInfo2. It must include at least one GPU usage flag (AHardwareBufferUsage_Gpu_*), even if none of the corresponding Vulkan usages or flags are requested.

**Note**

Requiring at least one GPU usage flag ensures that Android hardware buffer memory will be allocated in a memory pool accessible to the Vulkan implementation, and that specializing the memory layout based on usage flags does not prevent it from being compatible with Vulkan. Implementations may avoid unnecessary restrictions caused by this requirement by using vendor usage flags to indicate that only the Vulkan uses indicated in VkImageFormatProperties2.
Valid Usage (Implicit)

• VUID-VkAndroidHardwareBufferUsageANDROID-sType-sType
  sType must be VK_STRUCTURE_TYPE_ANDROID_HARDWARE_BUFFER_USAGE_ANDROID

To query if using VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT has a negative impact on device performance when accessing an image, add VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT to VkPhysicalDeviceImageFormatInfo2::usage, and add a VkHostImageCopyDevicePerformanceQueryEXT structure to the pNext chain of a VkImageFormatProperties2 structure passed to vkGetPhysicalDeviceImageFormatProperties2. This structure is defined as:

```c
// Provided by VK_EXT_host_image_copy
typedef struct VkHostImageCopyDevicePerformanceQueryEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 optimalDeviceAccess;
    VkBool32 identicalMemoryLayout;
} VkHostImageCopyDevicePerformanceQueryEXT;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• optimalDeviceAccess returns VK_TRUE if use of host image copy has no adverse effect on device access performance, compared to an image that is created with exact same creation parameters, and bound to the same VkDeviceMemory, except that VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT is replaced with VK_IMAGE_USAGE_TRANSFER_SRC_BIT and VK_IMAGE_USAGE_TRANSFER_DST_BIT.
• identicalMemoryLayout returns VK_TRUE if use of host image copy has no impact on memory layout compared to an image that is created with exact same creation parameters, and bound to the same VkDeviceMemory, except that VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT is replaced with VK_IMAGE_USAGE_TRANSFER_SRC_BIT and VK_IMAGE_USAGE_TRANSFER_DST_BIT.

The implementation may return VK_FALSE in optimalDeviceAccess if identicalMemoryLayout is VK_FALSE. If identicalMemoryLayout is VK_TRUE, optimalDeviceAccess must be VK_TRUE.

The implementation may return VK_TRUE in optimalDeviceAccess while identicalMemoryLayout is VK_FALSE. In this situation, any device performance impact should not be measurable.

If VkPhysicalDeviceImageFormatInfo2::format is a block-compressed format and vkGetPhysicalDeviceImageFormatProperties2 returns VK_SUCCESS, the implementation must return VK_TRUE in optimalDeviceAccess.

Note
Applications can make use of optimalDeviceAccess to determine their resource copying strategy. If a resource is expected to be accessed more on device than on
the host, and the implementation considers the resource sub-optimally accessed, it is likely better to use device copies instead.

**Note**

Layout not being identical yet still considered optimal for device access could happen if the implementation has different memory layout patterns, some of which are easier to access on the host.

**Note**

The most practical reason for `optimalDeviceAccess` to be `VK_FALSE` is that host image access may disable framebuffer compression where it would otherwise have been enabled. This represents far more efficient host image access since no compression algorithm is required to read or write to the image, but it would impact device access performance. Some implementations may only set `optimalDeviceAccess` to `VK_FALSE` if certain conditions are met, such as specific image usage flags or creation flags.

---

### Valid Usage (Implicit)

- VUID-VkHostImageCopyDevicePerformanceQueryEXT-sType-sType
  
  **sType** must be `VK_STRUCTURE_TYPE_HOST_IMAGE_COPY_DEVICE_PERFORMANCE_QUERY_EXT`

To determine if cubic filtering can be used with a given image format and a given image view type add a `VkPhysicalDeviceImageViewImageFormatInfoEXT` structure to the `pNext` chain of the `VkPhysicalDeviceImageFormatInfo2` structure, and a `VkFilterCubicImageViewImageFormatPropertiesEXT` structure to the `pNext` chain of the `VkImageFormatProperties2` structure.

The `VkPhysicalDeviceImageViewImageFormatInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_filter_cubic
typedef struct VkPhysicalDeviceImageViewImageFormatInfoEXT {
    VkStructureType sType;
    void* pNext;
    VkImageViewType imageViewType;
} VkPhysicalDeviceImageViewImageFormatInfoEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.
- **pNext** is `NULL` or a pointer to a structure extending this structure.
- **imageViewType** is a `VkImageViewType` value specifying the type of the image view.

---

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceImageViewImageFormatInfoEXT-sType-sType
sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_VIEW_IMAGE_FORMAT_INFO_EXT

- VUID-VkPhysicalDeviceImageViewImageFormatInfoEXT-imageViewType-parameter
  imageViewType must be a valid VkImageViewType value

The VkFilterCubicImageViewImageFormatPropertiesEXT structure is defined as:

```c
// Provided by VK_EXT_filter_cubic
typedef struct VkFilterCubicImageViewImageFormatPropertiesEXT {
    VkStructureType sType;
    void* pNext;
    VkBool32 filterCubic;
    VkBool32 filterCubicMinmax;
} VkFilterCubicImageViewImageFormatPropertiesEXT;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- filterCubic tells if image format, image type and image view type can be used with cubic filtering. This field is set by the implementation. User-specified value is ignored.
- filterCubicMinmax tells if image format, image type and image view type can be used with cubic filtering and minmax filtering. This field is set by the implementation. User-specified value is ignored.

Valid Usage (Implicit)

- VUID-VkFilterCubicImageViewImageFormatPropertiesEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_FILTER_CUBIC_IMAGE_VIEW_IMAGE_FORMAT_PROPERTIES_EXT

Valid Usage

- VUID-VkFilterCubicImageViewImageFormatPropertiesEXT-pNext-02627
  If the pNext chain of the VkImageFormatProperties2 structure includes a VkFilterCubicImageViewImageFormatPropertiesEXT structure, the pNext chain of the VkPhysicalDeviceImageFormatInfo2 structure must include a VkPhysicalDeviceImageViewImageFormatInfoEXT structure with an imageViewType that is compatible with imageType

49.1.1. Supported Sample Counts

vkGetPhysicalDeviceImageFormatProperties returns a bitmask of VkSampleCountFlagBits in sampleCounts specifying the supported sample counts for the image parameters.

sampleCounts will be set to VK_SAMPLE_COUNT_1_BIT if at least one of the following conditions is true:

- tiling is VK_IMAGE_TILING_LINEAR
- type is not VK_IMAGE_TYPE_2D
- flags contains VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT
- Neither the VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT flag nor the VK_FORMAT_FEATURE_DEPTH_STENCIL_ATTACHMENT_BIT flag in VkFormatProperties::optimalTilingFeatures returned by vkGetPhysicalDeviceFormatProperties is set
- VkPhysicalDeviceExternalImageFormatInfo::handleType is an external handle type for which multisampled image support is not required.
- format is one of the formats that require a sampler Y’C_bC_r conversion
- usage contains VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR
- usage contains VK_IMAGE_USAGE_FRAGMENT_DENSITY_MAP_BIT_EXT

Otherwise, the bits set in sampleCounts will be the sample counts supported for the specified values of usage and format. For each bit set in usage, the supported sample counts relate to the limits in VkPhysicalDeviceLimits as follows:

- If usage includes VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT and format is a floating- or fixed-point color format, a superset of VkPhysicalDeviceLimits::framebufferColorSampleCounts
- If usage includes VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT and format is an integer format, a superset of VkPhysicalDeviceVulkan12Properties::framebufferIntegerColorSampleCounts
- If usage includes VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT, and format includes a depth component, a superset of VkPhysicalDeviceLimits::framebufferDepthSampleCounts
- If usage includes VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT, and format includes a stencil component, a superset of VkPhysicalDeviceLimits::framebufferStencilSampleCounts
- If usage includes VK_IMAGE_USAGE_SAMPLED_BIT, and format includes a color component, a superset of VkPhysicalDeviceLimits::sampledImageColorSampleCounts
- If usage includes VK_IMAGE_USAGE_SAMPLED_BIT, and format includes a depth component, a superset of VkPhysicalDeviceLimits::sampledImageDepthSampleCounts
- If usage includes VK_IMAGE_USAGE_SAMPLED_BIT, and format is an integer format, a superset of VkPhysicalDeviceLimits::sampledImageIntegerSampleCounts
- If usage includes VK_IMAGE_USAGE_STORAGE_BIT, a superset of VkPhysicalDeviceLimits::storageImageSampleCounts

If multiple bits are set in usage, sampleCounts will be the intersection of the per-usage values described above.

If none of the bits described above are set in usage, then there is no corresponding limit in VkPhysicalDeviceLimits. In this case, sampleCounts must include at least VK_SAMPLE_COUNT_1_BIT.

### 49.1.2. Allowed Extent Values Based On Image Type

Implementations may support extent values larger than the required minimum/maximum values for certain types of images. VkImageFormatProperties::maxExtent for each type is subject to the constraints below.
Note
Implementations must support images with dimensions up to the required minimum/maximum values for all types of images. It follows that the query for additional capabilities must return extent values that are at least as large as the required values.

For VK_IMAGE_TYPE_1D:

- \( \text{maxExtent.width} \geq \text{VkPhysicalDeviceLimits::maxImageDimension1D} \)
- \( \text{maxExtent.height} = 1 \)
- \( \text{maxExtent.depth} = 1 \)

For VK_IMAGE_TYPE_2D when flags does not contain VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT:

- \( \text{maxExtent.width} \geq \text{VkPhysicalDeviceLimits::maxImageDimension2D} \)
- \( \text{maxExtent.height} \geq \text{VkPhysicalDeviceLimits::maxImageDimension2D} \)
- \( \text{maxExtent.depth} = 1 \)

For VK_IMAGE_TYPE_2D when flags contains VK_IMAGE_CREATE_CUBE_COMPATIBLE_BIT:

- \( \text{maxExtent.width} \geq \text{VkPhysicalDeviceLimits::maxImageDimensionCube} \)
- \( \text{maxExtent.height} \geq \text{VkPhysicalDeviceLimits::maxImageDimensionCube} \)
- \( \text{maxExtent.depth} = 1 \)

For VK_IMAGE_TYPE_3D:

- \( \text{maxExtent.width} \geq \text{VkPhysicalDeviceLimits::maxImageDimension3D} \)
- \( \text{maxExtent.height} \geq \text{VkPhysicalDeviceLimits::maxImageDimension3D} \)
- \( \text{maxExtent.depth} \geq \text{VkPhysicalDeviceLimits::maxImageDimension3D} \)

49.2. Additional Buffer Capabilities

To query the external handle types supported by buffers, call:

```c
// Provided by VK_VERSION_1_1
void vkGetPhysicalDeviceExternalBufferProperties(
    VkPhysicalDevice physicalDevice,
    const VkPhysicalDeviceExternalBufferInfo* pExternalBufferInfo,
    VkExternalBufferProperties* pExternalBufferProperties);
```
or the equivalent command

```c
// Provided by VK_KHR_external_memory_capabilities
void vkGetPhysicalDeviceExternalBufferPropertiesKHR(
    VkPhysicalDevice physicalDevice,
```

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const VkPhysicalDeviceExternalBufferInfo* pExternalBufferInfo,
VkExternalBufferProperties* pExternalBufferProperties);

• \texttt{physicalDevice} is the physical device from which to query the buffer capabilities.

• \texttt{pExternalBufferInfo} is a pointer to a \texttt{VkPhysicalDeviceExternalBufferInfo} structure describing the parameters that would be consumed by \texttt{vkCreateBuffer}.

• \texttt{pExternalBufferProperties} is a pointer to a \texttt{VkExternalBufferProperties} structure in which capabilities are returned.

### Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceExternalBufferProperties-physicalDevice-parameter \texttt{physicalDevice} must be a valid \texttt{VkPhysicalDevice} handle

- VUID-vkGetPhysicalDeviceExternalBufferProperties-pExternalBufferInfo-parameter \texttt{pExternalBufferInfo} must be a valid pointer to a valid \texttt{VkPhysicalDeviceExternalBufferInfo} structure

- VUID-vkGetPhysicalDeviceExternalBufferProperties-pExternalBufferProperties-parameter \texttt{pExternalBufferProperties} must be a valid pointer to a \texttt{VkExternalBufferProperties} structure

The \texttt{VkPhysicalDeviceExternalBufferInfo} structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceExternalBufferInfo {
    VkStructureType sType;
    const void*pNext;
    VkBufferCreateFlags flags;
    VkBufferUsageFlags usage;
    VkExternalMemoryHandleTypeFlagBits handleType;
} VkPhysicalDeviceExternalBufferInfo;
```

or the equivalent

```c
// Provided by VK_KHR_external_memory_capabilities
typedef VkPhysicalDeviceExternalBufferInfo VkPhysicalDeviceExternalBufferInfoKHR;
```

- \texttt{sType} is a \texttt{VkStructureType} value identifying this structure.

- \texttt{pNext} is \texttt{NULL} or a pointer to a structure extending this structure.

- \texttt{flags} is a bitmask of \texttt{VkBufferCreateFlagBits} describing additional parameters of the buffer, corresponding to \texttt{VkBufferCreateInfo::flags}.

- \texttt{usage} is a bitmask of \texttt{VkBufferUsageFlagBits} describing the intended usage of the buffer, corresponding to \texttt{VkBufferCreateInfo::usage}.
• **handleType** is a `VkExternalMemoryHandleTypeFlagBits` value specifying the memory handle type that will be used with the memory associated with the buffer.

Only usage flags representable in `VkBufferUsageFlags` are returned in this structure’s `usage`. If a `VkBufferUsageFlags2CreateInfoKHR` structure is present in the `pNext` chain, all usage flags of the buffer are returned in `VkBufferUsageFlags2CreateInfoKHR::usage`.

---

### Valid Usage (Implicit)

- **VUID-VkPhysicalDeviceExternalBufferInfo-sType-sType**
  - `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_BUFFER_INFO`

- **VUID-VkPhysicalDeviceExternalBufferInfo-pNext-pNext**
  - `pNext` must be `NULL` or a pointer to a valid instance of `VkBufferUsageFlags2CreateInfoKHR`

- **VUID-VkPhysicalDeviceExternalBufferInfo-sType-unique**
  - The `sType` value of each struct in the `pNext` chain must be unique

- **VUID-VkPhysicalDeviceExternalBufferInfo-flags-parameter**
  - `flags` must be a valid combination of `VkBufferCreateFlagBits` values

- **VUID-VkPhysicalDeviceExternalBufferInfo-usage-parameter**
  - `usage` must be a valid combination of `VkBufferUsageFlagBits` values

- **VUID-VkPhysicalDeviceExternalBufferInfo-usage-requiredbitmask**
  - `usage` must not be `0`

- **VUID-VkPhysicalDeviceExternalBufferInfo-handleType-parameter**
  - `handleType` must be a valid `VkExternalMemoryHandleTypeFlagBits` value

---

The `VkExternalBufferProperties` structure is defined as:

```
// Provided by VK_VERSION_1_1
typedef struct VkExternalBufferProperties {
    VkStructureType sType;
    void* pNext;
    VkExternalMemoryProperties externalMemoryProperties;
} VkExternalBufferProperties;
```

or the equivalent

```
// Provided by VK_KHR_external_memory_capabilities
typedef VkExternalBufferProperties VkExternalBufferPropertiesKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `externalMemoryProperties` is a `VkExternalMemoryProperties` structure specifying various capabilities of the external handle type when used with the specified buffer creation parameters.
49.3. Optional Semaphore Capabilities

Semaphores may support import and export of their payload to external handles. To query the external handle types supported by semaphores, call:

```c
// Provided by VK_VERSION_1_1
void vkGetPhysicalDeviceExternalSemaphoreProperties(  
    VkPhysicalDevice physicalDevice,  
    const VkPhysicalDeviceExternalSemaphoreInfo* pExternalSemaphoreInfo,  
    VkExternalSemaphoreProperties* pExternalSemaphoreProperties);
```

or the equivalent command

```c
// Provided by VK_KHR_external_semaphore_capabilities
void vkGetPhysicalDeviceExternalSemaphorePropertiesKHR(  
    VkPhysicalDevice physicalDevice,  
    const VkPhysicalDeviceExternalSemaphoreInfo* pExternalSemaphoreInfo,  
    VkExternalSemaphoreProperties* pExternalSemaphoreProperties);
```

- `physicalDevice` is the physical device from which to query the semaphore capabilities.
- `pExternalSemaphoreInfo` is a pointer to a `VkPhysicalDeviceExternalSemaphoreInfo` structure describing the parameters that would be consumed by `vkCreateSemaphore`.
- `pExternalSemaphoreProperties` is a pointer to a `VkExternalSemaphoreProperties` structure in which capabilities are returned.

Valid Usage (Implicit)

- VUID-vkGetPhysicalDeviceExternalSemaphoreProperties-physicalDevice-parameter  
  `physicalDevice` must be a valid `VkPhysicalDevice` handle
- VUID-vkGetPhysicalDeviceExternalSemaphoreProperties-pExternalSemaphoreInfo-parameter  
  `pExternalSemaphoreInfo` must be a valid pointer to a valid `VkPhysicalDeviceExternalSemaphoreInfo` structure
- VUID-vkGetPhysicalDeviceExternalSemaphoreProperties-pExternalSemaphoreProperties-parameter  
  `pExternalSemaphoreProperties` must be a valid pointer to a...
The `VkPhysicalDeviceExternalSemaphoreInfo` structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceExternalSemaphoreInfo {
    VkStructureType sType;
    const void* pNext;
    VkExternalSemaphoreHandleTypeFlagBits handleType;
} VkPhysicalDeviceExternalSemaphoreInfo;
```

or the equivalent

```c
// Provided by VK_KHR_external_semaphore_capabilities
typedef VkPhysicalDeviceExternalSemaphoreInfo
VkPhysicalDeviceExternalSemaphoreInfoKHR;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `handleType` is a `VkExternalSemaphoreHandleTypeFlagBits` value specifying the external semaphore handle type for which capabilities will be returned.

### Valid Usage (Implicit)

- VUID-VkPhysicalDeviceExternalSemaphoreInfo-sType-sType 
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_SEMAPHORE_INFO`
- VUID-VkPhysicalDeviceExternalSemaphoreInfo-pNext-pNext 
  `pNext` must be `NULL` or a pointer to a valid instance of `VkSemaphoreTypeCreateInfo`
- VUID-VkPhysicalDeviceExternalSemaphoreInfo-sType-unique 
  The `sType` value of each struct in the `pNext` chain must be unique
- VUID-VkPhysicalDeviceExternalSemaphoreInfo-handleType-parameter 
  `handleType` must be a valid `VkExternalSemaphoreHandleTypeFlagBits` value

Bits which *may* be set in `VkPhysicalDeviceExternalSemaphoreInfo::handleType`, specifying an external semaphore handle type, are:

```c
// Provided by VK_VERSION_1_1
typedef enum VkExternalSemaphoreHandleTypeFlagBits {
    VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_FD_BIT = 0x00000001,
    VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_BIT = 0x00000002,
    VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT = 0x00000004,
    VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_D3D12_FENCE_BIT = 0x00000008,
    VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_SYNC_FD_BIT = 0x00000010,
};
```


• **VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_FD_BIT** specifies a POSIX file descriptor handle that has only limited valid usage outside of Vulkan and other compatible APIs. It must be compatible with the POSIX system calls `dup`, `dup2`, `close`, and the non-standard system call `dup3`. Additionally, it must be transportable over a socket using an `SCM_RIGHTS` control message. It owns a reference to the underlying synchronization primitive represented by its Vulkan semaphore object.

• **VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_BIT** specifies an NT handle that has only limited valid usage outside of Vulkan and other compatible APIs. It must be compatible with the functions `DuplicateHandle`, `CloseHandle`, `CompareObjectHandles`, `GetHandleInformation`, and `SetHandleInformation`. It owns a reference to the underlying synchronization primitive represented by its Vulkan semaphore object.

• **VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT** specifies a global share handle that has only limited valid usage outside of Vulkan and other compatible APIs. It is not compatible with any native APIs. It does not own a reference to the underlying synchronization primitive represented by its Vulkan semaphore object, and will therefore become invalid when all Vulkan semaphore objects associated with it are destroyed.

• **VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_D3D12_FENCE_BIT** specifies an NT handle returned by `ID3D12Device::CreateSharedHandle` referring to a Direct3D 12 fence, or `ID3D11Device5::CreateFence` referring to a Direct3D 11 fence. It owns a reference to the underlying synchronization primitive associated with the Direct3D fence.
• **VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_D3D11_FENCE_BIT** is an alias of **VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_D3D12_FENCE_BIT** with the same meaning. It is provided for convenience and code clarity when interacting with D3D11 fences.

• **VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_SYNC_FD_BIT** specifies a POSIX file descriptor handle to a Linux Sync File or Android Fence object. It can be used with any native API accepting a valid sync file or fence as input. It owns a reference to the underlying synchronization primitive associated with the file descriptor. Implementations which support importing this handle type **must** accept any type of sync or fence FD supported by the native system they are running on.

• **VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_ZIRCON_EVENT_BIT_FUCHSIA** specifies a handle to a Zircon event object. It can be used with any native API that accepts a Zircon event handle. Zircon event handles are created with **ZX_RIGHTS_BASIC** and **ZX_RIGHTS_SIGNAL** rights. Vulkan on Fuchsia uses only the **ZX_EVENT_SIGNALED** bit when signaling or waiting.

---

**Note**

Handles of type **VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_SYNC_FD_BIT** generated by the implementation may represent either Linux Sync Files or Android Fences at the implementation's discretion. Applications **should** only use operations defined for both types of file descriptors, unless they know via means external to Vulkan the type of the file descriptor, or are prepared to deal with the system-defined operation failures resulting from using the wrong type.
Some external semaphore handle types can only be shared within the same underlying physical device and/or the same driver version, as defined in the following table:

Table 84. External semaphore handle types compatibility

<table>
<thead>
<tr>
<th>Handle type</th>
<th>VkPhysicalDeviceIDProperties::driverUUID</th>
<th>VkPhysicalDeviceIDProperties::deviceUUID</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_FD_BIT</td>
<td>Must match</td>
<td>Must match</td>
</tr>
<tr>
<td>VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_BIT</td>
<td>Must match</td>
<td>Must match</td>
</tr>
<tr>
<td>VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT</td>
<td>Must match</td>
<td>Must match</td>
</tr>
<tr>
<td>VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_D3D12_FENCE_BIT</td>
<td>Must match</td>
<td>Must match</td>
</tr>
<tr>
<td>VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_SYNC_FD_BIT</td>
<td>No restriction</td>
<td>No restriction</td>
</tr>
<tr>
<td>VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_ZIRCON_EVENT_BIT_FUCHSIA</td>
<td>No restriction</td>
<td>No restriction</td>
</tr>
</tbody>
</table>

// Provided by VK_VERSION_1_1

typedef VkFlags VkExternalSemaphoreHandleTypeFlags;

or the equivalent

// Provided by VK_KHR_external_semaphore_capabilities

typedef VkExternalSemaphoreHandleTypeFlags VkExternalSemaphoreHandleTypeFlagsKHR;

VkExternalSemaphoreHandleTypeFlags is a bitmask type for setting a mask of zero or more VkExternalSemaphoreHandleTypeFlagBits.

The VkExternalSemaphoreProperties structure is defined as:

// Provided by VK_VERSION_1_1

typedef struct VkExternalSemaphoreProperties {
    VkStructureType sType;
    void* pNext;
    VkExternalSemaphoreHandleTypeFlags exportFromImportedHandleTypes;
    VkExternalSemaphoreHandleTypeFlags compatibleHandleTypes;
    VkExternalSemaphoreFeatureFlags externalSemaphoreFeatures;
} VkExternalSemaphoreProperties;

or the equivalent

// Provided by VK_KHR_external_semaphore_capabilities

typedef VkExternalSemaphoreProperties VkExternalSemaphorePropertiesKHR;
• **sType** is a *VkStructureType* value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **exportFromImportedHandleTypes** is a bitmask of *VkExternalSemaphoreHandleTypeFlagBits* specifying which types of imported handle *handleType* can be exported from.

• **compatibleHandleTypes** is a bitmask of *VkExternalSemaphoreHandleTypeFlagBits* specifying handle types which can be specified at the same time as *handleType* when creating a semaphore.

• **externalSemaphoreFeatures** is a bitmask of *VkExternalSemaphoreFeatureFlagBits* describing the features of *handleType*.

If *handleType* is not supported by the implementation, then *VkExternalSemaphoreProperties::*externalSemaphoreFeatures* will be set to zero.

### Valid Usage (Implicit)

- **VUID-VkExternalSemaphoreProperties-sType-sType**
  
  *sType* must be *VK_STRUCTURE_TYPE_EXTERNAL_SEMAPHORE_PROPERTIES*

- **VUID-VkExternalSemaphoreProperties-pNext-pNext**
  
  *pNext* must be **NULL**

Bits which may be set in *VkExternalSemaphoreProperties::*externalSemaphoreFeatures*, specifying the features of an external semaphore handle type, are:

```c
// Provided by VK_VERSION_1_1
typedef enum VkExternalSemaphoreFeatureFlagBits {
    VK_EXTERNAL_SEMAPHORE_FEATURE_EXPORTABLE_BIT = 0x00000001,
    VK_EXTERNAL_SEMAPHORE_FEATURE_IMPORTABLE_BIT = 0x00000002,
    // Provided by VK_KHR_external_semaphore_capabilities
    VK_EXTERNAL_SEMAPHORE_FEATURE_EXPORTABLE_BIT_KHR = VK_EXTERNAL_SEMAPHORE_FEATURE_EXPORTABLE_BIT,
    // Provided by VK_KHR_external_semaphore_capabilities
    VK_EXTERNAL_SEMAPHORE_FEATURE_IMPORTABLE_BIT_KHR = VK_EXTERNAL_SEMAPHORE_FEATURE_IMPORTABLE_BIT,
} VkExternalSemaphoreFeatureFlagBits;
```

or the equivalent

```c
// Provided by VK_KHR_external_semaphore_capabilities
typedef VkExternalSemaphoreFeatureFlagBits VkExternalSemaphoreFeatureFlagBitsKHR;
```

- **VK_EXTERNAL_SEMAPHORE_FEATURE_EXPORTABLE_BIT** specifies that handles of this type can be exported from Vulkan semaphore objects.

- **VK_EXTERNAL_SEMAPHORE_FEATURE_IMPORTABLE_BIT** specifies that handles of this type can be imported as Vulkan semaphore objects.
typedef VkFlags VkExternalSemaphoreFeatureFlags;

or the equivalent

typedef VkExternalSemaphoreFeatureFlags VkExternalSemaphoreFeatureFlagsKHR;

VkExternalSemaphoreFeatureFlags is a bitmask type for setting a mask of zero or more VkExternalSemaphoreFeatureFlagBits.

49.4. Optional Fence Capabilities

Fences may support import and export of their payload to external handles. To query the external handle types supported by fences, call:

```c
// Provided by VK_VERSION_1_1
void vkGetPhysicalDeviceExternalFenceProperties(
    VkPhysicalDevice physicalDevice,
    const VkPhysicalDeviceExternalFenceInfo* pExternalFenceInfo,
    VkExternalFenceProperties* pExternalFenceProperties);
```

or the equivalent command

```c
// Provided by VK_KHR_external_fence_capabilities
void vkGetPhysicalDeviceExternalFencePropertiesKHR(
    VkPhysicalDevice physicalDevice,
    const VkPhysicalDeviceExternalFenceInfo* pExternalFenceInfo,
    VkExternalFenceProperties* pExternalFenceProperties);
```

- `physicalDevice` is the physical device from which to query the fence capabilities.
- `pExternalFenceInfo` is a pointer to a VkPhysicalDeviceExternalFenceInfo structure describing the parameters that would be consumed by `vkCreateFence`.
- `pExternalFenceProperties` is a pointer to a VkExternalFenceProperties structure in which capabilities are returned.

**Valid Usage (Implicit)**

- VUID-vkGetPhysicalDeviceExternalFenceProperties-physicalDevice-parameter
  `physicalDevice` must be a valid VkPhysicalDevice handle
- VUID-vkGetPhysicalDeviceExternalFenceProperties-pExternalFenceInfo-parameter
  `pExternalFenceInfo` must be a valid pointer to a valid VkPhysicalDeviceExternalFenceInfo structure
• VUID-vkGetPhysicalDeviceExternalFenceProperties-pExternalFenceProperties-parameter
  pExternalFenceProperties must be a valid pointer to a VkExternalFenceProperties structure.

The VkPhysicalDeviceExternalFenceInfo structure is defined as:

```c
// Provided by VK_VERSION_1_1
typedef struct VkPhysicalDeviceExternalFenceInfo {
    VkStructureType sType;
    const void* pNext;
    VkExternalFenceHandleTypeFlagBits handleType;
} VkPhysicalDeviceExternalFenceInfo;
```

or the equivalent

```c
// Provided by VK_KHR_external_fence_capabilities
typedef VkPhysicalDeviceExternalFenceInfo VkPhysicalDeviceExternalFenceInfoKHR;
```

• sType is a VkStructureType value identifying this structure.
• pNext is NULL or a pointer to a structure extending this structure.
• handleType is a VkExternalFenceHandleTypeFlagBits value specifying an external fence handle type for which capabilities will be returned.

**Note**

Handles of type VK_EXTERNAL_FENCE_HANDLE_TYPE_SYNC_FD_BIT generated by the implementation may represent either Linux Sync Files or Android Fences at the implementation's discretion. Applications should only use operations defined for both types of file descriptors, unless they know via means external to Vulkan the type of the file descriptor, or are prepared to deal with the system-defined operation failures resulting from using the wrong type.

**Valid Usage (Implicit)**

• VUID-VkPhysicalDeviceExternalFenceInfo-sType-sType
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_FENCE_INFO

• VUID-VkPhysicalDeviceExternalFenceInfo-pNext-pNext
  pNext must be NULL

• VUID-VkPhysicalDeviceExternalFenceInfo-handleType-parameter
  handleType must be a valid VkExternalFenceHandleTypeFlagBits value

Bits which may be set in

• VkPhysicalDeviceExternalFenceInfo::handleType
- `VkExternalFenceProperties::exportFromImportedHandleTypes`
- `VkExternalFenceProperties::compatibleHandleTypes`

indicate external fence handle types, and are:

```c
// Provided by VK_VERSION_1_1
typedef enum VkExternalFenceHandleTypeFlagBits {
    VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_FD_BIT = 0x00000001,
    VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_BIT = 0x00000002,
    VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT = 0x00000004,
    VK_EXTERNAL_FENCE_HANDLE_TYPE_SYNC_FD_BIT = 0x00000008,
    // Provided by VK_KHR_external_fence_capabilities
    VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_FD_BIT_KHR = VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_FD_BIT,
    // Provided by VK_KHR_external_fence_capabilities
    VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_BIT_KHR = VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_BIT,
    // Provided by VK_KHR_external_fence_capabilities
    VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT_KHR = VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT,
    // Provided by VK_KHR_external_fence_capabilities
    VK_EXTERNAL_FENCE_HANDLE_TYPE_SYNC_FD_BIT_KHR = VK_EXTERNAL_FENCE_HANDLE_TYPE_SYNC_FD_BIT
} VkExternalFenceHandleTypeFlagBits;
```

or the equivalent

```c
// Provided by VK_KHR_external_fence_capabilities
typedef VkExternalFenceHandleTypeFlagBits VkExternalFenceHandleTypeFlagBitsKHR;
```

- `VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_FD_BIT` specifies a POSIX file descriptor handle that has only limited valid usage outside of Vulkan and other compatible APIs. It must be compatible with the POSIX system calls `dup`, `dup2`, `close`, and the non-standard system call `dup3`. Additionally, it must be transportable over a socket using an `SCM_RIGHTS` control message. It owns a reference to the underlying synchronization primitive represented by its Vulkan fence object.

- `VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_BIT` specifies an NT handle that has only limited valid usage outside of Vulkan and other compatible APIs. It must be compatible with the functions `DuplicateHandle`, `CloseHandle`, `CompareObjectHandles`, `GetHandleInformation`, and `SetHandleInformation`. It owns a reference to the underlying synchronization primitive represented by its Vulkan fence object.

- `VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT` specifies a global share handle that has only limited valid usage outside of Vulkan and other compatible APIs. It is not compatible with any native APIs. It does not own a reference to the underlying synchronization primitive represented by its Vulkan fence object, and will therefore become invalid when all Vulkan fence objects associated with it are destroyed.

- `VK_EXTERNAL_FENCE_HANDLE_TYPE_SYNC_FD_BIT` specifies a POSIX file descriptor handle to a Linux 3828
Sync File or Android Fence. It can be used with any native API accepting a valid sync file or fence as input. It owns a reference to the underlying synchronization primitive associated with the file descriptor. Implementations which support importing this handle type must accept any type of sync or fence FD supported by the native system they are running on.
Some external fence handle types can only be shared within the same underlying physical device and/or the same driver version, as defined in the following table:

**Table 85. External fence handle types compatibility**

<table>
<thead>
<tr>
<th>Handle type</th>
<th>VkPhysicalDeviceIDProperties::driverUUID</th>
<th>VkPhysicalDeviceIDProperties::deviceUUID</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_FD_BIT</td>
<td>Must match</td>
<td>Must match</td>
</tr>
<tr>
<td>VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_BIT</td>
<td>Must match</td>
<td>Must match</td>
</tr>
<tr>
<td>VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT</td>
<td>Must match</td>
<td>Must match</td>
</tr>
<tr>
<td>VK_EXTERNAL_FENCE_HANDLE_TYPE_SYNC_FD_BIT</td>
<td>No restriction</td>
<td>No restriction</td>
</tr>
</tbody>
</table>

// Provided by VK_VERSION_1_1
typedef VkFlags VkExternalFenceHandleTypeFlags;

or the equivalent

// Provided by VK_KHR_external_fence_capabilities
typedef VkExternalFenceHandleTypeFlags VkExternalFenceHandleTypeFlagsKHR;

VkExternalFenceHandleTypeFlags is a bitmask type for setting a mask of zero or more VkExternalFenceHandleTypeFlagBits.

The VkExternalFenceProperties structure is defined as:

// Provided by VK_VERSION_1_1
typedef struct VKExternalFenceProperties {
    VkStructureType sType;
    void* pNext;
    VkExternalFenceHandleTypeFlags exportFromImportedHandleTypes;
    VkExternalFenceHandleTypeFlags compatibleHandleTypes;
    VkExternalFenceFeatureFlags externalFenceFeatures;
} VkExternalFenceProperties;

or the equivalent

// Provided by VK_KHR_external_fence_capabilities
typedef VkExternalFenceProperties VkExternalFencePropertiesKHR;

- exportFromImportedHandleTypes is a bitmask of VkExternalFenceHandleTypeFlagBits indicating which types of imported handle handleType can be exported from.
• **compatibleHandleTypes** is a bitmask of **VkExternalFenceHandleTypeFlagBits** specifying handle types which **can** be specified at the same time as **handleType** when creating a fence.

• **externalFenceFeatures** is a bitmask of **VkExternalFenceFeatureFlagBits** indicating the features of **handleType**.

If **handleType** is not supported by the implementation, then **VkExternalFenceProperties::externalFenceFeatures** will be set to zero.

### Valid Usage (Implicit)

- VUID-VkExternalFenceProperties-sType-sType
  
  **sType** must be **VK_STRUCTURE_TYPE_EXTERNAL_FENCE_PROPERTIES**

- VUID-VkExternalFenceProperties-pNext-pNext
  
  **pNext** must be **NULL**

Bits which **may** be set in **VkExternalFenceProperties::externalFenceFeatures**, indicating features of a fence external handle type, are:

```c
// Provided by VK_VERSION_1_1
typedef enum VkExternalFenceFeatureFlagBits {
    VK_EXTERNAL_FENCE_FEATURE_EXPORTABLE_BIT = 0x00000001,
    VK_EXTERNAL_FENCE_FEATURE_IMPORTABLE_BIT = 0x00000002,
} VkExternalFenceFeatureFlagBits;
```

or the equivalent

```c
// Provided by VK_KHR_external_fence_capabilities
typedef VkExternalFenceFeatureFlagBitsKHR;
```

- **VK_EXTERNAL_FENCE_FEATURE_EXPORTABLE_BIT** specifies handles of this type **can** be exported from Vulkan fence objects.

- **VK_EXTERNAL_FENCE_FEATURE_IMPORTABLE_BIT** specifies handles of this type **can** be imported to Vulkan fence objects.

```c
// Provided by VK_VERSION_1_1
typedef VkFlags VkExternalFenceFeatureFlags;
```

or the equivalent
VkExternalFenceFeatureFlags is a bitmask type for setting a mask of zero or more VkExternalFenceFeatureFlagBits.

### 49.5. Timestamp Calibration Capabilities

To query the set of time domains for which a physical device supports timestamp calibration, call:

```c
// Provided by VK_EXT_calibrated_timestamps
VkResult vkGetPhysicalDeviceCalibrateableTimeDomainsEXT(
    VkPhysicalDevice physicalDevice,
    uint32_t* pTimeDomainCount,
    VkTimeDomainEXT* pTimeDomains);
```

- **physicalDevice** is the physical device from which to query the set of calibrateable time domains.
- **pTimeDomainCount** is a pointer to an integer related to the number of calibrateable time domains available or queried, as described below.
- **pTimeDomains** is either **NULL** or a pointer to an array of VkTimeDomainEXT values, indicating the supported calibrateable time domains.

If **pTimeDomains** is **NULL**, then the number of calibrateable time domains supported for the given **physicalDevice** is returned in **pTimeDomainCount**. Otherwise, **pTimeDomainCount** must point to a variable set by the user to the number of elements in the **pTimeDomains** array, and on return the variable is overwritten with the number of values actually written to **pTimeDomains**. If the value of **pTimeDomainCount** is less than the number of calibrateable time domains supported, at most **pTimeDomainCount** values will be written to **pTimeDomains**, and **VK_INCOMPLETE** will be returned instead of **VK_SUCCESS**, to indicate that not all the available time domains were returned.

### Valid Usage (Implicit)

- **VUID-vkGetPhysicalDeviceCalibrateableTimeDomainsEXT-physicalDevice-parameter**
  **physicalDevice** must be a valid **VkPhysicalDevice** handle

- **VUID-vkGetPhysicalDeviceCalibrateableTimeDomainsEXT-pTimeDomainCount-parameter**
  **pTimeDomainCount** must be a valid pointer to a **uint32_t** value

- **VUID-vkGetPhysicalDeviceCalibrateableTimeDomainsEXT-pTimeDomains-parameter**
  If the value referenced by **pTimeDomainCount** is not 0, and **pTimeDomains** is not **NULL**,  
  **pTimeDomains** must be a valid pointer to an array of **pTimeDomainCount** **VkTimeDomainEXT** values
Return Codes

Success
• VK_SUCCESS
• VK_INCOMPLETE

Failure
• VK_ERROR_OUT_OF_HOST_MEMORY
• VK_ERROR_OUT_OF_DEVICE_MEMORY
Chapter 50. Debugging

To aid developers in tracking down errors in the application’s use of Vulkan, particularly in combination with an external debugger or profiler, debugging extensions may be available.

The VkObjectType enumeration defines values, each of which corresponds to a specific Vulkan handle type. These values can be used to associate debug information with a particular type of object through one or more extensions.

```c
// Provided by VK_VERSION_1_0
typedef enum VkObjectType {
    VK_OBJECT_TYPE_UNKNOWN = 0,
    VK_OBJECT_TYPE_INSTANCE = 1,
    VK_OBJECT_TYPE_PHYSICAL_DEVICE = 2,
    VK_OBJECT_TYPE_DEVICE = 3,
    VK_OBJECT_TYPE_QUEUE = 4,
    VK_OBJECT_TYPE_SEMAPHORE = 5,
    VK_OBJECT_TYPE_COMMAND_BUFFER = 6,
    VK_OBJECT_TYPE_FENCE = 7,
    VK_OBJECT_TYPE_DEVICE_MEMORY = 8,
    VK_OBJECT_TYPE_BUFFER = 9,
    VK_OBJECT_TYPE_IMAGE = 10,
    VK_OBJECT_TYPE_IMAGE_VIEW = 11,
    VK_OBJECT_TYPE_QUERY_POOL = 12,
    VK_OBJECT_TYPE_BUFFER_VIEW = 13,
    VK_OBJECT_TYPE_SHADER_MODULE = 14,
    VK_OBJECT_TYPE_PIPELINE_CACHE = 15,
    VK_OBJECT_TYPE_PIPELINE_LAYOUT = 16,
    VK_OBJECT_TYPE_RENDER_PASS = 17,
    VK_OBJECT_TYPE_PIPELINE = 18,
    VK_OBJECT_TYPE_DESCRIPTOR_SET_LAYOUT = 19,
    VK_OBJECT_TYPE_SAMPLER = 20,
    VK_OBJECT_TYPE_DESCRIPTOR_POOL = 21,
    VK_OBJECT_TYPE_DESCRIPTOR_SET = 22,
    VK_OBJECT_TYPE_FRAMEBUFFER = 23,
    VK_OBJECT_TYPE_COMMAND_POOL = 24,
    // Provided by VK_VERSION_1_1
    VK_OBJECT_TYPE_SAMPLER_YCBCR_CONVERSION = 1000156000,
    // Provided by VK_VERSION_1_1
    VK_OBJECT_TYPE_DESCRIPTOR_UPDATE_TEMPLATE = 1000085000,
    // Provided by VK_VERSION_1_3
    VK_OBJECT_TYPE_PRIVATE_DATA_SLOT = 1000295000,
    // Provided by VK_KHR_surface
    VK_OBJECT_TYPE_SURFACE_KHR = 1000000000,
    // Provided by VK_KHR_swapchain
    VK_OBJECT_TYPE_SWAPCHAIN_KHR = 1000001000,
    // Provided by VK_KHR_display
    VK_OBJECT_TYPE_DISPLAY_KHR = 1000002000,
    // Provided by VK_KHR_surface
    VK_OBJECT_TYPE_DISPLAY_KHR = 1000003000
} VkObjectType;
```
<table>
<thead>
<tr>
<th>VkObjectType</th>
<th>Vulkan Handle Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_OBJECT_TYPE_UNKNOWN</td>
<td>Unknown/Undefined Handle</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_INSTANCE</td>
<td>VkInstance</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_PHYSICAL_DEVICE</td>
<td>VkPhysicalDevice</td>
</tr>
</tbody>
</table>

Table 86. VkObjectType and Vulkan Handle Relationship
<table>
<thead>
<tr>
<th>VkObjectType</th>
<th>Vulkan Handle Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_OBJECT_TYPE_DEVICE</td>
<td>VkDevice</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_QUEUE</td>
<td>VkQueue</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_SEMAPHORE</td>
<td>VkSemaphore</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_COMMAND_BUFFER</td>
<td>VkCommandBuffer</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_FENCE</td>
<td>VkFence</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_DEVICE_MEMORY</td>
<td>VkDeviceMemory</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_BUFFER</td>
<td>VkBuffer</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_IMAGE</td>
<td>VkImage</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_EVENT</td>
<td>VkEvent</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_QUERY_POOL</td>
<td>VkQueryPool</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_BUFFER_VIEW</td>
<td>VkBufferView</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_IMAGE_VIEW</td>
<td>VkImageView</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_SHADER_MODULE</td>
<td>VkShaderModule</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_PIPELINE_CACHE</td>
<td>VkPipelineCache</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_PIPELINE_LAYOUT</td>
<td>VkPipelineLayout</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_RENDER_PASS</td>
<td>VkRenderPass</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_PIPELINE</td>
<td>VkPipeline</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_DESCRIPTOR_SET_LAYOUT</td>
<td>VkDescriptorSetLayout</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_SAMPLER</td>
<td>VkSampler</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_DESCRIPTOR_POOL</td>
<td>VkDescriptorPool</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_DESCRIPTOR_SET</td>
<td>VkDescriptorSet</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_FRAMEBUFFER</td>
<td>VkFramebuffer</td>
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<tr>
<td>VK_OBJECT_TYPE_COMMAND_POOL</td>
<td>VkCommandPool</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_SAMPLER_YCBCR_CONVERSION</td>
<td>VkSamplerYcbcrConversion</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_DESCRIPTOR_UPDATE_TEMPLATE</td>
<td>VkDescriptorUpdateTemplate</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_SURFACE_KHR</td>
<td>VkSurfaceKHR</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_SWAPCHAIN_KHR</td>
<td>VkSwapchainKHR</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_DISPLAY_KHR</td>
<td>VkDisplayKHR</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_DISPLAY_MODE_KHR</td>
<td>VkDisplayModeKHR</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_DEBUG_REPORT_CALLBACK_EXT</td>
<td>VkDebugReportCallbackEXT</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_INDIRECT_COMMANDS_LAYOUT_NV</td>
<td>VkIndirectCommandsLayoutNV</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_DEBUG_UTILS_MESSENGER_EXT</td>
<td>VkDebugUtilsMessengerEXT</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_VALIDATION_CACHE_EXT</td>
<td>VkValidationCacheEXT</td>
</tr>
<tr>
<td>VkObjectType</td>
<td>Vulkan Handle Type</td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_ACCELERATION_STRUCTURE_NV</td>
<td>VkAccelerationStructureNV</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_ACCELERATION_STRUCTURE_KHR</td>
<td>VkAccelerationStructureKHR</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_PERFORMANCE_CONFIGURATION_INTEL</td>
<td>VkPerformanceConfigurationINTEL</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_DEFERRED_OPERATION_KHR</td>
<td>VkDeferredOperationKHR</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_PRIVATE_DATA SLOT</td>
<td>VkPrivateDataSlot</td>
</tr>
<tr>
<td>VK_OBJECT_TYPE_OPTICAL_FLOW_SESSION_NV</td>
<td>VkOpticalFlowSessionNV</td>
</tr>
</tbody>
</table>

If this Specification was generated with any such extensions included, they will be described in the remainder of this chapter.

### 50.1. Debug Utilities

Vulkan provides flexible debugging utilities for debugging an application.

The **Object Debug Annotation** section describes how to associate either a name or binary data with a specific Vulkan object.

The **Queue Labels** section describes how to annotate and group the work submitted to a queue.

The **Command Buffer Labels** section describes how to associate logical elements of the scene with commands in a *VkCommandBuffer*.

The **Debug Messengers** section describes how to create debug messenger objects associated with an application supplied callback to capture debug messages from a variety of Vulkan components.

#### 50.1.1. Object Debug Annotation

It can be useful for an application to provide its own content relative to a specific Vulkan object.

The following commands allow application developers to associate user-defined information with Vulkan objects. These commands are device-level commands but they may reference instance-level objects (such as *VkInstance*) and physical device-level objects (such as *VkPhysicalDevice*) with a few restrictions: * The data for the corresponding object may still be available after the *VkDevice* used in the corresponding API call to set it is destroyed, but access to this data is not guaranteed and should be avoided. * Subsequent calls to change the data of the same object across multiple *VkDevice* objects, may result in the data being changed to the most recent version for all *VkDevice* objects and not just the *VkDevice* used in the most recent API call.

**Object Naming**

An object can be provided a user-defined name by calling `vkSetDebugUtilsObjectNameEXT` as defined below.

```c
// Provided by VK_EXT_debug_utils
```
VkResult vkSetDebugUtilsObjectNameEXT(
    VkDevice device,
    const VkDebugUtilsObjectNameInfoEXT* pNameInfo);

- **device** is the device that is associated with the named object passed in via objectHandle.
- **pNameInfo** is a pointer to a VkDebugUtilsObjectNameInfoEXT structure specifying parameters of the name to set on the object.

### Valid Usage

- VUID-vkSetDebugUtilsObjectNameEXT-pNameInfo-02587
  pNameInfo->objectType must not be VK_OBJECT_TYPE_UNKNOWN

- VUID-vkSetDebugUtilsObjectNameEXT-pNameInfo-02588
  pNameInfo->objectHandle must not be VK_NULL_HANDLE

- VUID-vkSetDebugUtilsObjectNameEXT-pNameInfo-07872
  If pNameInfo->objectHandle is the valid handle of an instance-level object, the VkDevice identified by device must be a descendent of the same VkInstance as the object identified by pNameInfo->objectHandle

- VUID-vkSetDebugUtilsObjectNameEXT-pNameInfo-07873
  If pNameInfo->objectHandle is the valid handle of a physical-device-level object, the VkDevice identified by device must be a descendent of the same VkPhysicalDevice as the object identified by pNameInfo->objectHandle

- VUID-vkSetDebugUtilsObjectNameEXT-pNameInfo-07874
  If pNameInfo->objectHandle is the valid handle of a device-level object, that object must be a descendent of the VkDevice identified by device

### Valid Usage (Implicit)

- VUID-vkSetDebugUtilsObjectNameEXT-device-parameter
  device must be a valid VkDevice handle

- VUID-vkSetDebugUtilsObjectNameEXT-pNameInfo-parameter
  pNameInfo must be a valid pointer to a valid VkDebugUtilsObjectNameInfoEXT structure

### Host Synchronization

- Host access to pNameInfo->objectHandle must be externally synchronized

### Return Codes

**Success**
- VK_SUCCESS
The `VkDebugUtilsObjectNameInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_debug_utils
typedef struct VkDebugUtilsObjectNameInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkObjectType objectType;
    uint64_t objectHandle;
    const char* pObjectName;
} VkDebugUtilsObjectNameInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `objectType` is a `VkObjectType` specifying the type of the object to be named.
- `objectHandle` is the object to be named.
- `pObjectName` is either `NULL` or a null-terminated UTF-8 string specifying the name to apply to `objectHandle`.

Applications may change the name associated with an object simply by calling `vkSetDebugUtilsObjectNameEXT` again with a new string. If `pObjectName` is either `NULL` or an empty string, then any previously set name is removed.

The `graphicsPipelineLibrary` feature allows the specification of pipelines without the creation of `VkShaderModule` objects beforehand. In order to continue to allow naming these shaders independently, `VkDebugUtilsObjectNameInfoEXT` can be included in the `pNext` chain of `VkPipelineShaderStageCreateInfo`, which associates a static name with that particular shader.

### Valid Usage

- **VUID-VkDebugUtilsObjectNameInfoEXT-objectType-02589**
  If `objectType` is `VK_OBJECT_TYPE_UNKNOWN`, `objectHandle` must not be `VK_NULL_HANDLE`

- **VUID-VkDebugUtilsObjectNameInfoEXT-objectType-02590**
  If `objectType` is not `VK_OBJECT_TYPE_UNKNOWN`, `objectHandle` must be `VK_NULL_HANDLE` or a valid Vulkan handle of the type associated with `objectType` as defined in the `VkObjectType` and Vulkan Handle Relationship table

### Valid Usage (Implicit)

- **VUID-VkDebugUtilsObjectNameInfoEXT-sType-sType**
**sType** must be `VK_STRUCTURE_TYPE_DEBUG_UTILS_OBJECT_NAME_INFO_EXT`

- VUID-VkDebugUtilsObjectNameInfoEXT-objectType-parameter
  **objectType** must be a valid `VkObjectType` value

- VUID-VkDebugUtilsObjectNameInfoEXT-pObjectName-parameter
  If `pObjectName` is not NULL, `pObjectName` must be a null-terminated UTF-8 string

---

**Object Data Association**

In addition to setting a name for an object, debugging and validation layers may have uses for additional binary data on a per-object basis that have no other place in the Vulkan API.

For example, a `VkShaderModule` could have additional debugging data attached to it to aid in offline shader tracing.

Additional data can be attached to an object by calling `vkSetDebugUtilsObjectTagEXT` as defined below.

```c
// Provided by VK_EXT_debug_utils
VkResult vkSetDebugUtilsObjectTagEXT(
    VkDevice device,
    const VkDebugUtilsObjectTagInfoEXT* pTagInfo);
```

- `device` is the device that created the object.
- `pTagInfo` is a pointer to a `VkDebugUtilsObjectTagInfoEXT` structure specifying parameters of the tag to attach to the object.

---

**Valid Usage**

- VUID-vkSetDebugUtilsObjectTagEXT-pNameInfo-07875
  If `pNameInfo->objectHandle` is the valid handle of an instance-level object, the `VkDevice` identified by `device` must be a descendent of the same `VkInstance` as the object identified by `pNameInfo->objectHandle`

- VUID-vkSetDebugUtilsObjectTagEXT-pNameInfo-07876
  If `pNameInfo->objectHandle` is the valid handle of a physical-device-level object, the `VkDevice` identified by `device` must be a descendent of the same `VkPhysicalDevice` as the object identified by `pNameInfo->objectHandle`

- VUID-vkSetDebugUtilsObjectTagEXT-pNameInfo-07877
  If `pNameInfo->objectHandle` is the valid handle of a device-level object, that object must be a descendent of the `VkDevice` identified by `device`

---

**Valid Usage (Implicit)**

- VUID-vkSetDebugUtilsObjectTagEXT-device-parameter
  `device` must be a valid `VkDevice` handle
Host Synchronization

- Host access to `pTagInfo->objectHandle` must be externally synchronized

Return Codes

**Success**

- VK_SUCCESS

**Failure**

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The `VkDebugUtilsObjectTagInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_debug_utils
typedef struct VkDebugUtilsObjectTagInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkObjectType objectType;
    uint64_t objectHandle;
    uint64_t tagName;
    size_t tagSize;
    const void* pTag;
} VkDebugUtilsObjectTagInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `objectType` is a `VkObjectType` specifying the type of the object to be named.
- `objectHandle` is the object to be tagged.
- `tagName` is a numerical identifier of the tag.
- `tagSize` is the number of bytes of data to attach to the object.
- `pTag` is a pointer to an array of `tagSize` bytes containing the data to be associated with the object.

The `tagName` parameter gives a name or identifier to the type of data being tagged. This can be used by debugging layers to easily filter for only data that can be used by that implementation.
Valid Usage

- **VUID-VkDebugUtilsObjectTagInfoEXT-objectType-01908**
  
  `objectType must not be VK_OBJECT_TYPE_UNKNOWN`

- **VUID-VkDebugUtilsObjectTagInfoEXT-objectHandle-01910**
  
  `objectHandle must be a valid Vulkan handle of the type associated with `objectType` as defined in the `VkObjectType` and `Vulkan Handle Relationship` table

Valid Usage (Implicit)

- **VUID-VkDebugUtilsObjectTagInfoEXT-sType-sType**
  
  `sType must be VK_STRUCTURE_TYPE_DEBUG_UTILS_OBJECT_TAG_INFO_EXT`

- **VUID-VkDebugUtilsObjectTagInfoEXT-pNext-pNext**
  
  `pNext must be NULL`

- **VUID-VkDebugUtilsObjectTagInfoEXT-objectType-parameter**
  
  `objectType must be a valid `VkObjectType` value`

- **VUID-VkDebugUtilsObjectTagInfoEXT-pTag-parameter**
  
  `pTag must be a valid pointer to an array of `tagSize` bytes`

- **VUID-VkDebugUtilsObjectTagInfoEXT-tagSize-arraylength**
  
  `tagSize must be greater than 0`

50.1.2. Queue Labels

All Vulkan work must be submitted using queues. It is possible for an application to use multiple queues, each containing multiple command buffers, when performing work. It can be useful to identify which queue, or even where in a queue, something has occurred.

To begin identifying a region using a debug label inside a queue, you may use the `vkQueueBeginDebugUtilsLabelEXT` command.

Then, when the region of interest has passed, you may end the label region using `vkQueueEndDebugUtilsLabelEXT`.

Additionally, a single debug label may be inserted at any time using `vkQueueInsertDebugUtilsLabelEXT`.

A queue debug label region is opened by calling:

```c
// Provided by VK_EXT_debug_utils
void vkQueueBeginDebugUtilsLabelEXT(
    VkQueue queue,
    const VkDebugUtilsLabelEXT* pLabelInfo);
```

- `queue` is the queue in which to start a debug label region.
• `pLabelInfo` is a pointer to a `VkDebugUtilsLabelEXT` structure specifying parameters of the label region to open.

Valid Usage (Implicit)

• VUID-vkQueueBeginDebugUtilsLabelEXT-queue-parameter `queue` must be a valid `VkQueue` handle

• VUID-vkQueueBeginDebugUtilsLabelEXT-pLabelInfo-parameter `pLabelInfo` must be a valid pointer to a valid `VkDebugUtilsLabelEXT` structure

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Any</td>
<td>-</td>
</tr>
</tbody>
</table>

Command Properties

The `VkDebugUtilsLabelEXT` structure is defined as:

```cpp
// Provided by VK_EXT_debug_utils
typedef struct VkDebugUtilsLabelEXT {
    VkStructureType sType;
    const void* pNext;
    const char* pLabelName;
    float color[4];
} VkDebugUtilsLabelEXT;
```

• `sType` is a `VkStructureType` value identifying this structure.

• `pNext` is `NULL` or a pointer to a structure extending this structure.

• `pLabelName` is a pointer to a null-terminated UTF-8 string containing the name of the label.

• `color` is an optional RGBA color value that can be associated with the label. A particular implementation may choose to ignore this color value. The values contain RGBA values in order, in the range 0.0 to 1.0. If all elements in `color` are set to 0.0 then it is ignored.

Valid Usage (Implicit)

• VUID-VkDebugUtilsLabelEXT-sType-sType `sType` must be `VK_STRUCTURE_TYPE_DEBUG_UTILS_LABEL_EXT`

• VUID-VkDebugUtilsLabelEXT-pNext-pNext `pNext` must be `NULL`

• VUID-VkDebugUtilsLabelEXT-pLabelName-parameter `pLabelName` must be a null-terminated UTF-8 string
A queue debug label region is closed by calling:

```c
// Provided by VK_EXT_debug_utils
void vkQueueEndDebugUtilsLabelEXT(
    VkQueue queue);
```

- `queue` is the queue in which a debug label region should be closed.

The calls to `vkQueueBeginDebugUtilsLabelEXT` and `vkQueueEndDebugUtilsLabelEXT` must be matched and balanced.

### Valid Usage

- VUID-vkQueueEndDebugUtilsLabelEXT-None-01911
  There must be an outstanding `vkQueueBeginDebugUtilsLabelEXT` command prior to the `vkQueueEndDebugUtilsLabelEXT` on the queue

### Valid Usage (Implicit)

- VUID-vkQueueEndDebugUtilsLabelEXT-queue-parameter
  `queue` must be a valid `VkQueue` handle

### Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Any</td>
<td>-</td>
</tr>
</tbody>
</table>

A single label can be inserted into a queue by calling:

```c
// Provided by VK_EXT_debug_utils
void vkQueueInsertDebugUtilsLabelEXT(
    VkQueue queue,
    const VkDebugUtilsLabelEXT* pLabelInfo);
```

- `queue` is the queue into which a debug label will be inserted.

- `pLabelInfo` is a pointer to a `VkDebugUtilsLabelEXT` structure specifying parameters of the label to insert.

### Valid Usage (Implicit)

- VUID-vkQueueInsertDebugUtilsLabelEXT-queue-parameter
queue must be a valid VkQueue handle

- VUID-vkQueueInsertDebugUtilsLabelEXT-pLabelInfo-parameter
  pLabelInfo must be a valid pointer to a valid VkDebugUtilsLabelEXT structure

---

**Command Properties**

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Any</td>
<td>-</td>
</tr>
</tbody>
</table>

---

### 50.1.3. Command Buffer Labels

Typical Vulkan applications will submit many command buffers in each frame, with each command buffer containing a large number of individual commands. Being able to logically annotate regions of command buffers that belong together as well as hierarchically subdivide the frame is important to a developer’s ability to navigate the commands viewed holistically.

To identify the beginning of a debug label region in a command buffer, `vkCmdBeginDebugUtilsLabelEXT` can be used as defined below.

To indicate the end of a debug label region in a command buffer, `vkCmdEndDebugUtilsLabelEXT` can be used.

To insert a single command buffer debug label inside of a command buffer, `vkCmdInsertDebugUtilsLabelEXT` can be used as defined below.

A command buffer debug label region can be opened by calling:

```c
// Provided by VK_EXT_debug_utils
void vkCmdBeginDebugUtilsLabelEXT(
    VkCommandBuffer commandBuffer,  
    const VkDebugUtilsLabelEXT* pLabelInfo);
```

- `commandBuffer` is the command buffer into which the command is recorded.
- `pLabelInfo` is a pointer to a VkDebugUtilsLabelEXT structure specifying parameters of the label region to open.

---

**Valid Usage (Implicit)**

- VUID-vkCmdBeginDebugUtilsLabelEXT-commandBuffer-parameter
  `commandBuffer` must be a valid VkCommandBuffer handle

- VUID-vkCmdBeginDebugUtilsLabelEXT-pLabelInfo-parameter
  `pLabelInfo` must be a valid pointer to a valid VkDebugUtilsLabelEXT structure

- VUID-vkCmdBeginDebugUtilsLabelEXT-commandBuffer-recording
**commandBuffer** must be in the recording state

- VUID-vkCmdBeginDebugUtilsLabelEXT-commandBuffer-cmddpool
  The **VkCommandPool** that **commandBuffer** was allocated from **must** support graphics, or compute operations

- VUID-vkCmdBeginDebugUtilsLabelEXT-videocoding
  This command **must** only be called outside of a video coding scope

**Host Synchronization**

- Host access to **commandBuffer** **must** be externally synchronized

- Host access to the **VkCommandPool** that **commandBuffer** was allocated from **must** be externally synchronized

**Command Properties**

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Both</td>
<td>Outside</td>
<td>Graphics, Compute</td>
<td>Action</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td>State</td>
</tr>
</tbody>
</table>

A command buffer label region can be closed by calling:

```c
// Provided by VK_EXT_debug_utils
void vkCmdEndDebugUtilsLabelEXT(
  VkCommandBuffer commandBuffer);
```

- **commandBuffer** is the command buffer into which the command is recorded.

An application **may** open a debug label region in one command buffer and close it in another, or otherwise split debug label regions across multiple command buffers or multiple queue submissions. When viewed from the linear series of submissions to a single queue, the calls to **vkCmdBeginDebugUtilsLabelEXT** and **vkCmdEndDebugUtilsLabelEXT** **must** be matched and balanced.

There **can** be problems reporting command buffer debug labels during the recording process because command buffers **may** be recorded out of sequence with the resulting execution order. Since the recording order **may** be different, a solitary command buffer **may** have an inconsistent view of the debug label regions by itself. Therefore, if an issue occurs during the recording of a command buffer, and the environment requires returning debug labels, the implementation **may** return only those labels it is aware of. This is true even if the implementation is aware of only the debug labels within the command buffer being actively recorded.
Valid Usage

- VUID-vkCmdEndDebugUtilsLabelEXT-commandBuffer-01912
  There must be an outstanding `vkCmdBeginDebugUtilsLabelEXT` command prior to the `vkCmdEndDebugUtilsLabelEXT` on the queue that `commandBuffer` is submitted to.

- VUID-vkCmdEndDebugUtilsLabelEXT-commandBuffer-01913
  If `commandBuffer` is a secondary command buffer, there must be an outstanding `vkCmdBeginDebugUtilsLabelEXT` command recorded to `commandBuffer` that has not previously been ended by a call to `vkCmdEndDebugUtilsLabelEXT`.

Valid Usage (Implicit)

- VUID-vkCmdEndDebugUtilsLabelEXT-commandBuffer-parameter
  `commandBuffer` must be a valid `VkCommandBuffer` handle.

- VUID-vkCmdEndDebugUtilsLabelEXT-commandBuffer-recording
  `commandBuffer` must be in the recording state.

- VUID-vkCmdEndDebugUtilsLabelEXT-commandBuffer-cmdpool
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, or compute operations.

- VUID-vkCmdEndDebugUtilsLabelEXT-videocoding
  This command must only be called outside of a video coding scope.

Host Synchronization

- Host access to `commandBuffer` must be externally synchronized.
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized.

Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
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<td>Graphics, Compute</td>
<td>Action State</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A single debug label can be inserted into a command buffer by calling:

```c
// Provided by VK_EXT_debug_utils
void vkCmdInsertDebugUtilsLabelEXT(
    VkCommandBuffer commandBuffer,
```
const VkDebugUtilsLabelEXT* pLabelInfo);

- `commandBuffer` is the command buffer into which the command is recorded.
- `pInfo` is a pointer to a `VkDebugUtilsLabelEXT` structure specifying parameters of the label to insert.

### Valid Usage (Implicit)

- VUID-vkCmdInsertDebugUtilsLabelEXT-commandBuffer-parameter  
  `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdInsertDebugUtilsLabelEXT-pLabelInfo-parameter  
  `pLabelInfo` must be a valid pointer to a valid `VkDebugUtilsLabelEXT` structure
- VUID-vkCmdInsertDebugUtilsLabelEXT-commandBuffer-recording  
  `commandBuffer` must be in the recording state
- VUID-vkCmdInsertDebugUtilsLabelEXT-commandBuffer-cmdpool  
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, or compute operations
- VUID-vkCmdInsertDebugUtilsLabelEXT-videocoding  
  This command must only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

### Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
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</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td>Compute</td>
<td></td>
</tr>
</tbody>
</table>

### 50.1.4. Debug Messengers

Vulkan allows an application to register multiple callbacks with any Vulkan component wishing to report debug information. Some callbacks may log the information to a file, others may cause a debug break point or other application defined behavior. A primary producer of callback messages are the validation layers. An application can register callbacks even when no validation layers are enabled, but they will only be called for the Vulkan loader and, if implemented, other layer and driver events.
A `VkDebugUtilsMessengerEXT` is a messenger object which handles passing along debug messages to a provided debug callback.

```c
// Provided by VK_EXT_debug_utils
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkDebugUtilsMessengerEXT)
```

The debug messenger will provide detailed feedback on the application's use of Vulkan when events of interest occur. When an event of interest does occur, the debug messenger will submit a debug message to the debug callback that was provided during its creation. Additionally, the debug messenger is responsible with filtering out debug messages that the callback is not interested in and will only provide desired debug messages.

A debug messenger triggers a debug callback with a debug message when an event of interest occurs. To create a debug messenger which will trigger a debug callback, call:

```c
// Provided by VK_EXT_debug_utils
VkResult vkCreateDebugUtilsMessengerEXT(VkInstance instance, const VkDebugUtilsMessengerCreateInfoEXT* pCreateInfo, const VkAllocationCallbacks* pAllocator, VkDebugUtilsMessengerEXT* pMessenger);
```

- `instance` is the instance the messenger will be used with.
- `pCreateInfo` is a pointer to a `VkDebugUtilsMessengerCreateInfoEXT` structure containing the callback pointer, as well as defining conditions under which this messenger will trigger the callback.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
- `pMessenger` is a pointer to a `VkDebugUtilsMessengerEXT` handle in which the created object is returned.

**Valid Usage (Implicit)**

- VUID-vkCreateDebugUtilsMessengerEXT-instance-parameter `instance` must be a valid `VkInstance` handle
- VUID-vkCreateDebugUtilsMessengerEXT-pCreateInfo-parameter `pCreateInfo` must be a valid pointer to a valid `VkDebugUtilsMessengerCreateInfoEXT` structure
- VUID-vkCreateDebugUtilsMessengerEXT-pAllocator-parameter If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure
- VUID-vkCreateDebugUtilsMessengerEXT-pMessenger-parameter `pMessenger` must be a valid pointer to a `VkDebugUtilsMessengerEXT` handle
Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY

The application **must** ensure that `vkCreateDebugUtilsMessengerEXT` is not executed in parallel with any Vulkan command that is also called with `instance` or child of `instance` as the dispatchable argument.

The definition of `VkDebugUtilsMessengerCreateInfoEXT` is:

```c
// Provided by VK_EXT_debug_utils
typedef struct VkDebugUtilsMessengerCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkDebugUtilsMessengerCreateFlagsEXT flags;
    VkDebugUtilsMessageSeverityFlagsEXT messageSeverity;
    VkDebugUtilsMessageTypeFlagsEXT messageType;
    PFN_vkDebugUtilsMessengerCallbackEXT pfnUserCallback;
    void* pUserData;
} VkDebugUtilsMessengerCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `flags` is 0 and is reserved for future use.
- `messageSeverity` is a bitmask of `VkDebugUtilsMessageSeverityFlagBitsEXT` specifying which severity of event(s) will cause this callback to be called.
- `messageType` is a bitmask of `VkDebugUtilsMessageTypeFlagBitsEXT` specifying which type of event(s) will cause this callback to be called.
- `pfnUserCallback` is the application callback function to call.
- `pUserData` is user data to be passed to the callback.

For each `VkDebugUtilsMessengerEXT` that is created the `VkDebugUtilsMessengerCreateInfoEXT::messageSeverity` and `VkDebugUtilsMessengerCreateInfoEXT::messageType` determine when that `VkDebugUtilsMessengerCreateInfoEXT::pfnUserCallback` is called. The process to determine if the user’s `pfnUserCallback` is triggered when an event occurs is as follows:

1. The implementation will perform a bitwise AND of the event’s `VkDebugUtilsMessageSeverityFlagBitsEXT` with the `messageSeverity` provided during creation of the `VkDebugUtilsMessengerEXT` object.
   a. If the value is 0, the message is skipped.
2. The implementation will perform bitwise AND of the event’s `VkDebugUtilsMessageTypeFlagBitsEXT` with the `messageType` provided during the creation of the `VkDebugUtilsMessengerEXT` object.

   a. If the value is 0, the message is skipped.

3. The callback will trigger a debug message for the current event

The callback will come directly from the component that detected the event, unless some other layer intercepts the calls for its own purposes (filter them in a different way, log to a system error log, etc.).

An application can receive multiple callbacks if multiple `VkDebugUtilsMessengerEXT` objects are created. A callback will always be executed in the same thread as the originating Vulkan call.

A callback can be called from multiple threads simultaneously (if the application is making Vulkan calls from multiple threads).

---

### Valid Usage

- **VUID-VkDebugUtilsMessengerCreateInfoEXT-pfnUserCallback-01914**
  
  `pfnUserCallback` must be a valid `PFN_vkDebugUtilsMessengerCallbackEXT`

---

### Valid Usage (Implicit)

- **VUID-VkDebugUtilsMessengerCreateInfoEXT-sType-sType**
  
  `sType` must be `VK_STRUCTURE_TYPE_DEBUG_UTILS_MESSENGER_CREATE_INFO_EXT`

- **VUID-VkDebugUtilsMessengerCreateInfoEXT-flags-zero bitmask**
  
  `flags` must be 0

- **VUID-VkDebugUtilsMessengerCreateInfoEXT-messageSeverity-parameter**
  
  `messageSeverity` must be a valid combination of `VkDebugUtilsMessageSeverityFlagBitsEXT` values

- **VUID-VkDebugUtilsMessengerCreateInfoEXT-messageSeverity-required bitmask**
  
  `messageSeverity` must not be 0

- **VUID-VkDebugUtilsMessengerCreateInfoEXT-messageType-parameter**
  
  `messageType` must be a valid combination of `VkDebugUtilsMessageTypeFlagBitsEXT` values

- **VUID-VkDebugUtilsMessengerCreateInfoEXT-messageType-required bitmask**
  
  `messageType` must not be 0

---

```c
// Provided by VK_EXT_debug_utils
typedef VkFlags VkDebugUtilsMessengerCreateFlagsEXT;
```
VkDebugUtilsMessengerCreateFlagsEXT is a bitmask type for setting a mask, but is currently reserved for future use.

Bits which can be set in VkDebugUtilsMessengerCreateInfoEXT::messageSeverity, specifying event severities which cause a debug messenger to call the callback, are:

```c
// Provided by VK_EXT_debug_utils
typedef enum VkDebugUtilsMessageSeverityFlagBitsEXT {
    VK_DEBUG_UTILS_MESSAGE_SEVERITY_VERBOSE_BIT_EXT = 0x00000001,
    VK_DEBUG_UTILS_MESSAGE_SEVERITY_INFO_BIT_EXT = 0x00000010,
    VK_DEBUG_UTILS_MESSAGE_SEVERITY_WARNING_BIT_EXT = 0x00000100,
    VK_DEBUG_UTILS_MESSAGE_SEVERITY_ERROR_BIT_EXT = 0x00001000,
} VkDebugUtilsMessageSeverityFlagBitsEXT;
```

- **VK_DEBUG_UTILS_MESSAGE_SEVERITY_VERBOSE_BIT_EXT** specifies the most verbose output indicating all diagnostic messages from the Vulkan loader, layers, and drivers should be captured.
- **VK_DEBUG_UTILS_MESSAGE_SEVERITY_INFO_BIT_EXT** specifies an informational message such as resource details that may be handy when debugging an application.
- **VK_DEBUG_UTILS_MESSAGE_SEVERITY_WARNING_BIT_EXT** specifies use of Vulkan that may expose an app bug. Such cases may not be immediately harmful, such as a fragment shader outputting to a location with no attachment. Other cases may point to behavior that is almost certainly bad when unintended such as using an image whose memory has not been filled. In general if you see a warning but you know that the behavior is intended/desired, then simply ignore the warning.
- **VK_DEBUG_UTILS_MESSAGE_SEVERITY_ERROR_BIT_EXT** specifies that the application has violated a valid usage condition of the specification.

**Note**

The values of VkDebugUtilsMessageSeverityFlagBitsEXT are sorted based on severity. The higher the flag value, the more severe the message. This allows for simple boolean operation comparisons when looking at VkDebugUtilsMessageSeverityFlagBitsEXT values.

For example:

```c
if (messageSeverity >= VK_DEBUG_UTILS_MESSAGE_SEVERITY_WARNING_BIT_EXT) {
    // Do something for warnings and errors
}
```

In addition, space has been left between the enums to allow for later addition of new severities in between the existing values.
typedef VkFlags VkDebugUtilsMessageSeverityFlagsEXT;

VkDebugUtilsMessageSeverityFlagsEXT is a bitmask type for setting a mask of zero or more VkDebugUtilsMessageSeverityFlagBitsEXT.

Bits which can be set in VkDebugUtilsMessengerCreateInfoEXT::messageType, specifying event types which cause a debug messenger to call the callback, are:

```
// Provided by VK_EXT_debug_utils
typedef enum VkDebugUtilsMessageTypeFlagBitsEXT { 
    VK_DEBUG_UTILS_MESSAGE_TYPE_GENERAL_BIT_EXT = 0x00000001,
    VK_DEBUG_UTILS_MESSAGE_TYPE_VALIDATION_BIT_EXT = 0x00000002,
    VK_DEBUG_UTILS_MESSAGE_TYPE_PERFORMANCE_BIT_EXT = 0x00000004,
    // Provided by VK_EXT_device_address_binding_report
    VK_DEBUG_UTILS_MESSAGE_TYPE_DEVICE_ADDRESS_BINDING_BIT_EXT = 0x00000008,
} VkDebugUtilsMessageTypeFlagBitsEXT;
```

- **VK_DEBUG_UTILS_MESSAGE_TYPE_GENERAL_BIT_EXT** specifies that some general event has occurred. This is typically a non-specification, non-performance event.
- **VK_DEBUG_UTILS_MESSAGE_TYPE_VALIDATION_BIT_EXT** specifies that something has occurred during validation against the Vulkan specification that may indicate invalid behavior.
- **VK_DEBUG_UTILS_MESSAGE_TYPE_PERFORMANCE_BIT_EXT** specifies a potentially non-optimal use of Vulkan, e.g. using `vkCmdClearColorImage` when setting `VkAttachmentDescription::loadOp` to `VK_ATTACHMENT_LOAD_OP_CLEAR` would have worked.
- **VK_DEBUG_UTILS_MESSAGE_TYPE_DEVICE_ADDRESS_BINDING_BIT_EXT** specifies that the implementation has modified the set of GPU-visible virtual addresses associated with a Vulkan object.

```
// Provided by VK_EXT_debug_utils
typedef VkFlags VkDebugUtilsMessageTypeFlagsEXT;

VkDebugUtilsMessageTypeFlagsEXT is a bitmask type for setting a mask of zero or more VkDebugUtilsMessageTypeFlagBitsEXT.

The prototype for the VkDebugUtilsMessengerCreateInfoEXT::pfnUserCallback function implemented by the application is:

```
// Provided by VK_EXT_debug_utils
typedef VkBool32 (VKAPI_PTR *PFN_vkDebugUtilsMessengerCallbackEXT)(
    VkDebugUtilsMessageSeverityFlagBitsEXT messageSeverity,
    VkDebugUtilsMessageTypeFlagsEXT messageTypes,
    const VkDebugUtilsMessengerCallbackDataEXT* pCallbackData,
    void* pUserData);
```

- **messageSeverity** specifies the VkDebugUtilsMessageSeverityFlagBitsEXT that triggered this callback.

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• **messageTypes** is a bitmask of `VkDebugUtilsMessageTypeFlagBitsEXT` specifying which type of event(s) triggered this callback.

• **pCallbackData** contains all the callback related data in the `VkDebugUtilsMessengerCallbackDataEXT` structure.

• **pUserData** is the user data provided when the `VkDebugUtilsMessengerEXT` was created.

The callback returns a `VkBool32`, which is interpreted in a layer-specified manner. The application **should** always return `VK_FALSE`. The `VK_TRUE` value is reserved for use in layer development.

### Valid Usage

- VUID-PFN_vkDebugUtilsMessengerCallbackEXT-None-04769
  The callback **must** not make calls to any Vulkan commands

The definition of `VkDebugUtilsMessengerCallbackDataEXT` is:

```c
// Provided by VK_EXT_debug_utils
typedef struct VkDebugUtilsMessengerCallbackDataEXT {
    VkStructureType sType;
    const void* pNext;
    VkDebugUtilsMessengerCallbackDataFlagsEXT flags;
    const char* pMessageIdName;
    int32_t messageIdNumber;
    const char* pMessage;
    uint32_t queueLabelCount;
    const VkDebugUtilsLabelEXT* pQueueLabels;
    uint32_t cmdBufLabelCount;
    const VkDebugUtilsLabelEXT* pCmdBufLabels;
    uint32_t objectCount;
    const VkDebugUtilsObjectNameInfoEXT* pObjects;
} VkDebugUtilsMessengerCallbackDataEXT;
```

- **sType** is a `VkStructureType` value identifying this structure.

- **pNext** is `NULL` or a pointer to a structure extending this structure.

- **flags** is `0` and is reserved for future use.

- **pMessageIdName** is a null-terminated string that identifies the particular message ID that is associated with the provided message. If the message corresponds to a validation layer message, then this string may contain the portion of the Vulkan specification that is believed to have been violated.

- **messageIdNumber** is the ID number of the triggering message. If the message corresponds to a validation layer message, then this number is related to the internal number associated with the message being triggered.

- **pMessage** is a null-terminated string detailing the trigger conditions.

- **queueLabelCount** is a count of items contained in the `pQueueLabels` array.
• **pQueueLabels** is **NULL** or a pointer to an array of *VkDebugUtilsLabelEXT* active in the current *VkQueue* at the time the callback was triggered. Refer to [Queue Labels](#) for more information.

• **cmdBufLabelCount** is a count of items contained in the **pCmdBufLabels** array.

• **pCmdBufLabels** is **NULL** or a pointer to an array of *VkDebugUtilsLabelEXT* active in the current *VkCommandBuffer* at the time the callback was triggered. Refer to [Command Buffer Labels](#) for more information.

• **objectCount** is a count of items contained in the **pObjects** array.

• **pObjects** is a pointer to an array of *VkDebugUtilsObjectNameInfoEXT* objects related to the detected issue. The array is roughly in order or importance, but the 0th element is always guaranteed to be the most important object for this message.

---

**Note**

This structure should only be considered valid during the lifetime of the triggered callback.

Since adding queue and command buffer labels behaves like pushing and popping onto a stack, the order of both **pQueueLabels** and **pCmdBufLabels** is based on the order the labels were defined. The result is that the first label in either **pQueueLabels** or **pCmdBufLabels** will be the first defined (and therefore the oldest) while the last label in each list will be the most recent.

---

**Note**

**pQueueLabels** will only be non-**NULL** if one of the objects in **pObjects** can be related directly to a defined *VkQueue* which has had one or more labels associated with it.

Likewise, **pCmdBufLabels** will only be non-**NULL** if one of the objects in **pObjects** can be related directly to a defined *VkCommandBuffer* which has had one or more labels associated with it. Additionally, while command buffer labels allow for beginning and ending across different command buffers, the debug messaging framework cannot guarantee that labels in **pCmdBufLabels** will contain those defined outside of the associated command buffer. This is partially due to the fact that the association of one command buffer with another may not have been defined at the time the debug message is triggered.

---

**Valid Usage (Implicit)**

- VUID-VkDebugUtilsMessengerCallbackDataEXT-sType-sType
  - **sType** must be **VK_STRUCTURE_TYPE_DEBUG_UTILS_MESSENGER_CALLBACK_DATA_EXT**

- VUID-VkDebugUtilsMessengerCallbackDataEXT-pNext-pNext
  - **pNext** must be **NULL** or a pointer to a valid instance of *VkDeviceAddressBindingCallbackDataEXT*

- VUID-VkDebugUtilsMessengerCallbackDataEXT-sType-unique
  - The **sType** value of each struct in the **pNext** chain must be unique

- VUID-VkDebugUtilsMessengerCallbackDataEXT-flags-zerobitmask
  - **flags** must be 0
If `pMessageIdName` is not NULL, `pMessageIdName` must be a null-terminated UTF-8 string.

If `pMessage` is not NULL, `pMessage` must be a null-terminated UTF-8 string.

If `queueLabelCount` is not 0, `pQueueLabels` must be a valid pointer to an array of `queueLabelCount` valid `VkDebugUtilsLabelEXT` structures.

If `cmdBufLabelCount` is not 0, `pCmdBufLabels` must be a valid pointer to an array of `cmdBufLabelCount` valid `VkDebugUtilsLabelEXT` structures.

If `objectCount` is not 0, `pObjects` must be a valid pointer to an array of `objectCount` valid `VkDebugUtilsObjectNameInfoEXT` structures.

// Provided by VK_EXT_debug_utils
typedef VkFlags VkDebugUtilsMessengerCallbackDataFlagsEXT;

`VkDebugUtilsMessengerCallbackDataFlagsEXT` is a bitmask type for setting a mask, but is currently reserved for future use.

The definition of `VkDeviceAddressBindingCallbackDataEXT` is:

// Provided by VK_EXT_device_address_binding_report
typedef struct VkDeviceAddressBindingCallbackDataEXT {
    VkStructureType sType;
    void* pNext;
    VkDeviceAddressBindingFlagsEXT flags;
    VkDeviceAddress baseAddress;
    VkDeviceSize size;
    VkDeviceAddressBindingTypeEXT bindingType;
} VkDeviceAddressBindingCallbackDataEXT;

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkDeviceAddressBindingFlagBitsEXT` specifying additional information about the binding event that caused the callback to be called.
- `baseAddress` is a GPU-accessible virtual address identifying the start of a region of the virtual address space associated with a Vulkan object, as identified by the `pObjects` member of `VkDebugUtilsMessengerCallbackDataEXT`.
- `size` is the size in bytes of a region of GPU-accessible virtual address space.
- `bindingType` is a `VkDeviceAddressBindingTypeEXT` specifying the type of binding event that caused the callback to be called.
If the `reportAddressBinding` feature is enabled and the implementation binds or unbinds a region of virtual address space associated with a Vulkan object, the implementation must submit a debug message with the following properties:

- `messageSeverity` equal to `VK_DEBUG_UTILS_MESSAGE_SEVERITY_INFO_BIT_EXT`
- `messageType` equal to `VK_DEBUG_UTILS_MESSAGE_TYPE_DEVICE_ADDRESS_BINDING_BIT_EXT`
- `VkDebugUtilsMessengerCallbackDataEXT::pObjects` must identify the associated Vulkan object
- `VkDeviceAddressBindingCallbackDataEXT` must be included in the `pNext` chain of `VkDebugUtilsMessengerCallbackDataEXT`

These debug messages must be emitted both for GPU virtual address space regions that are explicitly bound to a Vulkan object via the `vkBind*Memory/vkBind*Memory2` functions, and for those that are implicitly generated via memory allocation or importing external memory.

An implementation may report binding events associated with a Vulkan object via `VkDebugUtilsMessengerEXT` prior to the object becoming visible to an application via other Vulkan commands. For example, object creation functions may report binding events that occur during an objects creation. In such cases, `VkDeviceAddressBindingCallbackDataEXT::flags` must include `VK_DEVICE_ADDRESS_BINDING_INTERNAL_OBJECT_BIT_EXT`.

Object handles reported in this manner are not valid object handles, and must not be used as an input parameter to any Vulkan command.

Any valid object handle returned by an object creation function must match the handle specified via any previously reported binding events associated with the object's creation.

---

### Valid Usage (Implicit)

- `VUID-VkDeviceAddressBindingCallbackDataEXT-sType-sType`  
  sType must be `VK_STRUCTURE_TYPE_DEVICE_ADDRESS_BINDING_CALLBACK_DATA_EXT`
- `VUID-VkDeviceAddressBindingCallbackDataEXT-flags-parameter`  
  flags must be a valid combination of `VkDeviceAddressBindingFlagBitsEXT` values
- `VUID-VkDeviceAddressBindingCallbackDataEXT-bindingType-parameter`  
  bindingType must be a valid `VkDeviceAddressBindingTypeEXT` value

Bits which can be set in `VkDeviceAddressBindingCallbackDataEXT::flags` specifying additional information about a binding event are:

```c
// Provided by VK_EXT_device_address_binding_report
typedef enum VkDeviceAddressBindingFlagBitsEXT {
    VK_DEVICE_ADDRESS_BINDING_INTERNAL_OBJECT_BIT_EXT = 0x00000001,
} VkDeviceAddressBindingFlagBitsEXT;
```

- `VK_DEVICE_ADDRESS_BINDING_INTERNAL_OBJECT_BIT_EXT` specifies that `VkDeviceAddressBindingCallbackDataEXT` describes a Vulkan object that has not been made
visible to the application via a Vulkan command.

```c
// Provided by VK_EXT_device_address_binding_report
typedef VkFlags VkDeviceAddressBindingFlagsEXT;
```

**VkDeviceAddressBindingFlagsEXT** is a bitmask type for setting a mask of zero or more **VkDeviceAddressBindingFlagBitsEXT**.

The **VkDeviceAddressBindingTypeEXT** enum is defined as:

```c
// Provided by VK_EXT_device_address_binding_report
typedef enum VkDeviceAddressBindingTypeEXT {
    VK_DEVICE_ADDRESS_BINDING_TYPE_BIND_EXT = 0,
    VK_DEVICE_ADDRESS_BINDING_TYPE_UNBIND_EXT = 1,
} VkDeviceAddressBindingTypeEXT;
```

- **VK_DEVICE_ADDRESS_BINDING_TYPE_BIND_EXT** specifies that a new GPU-accessible virtual address range has been bound.
- **VK_DEVICE_ADDRESS_BINDING_TYPE_UNBIND_EXT** specifies that a GPU-accessible virtual address range has been unbound.

There may be times that a user wishes to intentionally submit a debug message. To do this, call:

```c
// Provided by VK_EXT_debug_utils
void vkSubmitDebugUtilsMessageEXT(
    VkInstance instance,
    VkDebugUtilsMessageSeverityFlagBitsEXT messageSeverity,
    VkDebugUtilsMessageTypeFlagsEXT messageTypes,
    const VkDebugUtilsMessengerCallbackDataEXT* pCallbackData);
```

- **instance** is the debug stream's VkInstance.
- **messageSeverity** is a **VkDebugUtilsMessageSeverityFlagBitsEXT** value specifying the severity of this event/message.
- **messageTypes** is a bitmask of **VkDebugUtilsMessageTypeFlagBitsEXT** specifying which type of event(s) to identify with this message.
- **pCallbackData** contains all the callback related data in the **VkDebugUtilsMessengerCallbackDataEXT** structure.

The call will propagate through the layers and generate callback(s) as indicated by the message's flags. The parameters are passed on to the callback in addition to the **pUserData** value that was defined at the time the messenger was registered.

**Valid Usage**

- **VUID-vkSubmitDebugUtilsMessageEXT-objectType-02591**
The `objectType` member of each element of `pCallbackData->pObjects` must not be `VK_OBJECT_TYPE_UNKNOWN`.

**Valid Usage (Implicit)**

- VUID-vkSubmitDebugUtilsMessageEXT-instance-parameter
  - `instance` must be a valid `VkInstance` handle
- VUID-vkSubmitDebugUtilsMessageEXT-messageSeverity-parameter
  - `messageSeverity` must be a valid `VkDebugUtilsMessageSeverityFlagBitsEXT` value
- VUID-vkSubmitDebugUtilsMessageEXT-messageTypes-parameter
  - `messageTypes` must be a valid combination of `VkDebugUtilsMessageTypeFlagBitsEXT` values
- VUID-vkSubmitDebugUtilsMessageEXT-messageTypes-required bitmask
  - `messageTypes` must not be 0
- VUID-vkSubmitDebugUtilsMessageEXT-pCallbackData-parameter
  - `pCallbackData` must be a valid pointer to a valid `VkDebugUtilsMessengerCallbackDataEXT` structure

To destroy a `VkDebugUtilsMessengerEXT` object, call:

```c
// Provided by VK_EXT_debug_utils
void vkDestroyDebugUtilsMessengerEXT(
    VkInstance instance,                // the instance where the callback was created.
    VkDebugUtilsMessengerEXT messenger, // the `VkDebugUtilsMessengerEXT` object to destroy. `messenger` is an externally synchronized object and must not be used on more than one thread at a time. This means that `vkDestroyDebugUtilsMessengerEXT` must not be called when a callback is active.
    const VkAllocationCallbacks* pAllocator); // controls host memory allocation as described in the Memory Allocation chapter.
```

- `instance` is the instance where the callback was created.
- `messenger` is the `VkDebugUtilsMessengerEXT` object to destroy. `messenger` is an externally synchronized object and must not be used on more than one thread at a time. This means that `vkDestroyDebugUtilsMessengerEXT` must not be called when a callback is active.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.

**Valid Usage**

- VUID-vkDestroyDebugUtilsMessengerEXT-messenger-01915
  - If `VkAllocationCallbacks` were provided when `messenger` was created, a compatible set of callbacks must be provided here
- VUID-vkDestroyDebugUtilsMessengerEXT-messenger-01916
  - If no `VkAllocationCallbacks` were provided when `messenger` was created, `pAllocator` must be NULL
Valid Usage (Implicit)

- **VUID-vkDestroyDebugUtilsMessengerEXT-instance-parameter**
  
  instance must be a valid VkInstance handle

- **VUID-vkDestroyDebugUtilsMessengerEXT-messenger-parameter**
  
  If messenger is not VK_NULL_HANDLE, messenger must be a valid VkDebugUtilsMessengerEXT handle

- **VUID-vkDestroyDebugUtilsMessengerEXT-pAllocator-parameter**
  
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure

- **VUID-vkDestroyDebugUtilsMessengerEXT-messenger-parent**
  
  If messenger is a valid handle, it must have been created, allocated, or retrieved from instance

Host Synchronization

- Host access to messenger must be externally synchronized

The application must ensure that vkDestroyDebugUtilsMessengerEXT is not executed in parallel with any Vulkan command that is also called with instance or child of instance as the dispatchable argument.

50.2. Debug Markers

Debug markers provide a flexible way for debugging and validation layers to receive annotation and debug information.

The **Object Annotation** section describes how to associate a name or binary data with a Vulkan object.

The **Command Buffer Markers** section describes how to associate logical elements of the scene with commands in the command buffer.

50.2.1. Object Annotation

The commands in this section allow application developers to associate user-defined information with Vulkan objects at will.

An object can be given a user-friendly name by calling:

```c
// Provided by VK_EXT_debug_marker
VkResult vkDebugMarkerSetObjectNameEXT(VkDevice device,
                                        const VkDebugMarkerObjectNameInfoEXT* pNameInfo);
```
• **device** is the device that created the object.

• **pNameInfo** is a pointer to a `VkDebugMarkerObjectNameInfoEXT` structure specifying the parameters of the name to set on the object.

## Valid Usage (Implicit)

- VUID-vkDebugMarkerSetObjectNameEXT-device-parameter  
  *device* **must** be a valid `VkDevice` handle

- VUID-vkDebugMarkerSetObjectNameEXT-pNameInfo-parameter  
  *pNameInfo* **must** be a valid pointer to a valid `VkDebugMarkerObjectNameInfoEXT` structure

## Host Synchronization

- Host access to `pNameInfo->object` **must** be externally synchronized

## Return Codes

**Success**

- **VK_SUCCESS**

**Failure**

- **VK_ERROR_OUT_OF_HOST_MEMORY**
- **VK_ERROR_OUT_OF_DEVICE_MEMORY**

The `VkDebugMarkerObjectNameInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_debug_marker
typedef struct VkDebugMarkerObjectNameInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkDebugReportObjectTypeEXT objectType;
    uint64_t object;
    const char* pObjectName;
} VkDebugMarkerObjectNameInfoEXT;
```

• **sType** is a `VkStructureType` value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **objectType** is a `VkDebugReportObjectTypeEXT` specifying the type of the object to be named.

• **object** is the object to be named.

• **pObjectName** is a null-terminated UTF-8 string specifying the name to apply to `object`. 
Applications may change the name associated with an object simply by calling `vkDebugMarkerSetObjectNameEXT` again with a new string. To remove a previously set name, `pObjectName` should be set to an empty string.

### Valid Usage

- VUID-VkDebugMarkerObjectNameInfoEXT-objectType-01490
  - `objectType` must not be `VK_DEBUG_REPORT_OBJECT_TYPE_UNKNOWN_EXT`
- VUID-VkDebugMarkerObjectNameInfoEXT-object-01491
  - `object` must not be `VK_NULL_HANDLE`
- VUID-VkDebugMarkerObjectNameInfoEXT-object-01492
  - `object` must be a Vulkan object of the type associated with `objectType` as defined in `VkDebugReportObjectTypeEXT` and Vulkan Handle Relationship

### Valid Usage (Implicit)

- VUID-VkDebugMarkerObjectNameInfoEXT-sType-sType
  - `sType` must be `VK_STRUCTURE_TYPE_DEBUG_MARKER_OBJECT_NAME_INFO_EXT`
- VUID-VkDebugMarkerObjectNameInfoEXT-pNext-pNext
  - `pNext` must be `NULL`
- VUID-VkDebugMarkerObjectNameInfoEXT-objectType-parameter
  - `objectType` must be a valid `VkDebugReportObjectTypeEXT` value
- VUID-VkDebugMarkerObjectNameInfoEXT-pObjectName-parameter
  - `pObjectName` must be a null-terminated UTF-8 string

In addition to setting a name for an object, debugging and validation layers may have uses for additional binary data on a per-object basis that has no other place in the Vulkan API. For example, a `VkShaderModule` could have additional debugging data attached to it to aid in offline shader tracing. To attach data to an object, call:

```c
// Provided by VK_EXT_debug_marker
VkResult vkDebugMarkerSetObjectTagEXT(
    VkDevice device,
    const VkDebugMarkerObjectTagInfoEXT* pTagInfo);
```

- `device` is the device that created the object.
- `pTagInfo` is a pointer to a `VkDebugMarkerObjectTagInfoEXT` structure specifying the parameters of the tag to attach to the object.

### Valid Usage (Implicit)

- VUID-vkDebugMarkerSetObjectTagEXT-device-parameter

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device must be a valid VkDevice handle

- VUID-vkDebugMarkerSetObjectTagEXT-pTagInfo-parameter
  pTagInfo must be a valid pointer to a valid VkDebugMarkerObjectTagInfoEXT structure

Host Synchronization

- Host access to pTagInfo->object must be externally synchronized

Return Codes

Success

- VK_SUCCESS

Failure

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_OUT_OF_DEVICE_MEMORY

The VkDebugMarkerObjectTagInfoEXT structure is defined as:

```c
// Provided by VK_EXT_debug_marker
typedef struct VkDebugMarkerObjectTagInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkDebugReportObjectTypeEXT objectType;
    uint64_t object;
    uint64_t tagName;
    size_t tagSize;
    const void* pTag;
} VkDebugMarkerObjectTagInfoEXT;
```

- sType is a VkStructureType value identifying this structure.
- pNext is NULL or a pointer to a structure extending this structure.
- objectType is a VkDebugReportObjectTypeEXT specifying the type of the object to be named.
- object is the object to be tagged.
- tagName is a numerical identifier of the tag.
- tagSize is the number of bytes of data to attach to the object.
- pTag is a pointer to an array of tagSize bytes containing the data to be associated with the object.

The tagName parameter gives a name or identifier to the type of data being tagged. This can be used by debugging layers to easily filter for only data that can be used by that implementation.
50.2.2. Command Buffer Markers

Typical Vulkan applications will submit many command buffers in each frame, with each command buffer containing a large number of individual commands. Being able to logically annotate regions of command buffers that belong together as well as hierarchically subdivide the frame is important to a developer's ability to navigate the commands viewed holistically.

The marker commands `vkCmdDebugMarkerBeginEXT` and `vkCmdDebugMarkerEndEXT` define regions of a series of commands that are grouped together, and they can be nested to create a hierarchy. The `vkCmdDebugMarkerInsertEXT` command allows insertion of a single label within a command buffer.

A marker region can be opened by calling:

```c
// Provided by VK_EXT_debug_marker
void vkCmdDebugMarkerBeginEXT(
    VkCommandBuffer
    commandBuffer,
    const VkDebugMarkerMarkerInfoEXT* pMarkerInfo);
```

- `commandBuffer` is the command buffer into which the command is recorded.
• **pMarkerInfo** is a pointer to a **VkDebugMarkerMarkerInfoEXT** structure specifying the parameters of the marker region to open.

## Valid Usage (Implicit)

- VUID-vkCmdDebugMarkerBeginEXT-commandBuffer-parameter  
  CommandBuffer **must** be a valid **VkCommandBuffer** handle

- VUID-vkCmdDebugMarkerBeginEXT-pMarkerInfo-parameter  
  **pMarkerInfo** **must** be a valid pointer to a valid **VkDebugMarkerMarkerInfoEXT** structure

- VUID-vkCmdDebugMarkerBeginEXT-commandBuffer-recording  
  CommandBuffer **must** be in the **recording state**

- VUID-vkCmdDebugMarkerBeginEXT-commandBuffer-cmdpool  
  The **VkCommandPool** that commandBuffer **was allocated from** **must** support graphics, or compute operations

- VUID-vkCmdDebugMarkerBeginEXT-videocoding  
  This command **must** only be called outside of a video coding scope

## Host Synchronization

- Host access to commandBuffer **must** be externally synchronized

- Host access to the **VkCommandPool** that commandBuffer **was allocated from** **must** be externally synchronized

## Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
<th>Render Pass Scope</th>
<th>Video Coding Scope</th>
<th>Supported Queue Types</th>
<th>Command Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Both</td>
<td>Outside</td>
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<td>Action</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The **VkDebugMarkerMarkerInfoEXT** structure is defined as:

```c
// Provided by VK_EXT_debug_marker
typedef struct VkDebugMarkerMarkerInfoEXT {
    VkStructureType     sType;
    const void*         pNext;
    const char*         pMarkerName;
    float                color[4];
} VkDebugMarkerMarkerInfoEXT;
```

• **sType** is a **VkStructureType** value identifying this structure.
• **pNext** is `NULL` or a pointer to a structure extending this structure.

• **pMarkerName** is a pointer to a null-terminated UTF-8 string containing the name of the marker.

• **color** is an **optional** RGBA color value that can be associated with the marker. A particular implementation **may** choose to ignore this color value. The values contain RGBA values in order, in the range 0.0 to 1.0. If all elements in **color** are set to 0.0 then it is ignored.

### Valid Usage (Implicit)

- VUID-VkDebugMarkerMarkerInfoEXT-sType-sType
  
  *sType** must be **VK_STRUCTURE_TYPE_DEBUG_MARKER_MARKER_INFO_EXT**

- VUID-VkDebugMarkerMarkerInfoEXT-pNext-pNext
  
  *pNext** must be **NULL**

- VUID-VkDebugMarkerMarkerInfoEXT-pMarkerName-parameter
  
  *pMarkerName** must be a null-terminated UTF-8 string

A marker region can be closed by calling:

```c
// Provided by VK_EXT_debug_marker
void vkCmdDebugMarkerEndEXT(
    VkCommandBuffer commandBuffer);
```

• **commandBuffer** is the command buffer into which the command is recorded.

An application **may** open a marker region in one command buffer and close it in another, or otherwise split marker regions across multiple command buffers or multiple queue submissions.

When viewed from the linear series of submissions to a single queue, the calls to **vkCmdDebugMarkerBeginEXT** and **vkCmdDebugMarkerEndEXT** **must** be matched and balanced.

### Valid Usage

- VUID-vkCmdDebugMarkerEndEXT-commandBuffer-01239
  
  There **must** be an outstanding **vkCmdDebugMarkerBeginEXT** command prior to the **vkCmdDebugMarkerEndEXT** on the queue that **commandBuffer** is submitted to

- VUID-vkCmdDebugMarkerEndEXT-commandBuffer-01240
  
  If **commandBuffer** is a secondary command buffer, there **must** be an outstanding **vkCmdDebugMarkerBeginEXT** command recorded to **commandBuffer** that has not previously been ended by a call to **vkCmdDebugMarkerEndEXT**

### Valid Usage (Implicit)

- VUID-vkCmdDebugMarkerEndEXT-commandBuffer-parameter
  
  **commandBuffer** **must** be a valid **VkCommandBuffer** handle

- VUID-vkCmdDebugMarkerEndEXT-commandBuffer-recording
  
  **commandBuffer** **must** be a valid **VkCommandBuffer** handle
commandBuffer must be in the recording state

- VUID-vkCmdDebugMarkerEndEXT-commandBuffer-cmdpool
  The VkCommandPool that commandBuffer was allocated from must support graphics, or compute operations

- VUID-vkCmdDebugMarkerEndEXT-videocoding
  This command must only be called outside of a video coding scope

**Host Synchronization**

- Host access to commandBuffer must be externally synchronized
- Host access to the VkCommandPool that commandBuffer was allocated from must be externally synchronized

**Command Properties**

<table>
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<tr>
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<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

A single marker label can be inserted into a command buffer by calling:

```c
// Provided by VK_EXT_debug_marker
void vkCmdDebugMarkerInsertEXT(
    VkCommandBuffer commandBuffer,
    const VkDebugMarkerMarkerInfoEXT* pMarkerInfo);
```

- commandBuffer is the command buffer into which the command is recorded.
- pMarkerInfo is a pointer to a VkDebugMarkerMarkerInfoEXT structure specifying the parameters of the marker to insert.

**Valid Usage (Implicit)**

- VUID-vkCmdDebugMarkerInsertEXT-commandBuffer-parameter
  commandBuffer must be a valid VkCommandBuffer handle

- VUID-vkCmdDebugMarkerInsertEXT-pMarkerInfo-parameter
  pMarkerInfo must be a valid pointer to a valid VkDebugMarkerMarkerInfoEXT structure

- VUID-vkCmdDebugMarkerInsertEXT-commandBuffer-recording
  commandBuffer must be in the recording state

- VUID-vkCmdDebugMarkerInsertEXT-commandBuffer-cmdpool
The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, or compute operations

- VUID-vkCmdDebugMarkerInsertEXT-videocoding
  This command must only be called outside of a video coding scope

### Host Synchronization

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

### Command Properties

<table>
<thead>
<tr>
<th>Command Buffer Levels</th>
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<td></td>
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</tbody>
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### 50.3. Debug Report Callbacks

Debug report callbacks are represented by `VkDebugReportCallbackEXT` handles:

```c
// Provided by VK_EXT_debug_report
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkDebugReportCallbackEXT)
```

Debug report callbacks give more detailed feedback on the application's use of Vulkan when events of interest occur.

To register a debug report callback, an application uses `vkCreateDebugReportCallbackEXT`.

```c
// Provided by VK_EXT_debug_report
VkResult vkCreateDebugReportCallbackEXT(
    VkInstance instance,
    const VkDebugReportCallbackCreateInfoEXT* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkDebugReportCallbackEXT* pCallback);
```

- `instance` is the instance the callback will be logged on.
- `pCreateInfo` is a pointer to a `VkDebugReportCallbackCreateInfoEXT` structure defining the conditions under which this callback will be called.
- `pAllocator` controls host memory allocation as described in the Memory Allocation chapter.
• `pCallback` is a pointer to a `VkDebugReportCallbackEXT` handle in which the created object is returned.

**Valid Usage (Implicit)**

- VUID-vkCreateDebugReportCallbackEXT-instance-parameter
  - `instance` must be a valid `VkInstance` handle
- VUID-vkCreateDebugReportCallbackEXT-pCreateInfo-parameter
  - `pCreateInfo` must be a valid pointer to a valid `VkDebugReportCallbackCreateInfoEXT` structure
- VUID-vkCreateDebugReportCallbackEXT-pAllocator-parameter
  - If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure
- VUID-vkCreateDebugReportCallbackEXT-pCallback-parameter
  - `pCallback` must be a valid pointer to a `VkDebugReportCallbackEXT` handle

**Return Codes**

**Success**
- `VK_SUCCESS`

**Failure**
- `VK_ERROR_OUT_OF_HOST_MEMORY`

The definition of `VkDebugReportCallbackCreateInfoEXT` is:

```c
// Provided by VK_EXT_debug_report
typedef struct VkDebugReportCallbackCreateInfoEXT {
    VkStructureType sType;
    const void* pNext;
    VkDebugReportFlagsEXT flags;
    PFN_vkDebugReportCallbackEXT pfnCallback;
    void* pUserData;
} VkDebugReportCallbackCreateInfoEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `flags` is a bitmask of `VkDebugReportFlagBitsEXT` specifying which event(s) will cause this callback to be called.
- `pfnCallback` is the application callback function to call.
- `pUserData` is user data to be passed to the callback.

For each `VkDebugReportCallbackEXT` that is created the `VkDebugReportCallbackCreateInfoEXT::flags`
determine when `VkDebugReportCallbackCreateInfoEXT::pfnCallback` is called. When an event happens, the implementation will do a bitwise AND of the event’s `VkDebugReportFlagBitsEXT` flags to each `VkDebugReportCallbackEXT` object’s flags. For each non-zero result the corresponding callback will be called. The callback will come directly from the component that detected the event, unless some other layer intercepts the calls for its own purposes (filter them in a different way, log to a system error log, etc.).

An application may receive multiple callbacks if multiple `VkDebugReportCallbackEXT` objects were created. A callback will always be executed in the same thread as the originating Vulkan call.

A callback may be called from multiple threads simultaneously (if the application is making Vulkan calls from multiple threads).

**Valid Usage (Implicit)**

- `VUID-VkDebugReportCallbackCreateInfoEXT-sType-sType` must be `VK_STRUCTURE_TYPE_DEBUG_REPORT_CALLBACK_CREATE_INFO_EXT`
- `VUID-VkDebugReportCallbackCreateInfoEXT-flags-parameter` flags must be a valid combination of `VkDebugReportFlagBitsEXT` values
- `VUID-VkDebugReportCallbackCreateInfoEXT-pfnCallback-parameter` `pfnCallback` must be a valid `PFN_vkDebugReportCallbackEXT` value

Bits which can be set in `VkDebugReportCallbackCreateInfoEXT::flags`, specifying events which cause a debug report, are:

// Provided by VK_EXT_debug_report

typedef enum VkDebugReportFlagBitsEXT {
    VK_DEBUG_REPORT_INFORMATION_BIT_EXT = 0x00000001,
    VK_DEBUG_REPORT_WARNING_BIT_EXT = 0x00000002,
    VK_DEBUG_REPORT_PERFORMANCE_WARNING_BIT_EXT = 0x00000004,
    VK_DEBUG_REPORT_ERROR_BIT_EXT = 0x00000008,
    VK_DEBUG_REPORT_DEBUG_BIT_EXT = 0x00000010,
} VkDebugReportFlagBitsEXT;

- `VK_DEBUG_REPORT_ERROR_BIT_EXT` specifies that the application has violated a valid usage condition of the specification.
- `VK_DEBUG_REPORT_WARNING_BIT_EXT` specifies use of Vulkan that may expose an app bug. Such cases may not be immediately harmful, such as a fragment shader outputting to a location with no attachment. Other cases may point to behavior that is almost certainly bad when unintended such as using an image whose memory has not been filled. In general if you see a warning but you know that the behavior is intended/desired, then simply ignore the warning.
- `VK_DEBUG_REPORT_PERFORMANCE_WARNING_BIT_EXT` specifies a potentially non-optimal use of Vulkan, e.g. using `vkCmdClearColorImage` when setting `VkAttachmentDescription::loadOp` to `VK_ATTACHMENT_LOAD_OP_CLEAR` would have worked.
- `VK_DEBUG_REPORT_INFORMATION_BIT_EXT` specifies an informational message such as resource
details that may be handy when debugging an application.

- **VK_DEBUG_REPORT_DEBUG_BIT_EXT** specifies diagnostic information from the implementation and layers.

```c
// Provided by VK_EXT_debug_report
typedef VkFlags VkDebugReportFlagsEXT;
```

`VkDebugReportFlagsEXT` is a bitmask type for setting a mask of zero or more `VkDebugReportFlagBitsEXT`.

The prototype for the `VkDebugReportCallbackCreateInfoEXT::pfnCallback` function implemented by the application is:

```c
// Provided by VK_EXT_debug_report
typedef VkBool32 (VKAPI_PTR *PFN_vkDebugReportCallbackEXT)(
    VkDebugReportFlagsEXT flags,
    VkDebugReportObjectTypeEXT objectType,
    uint64_t object,
    size_t location,
    int32_t messageCode,
    const char* pLayerPrefix,
    const char* pMessage,
    void* pUserData);
```

- **flags** specifies the `VkDebugReportFlagBitsEXT` that triggered this callback.
- **objectType** is a `VkDebugReportObjectTypeEXT` value specifying the type of object being used or created at the time the event was triggered.
- **object** is the object where the issue was detected. If `objectType` is `VK_DEBUG_REPORT_OBJECT_TYPE_UNKNOWN_EXT`, `object` is undefined.
- **location** is a component (layer, driver, loader) defined value specifying the location of the trigger. This is an optional value.
- **messageCode** is a layer-defined value indicating what test triggered this callback.
- **pLayerPrefix** is a null-terminated string that is an abbreviation of the name of the component making the callback. *pLayerPrefix* is only valid for the duration of the callback.
- **pMessage** is a null-terminated string detailing the trigger conditions. *pMessage* is only valid for the duration of the callback.
- **pUserData** is the user data given when the `VkDebugReportCallbackEXT` was created.

The callback **must** not call `vkDestroyDebugReportCallbackEXT`.

The callback returns a `VkBool32`, which is interpreted in a layer-specified manner. The application **should** always return `VK_FALSE`. The `VK_TRUE` value is reserved for use in layer development.

**object** **must** be a Vulkan object or `VK_NULL_HANDLE`. If **objectType** is not
VK_DEBUG_REPORT_OBJECT_TYPE_UNKNOWN_EXT and object is not VK_NULL_HANDLE, object must be a Vulkan object of the corresponding type associated with objectType as defined in VkDebugReportObjectTypeEXT and Vulkan Handle Relationship.

Possible values passed to the objectType parameter of the callback function specified by VkDebugReportCallbackCreateInfoEXT::pfnCallback, specifying the type of object handle being reported, are:

```c
typedef enum VkDebugReportObjectTypeEXT {
    VK_DEBUG_REPORT_OBJECT_TYPE_UNKNOWN_EXT = 0,
    VK_DEBUG_REPORT_OBJECT_TYPE_INSTANCE_EXT = 1,
    VK_DEBUG_REPORT_OBJECT_TYPE_PHYSICAL_DEVICE_EXT = 2,
    VK_DEBUG_REPORT_OBJECT_TYPE_DEVICE_EXT = 3,
    VK_DEBUG_REPORT_OBJECT_TYPE_QUEUE_EXT = 4,
    VK_DEBUG_REPORT_OBJECT_TYPE_SEMAPHORE_EXT = 5,
    VK_DEBUG_REPORT_OBJECT_TYPE_COMMAND_BUFFER_EXT = 6,
    VK_DEBUG_REPORT_OBJECT_TYPE_FENCE_EXT = 7,
    VK_DEBUG_REPORT_OBJECT_TYPE_DEVICE_MEMORY_EXT = 8,
    VK_DEBUG_REPORT_OBJECT_TYPE_BUFFER_EXT = 9,
    VK_DEBUG_REPORT_OBJECT_TYPE_IMAGE_EXT = 10,
    VK_DEBUG_REPORT_OBJECT_TYPE_EVENT_EXT = 11,
    VK_DEBUG_REPORT_OBJECT_TYPE_QUERY_POOL_EXT = 12,
    VK_DEBUG_REPORT_OBJECT_TYPE_BUFFER_VIEW_EXT = 13,
    VK_DEBUG_REPORT_OBJECT_TYPE_IMAGE_VIEW_EXT = 14,
    VK_DEBUG_REPORT_OBJECT_TYPE_SHADER_MODULE_EXT = 15,
    VK_DEBUG_REPORT_OBJECT_TYPE_PIPELINE_CACHE_EXT = 16,
    VK_DEBUG_REPORT_OBJECT_TYPE_PIPELINE_LAYOUT_EXT = 17,
    VK_DEBUG_REPORT_OBJECT_TYPE_RENDER_PASS_EXT = 18,
    VK_DEBUG_REPORT_OBJECT_TYPE_PIPELINE_EXT = 19,
    VK_DEBUG_REPORT_OBJECT_TYPE_DESCRIPTOR_SET_LAYOUT_EXT = 20,
    VK_DEBUG_REPORT_OBJECT_TYPE_SAMPLER_EXT = 21,
    VK_DEBUG_REPORT_OBJECT_TYPE_DESCRIPTOR_POOL_EXT = 22,
    VK_DEBUG_REPORT_OBJECT_TYPE_DESCRIPTOR_SET_EXT = 23,
    VK_DEBUG_REPORT_OBJECT_TYPE_FRAMEBUFFER_EXT = 24,
    VK_DEBUG_REPORT_OBJECT_TYPE_COMMAND_POOL_EXT = 25,
    VK_DEBUG_REPORT_OBJECT_TYPE_SURFACE_KHR_EXT = 26,
    VK_DEBUG_REPORT_OBJECT_TYPE_SWAPCHAIN_KHR_EXT = 27,
    VK_DEBUG_REPORT_OBJECT_TYPE_DEBUG_REPORT_CALLBACK_EXT_EXT = 28,
    VK_DEBUG_REPORT_OBJECT_TYPE_DISPLAY_KHR_EXT = 29,
    VK_DEBUG_REPORT_OBJECT_TYPE_DISPLAY_MODE_KHR_EXT = 30,
    VK_DEBUG_REPORT_OBJECT_TYPE_VALIDATION_CACHE_EXT_EXT = 33,
    // Provided by VK_VERSION_1_1 with VK_EXT_debug_report,
    VK_KHR_sampler_ycbcr_conversion with VK_EXT_debug_report
    VK_DEBUG_REPORT_OBJECT_TYPE_SAMPLER_YCBCR_CONVERSION_EXT = 1000156000,
    // Provided by VK_VERSION_1_1 with VK_EXT_debug_report
    VK_DEBUG_REPORT_OBJECT_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_EXT = 1000085000,
    // Provided by VK_EXT_debug_report with VK_NVX_binary_import
    VK_DEBUG_REPORT_OBJECT_TYPE_CU_MODULE_NVX_EXT = 1000029000,
    // Provided by VK_EXT_debug_report with VK_NVX_binary_import
    VK_DEBUG_REPORT_OBJECT_TYPE_CU_MODULE_NVX_EXT = 1000029000,
} VkDebugReportObjectTypeEXT;
```
Table 87. VkDebugReportObjectTypeEXT and Vulkan Handle Relationship

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<th>Vulkan Handle Type</th>
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<tbody>
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<td>Unknown/Undefined Handle</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_INSTANCE_EXT</td>
<td>VkInstance</td>
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<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_PHYSICAL_DEVICE_EXT</td>
<td>VkPhysicalDevice</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_DEVICE_EXT</td>
<td>VkDevice</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_QUEUE_EXT</td>
<td>VkQueue</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_SEMAPHORE_EXT</td>
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</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_COMMAND_BUFFER_EXT</td>
<td>VkCommandBuffer</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_FENCE_EXT</td>
<td>VkFence</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_DEVICE_MEMORY_EXT</td>
<td>VkDeviceMemory</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_BUFFER_EXT</td>
<td>VkBuffer</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_IMAGE_EXT</td>
<td>VkImage</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_EVENT_EXT</td>
<td>VkEvent</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_QUERY_POOL_EXT</td>
<td>VkQueryPool</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_BUFFER_VIEW_EXT</td>
<td>VkBufferView</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_IMAGE_VIEW_EXT</td>
<td>VkImageView</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_SHADER_MODULE_EXT</td>
<td>VkShaderModule</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_PIPELINE_CACHE_EXT</td>
<td>VkPipelineCache</td>
</tr>
</tbody>
</table>

VK_DEBUG_REPORT_OBJECT_TYPE_CU_FUNCTION_NVX_EXT = 1000029001,
// Provided by VK_KHR_acceleration_structure with VK_EXT_debug_report
VK_DEBUG_REPORT_OBJECT_TYPE_ACCELERATION_STRUCTURE_KHR_EXT = 1000150000,
// Provided by VK_EXT_debug_report with VK_NV_ray_tracing
VK_DEBUG_REPORT_OBJECT_TYPE_ACCELERATION_STRUCTURE_NV_EXT = 1000165000,
// Provided by VK_EXT_debug_report with VK_FUCHSIA_buffer_collection
VK_DEBUG_REPORT_OBJECT_TYPE_BUFFER_COLLECTION_FUCHSIA_EXT = 1000366000,
VK_DEBUG_REPORT_OBJECT_TYPE_DEBUG_REPORT_CALLBACK_EXT =
VK_DEBUG_REPORT_OBJECT_TYPE_VALIDATION_CACHE_EXT =
VK_DEBUG_REPORT_OBJECT_TYPE_DEBUG_REPORT_CALLBACK_EXT_EXT =
VK_DEBUG_REPORT_OBJECT_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_KHR_EXT =
// Provided by VK_KHR_descriptor_update_template with VK_EXT_debug_report
VK_DEBUG_REPORT_OBJECT_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_KHR_EXT =
// Provided by VK_KHR_sampler_ycbcr_conversion with VK_EXT_debug_report
VK_DEBUG_REPORT_OBJECT_TYPE_SAMPLER_YCBCR_CONVERSION_KHR_EXT =
VK_DEBUG_REPORT_OBJECT_TYPE_SAMPLER_YCBCR_CONVERSION_EXT =
} VkDebugReportObjectTypeEXT;
<table>
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<tr>
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<td>VkPipelineLayout</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_RENDER.Pass_EXT</td>
<td>VkRenderPass</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_PIPELINE_EXT</td>
<td>VkPipeline</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_DESCRIPTOR_SET_LAYOUT_EXT</td>
<td>VkDescriptorSetLayout</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_SAMPLER_EXT</td>
<td>VkSampler</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_DESCRIPTOR_POOL_EXT</td>
<td>VkDescriptorPool</td>
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<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_DESCRIPTOR_SET_EXT</td>
<td>VkDescriptorSet</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_FRAMEBUFFER_EXT</td>
<td>VkFramebuffer</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_COMMAND_POOL_EXT</td>
<td>VkCommandPool</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_SURFACE_KHR_EXT</td>
<td>VkSurfaceKHR</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_SWAPCHAIN_KHR_EXT</td>
<td>VkSwapchainKHR</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_DEBUG_REPORT_CALLBACK_EXT</td>
<td>VkDebugReportCallbackEXT</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_DISPLAY_KHR_EXT</td>
<td>VkDisplayKHR</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_DISPLAY_MODE_KHR_EXT</td>
<td>VkDisplayModeKHR</td>
</tr>
<tr>
<td>VK_DEBUG_REPORT_OBJECT_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_EXT</td>
<td>VkDescriptorUpdateTemplate</td>
</tr>
</tbody>
</table>

**Note**

The primary expected use of `VK_ERROR_VALIDATION_FAILED_EXT` is for validation layer testing. It is not expected that an application would see this error code during normal use of the validation layers.

To inject its own messages into the debug stream, call:

```c
// Provided by VK_EXT_debug_report

void vkDebugReportMessageEXT(
    VkInstance instance,
    VkDebugReportFlagsEXT flags,
    VkDebugReportObjectTypeEXT objectType,
    uint64_t object,
    size_t location,
    int32_t messageCode,
    const char* pLayerPrefix,
    const char* pMessage);
```

- `instance` is the debug stream’s `VkInstance`. 
• **flags** specifies the *VkDebugReportFlagBitsEXT* classification of this event/message.
• **objectType** is a *VkDebugReportObjectTypeEXT* specifying the type of object being used or created at the time the event was triggered.
• **object** is the object where the issue was detected. **object can be** *VK_NULL_HANDLE* if there is no object associated with the event.
• **location** is an application defined value.
• **messageCode** is an application defined value.
• **pLayerPrefix** is the abbreviation of the component making this event/message.
• **pMessage** is a null-terminated string detailing the trigger conditions.

The call will propagate through the layers and generate callback(s) as indicated by the message’s flags. The parameters are passed on to the callback in addition to the **pUserData** value that was defined at the time the callback was registered.

### Valid Usage

• VUID-vkDebugReportMessageEXT-object-01241  
  **object** **must** be a Vulkan object or *VK_NULL_HANDLE*

• VUID-vkDebugReportMessageEXT-objectType-01498  
  If **objectType** is not *VK_DEBUG_REPORT_OBJECT_TYPE_UNKNOWN_EXT* and **object** is not *VK_NULL_HANDLE*, **object** **must** be a Vulkan object of the corresponding type associated with **objectType** as defined in *VkDebugReportObjectTypeEXT* and Vulkan Handle Relationship

### Valid Usage (Implicit)

• VUID-vkDebugReportMessageEXT-instance-parameter  
  **instance** **must** be a valid *VkInstance* handle

• VUID-vkDebugReportMessageEXT-flags-parameter  
  **flags** **must** be a valid combination of *VkDebugReportFlagBitsEXT* values

• VUID-vkDebugReportMessageEXT-flags-required bitmask  
  **flags** **must** not be 0

• VUID-vkDebugReportMessageEXT-objectType-parameter  
  **objectType** **must** be a valid *VkDebugReportObjectTypeEXT* value

• VUID-vkDebugReportMessageEXT-pLayerPrefix-parameter  
  **pLayerPrefix** **must** be a null-terminated UTF-8 string

• VUID-vkDebugReportMessageEXT-pMessage-parameter  
  **pMessage** **must** be a null-terminated UTF-8 string

To destroy a *VkDebugReportCallbackEXT* object, call:

```c
// Provided by VK_EXT_debug_report
```
void vkDestroyDebugReportCallbackEXT(
    VkInstance instance,  
    VkDebugReportCallbackEXT callback,  
    const VkAllocationCallbacks* pAllocator);

• instance is the instance where the callback was created.

• callback is the VkDebugReportCallbackEXT object to destroy. callback is an externally synchronized object and must not be used on more than one thread at a time. This means that vkDestroyDebugReportCallbackEXT must not be called when a callback is active.

• pAllocator controls host memory allocation as described in the Memory Allocation chapter.

Valid Usage

• VUID-vkDestroyDebugReportCallbackEXT-instance-01242
  If VkAllocationCallbacks were provided when callback was created, a compatible set of callbacks must be provided here.

• VUID-vkDestroyDebugReportCallbackEXT-instance-01243
  If no VkAllocationCallbacks were provided when callback was created, pAllocator must be NULL.

Valid Usage (Implicit)

• VUID-vkDestroyDebugReportCallbackEXT-instance-parameter
  instance must be a valid VkInstance handle.

• VUID-vkDestroyDebugReportCallbackEXT-callback-parameter
  If callback is not VK_NULL_HANDLE, callback must be a valid VkDebugReportCallbackEXT handle.

• VUID-vkDestroyDebugReportCallbackEXT-pAllocator-parameter
  If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure.

• VUID-vkDestroyDebugReportCallbackEXT-callback-parent
  If callback is a valid handle, it must have been created, allocated, or retrieved from instance.

Host Synchronization

• Host access to callback must be externally synchronized.

50.4. Device Loss Debugging
50.4.1. Device Diagnostic Checkpoints

Device execution progress can be tracked for the purposes of debugging a device loss by annotating the command stream with application-defined diagnostic checkpoints.

Device diagnostic checkpoints are inserted into the command stream by calling `vkCmdSetCheckpointNV`.

```c
// Provided by VK_NV_device_diagnostic_checkpoints
void vkCmdSetCheckpointNV(
    VkCommandBuffer commandBuffer,
    const void* pCheckpointMarker);
```

- `commandBuffer` is the command buffer that will receive the marker
- `pCheckpointMarker` is an opaque application-provided value that will be associated with the checkpoint.

**Valid Usage (Implicit)**

- VUID-vkCmdSetCheckpointNV-commandBuffer-parameter `commandBuffer` must be a valid `VkCommandBuffer` handle
- VUID-vkCmdSetCheckpointNV-commandBuffer-recording `commandBuffer` must be in the recording state
- VUID-vkCmdSetCheckpointNV-commandBuffer-cmdpool The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, compute, or transfer operations
- VUID-vkCmdSetCheckpointNV-videocoding This command must only be called outside of a video coding scope

**Host Synchronization**

- Host access to `commandBuffer` must be externally synchronized
- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

**Command Properties**

<table>
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</table>
Note that \text{pCheckpointMarker} is treated as an opaque value. It does not need to be a valid pointer and will not be dereferenced by the implementation.

If the device encounters an error during execution, the implementation will return a \text{VK_ERROR_DEVICE_LOST} error to the application at some point during host execution. When this happens, the application \textbf{can} call \texttt{vkGetQueueCheckpointData2NV} to retrieve information on the most recent diagnostic checkpoints that were executed by the device.

```c
// Provided by VK_KHR_synchronization2 with VK_NV_device_diagnostic_checkpoints
void vkGetQueueCheckpointData2NV(
    VkQueue queue,
    uint32_t* pCheckpointDataCount,
    VkCheckpointData2NV* pCheckpointData);
```

- \texttt{queue} is the \texttt{VkQueue} object the caller would like to retrieve checkpoint data for.
- \texttt{pCheckpointDataCount} is a pointer to an integer related to the number of checkpoint markers available or queried, as described below.
- \texttt{pCheckpointData} is either \texttt{NULL} or a pointer to an array of \texttt{VkCheckpointData2NV} structures.

If \texttt{pCheckpointData} is \texttt{NULL}, then the number of checkpoint markers available is returned in \texttt{pCheckpointDataCount}. Otherwise, \texttt{pCheckpointDataCount} \textbf{must} point to a variable set by the user to the number of elements in the \texttt{pCheckpointData} array, and on return the variable is overwritten with the number of structures actually written to \texttt{pCheckpointData}.

If \texttt{pCheckpointDataCount} is less than the number of checkpoint markers available, at most \texttt{pCheckpointDataCount} structures will be written.

### Valid Usage

- \textbf{VUID-vkGetQueueCheckpointData2NV-queue-03892} The device that \texttt{queue} belongs to \textbf{must} be in the lost state

### Valid Usage (Implicit)

- \textbf{VUID-vkGetQueueCheckpointData2NV-queue-parameter} \texttt{queue} \textbf{must} be a valid \texttt{VkQueue} handle
- \textbf{VUID-vkGetQueueCheckpointData2NV-pCheckpointDataCount-parameter} \texttt{pCheckpointDataCount} \textbf{must} be a valid pointer to a \texttt{uint32_t} value
- \textbf{VUID-vkGetQueueCheckpointData2NV-pCheckpointData-parameter} If the value referenced by \texttt{pCheckpointDataCount} is not 0, and \texttt{pCheckpointData} is not \texttt{NULL}, \texttt{pCheckpointData} \textbf{must} be a valid pointer to an array of \texttt{pCheckpointDataCount} \texttt{VkCheckpointData2NV} structures

The \texttt{VkCheckpointData2NV} structure is defined as:
typedef struct VkCheckpointData2NV {
  VkStructureType sType;
  void* pNext;
  VkPipelineStageFlags2 stage;
  void* pCheckpointMarker;
} VkCheckpointData2NV;

• `sType` is a `VkStructureType` value identifying this structure.
• `pNext` is `NULL` or a pointer to a structure extending this structure.
• `stage` indicates a single pipeline stage which the checkpoint marker data refers to.
• `pCheckpointMarker` contains the value of the last checkpoint marker executed in the stage that `stage` refers to.

**Valid Usage (Implicit)**

• VUID-VkCheckpointData2NV-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_CHECKPOINT_DATA_2_NV`
• VUID-VkCheckpointData2NV-pNext-pNext
  `pNext` must be `NULL`

The stages at which a checkpoint marker can be executed are implementation-defined and can be queried by calling `vkGetPhysicalDeviceQueueFamilyProperties2`.

If the device encounters an error during execution, the implementation will return a `VK_ERROR_DEVICE_LOST` error to the application at a certain point during host execution. When this happens, the application can call `vkGetQueueCheckpointDataNV` to retrieve information on the most recent diagnostic checkpoints that were executed by the device.

```c
void vkGetQueueCheckpointDataNV(
  VkQueue queue,
  uint32_t* pCheckpointDataCount,
  VkCheckpointDataNV* pCheckpointData);
```

• `queue` is the `VkQueue` object the caller would like to retrieve checkpoint data for.
• `pCheckpointDataCount` is a pointer to an integer related to the number of checkpoint markers available or queried, as described below.
• `pCheckpointData` is either `NULL` or a pointer to an array of `VkCheckpointDataNV` structures.

If `pCheckpointData` is `NULL`, then the number of checkpoint markers available is returned in `pCheckpointDataCount`.

Otherwise, `pCheckpointDataCount` must point to a variable set by the user to the number of elements
in the `pCheckpointData` array, and on return the variable is overwritten with the number of structures actually written to `pCheckpointData`.

If `pCheckpointDataCount` is less than the number of checkpoint markers available, at most `pCheckpointDataCount` structures will be written.

### Valid Usage

- VUID-vkGetQueueCheckpointDataNV-queue-02025
  The device that `queue` belongs to must be in the lost state

### Valid Usage (Implicit)

- VUID-vkGetQueueCheckpointDataNV-queue-parameter
  `queue` must be a valid `VkQueue` handle

- VUID-vkGetQueueCheckpointDataNV-pCheckpointDataCount-parameter
  `pCheckpointDataCount` must be a valid pointer to a `uint32_t` value

- VUID-vkGetQueueCheckpointDataNV-pCheckpointData-parameter
  If the value referenced by `pCheckpointDataCount` is not 0, and `pCheckpointData` is not NULL, `pCheckpointData` must be a valid pointer to an array of `pCheckpointDataCount` `VkCheckpointDataNV` structures

The `VkCheckpointDataNV` structure is defined as:

```c
// Provided by VK_NV_device_diagnostic_checkpoints
typedef struct VkCheckpointDataNV {
    VkStructureType sType;
    void* pNext;
    VkPipelineStageFlagBits stage;
    void* pCheckpointMarker;
} VkCheckpointDataNV;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `stage` is a `VkPipelineStageFlagBits` value specifying which pipeline stage the checkpoint marker data refers to.
- `pCheckpointMarker` contains the value of the last checkpoint marker executed in the stage that `stage` refers to.

The stages at which a checkpoint marker can be executed are implementation-defined and can be queried by calling `vkGetPhysicalDeviceQueueFamilyProperties2`.
50.4.2. Device Fault Diagnosis

To retrieve diagnostic information about faults that may have caused device loss, call:

```c
// Provided by VK_EXT_device_fault
VkResult vkGetDeviceFaultInfoEXT(
    VkDevice device,
    VkDeviceFaultCountsEXT* pFaultCounts,
    VkDeviceFaultInfoEXT* pFaultInfo);
```

- **device** is the logical device from which to query the diagnostic fault information.
- **pFaultCounts** is a pointer to a `VkDeviceFaultCountsEXT` structure in which counts for structures describing additional fault information are returned.
- **pFaultInfo** is **NULL** or a pointer to a `VkDeviceFaultInfoEXT` structure in which fault information is returned.

If **pFaultInfo** is **NULL**, then the counts of corresponding additional fault information structures available are returned in the `addressInfoCount` and `vendorInfoCount` members of **pFaultCounts**. Additionally, the size of any vendor-specific binary crash dump is returned in the `vendorBinarySize` member of **pFaultCounts**.

If **pFaultInfo** is not **NULL**, **pFaultCounts** must point to a `VkDeviceFaultCountsEXT` structure with each structure count or size member (`addressInfoCount`, `vendorInfoCount`, `vendorBinarySize`) set by the user to the number of elements in the corresponding output array member of **pFaultInfo** (`pAddressInfos` and `pVendorInfos`), or to the size of the output buffer in bytes (`pVendorBinaryData`). On return, each structure count member is overwritten with the number of structures actually written to the corresponding output array member of **pFaultInfo**. Similarly, `vendorBinarySize` is overwritten with the number of bytes actually written to the `pVendorBinaryData` member of **pFaultInfo**.

If the **vendor-specific crash dumps** feature is not enabled, then implementations must set `pFaultCounts->vendorBinarySize` to zero and must not modify `pFaultInfo->pVendorBinaryData`.

If any **pFaultCounts** structure count member is less than the number of corresponding fault properties available, at most structure count (`addressInfoCount`, `vendorInfoCount`) elements will be written to the associated **pFaultInfo** output array. Similarly, if `vendorBinarySize` is less than the size in bytes of the available crash dump data, at most `vendorBinarySize` elements will be written to `pVendorBinaryData`.

If **pFaultInfo** is **NULL**, then subsequent calls to `vkGetDeviceFaultInfoEXT` for the same **device** must
return identical values in the `addressInfoCount`, `vendorInfoCount` and `vendorBinarySize` members of `pFaultCounts`.

If `pFaultInfo` is not `NULL`, then subsequent calls to `vkGetDeviceFaultInfoEXT` for the same `device` must return identical values in the output members of `pFaultInfo` (`pAddressInfos`, `pVendorInfos`, `pVendorBinaryData`), up to the limits described by the structure count and buffer size members of `pFaultCounts` (`addressInfoCount`, `vendorInfoCount`, `vendorBinarySize`). If the sizes of the output members of `pFaultInfo` increase for a subsequent call to `vkGetDeviceFaultInfoEXT`, then supplementary information may be returned in the additional available space.

If any `pFaultCounts` structure count member is smaller than the number of corresponding fault properties available, or if `pFaultCounts->vendorBinarySize` is smaller than the size in bytes of the generated binary crash dump data, `VK_INCOMPLETE` will be returned instead of `VK_SUCCESS`, to indicate that not all the available properties were returned.

If `pFaultCounts->vendorBinarySize` is less than what is necessary to store the binary crash dump header, nothing will be written to `pFaultInfo->pVendorBinaryData` and zero will be written to `pFaultCounts->vendorBinarySize`.

---

### Valid Usage

- **VUID-vkGetDeviceFaultInfoEXT-device-07336**
  
  `device` must be in the lost state

- **VUID-vkGetDeviceFaultInfoEXT-pFaultCounts-07337**
  
  If the value referenced by `pFaultCounts->addressInfoCount` is not 0, and `pFaultInfo->pAddressInfos` is not `NULL`, `pFaultInfo->pAddressInfos` must be a valid pointer to an array of `pFaultCounts->addressInfoCount` `VkDeviceFaultAddressInfoEXT` structures

- **VUID-vkGetDeviceFaultInfoEXT-pFaultCounts-07338**
  
  If the value referenced by `pFaultCounts->vendorInfoCount` is not 0, and `pFaultInfo->pVendorInfos` is not `NULL`, `pFaultInfo->pVendorInfos` must be a valid pointer to an array of `pFaultCounts->vendorInfoCount` `VkDeviceFaultVendorInfoEXT` structures

- **VUID-vkGetDeviceFaultInfoEXT-pFaultCounts-07339**
  
  If the value referenced by `pFaultCounts->vendorBinarySize` is not 0, and `pFaultInfo->pVendorBinaryData` is not `NULL`, `pFaultInfo->pVendorBinaryData` must be a valid pointer to an array of `pFaultCounts->vendorBinarySize` bytes

---

### Valid Usage (Implicit)

- **VUID-vkGetDeviceFaultInfoEXT-device-parameter**
  
  `device` must be a valid `VkDevice` handle

- **VUID-vkGetDeviceFaultInfoEXT-pFaultCounts-parameter**
  
  `pFaultCounts` must be a valid pointer to a `VkDeviceFaultCountsEXT` structure

- **VUID-vkGetDeviceFaultInfoEXT-pFaultInfo-parameter**
  
  If `pFaultInfo` is not `NULL`, `pFaultInfo` must be a valid pointer to a `VkDeviceFaultInfoEXT` structure
Return Codes

**Success**
- VK_SUCCESS
- VK_INCOMPLETE

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY

The `VkDeviceFaultCountsEXT` structure is defined as:

```c
// Provided by VK_EXT_device_fault
typedef struct VkDeviceFaultCountsEXT {
    VkStructureType sType;
    void* pNext;
    uint32_t addressInfoCount;
    uint32_t vendorInfoCount;
    VkDeviceSize vendorBinarySize;
} VkDeviceFaultCountsEXT;
```

- `sType` is a `VkStructureType` value identifying this structure.
- `pNext` is `NULL` or a pointer to a structure extending this structure.
- `addressInfoCount` is the number of `VkDeviceFaultAddressInfoEXT` structures describing either memory accesses which may have caused a page fault, or the addresses of active instructions at the time of the fault.
- `vendorInfoCount` is the number of `VkDeviceFaultVendorInfoEXT` structures describing vendor-specific fault information.
- `vendorBinarySize` is the size in bytes of a vendor-specific binary crash dump, which may provide additional information when imported into external tools.

**Valid Usage (Implicit)**

- VUID-VkDeviceFaultCountsEXT-sType-sType
  *sType* must be `VK_STRUCTURE_TYPE_DEVICE_FAULT_COUNTS_EXT`
- VUID-VkDeviceFaultCountsEXT-pNext-pNext
  *pNext* must be `NULL`

The `VkDeviceFaultInfoEXT` structure is defined as:

```c
// Provided by VK_EXT_device_fault
typedef struct VkDeviceFaultInfoEXT {
    VkStructureType sType;
    void* pNext;
} VkDeviceFaultInfoEXT;
```
char VkDeviceFaultAddressInfoEXT*
pAddressInfos;
VkDeviceFaultVendorInfoEXT*
pVendorInfos;
void* pVendorBinaryData;
}

VkDeviceFaultInfoEXT;

• **sType** is a VkStructureType value identifying this structure.

• **pNext** is **NULL** or a pointer to a structure extending this structure.

• **description** is an array of VK_MAX_DESCRIPTION_SIZE char containing a null-terminated UTF-8 string which is a human readable description of the fault.

• **pAddressInfos** is **NULL** or a pointer to an array of VkDeviceFaultAddressInfoEXT structures describing either memory accesses which **may** have caused a page fault, or describing active instruction pointers at the time of the fault. If not **NULL**, each element of **pAddressInfos** describes the a bounded region of GPU virtual address space containing either the GPU virtual address accessed, or the value of an active instruction pointer.

• **pVendorInfos** is **NULL** or a pointer to an array of VkDeviceFaultVendorInfoEXT structures describing vendor-specific fault information.

• **pVendorBinaryData** is **NULL** or a pointer to vendorBinarySize number of bytes of data, which will be populated with a vendor-specific binary crash dump, as described in Vendor Binary Crash Dumps.

An implementation **should** populate as many members of VkDeviceFaultInfoEXT as possible, given the information available at the time of the fault and the constraints of the implementation itself.

Due to hardware limitations, **pAddressInfos** describes ranges of GPU virtual address space, rather than precise addresses. The precise memory address accessed or the precise value of the instruction pointer **must** lie within the region described.

**Note**

Each element of **pAddressInfos** describes either:

• A memory access which may have triggered a page fault and may have contributed to device loss

• The value of an active instruction pointer at the time a fault occurred. This value may be indicative of the active pipeline or shader at the time of device loss

Comparison of the GPU virtual addresses described by **pAddressInfos** to GPU virtual address ranges reported by the VK_EXT_device_address_binding_report extension may allow applications to correlate between these addresses and Vulkan objects. Applications should be aware that these addresses may also correspond to resources internal to an implementation, which will not be reported via the VK_EXT_device_address_binding_report extension.
Valid Usage (Implicit)

- VUID-VkDeviceFaultInfoEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_DEVICE_FAULT_INFO_EXT

- VUID-VkDeviceFaultInfoEXT-pNext-pNext
  pNext must be NULL

- VUID-VkDeviceFaultInfoEXT-pAddressInfos-parameter
  If pAddressInfos is not NULL, pAddressInfos must be a valid pointer to a VkDeviceFaultAddressInfoEXT structure

- VUID-VkDeviceFaultInfoEXT-pVendorInfos-parameter
  If pVendorInfos is not NULL, pVendorInfos must be a valid pointer to a VkDeviceFaultVendorInfoEXT structure

The VkDeviceFaultAddressInfoEXT structure is defined as:

```c
// Provided by VK_EXT_device_fault
typedef struct VkDeviceFaultAddressInfoEXT {
    VkDeviceFaultAddressTypeEXT addressType;
    VkDeviceAddress reportedAddress;
    VkDeviceSize addressPrecision;
} VkDeviceFaultAddressInfoEXT;
```

- addressType is either the type of memory operation that triggered a page fault, or the type of association between an instruction pointer and a fault.
- reportedAddress is the GPU virtual address recorded by the device.
- addressPrecision is a power of two value that specifies how precisely the device can report the address.

The combination of reportedAddress and addressPrecision allow the possible range of addresses to be calculated, such that:

```c
lower_address = (pInfo->reportedAddress & ~(pInfo->addressPrecision-1))
upper_address = (pInfo->reportedAddress | (pInfo->addressPrecision-1))
```

Note

It is valid for the reportedAddress to contain a more precise address than indicated by addressPrecision. In this case, the value of reportedAddress should be treated as an additional hint as to the value of the address that triggered the page fault, or to the value of an instruction pointer.
addressType must be a valid VkDeviceFaultAddressTypeEXT value

Possible values of VkDeviceFaultAddressInfoEXT::addressType are:

// Provided by VK_EXT_device_fault
typedef enum VkDeviceFaultAddressTypeEXT {
    VK_DEVICE_FAULT_ADDRESS_TYPE_NONE_EXT = 0,
    VK_DEVICE_FAULT_ADDRESS_TYPE_READ_INVALID_EXT = 1,
    VKDEVICEFAULTADDRESSTYPE_WRITE_INVALID_EXT = 2,
    VK_DEVICE_FAULT_ADDRESS_TYPE_EXECUTE_INVALID_EXT = 3,
    VKDEVICEFAULTADDRESSTYPE_INSTRUCTION_POINTER_UNKNOWN_EXT = 4,
    VKDEVICEFAULTADDRESSTYPE_INSTRUCTION_POINTER_INVALID_EXT = 5,
    VK_DEVICE_FAULT_ADDRESS_TYPE_INSTRUCTION_POINTER_FAULT_EXT = 6,
} VkDeviceFaultAddressTypeEXT;

• VK_DEVICE_FAULT_ADDRESS_TYPE_NONE_EXT specifies that VkDeviceFaultAddressInfoEXT does not describe a page fault, or an instruction address.
• VK_DEVICE_FAULT_ADDRESS_TYPE_READ_INVALID_EXT specifies that VkDeviceFaultAddressInfoEXT describes a page fault triggered by an invalid read operation.
• VK_DEVICE_FAULT_ADDRESS_TYPE_WRITE_INVALID_EXT specifies that VkDeviceFaultAddressInfoEXT describes a page fault triggered by an invalid write operation.
• VK_DEVICE_FAULT_ADDRESS_TYPE_EXECUTE_INVALID_EXT describes a page fault triggered by an attempt to execute non-executable memory.
• VKDEVICEFAULTADDRESSTYPE_INSTRUCTION_POINTER_UNKNOWN_EXT specifies an instruction pointer value at the time the fault occurred. This may or may not be related to a fault.
• VKDEVICEFAULTADDRESSTYPE_INSTRUCTION_POINTER_INVALID_EXT specifies an instruction pointer value associated with an invalid instruction fault.
• VKDEVICEFAULTADDRESSTYPE_INSTRUCTION_POINTER_FAULT_EXT specifies an instruction pointer value associated with a fault.

Note
The instruction pointer values recorded may not identify the specific instruction(s) that triggered the fault. The relationship between the instruction pointer reported and triggering instruction will be vendor-specific.

The VkDeviceFaultVendorInfoEXT structure is defined as:

// Provided by VK_EXT_device_fault
typedef struct VkDeviceFaultVendorInfoEXT {
    char description[VK_MAX_DESCRIPTION_SIZE];
    uint64_t vendorFaultCode;
    uint64_t vendorFaultData;
} VkDeviceFaultVendorInfoEXT;
• **description** is an array of `VK_MAX_DESCRIPTION_SIZE` char containing a null-terminated UTF-8 string which is a human readable description of the fault.

• **vendorFaultCode** is the vendor-specific fault code for this fault.

• **vendorFaultData** is the vendor-specific fault data associated with this fault.

**Vendor Binary Crash Dumps**

Applications can store the vendor-specific binary crash dump data retrieved by calling `vkGetDeviceFaultInfoEXT` for later analysis using external tools.

However, the format of this data may depend on the vendor ID, device ID, driver version, and other details of the device. To enable external applications to identify the original device from which a crash dump was generated, the initial bytes written to `VkDeviceFaultInfoEXT::pVendorBinaryData` must begin with a valid crash dump header.

Version one of the crash dump header is defined as:

```c
// Provided by VK_EXT_device_fault
typedef struct VkDeviceFaultVendorBinaryHeaderVersionOneEXT {
    uint32_t headerSize;
    VkDeviceFaultVendorBinaryHeaderVersionEXT headerVersion;
    uint32_t vendorID;
    uint32_t deviceID;
    uint32_t driverVersion;
    uint8_t pipelineCacheUUID[VK_UUID_SIZE];
    uint32_t applicationNameOffset;
    uint32_t applicationVersion;
    uint32_t engineNameOffset;
    uint32_t engineVersion;
    uint32_t apiVersion;
} VkDeviceFaultVendorBinaryHeaderVersionOneEXT;
```

• **headerSize** is the length in bytes of the crash dump header.

• **headerVersion** is a `VkDeviceFaultVendorBinaryHeaderVersionEXT` enum value specifying the version of the header. A consumer of the crash dump should use the header version to interpret the remainder of the header.

• **vendorID** is the `VkPhysicalDeviceProperties::vendorID` of the implementation.

• **deviceID** is the `VkPhysicalDeviceProperties::deviceID` of the implementation.

• **driverVersion** is the `VkPhysicalDeviceProperties::driverVersion` of the implementation.

• **pipelineCacheUUID** is an array of `VK_UUID_SIZE` uint8_t values matching the `VkPhysicalDeviceProperties::pipelineCacheUUID` property of the implementation.

• **applicationNameOffset** is zero, or an offset from the base address of the crash dump header to a null-terminated UTF-8 string containing the name of the application. If **applicationNameOffset** is non-zero, this string must match the application name specified via `VkApplicationInfo::pApplicationName` during instance creation.
• **applicationVersion** must be zero or the value specified by `VkApplicationInfo::applicationVersion` during instance creation.

• **engineNameOffset** is zero, or an offset from the base address of the crash dump header to a null-terminated UTF-8 string containing the name of the engine (if any) used to create the application. If **engineNameOffset** is non-zero, this string must match the engine name specified via `VkApplicationInfo::pEngineName` during instance creation.

• **engineVersion** must be zero or the value specified by `VkApplicationInfo::engineVersion` during instance creation.

• **apiVersion** must be zero or the value specified by `VkApplicationInfo::apiVersion` during instance creation.

Unlike most structures declared by the Vulkan API, all fields of this structure are written with the least significant byte first, regardless of host byte-order.

The C language specification does not define the packing of structure members. This layout assumes tight structure member packing, with members laid out in the order listed in the structure, and the intended size of the structure is 56 bytes. If a compiler produces code that diverges from that pattern, applications must employ another method to set values at the correct offsets.

### Valid Usage

- **VUID-VkDeviceFaultVendorBinaryHeaderVersionOneEXT-headerSize-07340**
  - `headerSize` must be 56

- **VUID-VkDeviceFaultVendorBinaryHeaderVersionOneEXT-headerVersion-07341**
  - `headerVersion` must be `VK_DEVICE_FAULT_VENDOR_BINARY_HEADER_VERSION_ONE_EXT`

### Valid Usage (Implicit)

- **VUID-VkDeviceFaultVendorBinaryHeaderVersionOneEXT-headerVersion-parameter**
  - `headerVersion` must be a valid `VkDeviceFaultVendorBinaryHeaderVersionEXT` value

Possible values of the **headerVersion** value of the crash dump header are:

```c
// Provided by VK_EXT_device_fault
typedef enum VkDeviceFaultVendorBinaryHeaderVersionEXT {
  VK_DEVICE_FAULT_VENDOR_BINARY_HEADER_VERSION_ONE_EXT = 1,
} VkDeviceFaultVendorBinaryHeaderVersionEXT;

• **VK_DEVICE_FAULT_VENDOR_BINARY_HEADER_VERSION_ONE_EXT** specifies version one of the binary crash dump header.
50.5. Active Tooling Information

Information about tools providing debugging, profiling, or similar services, active for a given physical device, can be obtained by calling:

```c
// Provided by VK_VERSION_1_3
VkResult vkGetPhysicalDeviceToolProperties(
    VkPhysicalDevice physicalDevice,
    uint32_t* pToolCount,
    VkPhysicalDeviceToolProperties* pToolProperties);
```

or the equivalent command

```c
// Provided by VK_EXT_tooling_info
VkResult vkGetPhysicalDeviceToolPropertiesEXT(
    VkPhysicalDevice physicalDevice,
    uint32_t* pToolCount,
    VkPhysicalDeviceToolProperties* pToolProperties);
```

- `physicalDevice` is the handle to the physical device to query for active tools.
- `pToolCount` is a pointer to an integer describing the number of tools active on `physicalDevice`.
- `pToolProperties` is either `NULL` or a pointer to an array of `VkPhysicalDeviceToolProperties` structures.

If `pToolProperties` is `NULL`, then the number of tools currently active on `physicalDevice` is returned in `pToolCount`. Otherwise, `pToolCount` must point to a variable set by the user to the number of elements in the `pToolProperties` array, and on return the variable is overwritten with the number of structures actually written to `pToolProperties`. If `pToolCount` is less than the number of currently active tools, at most `pToolCount` structures will be written.

The count and properties of active tools may change in response to events outside the scope of the specification. An application should assume these properties might change at any given time.

**Valid Usage (Implicit)**

- VUID-vkGetPhysicalDeviceToolProperties-physicalDevice-parameter
  `physicalDevice` must be a valid `VkPhysicalDevice` handle

- VUID-vkGetPhysicalDeviceToolProperties-pToolCount-parameter
  `pToolCount` must be a valid pointer to a `uint32_t` value

- VUID-vkGetPhysicalDeviceToolProperties-pToolProperties-parameter
  If the value referenced by `pToolCount` is not 0, and `pToolProperties` is not `NULL`, `pToolProperties` must be a valid pointer to an array of `pToolCount` `VkPhysicalDeviceToolProperties` structures
Return Codes

Success

• VK_SUCCESS
• VK_INCOMPLETE

Failure

• VK_ERROR_OUT_OF_HOST_MEMORY

The VkPhysicalDeviceToolProperties structure is defined as:

```c
// Provided by VK_VERSION_1_3
typedef struct VkPhysicalDeviceToolProperties {
    VkStructureType  sType;
    void*             pNext;
    char              name[VK_MAX_EXTENSION_NAME_SIZE];
    char              version[VK_MAX_EXTENSION_NAME_SIZE];
    VkToolPurposeFlags purposes;
    char              description[VK_MAX_DESCRIPTION_SIZE];
    char              layer[VK_MAX_EXTENSION_NAME_SIZE];
} VkPhysicalDeviceToolProperties;
```

or the equivalent

```c
// Provided by VK_EXT_tooling_info
typedef VkPhysicalDeviceToolProperties VkPhysicalDeviceToolPropertiesEXT;
```

- `sType` is a VkStructureType value identifying this structure.
- `pNext` is NULL or a pointer to a structure extending this structure.
- `name` is a null-terminated UTF-8 string containing the name of the tool.
- `version` is a null-terminated UTF-8 string containing the version of the tool.
- `purposes` is a bitmask of VkToolPurposeFlagBits which is populated with purposes supported by the tool.
- `description` is a null-terminated UTF-8 string containing a description of the tool.
- `layer` is a null-terminated UTF-8 string containing the name of the layer implementing the tool, if the tool is implemented in a layer - otherwise it may be an empty string.

Valid Usage (Implicit)

- `VUID-VkPhysicalDeviceToolProperties-sType-sType` 
  `sType` must be `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TOOL_PROPERTIES`
- `VUID-VkPhysicalDeviceToolProperties-pNext-pNext`
Bits which can be set in `VkPhysicalDeviceToolProperties::purposes`, specifying the purposes of an active tool, are:

```c
// Provided by VK_VERSION_1_3
typedef enum VkToolPurposeFlagBits {
    VK_TOOL_PURPOSE_VALIDATION_BIT = 0x00000001,
    VK_TOOL_PURPOSE_PROFILING_BIT = 0x00000002,
    VK_TOOL_PURPOSE_TRACING_BIT = 0x00000004,
    VK_TOOL_PURPOSE_ADDITIONAL_FEATURES_BIT = 0x00000008,
    VK_TOOL_PURPOSE_MODIFYING_FEATURES_BIT = 0x00000010,
    VK_TOOL_PURPOSE_DEBUG_REPORTING_BIT_EXT = 0x00000020,
    VK_TOOL_PURPOSE_DEBUG_MARKERS_BIT_EXT = 0x00000040,
    VK_TOOL_PURPOSE_VALIDATION_BIT_EXT = VK_TOOL_PURPOSE_VALIDATION_BIT,
    VK_TOOL_PURPOSE_PROFILING_BIT_EXT = VK_TOOL_PURPOSE_PROFILING_BIT,
    VK_TOOL_PURPOSE_TRACING_BIT_EXT = VK_TOOL_PURPOSE_TRACING_BIT,
    VK_TOOL_PURPOSE_ADDITIONAL_FEATURES_BIT_EXT = VK_TOOL_PURPOSE_ADDITIONAL_FEATURES_BIT,
    VK_TOOL_PURPOSE_MODIFYING_FEATURES_BIT_EXT = VK_TOOL_PURPOSE_MODIFYING_FEATURES_BIT
} VkToolPurposeFlagBits;
```

or the equivalent

```c
// Provided by VK_EXT_tooling_info
typedef VkToolPurposeFlagBits VkToolPurposeFlagBitsEXT;
```

- `VK_TOOL_PURPOSE_VALIDATION_BIT` specifies that the tool provides validation of API usage.
- `VK_TOOL_PURPOSE_PROFILING_BIT` specifies that the tool provides profiling of API usage.
- `VK_TOOL_PURPOSE_TRACING_BIT` specifies that the tool is capturing data about the application's API usage, including anything from simple logging to capturing data for later replay.
- `VK_TOOL_PURPOSE_ADDITIONAL_FEATURES_BIT` specifies that the tool provides additional API features/extensions on top of the underlying implementation.
- `VK_TOOL_PURPOSE_MODIFYING_FEATURES_BIT` specifies that the tool modifies the API features/limits/extensions presented to the application.
- `VK_TOOL_PURPOSE_DEBUG_REPORTING_BIT_EXT` specifies that the tool reports additional information to the application via callbacks specified by `vkCreateDebugReportCallbackEXT` or `vkCreateDebugUtilsMessengerEXT`.
- `VK_TOOL_PURPOSE_DEBUG_MARKERS_BIT_EXT` specifies that the tool consumes debug markers or object
debug annotation, queue labels, or command buffer labels

```c
// Provided by VK_VERSION_1_3
typedef VkFlags VkToolPurposeFlags;
```

or the equivalent

```c
// Provided by VK_EXT_tooling_info
typedef VkToolPurposeFlags VkToolPurposeFlagsEXT;
```

**VkToolPurposeFlags** is a bitmask type for setting a mask of zero or more **VkToolPurposeFlagBits**.

## 50.6. Frame Boundary

The **VkFrameBoundaryEXT** structure is defined as:

```c
// Provided by VK_EXT_frame_boundary
typedef struct VkFrameBoundaryEXT {
    VkStructureType sType;
    const void* pNext;
    VkFrameBoundaryFlagsEXT flags;
    uint64_t frameID;
    uint32_t imageCount;
    const VkImage* pImages;
    uint32_t bufferCount;
    const VkBuffer* pBuffers;
    uint64_t tagName;
    size_t tagSize;
    const void* pTag;
} VkFrameBoundaryEXT;
```

- **sType** is a **VkStructureType** value identifying this structure.
- **pNext** is NULL or a pointer to a structure extending this structure.
- **flags** is a bitmask of **VkFrameBoundaryFlagBitsEXT** that can flag the last submission of a frame identifier.
- **frameID** is the frame identifier.
- **imageCount** is the number of images that store frame results.
- **pImages** is a pointer to an array of **VkImage** objects with imageCount entries.
- **bufferCount** is the number of buffers that store the frame results.
- **pBuffers** is a pointer to an array of **VkBuffer** objects with bufferCount entries.
- **tagName** is a numerical identifier for tag data.
- **tagSize** is the number of bytes of tag data.
pTag is a pointer to an array of tagSize bytes containing tag data.

The application can associate frame boundary information to a queue submission call by adding a VkFrameBoundaryEXT structure to the pNext chain of queue submission, VkPresentInfoKHR, or VkBindSparseInfo.

The frame identifier is used to associate one or more queue submission to a frame, it is thus meant to be unique within a frame lifetime, i.e. it is possible (but not recommended) to reuse frame identifiers, as long as any two frames with any chance of having overlapping queue submissions (as in the example above) use two different frame identifiers.

Note
Since the concept of frame is application-dependent, there is no way to validate the use of frame identifier. It is good practice to use a monotonically increasing counter as the frame identifier and not reuse identifiers between frames.

The pImages and pBuffers arrays contain a list of images and buffers which store the "end result" of the frame. As the concept of frame is application-dependent, not all frames may produce their results in images or buffers, yet this is a sufficiently common case to be handled by VkFrameBoundaryEXT. Note that no extra information, such as image layout is being provided, since the images are meant to be used by tools which would already be tracking this required information. Having the possibility of passing a list of end-result images makes VkFrameBoundaryEXT as expressive as vkQueuePresentKHR, which is often the default frame boundary delimiter.

The application can also associate arbitrary extra information via tag data using tagName, tagSize and pTag. This extra information is typically tool-specific.

Valid Usage (Implicit)

- VUID-VkFrameBoundaryEXT-sType-sType
  sType must be VK_STRUCTURE_TYPE_FRAME_BOUNDARY_EXT

- VUID-VkFrameBoundaryEXT-flags-parameter
  flags must be a valid combination of VkFrameBoundaryFlagBitsEXT values

- VUID-VkFrameBoundaryEXT-pImages-parameter
  If imageCount is not 0, and pImages is not NULL, pImages must be a valid pointer to an array of imageCount valid VkImage handles

- VUID-VkFrameBoundaryEXT-pBuffers-parameter
  If bufferCount is not 0, and pBuffers is not NULL, pBuffers must be a valid pointer to an array of bufferCount valid VkBuffer handles

- VUID-VkFrameBoundaryEXT-commonparent
  Both of the elements of pBuffers, and the elements of pImages that are valid handles of non-ignored parameters must have been created, allocated, or retrieved from the same VkDevice

The bit which can be set in VkFrameBoundaryEXT::flags is:
**VK_FRAME_BOUNDARY_FRAME_END_BIT_EXT** specifies that this queue submission is the last one for this frame, i.e. once this queue submission has terminated, then the work for this frame is completed.

Note that in the presence of timeline semaphores, the last queue submission might not be the last one to be submitted, as timeline semaphores allow for wait-before-signal submissions. In the context of frame boundary, the queue submission that should be done flagged as the last one is the one that is meant to be executed last, even if it may not be the last one to be submitted.

**VkFramebufferFlagsEXT** is a bitmask type for setting a mask of zero or more VkFramebufferFlagBitsEXT.
Appendix A: Vulkan Environment for SPIR-V

Shaders for Vulkan are defined by the [Khronos SPIR-V Specification](https://www.khronos.org/registry/spirv/specs/latest/spirv.txt) as well as the [Khronos SPIR-V Extended Instructions for GLSL](https://www.khronos.org/registry/spirv-extended/specs/latest/spirv-extended.txt) Specification. This appendix defines additional SPIR-V requirements applying to Vulkan shaders.

### Versions and Formats

A Vulkan 1.3 implementation **must** support the 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, and 1.6 versions of SPIR-V and the 1.0 version of the SPIR-V Extended Instructions for GLSL.

A SPIR-V module passed into `vkCreateShaderModule` is interpreted as a series of 32-bit words in host endianness, with literal strings packed as described in section 2.2 of the SPIR-V Specification. The first few words of the SPIR-V module **must** be a magic number and a SPIR-V version number, as described in section 2.3 of the SPIR-V Specification.

### Capabilities

The table below lists the set of SPIR-V capabilities that **may** be supported in Vulkan implementations. The application **must** not use any of these capabilities in SPIR-V passed to `vkCreateShaderModule` unless one of the following conditions is met for the `VkDevice` specified in the `device` parameter of `vkCreateShaderModule`:

- The corresponding field in the table is blank.
- Any corresponding Vulkan feature is enabled.
- Any corresponding Vulkan extension is enabled.
- Any corresponding Vulkan property is supported.
- The corresponding core version is supported (as returned by `VkPhysicalDeviceProperties::apiVersion`).

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### SPIR-V OpCapability

**Vulkan feature, extension, or core version**

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#### Geometry

- VkPhysicalDeviceFeatures::geometryShader

#### Tessellation

- VkPhysicalDeviceFeatures::tessellationShader

#### Float64

- VkPhysicalDeviceFeatures::shaderFloat64

#### Int64

- VkPhysicalDeviceFeatures::shaderInt64

#### Int64Atomics

- VkPhysicalDeviceVulkan12Features::shaderBufferInt64Atomics
- VkPhysicalDeviceVulkan12Features::shaderSharedInt64Atomics
- VkPhysicalDeviceShaderImageAtomicInt64FeaturesEXT::shaderImageInt64Atomics

#### AtomicFloat16AddEXT

- VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT::shaderBufferFloat16AtomicAdd
- VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT::shaderSharedFloat16AtomicAdd

#### AtomicFloat32AddEXT

- VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT::shaderBufferFloat32AtomicAdd
- VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT::shaderSharedFloat32AtomicAdd
- VkPhysicalDeviceShaderAtomicFloatFeaturesEXT::shaderImageFloat32AtomicAdd

#### AtomicFloat64AddEXT

- VkPhysicalDeviceShaderAtomicFloatFeaturesEXT::shaderBufferFloat64AtomicAdd
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#### AtomicFloat16MinMaxEXT

- VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT::shaderBufferFloat16AtomicMinMax
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#### AtomicFloat32MinMaxEXT

- VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT::shaderBufferFloat32AtomicMinMax
- VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT::shaderSharedFloat32AtomicMinMax
- VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT::shaderImageFloat32AtomicMinMax

#### AtomicFloat32MinMaxEXT

- VkPhysicalDeviceShaderAtomicFloatFeaturesEXT::shaderBufferFloat32AtomicMinMax
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**Vulkan feature, extension, or core version**

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### SPIR-V OpCapability

**Vulkan feature, extension, or core version**

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<td>WorkgroupMemoryExplicitLayout16BitAccessKHR</td>
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<td>VkPhysicalDeviceVulkan13Features::shaderIntegerDotProduct, VkPhysicalDeviceShaderIntegerDotProductFeaturesKHR::shaderIntegerDotProduct</td>
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The application **must** not pass a SPIR-V module containing any of the following to `vkCreateShaderModule`:

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<td>RayTracingOpacityMicromapEXT</td>
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<tr>
<td>CoreBuiltinsARM</td>
<td>VkPhysicalDeviceShaderCoreBuiltinsFeaturesARM::shaderCoreBuiltins</td>
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<td>ClusterCullingShadingHUAWEI</td>
<td>VkPhysicalDeviceClusterCullingShaderFeaturesHUAWEI::clustercullingShader</td>
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<td>VkPhysicalDeviceShaderEnqueueFeaturesAMDX::shaderEnqueue</td>
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• any OpCapability not listed above,
• an unsupported capability, or
• a capability which corresponds to a Vulkan feature or extension which has not been enabled.

**SPIR-V Extensions**

The following table lists SPIR-V extensions that implementations may support. The application must not pass a SPIR-V module to `vkCreateShaderModule` that uses the following SPIR-V extensions unless one of the following conditions is met for the `VkDevice` specified in the `device` parameter of `vkCreateShaderModule`:

• Any corresponding Vulkan extension is enabled.

• The corresponding core version is supported (as returned by `VkPhysicalDeviceProperties::apiVersion`).

Table 89. List of SPIR-V Extensions and corresponding Vulkan extensions or core version

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### Validation Rules within a Module

A SPIR-V module passed to `vkCreateShaderModule` must conform to the following rules:

#### Standalone SPIR-V Validation

The following rules can be validated with only the SPIR-V module itself. They do not depend on knowledge of the implementation and its capabilities or knowledge of runtime information, such as enabled features.

**Valid Usage**

- VUID-StandaloneSpirv-None-04633
Every entry point must have no return value and accept no arguments

- **VUID-StandaloneSpirv-None-04634**
  The static function-call graph for an entry point must not contain cycles; that is, static recursion is not allowed

- **VUID-StandaloneSpirv-None-04635**
  The Logical or PhysicalStorageBuffer64 addressing model must be selected

- **VUID-StandaloneSpirv-None-04636**
  Scope for execution must be limited to Workgroup or Subgroup

- **VUID-StandaloneSpirv-None-04637**
  If the Scope for execution is Workgroup, then it must only be used in the task, mesh, tessellation control, or compute Execution Model

- **VUID-StandaloneSpirv-None-04638**
  Scope for memory must be limited to Device, QueueFamily, Workgroup, ShaderCallKHR, Subgroup, or Invocation

- **VUID-StandaloneSpirv-ExecutionModel-07320**
  If the Execution Model is TessellationControl, and the MemoryModel is GLSL450, the Scope for memory must not be Workgroup

- **VUID-StandaloneSpirv-None-07321**
  If the Scope for memory is Workgroup, then it must only be used in the task, mesh, tessellation control, or compute Execution Model

- **VUID-StandaloneSpirv-None-04640**
  If the Scope for memory is ShaderCallKHR, then it must only be used in ray generation, intersection, closest hit, any-hit, miss, and callable Execution Model

- **VUID-StandaloneSpirv-None-04641**
  If the Scope for memory is Invocation, then memory semantics must be None

- **VUID-StandaloneSpirv-None-04642**
  Scope for group operations must be limited to Subgroup

- **VUID-StandaloneSpirv-SubgroupVoteKHR-07951**
  If none of the SubgroupVoteKHR, GroupNonUniform, or SubgroupBallotKHR capabilities are declared, Scope for memory must not be Subgroup

- **VUID-StandaloneSpirv-None-04643**
  Storage Class must be limited to UniformConstant, Input, Uniform, Output, Workgroup, Private, Function, PushConstant, Image, StorageBuffer, RayPayloadKHR, IncomingRayPayloadKHR, HitAttributeKHR, CallableDataKHR, IncomingCallableDataKHR, ShaderRecordBufferKHR, PhysicalStorageBuffer, or TileImageEXT

- **VUID-StandaloneSpirv-None-04644**
  If the Storage Class is Output, then it must not be used in the GlCompute, RayGenerationKHR, IntersectionKHR, AnyHitKHR, ClosestHitKHR, MissKHR, or CallableKHR Execution Model

- **VUID-StandaloneSpirv-None-04645**
  If the Storage Class is Workgroup, then it must only be used in the task, mesh, or compute Execution Model

- **VUID-StandaloneSpirv-None-08720**
If the Storage Class is TileImageEXT, then it must only be used in the fragment execution model

- **VUID-StandaloneSpirv-OpAtomicStore-04730**
  
  OpAtomicStore must not use Acquire, AcquireRelease, or SequentiallyConsistent memory semantics

- **VUID-StandaloneSpirv-OpAtomicLoad-04731**
  
  OpAtomicLoad must not use Release, AcquireRelease, or SequentiallyConsistent memory semantics

- **VUID-StandaloneSpirv-OpMemoryBarrier-04732**
  
  OpMemoryBarrier must use one of Acquire, Release, AcquireRelease, or SequentiallyConsistent memory semantics

- **VUID-StandaloneSpirv-OpMemoryBarrier-04733**
  
  OpMemoryBarrier must include at least one Storage Class

- **VUID-StandaloneSpirv-OpControlBarrier-04650**
  
  If the semantics for OpControlBarrier includes one of Acquire, Release, AcquireRelease, or SequentiallyConsistent memory semantics, then it must include at least one Storage Class

- **VUID-StandaloneSpirv-OpVariable-04651**
  
  Any OpVariable with an Initializer operand must have Output, Private, Function, or Workgroup as its Storage Class operand

- **VUID-StandaloneSpirv-OpVariable-04734**
  
  Any OpVariable with an Initializer operand and Workgroup as its Storage Class operand must use OpConstantNull as the initializer

- **VUID-StandaloneSpirv-OpReadClockKHR-04652**
  
  Scope for OpReadClockKHR must be limited to Subgroup or Device

- **VUID-StandaloneSpirv-OriginLowerLeft-04653**
  
  The OriginLowerLeft Execution Mode must not be used; fragment entry points must declare OriginUpperLeft

- **VUID-StandaloneSpirv-PixelCenterInteger-04654**
  
  The PixelCenterInteger Execution Mode must not be used (pixels are always centered at half-integer coordinates)

- **VUID-StandaloneSpirv-UniformConstant-04655**
  
  Any variable in the UniformConstant Storage Class must be typed as either OpTypeImage, OpTypeSampler, OpTypeSampledImage, OpTypeAccelerationStructureKHR, or an array of one of these types

- **VUID-StandaloneSpirv-Uniform-06807**
  
  Any variable in the Uniform or StorageBuffer Storage Class must be typed as OpTypeStruct or an array of this type

- **VUID-StandaloneSpirv-PushConstant-06808**
  
  Any variable in the PushConstant Storage Class must be typed as OpTypeStruct

- **VUID-StandaloneSpirv-OpTypeImage-04656**
  
  OpTypeImage must declare a scalar 32-bit float, 64-bit integer, or 32-bit integer type for the “Sampled Type” (RelaxedPrecision can be applied to a sampling instruction and to the
variable holding the result of a sampling instruction)

- VUID-StandaloneSpirv-OpTypeImage-04657
  - **OpTypeImage** must have a “Sampled” operand of 1 (sampled image) or 2 (storage image).

- VUID-StandaloneSpirv-OpTypeSampledImage-06671
  - **OpTypeSampledImage** must have a **OpTypeImage** with a “Sampled” operand of 1 (sampled image).

- VUID-StandaloneSpirv-Image-04965
  - The **SPIR-V Type** of the **Image Format** operand of an **OpTypeImage** must match the **Sampled Type**, as defined in **Image Format and Type Matching**.

- VUID-StandaloneSpirv-OpImageTexelPointer-04658
  - If an **OpImageTexelPointer** is used in an atomic operation, the image type of the image parameter to **OpImageTexelPointer** must have an image format of R64f, R64ui, R32f, R32i, or R32ui.

- VUID-StandaloneSpirv-OpImageQuerySizeLod-04659

- VUID-StandaloneSpirv-OpTypeImage-06214
  - An **OpTypeImage** with a “Dim” operand of **SubpassData** must have an “Arrayed” operand of 0 (non-arrayed) and a “Sampled” operand of 2 (storage image).

- VUID-StandaloneSpirv-SubpassData-04660
  - The (u,v) coordinates used for a **SubpassData** must be the <id> of a constant vector (0,0), or if a layer coordinate is used, must be a vector that was formed with constant 0 for the u and v components.

- VUID-StandaloneSpirv-OpTypeImage-06924
  - Objects of types **OpTypeImage**, **OpTypeSampler**, **OpTypeSampledImage**, **OpTypeAccelerationStructureKHR**, and arrays of these types must not be stored to or modified.

- VUID-StandaloneSpirv-Uniform-06925
  - Any variable in the **Uniform Storage Class** decorated as **Block** must not be stored to or modified.

- VUID-StandaloneSpirv-Offset-04663
  - **Image operand**: **Offset** must only be used with **OpImage*Gather** instructions.

- VUID-StandaloneSpirv-Offset-04865
  - Any image instruction which uses an **Offset**, **ConstOffset**, or **ConstOffsets** image operand, must only consume a “Sampled Image” operand whose type has its “Sampled” operand set to 1.

- VUID-StandaloneSpirv-OpImageGather-04664
  - The “Component” operand of **OpImageGather**, and **OpImageSparseGather** must be the <id> of a constant instruction.

- VUID-StandaloneSpirv-OpImage-04777
  - **OpImage*Dref* instructions** must not consume an image whose **Dim** is 3D.

- VUID-StandaloneSpirv-None-04667
Structure types must not contain opaque types

- **VUID-StandaloneSpirv-BuiltIn-04668**
  Any `BuiltIn` decoration not listed in `Built-In Variables` must not be used

- **VUID-StandaloneSpirv-Location-06672**
  The `Location` or `Component` decorations must only be used with the `Input`, `Output`, `RayPayloadKHR`, `IncomingRayPayloadKHR`, `HitAttributeKHR`, `HitObjectAttributeNV`, `CallableDataKHR`, `IncomingCallableDataKHR`, or `ShaderRecordBufferKHR` storage classes

- **VUID-StandaloneSpirv-Location-04915**
  The `Location` or `Component` decorations must not be used with `BuiltIn`

- **VUID-StandaloneSpirv-Location-04916**
  The `Location` decorations must be used on user-defined variables

- **VUID-StandaloneSpirv-Location-04917**
  If a user-defined variable is a pointer to a `Block` decorated `OpTypeStruct`, then the `OpVariable` must have a `Location` decoration

- **VUID-StandaloneSpirv-Location-04918**
  If a user-defined variable has a `Location` decoration, and the variable is a pointer to a `OpTypeStruct`, then the members of that structure must not have `Location` decorations

- **VUID-StandaloneSpirv-Location-04919**
  If a user-defined variable does not have a `Location` decoration, and the variable is a pointer to a `Block` decorated `OpTypeStruct`, then each member of the struct must have a `Location` decoration

- **VUID-StandaloneSpirv-Component-04920**
  The `Component` decoration value must not be greater than 3

- **VUID-StandaloneSpirv-Component-04921**
  If the `Component` decoration is used on an `OpVariable` that has a `OpTypeVector` type with a `Component Type` with a `Width` that is less than or equal to 32, the sum of its `Component Count` and the `Component` decoration value must be less than or equal to 4

- **VUID-StandaloneSpirv-Component-04922**
  If the `Component` decoration is used on an `OpVariable` that has a `OpTypeVector` type with a `Component Type` with a `Width` that is equal to 64, the sum of two times its `Component Count` and the `Component` decoration value must be less than or equal to 4

- **VUID-StandaloneSpirv-Component-04923**
  The `Component` decorations value must not be 1 or 3 for scalar or two-component 64-bit data types

- **VUID-StandaloneSpirv-Component-04924**
  The `Component` decorations must not be used with any type that is not a scalar or vector, or an array of such a type

- **VUID-StandaloneSpirv-Component-07703**
  The `Component` decorations must not be used for a 64-bit vector type with more than two components

- **VUID-StandaloneSpirv-GLSLShared-GLSLPacked-04669**
  The `GLSLShared` and `GLSLPacked` decorations must not be used
• VUID-StandaloneSpirv-Flat-04670
  The Flat, NoPerspective, Sample, and Centroid decorations must only be used on variables with the Output or Input Storage Class

• VUID-StandaloneSpirv-Flat-06201
  The Flat, NoPerspective, Sample, and Centroid decorations must not be used on variables with the Output storage class in a fragment shader

• VUID-StandaloneSpirv-Flat-06202
  The Flat, NoPerspective, Sample, and Centroid decorations must not be used on variables with the Input storage class in a vertex shader

• VUID-StandaloneSpirv-PerVertexKHR-06777
  The PerVertexKHR decoration must only be used on variables with the Input Storage Class in a fragment shader

• VUID-StandaloneSpirv-Flat-04744
  Any variable with integer or double-precision floating-point type and with Input Storage Class in a fragment shader, must be decorated Flat

• VUID-StandaloneSpirv-ViewportRelativeNV-04672
  The ViewportRelativeNV decoration must only be used on a variable decorated with Layer in the vertex, tessellation evaluation, or geometry shader stages

• VUID-StandaloneSpirv-ViewportRelativeNV-04673
  The ViewportRelativeNV decoration must not be used unless a variable decorated with one of ViewportIndex or ViewportMaskNV is also statically used by the same OpEntryPoint

• VUID-StandaloneSpirv-ViewportMaskNV-04674
  The ViewportMaskNV and ViewportIndex decorations must not both be statically used by one or more OpEntryPoint’s that form the pre-rasterization shader stages of a graphics pipeline

• VUID-StandaloneSpirv-FPRoundingMode-04675
  Rounding modes other than round-to-nearest-even and round-towards-zero must not be used for the FPRoundingMode decoration

• VUID-StandaloneSpirv-Invariant-04677
  Variables decorated with Invariant and variables with structure types that have any members decorated with Invariant must be in the Output or Input Storage Class, Invariant used on an Input Storage Class variable or structure member has no effect

• VUID-StandaloneSpirv-VulkanMemoryModel-04678
  If the VulkanMemoryModel capability is not declared, the Volatile decoration must be used on any variable declaration that includes one of the SMIDNV, WarpIDNV, SubgroupSize, SubgroupLocalInvocationId, SubgroupEqMask, SubgroupGeMask, SubgroupGtMask, SubgroupLeMask, or SubgroupLtMask BuiltIn decorations when used in the ray generation, closest hit, miss, intersection, or callable shaders, or with the RayTmaxKHR Builtin decoration when used in an intersection shader

• VUID-StandaloneSpirv-VulkanMemoryModel-04679
  If the VulkanMemoryModel capability is declared, the OpLoad instruction must use the Volatile memory semantics when it accesses into any variable that includes one of the SMIDNV, WarpIDNV, SubgroupSize, SubgroupLocalInvocationId, SubgroupEqMask, SubgroupGeMask, SubgroupGtMask, SubgroupLeMask, or SubgroupLtMask BuiltIn decorations when used in the...
ray generation, closest hit, miss, intersection, or callable shaders, or with the RayTmaxKHR Builtin decoration when used in an intersection shader

- **VUID-StandaloneSpirv-OpTypeRuntimeArray-04680**
  OpTypeRuntimeArray must only be used for:
  - the last member of a Block-decorated OpTypeStruct in StorageBuffer or PhysicalStorageBuffer storage Storage Class
  - BufferBlock-decorated OpTypeStruct in the Uniform storage Storage Class
  - the outermost dimension of an arrayed variable in the StorageBuffer, Uniform, or UniformConstant storage Storage Class
  - variables in the NodePayloadAMDX storage Storage Class when the CoalescingAMDX Execution Mode is specified

- **VUID-StandaloneSpirv-Function-04681**
  A type \( T \) that is an array sized with a specialization constant must neither be, nor be contained in, the type \( T_2 \) of a variable \( V \), unless either: a) \( T \) is equal to \( T_2 \), b) \( V \) is declared in the Function, or Private Storage Class, c) \( V \) is a non-Block variable in the Workgroup Storage Class, or d) \( V \) is an interface variable with an additional level of arrayness, as described in interface matching, and \( T \) is the member type of the array type \( T_2 \)

- **VUID-StandaloneSpirv-OpControlBarrier-04682**
  If OpControlBarrier is used in ray generation, intersection, any-hit, closest hit, miss, fragment, vertex, tessellation evaluation, or geometry shaders, the execution Scope must be Subgroup

- **VUID-StandaloneSpirv-LocalSize-06426**
  For each compute shader entry point, either a LocalSize or LocalSizeId Execution Mode, or an object decorated with the WorkgroupSize decoration must be specified

- **VUID-StandaloneSpirv-DerivativeGroupQuadsNV-04684**
  For compute shaders using the DerivativeGroupQuadsNV execution mode, the first two dimensions of the local workgroup size must be a multiple of two

- **VUID-StandaloneSpirv-DerivativeGroupLinearNV-04778**
  For compute shaders using the DerivativeGroupLinearNV execution mode, the product of the dimensions of the local workgroup size must be a multiple of four

- **VUID-StandaloneSpirv-OpGroupNonUniformBallotBitCount-04685**
  If OpGroupNonUniformBallotBitCount is used, the group operation must be limited to Reduce, InclusiveScan, or ExclusiveScan

- **VUID-StandaloneSpirv-None-04686**
  The Pointer operand of all atomic instructions must have a Storage Class limited to Uniform, Workgroup, Image, StorageBuffer, PhysicalStorageBuffer, or TaskPayloadWorkgroupEXT

- **VUID-StandaloneSpirv-Offset-04687**
  Output variables or block members decorated with Offset that have a 64-bit type, or a composite type containing a 64-bit type, must specify an Offset value aligned to a 8 byte boundary

- **VUID-StandaloneSpirv-Offset-04689**
  The size of any output block containing any member decorated with Offset that is a 64-bit
The first member of an output block specifying a `Offset` decoration must specify a `Offset` value that is aligned to an 8 byte boundary if that block contains any member decorated with `Offset` and is a 64-bit type.

Output variables or block members decorated with `Offset` that have a 32-bit type, or a composite type contains a 32-bit type, must specify an `Offset` value aligned to a 4 byte boundary.

Output variables, blocks or block members decorated with `Offset` must only contain base types that have components that are either 32-bit or 64-bit in size.

Only variables or block members in the output interface decorated with `Offset` can be captured for transform feedback, and those variables or block members must also be decorated with `XfbBuffer` and `XfbStride`, or inherit `XfbBuffer` and `XfbStride` decorations from a block containing them.

All variables or block members in the output interface of the entry point being compiled decorated with a specific `XfbBuffer` value must all be decorated with identical `XfbStride` values.

If any variables or block members in the output interface of the entry point being compiled are decorated with `Stream`, then all variables belonging to the same `XfbBuffer` must specify the same `Stream` value.

For any two variables or block members in the output interface of the entry point being compiled with the same `XfbBuffer` value, the ranges determined by the `Offset` decoration and the size of the type must not overlap.

All block members in the output interface of the entry point being compiled that are in the same block and have a declared or inherited `XfbBuffer` decoration must specify the same `XfbBuffer` value.

RayPayloadKHR Storage Class must only be used in ray generation, closest hit or miss shaders.

IncomingRayPayloadKHR Storage Class must only be used in closest hit, any-hit, or miss shaders.

There must be at most one variable with the IncomingRayPayloadKHR Storage Class in the input interface of an entry point.
**HitAttributeKHR Storage Class** must only be used in intersection, any-hit, or closest hit shaders

- VUID-StandaloneSpirv-HitAttributeKHR-04702
  There **must** be at most one variable with the **HitAttributeKHR Storage Class** in the input interface of an entry point

- VUID-StandaloneSpirv-HitAttributeKHR-04703
  A variable with **HitAttributeKHR Storage Class** **must** only be written to in an intersection shader

- VUID-StandaloneSpirv-CallableDataKHR-04704
  **CallableDataKHR Storage Class** **must** only be used in ray generation, closest hit, miss, and callable shaders

- VUID-StandaloneSpirv-IncomingCallableDataKHR-04705
  **IncomingCallableDataKHR Storage Class** **must** only be used in callable shaders

- VUID-StandaloneSpirv-IncomingCallableDataKHR-04706
  There **must** be at most one variable with the **IncomingCallableDataKHR Storage Class** in the input interface of an entry point

- VUID-StandaloneSpirv-ShaderRecordBufferKHR-07119
  **ShaderRecordBufferKHR Storage Class** **must** only be used in ray generation, intersection, any-hit, closest hit, callable, or miss shaders

- VUID-StandaloneSpirv-Base-07650
  The **Base** operand of **OpPtrAccessChain** **must** have a storage class of **Workgroup, StorageBuffer, or PhysicalStorageBuffer**

- VUID-StandaloneSpirv-Base-07651
  If the **Base** operand of **OpPtrAccessChain** has a **Workgroup Storage Class**, then the **VariablePointers** capability **must** be declared

- VUID-StandaloneSpirv-Base-07652
  If the **Base** operand of **OpPtrAccessChain** has a **StorageBuffer Storage Class**, then the **VariablePointers** or **VariablePointersStorageBuffer** capability **must** be declared

- VUID-StandaloneSpirv-PhysicalStorageBuffer64-04708
  If the **PhysicalStorageBuffer64** addressing model is enabled, all instructions that support memory access operands and that use a physical pointer **must** include the **Aligned** operand

- VUID-StandaloneSpirv-PhysicalStorageBuffer64-04709
  If the **PhysicalStorageBuffer64** addressing model is enabled, any access chain instruction that accesses into a **RowMajor** matrix **must** only be used as the **Pointer** operand to **OpLoad** or **OpStore**

- VUID-StandaloneSpirv-PhysicalStorageBuffer64-04710
  If the **PhysicalStorageBuffer64** addressing model is enabled, **OpConvertUToPtr** and **OpConvertPtrToU** **must** use an integer type whose **Width** is 64

- VUID-StandaloneSpirv-None-04745
  **OpTypeForwardPointer** **must** have a **Storage Class** of **PhysicalStorageBuffer**
All block members in a variable with a Storage Class of PushConstant declared as an array must only be accessed by dynamically uniform indices

- VUID-StandaloneSpirv-OpVariable-06673
  There must not be more than one OpVariable in the PushConstant Storage Class listed in the Interface for each OpEntryPoint

- VUID-StandaloneSpirv-OpEntryPoint-06674
  Each OpEntryPoint must not statically use more than one OpVariable in the PushConstant Storage Class

- VUID-StandaloneSpirv-OpEntryPoint-08721
  Each OpEntryPoint must not have more than one Input variable assigned the same Component word inside a Location slot, either explicitly or implicitly

- VUID-StandaloneSpirv-OpEntryPoint-08722
  Each OpEntryPoint must not have more than one Output variable assigned the same Component word inside a Location slot, either explicitly or implicitly

- VUID-StandaloneSpirv-Result-04780
  The Result Type operand of any OpImageRead or OpImageSparseRead instruction must be a vector of four components

- VUID-StandaloneSpirv-Base-04781
  The Base operand of any OpBitCount, OpBitReverse, OpBitFieldInsert, OpBitFieldSExtract, or OpBitFieldUExtract instruction must be a 32-bit integer scalar or a vector of 32-bit integers

- VUID-StandaloneSpirv-PushConstant-06675
  Any variable in the PushConstant or StorageBuffer storage class must be decorated as Block

- VUID-StandaloneSpirv-Uniform-06676
  Any variable in the Uniform Storage Class must be decorated as Block or BufferBlock

- VUID-StandaloneSpirv-UniformConstant-06677
  Any variable in the UniformConstant, StorageBuffer, or Uniform Storage Class must be decorated with DescriptorSet and Binding

- VUID-StandaloneSpirv-InputAttachmentIndex-06678
  Variables decorated with InputAttachmentIndex must be in the UniformConstant Storage Class

- VUID-StandaloneSpirv-DescriptorSet-06491
  If a variable is decorated by DescriptorSet or Binding, the Storage Class must correspond to an entry in Shader Resource and Storage Class Correspondence

- VUID-StandaloneSpirv-Input-06778
  Variables with a Storage Class of Input in a fragment shader stage that are decorated with PerVertexKHR must be declared as arrays

- VUID-StandaloneSpirv-MeshEXT-07102
  The module must not contain both an entry point that uses the TaskEXT or MeshEXT Execution Model and an entry point that uses the TaskNV or MeshNV Execution Model

- VUID-StandaloneSpirv-MeshEXT-07106
  In mesh shaders using the MeshEXT Execution Model OpSetMeshOutputsEXT must be called
before any outputs are written

• VUID-StandaloneSpirv-MeshEXT-07107
  In mesh shaders using the MeshEXT Execution Model all variables declared as output must
  not be read from

• VUID-StandaloneSpirv-MeshEXT-07108
  In mesh shaders using the MeshEXT Execution Model for OpSetMeshOutputsEXT instructions,
  the “Vertex Count” and “Primitive Count” operands must not depend on ViewIndex

• VUID-StandaloneSpirv-MeshEXT-07109
  In mesh shaders using the MeshEXT Execution Model variables decorated with
  PrimitivePointIndicesEXT, PrimitiveLineIndicesEXT, or PrimitiveTriangleIndicesEXT
  declared as an array must not be accessed by indices that depend on ViewIndex

• VUID-StandaloneSpirv-MeshEXT-07110
  In mesh shaders using the MeshEXT Execution Model any values stored in variables
  decorated with PrimitivePointIndicesEXT, PrimitiveLineIndicesEXT, or
  PrimitiveTriangleIndicesEXT must not depend on ViewIndex

• VUID-StandaloneSpirv-MeshEXT-07111
  In mesh shaders using the MeshEXT Execution Model variables in workgroup or private
  Storage Class declared as or containing a composite type must not be accessed by indices
  that depend on ViewIndex

• VUID-StandaloneSpirv-MeshEXT-07330
  In mesh shaders using the MeshEXT Execution Model the OutputVertices Execution Mode must
  be greater than 0

• VUID-StandaloneSpirv-MeshEXT-07331
  In mesh shaders using the MeshEXT Execution Model the OutputPrimitivesEXT Execution Mode
  must be greater than 0

• VUID-StandaloneSpirv-Input-07290
  Variables with a Storage Class of Input or Output and a type of OpTypeBool must be
  decorated with the BuiltIn decoration

• VUID-StandaloneSpirv-TileImageEXT-08723
  The tile image variable declarations must obey the constraints on the TileImageEXT
  Storage Class and the Location decoration described in Fragment Tile Image Interface

• VUID-StandaloneSpirv-None-08724
  The TileImageEXT Storage Class must only be used for declaring tile image variables.

• VUID-StandaloneSpirv-Pointer-08973
  The Storage Class of the Pointer operand to OpCooperativeMatrixLoadKHR or
  OpCooperativeMatrixStoreKHR must be limited to Workgroup, StorageBuffer, or
  PhysicalStorageBuffer.

### Runtime SPIR-V Validation

The following rules must be validated at runtime. These rules depend on knowledge of the
implementation and its capabilities and knowledge of runtime information, such as enabled
features.
Valid Usage

- **VUID-RuntimeSpirv-vulkanMemoryModel-06265**
  If `vulkanMemoryModel` is enabled and `vulkanMemoryModelDeviceScope` is not enabled, Device memory scope must not be used.

- **VUID-RuntimeSpirv-vulkanMemoryModel-06266**
  If `vulkanMemoryModel` is not enabled, QueueFamily memory scope must not be used.

- **VUID-RuntimeSpirv-shaderSubgroupClock-06267**
  If `shaderSubgroupClock` is not enabled, the Subgroup scope must not be used for `OpReadClockKHR`.

- **VUID-RuntimeSpirv-shaderDeviceClock-06268**
  If `shaderDeviceClock` is not enabled, the Device scope must not be used for `OpReadClockKHR`.

- **VUID-RuntimeSpirv-apiVersion-07954**
  If `VkPhysicalDeviceProperties::apiVersion` is less than Vulkan 1.3, the `VK_KHR_format_feature_flags2` extension is not supported, and `shaderStorageImageWriteWithoutFormat` is not enabled, any variable created with a “Type” of `OpTypeImage` that has a “Sampled” operand of 2 and an “Image Format” operand of Unknown must be decorated with `NonWritable`.

- **VUID-RuntimeSpirv-apiVersion-07955**
  If `VkPhysicalDeviceProperties::apiVersion` is less than Vulkan 1.3, the `VK_KHR_format_feature_flags2` extension is not supported, and `shaderStorageImageReadWithoutFormat` is not enabled, any variable created with a “Type” of `OpTypeImage` that has a “Sampled” operand of 2 and an “Image Format” operand of Unknown must be decorated with `NonReadable`.

- **VUID-RuntimeSpirv-OpImageWrite-07112**
  `OpImageWrite` to any `Image` whose `Image Format` is not Unknown must have the Texel operand contain at least as many components as the corresponding `VkFormat` as given in the SPIR-V Image Format compatibility table.

- **VUID-RuntimeSpirv-Location-06272**
  The sum of Location and the number of locations the variable it decorates consumes must be less than or equal to the value for the matching Execution Model defined in Shader Input and Output Locations.

- **VUID-RuntimeSpirv-Location-06428**
  The maximum number of storage buffers, storage images, and output Location decorated color attachments written to in the Fragment Execution Model must be less than or equal to `maxFragmentCombinedOutputResources`.

- **VUID-RuntimeSpirv-NonUniform-06274**
  If an instruction loads from or stores to a resource (including atomics and image instructions) and the resource descriptor being accessed is not dynamically uniform, then the operand corresponding to that resource (e.g. the pointer or sampled image operand) must be decorated with `NonUniform`.

- **VUID-RuntimeSpirv-None-06275**
  `shaderSubgroupExtendedTypes` must be enabled for group operations to use 8-bit integer,
16-bit integer, 64-bit integer, 16-bit floating-point, and vectors of these types

- **VUID-RuntimeSpirv-subgroupBroadcastDynamicId-06276**
  If `subgroupBroadcastDynamicId` is `VK_TRUE`, and the shader module version is 1.5 or higher, the “Index” for `OpGroupNonUniformQuadBroadcast` **must** be dynamically uniform within the derivative group. Otherwise, “Index” **must** be a constant.

- **VUID-RuntimeSpirv-subgroupBroadcastDynamicId-06277**
  If `subgroupBroadcastDynamicId` is `VK_TRUE`, and the shader module version is 1.5 or higher, the “Id” for `OpGroupNonUniformBroadcast` **must** be dynamically uniform within the subgroup. Otherwise, “Id” **must** be a constant.

- **VUID-RuntimeSpirv-None-06278**
  `shaderBufferInt64Atomics` **must** be enabled for 64-bit integer atomic operations to be supported on a `Pointer` with a `Storage Class` of `StorageBuffer` or `Uniform`.

- **VUID-RuntimeSpirv-None-06279**
  `shaderSharedInt64Atomics` **must** be enabled for 64-bit integer atomic operations to be supported on a `Pointer` with a `Storage Class` of `Workgroup`.

- **VUID-RuntimeSpirv-None-06284**
  `shaderBufferFloat32Atomics`, `or` `shaderBufferFloat32AtomicAdd`, `or` `shaderBufferFloat64Atomics`, `or` `shaderBufferFloat64AtomicAdd`, `or` `shaderBufferFloat16Atomics`, `or` `shaderBufferFloat16AtomicAdd`, `or` `shaderBufferFloat16AtomicMinMax`, `or` `shaderBufferFloat64AtomicMinMax`, `must` be enabled for floating-point atomic operations to be supported on a `Pointer` with a `Storage Class` of `StorageBuffer`.

- **VUID-RuntimeSpirv-None-06285**
  `shaderSharedFloat32Atomics`, `or` `shaderSharedFloat32AtomicAdd`, `or` `shaderSharedFloat64Atomics`, `or` `shaderSharedFloat64AtomicAdd`, `or` `shaderSharedFloat16Atomics`, `or` `shaderSharedFloat16AtomicAdd`, `or` `shaderSharedFloat16AtomicMinMax`, `or` `shaderSharedFloat32AtomicMinMax`, `or` `shaderSharedFloat64AtomicMinMax`, `must` be enabled for floating-point atomic operations to be supported on a `Pointer` with a `Storage Class` of `Workgroup`.

- **VUID-RuntimeSpirv-None-06286**
  `shaderImageFloat32Atomics`, `or` `shaderImageFloat32AtomicAdd`, `or` `shaderImageFloat32AtomicMinMax`, `must` be enabled for 32-bit floating-point atomic operations to be supported on a `Pointer` with a `Storage Class` of `Image`.

- **VUID-RuntimeSpirv-None-06287**
  `sparseImageFloat32Atomics`, `or` `sparseImageFloat32AtomicAdd`, `or` `sparseImageFloat32AtomicMinMax`, `must` be enabled for 32-bit floating-point atomic operations to be supported on sparse images.

- **VUID-RuntimeSpirv-None-06288**
  `shaderImageInt64Atomics` **must** be enabled for 64-bit integer atomic operations to be supported on a `Pointer` with a `Storage Class` of `Image`.

- **VUID-RuntimeSpirv-denormBehaviorIndependence-06289**
  If `denormBehaviorIndependence` is `VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_32_BIT_ONLY`, then the entry point **must** use the same denormals `Execution Mode` for both 16-bit and 64-bit floating-point types.
• VUID-RuntimeSpirv-denormBehaviorIndependence-06290
  If `denormBehaviorIndependence` is `VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_NONE`, then the entry point **must** use the same denormals Execution Mode for all floating-point types.

• VUID-RuntimeSpirv-roundingModeIndependence-06291
  If `roundingModeIndependence` is `VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_32_BIT_ONLY`, then the entry point **must** use the same rounding Execution Mode for both 16-bit and 64-bit floating-point types.

• VUID-RuntimeSpirv-roundingModeIndependence-06292
  If `roundingModeIndependence` is `VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_NONE`, then the entry point **must** use the same rounding Execution Mode for all floating-point types.

• VUID-RuntimeSpirv-shaderSignedZeroInfNanPreserveFloat16-06293
  If `shaderSignedZeroInfNanPreserveFloat16` is `VK_FALSE`, then `SignedZeroInfNanPreserve` for 16-bit floating-point type **must** not be used.

• VUID-RuntimeSpirv-shaderSignedZeroInfNanPreserveFloat32-06294
  If `shaderSignedZeroInfNanPreserveFloat32` is `VK_FALSE`, then `SignedZeroInfNanPreserve` for 32-bit floating-point type **must** not be used.

• VUID-RuntimeSpirv-shaderSignedZeroInfNanPreserveFloat64-06295
  If `shaderSignedZeroInfNanPreserveFloat64` is `VK_FALSE`, then `SignedZeroInfNanPreserve` for 64-bit floating-point type **must** not be used.

• VUID-RuntimeSpirv-shaderDenormPreserveFloat16-06296
  If `shaderDenormPreserveFloat16` is `VK_FALSE`, then `DenormPreserve` for 16-bit floating-point type **must** not be used.

• VUID-RuntimeSpirv-shaderDenormPreserveFloat32-06297
  If `shaderDenormPreserveFloat32` is `VK_FALSE`, then `DenormPreserve` for 32-bit floating-point type **must** not be used.

• VUID-RuntimeSpirv-shaderDenormPreserveFloat64-06298
  If `shaderDenormPreserveFloat64` is `VK_FALSE`, then `DenormPreserve` for 64-bit floating-point type **must** not be used.

• VUID-RuntimeSpirv-shaderDenormFlushToZeroFloat16-06299
  If `shaderDenormFlushToZeroFloat16` is `VK_FALSE`, then `DenormFlushToZero` for 16-bit floating-point type **must** not be used.

• VUID-RuntimeSpirv-shaderDenormFlushToZeroFloat32-06300
  If `shaderDenormFlushToZeroFloat32` is `VK_FALSE`, then `DenormFlushToZero` for 32-bit floating-point type **must** not be used.

• VUID-RuntimeSpirv-shaderDenormFlushToZeroFloat64-06301
  If `shaderDenormFlushToZeroFloat64` is `VK_FALSE`, then `DenormFlushToZero` for 64-bit floating-point type **must** not be used.

• VUID-RuntimeSpirv-shaderRoundingModeRTEFloat16-06302
  If `shaderRoundingModeRTEFloat16` is `VK_FALSE`, then `RoundingModeRTE` for 16-bit floating-point type **must** not be used.

• VUID-RuntimeSpirv-shaderRoundingModeRTEFloat32-06303
  If `shaderRoundingModeRTEFloat32` is `VK_FALSE`, then `RoundingModeRTE` for 32-bit floating-point type **must** not be used.
• VUID-RuntimeSpirv-shaderRoundingModeRTEFloat64-06304
  If shaderRoundingModeRTEFloat64 is VK_FALSE, then RoundingModeRTE for 64-bit floating-point type must not be used

• VUID-RuntimeSpirv-shaderRoundingModeRTZFloat16-06305
  If shaderRoundingModeRTZFloat16 is VK_FALSE, then RoundingModeRTZ for 16-bit floating-point type must not be used

• VUID-RuntimeSpirv-shaderRoundingModeRTZFloat32-06306
  If shaderRoundingModeRTZFloat32 is VK_FALSE, then RoundingModeRTZ for 32-bit floating-point type must not be used

• VUID-RuntimeSpirv-shaderRoundingModeRTZFloat64-06307
  If shaderRoundingModeRTZFloat64 is VK_FALSE, then RoundingModeRTZ for 64-bit floating-point type must not be used

• VUID-RuntimeSpirv-Offset-06308
  The Offset plus size of the type of each variable, in the output interface of the entry point being compiled, decorated with XfbBuffer must not be greater than VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackBufferDataSize

• VUID-RuntimeSpirv-XfbBuffer-06309
  For any given XfbBuffer value, define the buffer data size to be smallest number of bytes such that, for all outputs decorated with the same XfbBuffer value, the size of the output interface variable plus the Offset is less than or equal to the buffer data size. For a given Stream, the sum of all the buffer data sizes for all buffers writing to that stream the must not exceed VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackStreamDataSize

• VUID-RuntimeSpirv-OpEmitStreamVertex-06310
  The Stream value to OpEmitStreamVertex and OpEndStreamPrimitive must be less than VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackStreams

• VUID-RuntimeSpirv-transformFeedbackStreamsLinesTriangles-06311
  If the geometry shader emits to more than one vertex stream and VkPhysicalDeviceTransformFeedbackPropertiesEXT::transformFeedbackStreamsLinesTriangles is VK_FALSE, then Execution Mode must be OutputPoints

• VUID-RuntimeSpirv-Stream-06312
  The stream number value to Stream must be less than VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackStreams

• VUID-RuntimeSpirv-XfbStride-06313
  The XFB Stride value to XfbStride must be less than or equal to VkPhysicalDeviceTransformFeedbackPropertiesEXT::maxTransformFeedbackBufferDataStride

• VUID-RuntimeSpirv-PhysicalStorageBuffer64-06314
  If the PhysicalStorageBuffer64 addressing model is enabled any load or store through a physical pointer type must be aligned to a multiple of the size of the largest scalar type in the pointed-to type

• VUID-RuntimeSpirv-PhysicalStorageBuffer64-06315
  If the PhysicalStorageBuffer64 addressing model is enabled the pointer value of a memory...
access instruction **must** be at least as aligned as specified by the **Aligned** memory access operand

- **VUID-RuntimeSpirv-OpTypeCooperativeMatrixNV-06316**
  For **OpTypeCooperativeMatrixNV**, the component type, scope, number of rows, and number of columns **must** match one of the matrices in any of the supported **VkCooperativeMatrixPropertiesNV**

- **VUID-RuntimeSpirv-OpCooperativeMatrixMulAddNV-06317**
  For **OpCooperativeMatrixMulAddNV**, the type of **A** **must** have **VkCooperativeMatrixPropertiesNV**::MSize rows and **VkCooperativeMatrixPropertiesNV**::KSize columns and have a component type that matches **VkCooperativeMatrixPropertiesNV**::AType

- **VUID-RuntimeSpirv-OpCooperativeMatrixMulAddNV-06318**
  For **OpCooperativeMatrixMulAddNV**, the type of **B** **must** have **VkCooperativeMatrixPropertiesNV**::KSize rows and **VkCooperativeMatrixPropertiesNV**::NSize columns and have a component type that matches **VkCooperativeMatrixPropertiesNV**::BType

- **VUID-RuntimeSpirv-OpCooperativeMatrixMulAddNV-06319**
  For **OpCooperativeMatrixMulAddNV**, the type of **C** **must** have **VkCooperativeMatrixPropertiesNV**::MSize rows and **VkCooperativeMatrixPropertiesNV**::NSize columns and have a component type that matches **VkCooperativeMatrixPropertiesNV**:: CType

- **VUID-RuntimeSpirv-OpCooperativeMatrixMulAddNV-06320**
  For **OpCooperativeMatrixMulAddNV**, the type of **Result** **must** have **VkCooperativeMatrixPropertiesNV**::MSize rows and **VkCooperativeMatrixPropertiesNV**::NSize columns and have a component type that matches **VkCooperativeMatrixPropertiesNV**::DType

- **VUID-RuntimeSpirv-OpCooperativeMatrixMulAddNV-06321**
  For **OpCooperativeMatrixMulAddNV**, the type of **A**, **B**, **C**, and **Result** **must** all have a scope of **scope**

- **VUID-RuntimeSpirv-OpTypeCooperativeMatrixNV-06322**
  **OpTypeCooperativeMatrixNV** and **OpCooperativeMatrix*** instructions **must** not be used in shader stages not included in **VkPhysicalDeviceCooperativeMatrixPropertiesNV**::cooperativeMatrixSupportedStages

- **VUID-RuntimeSpirv-OpTypeCooperativeMatrixKHR-08974**
  For **OpTypeCooperativeMatrixKHR**, the component type, scope, number of rows, and number of columns **must** match one of the matrices in any of the supported **VkCooperativeMatrixPropertiesKHR**.

- **VUID-RuntimeSpirv-MSize-08975**
  For **OpCooperativeMatrixMulAddKHR**, the type of **A** **must** have **VkCooperativeMatrixPropertiesKHR**::MSize rows and **VkCooperativeMatrixPropertiesKHR**::KSize columns and have a component type that matches **VkCooperativeMatrixPropertiesKHR**::AType.

- **VUID-RuntimeSpirv-OpCooperativeMatrixMulAddKHR-08976**
  For **OpCooperativeMatrixMulAddKHR**, when the component type of **A** is a signed integer type,
the MatrixASignedComponents cooperative matrix operand must be present.

- VUID-RuntimeSpirv-KSize-08977
  For OpCooperativeMatrixMulAddKHR, the type of B must have
  VkCooperativeMatrixPropertiesKHR::KSize rows and
  VkCooperativeMatrixPropertiesKHR::NSize columns and have a component type that
  matches VkCooperativeMatrixPropertiesKHR::BType.

- VUID-RuntimeSpirv-OpCooperativeMatrixMulAddKHR-08978
  For OpCooperativeMatrixMulAddKHR, when the component type of B is a signed integer type,
  the MatrixBSignedComponents cooperative matrix operand must be present.

- VUID-RuntimeSpirv-MSize-08979
  For OpCooperativeMatrixMulAddKHR, the type of C must have
  VkCooperativeMatrixPropertiesKHR::MSize rows and
 VkCooperativeMatrixPropertiesKHR::NSize columns and have a component type that
  matches VkCooperativeMatrixPropertiesKHR::CType.

- VUID-RuntimeSpirv-OpCooperativeMatrixMulAddKHR-08980
  For OpCooperativeMatrixMulAddKHR, when the component type of C is a signed integer type,
  the MatrixCSignedComponents cooperative matrix operand must be present.

- VUID-RuntimeSpirv-MSize-08981
  For OpCooperativeMatrixMulAddKHR, the type of Result must have
  VkCooperativeMatrixPropertiesKHR::MSize rows and
  VkCooperativeMatrixPropertiesKHR::NSize columns and have a component type that
  matches VkCooperativeMatrixPropertiesKHR::ResultType.

- VUID-RuntimeSpirv-OpCooperativeMatrixMulAddKHR-08982
  For OpCooperativeMatrixMulAddKHR, when the component type of Result is a signed integer
  type, the MatrixResultSignedComponents cooperative matrix operand must be present.

- VUID-RuntimeSpirv-saturatingAccumulation-08983
  For OpCooperativeMatrixMulAddKHR, the SaturatingAccumulation cooperative matrix operand
  must be present if and only if VkCooperativeMatrixPropertiesKHR::saturatingAccumulation is VK_TRUE.

- VUID-RuntimeSpirv-scope-08984
  For OpCooperativeMatrixMulAddKHR, the type of A, B, C, and Result must all have a scope of
  scope.

- VUID-RuntimeSpirv-cooperativeMatrixSupportedStages-08985
  OpTypeCooperativeMatrixKHR and OpCooperativeMatrix* instructions must not be used in
  shader stages not included in VkPhysicalDeviceCooperativeMatrixPropertiesKHR
  ::cooperativeMatrixSupportedStages.

- VUID-RuntimeSpirv-DescriptorSet-06323
  DescriptorSet and Binding decorations must obey the constraints on Storage Class, type,
  and descriptor type described in DescriptorSet and Binding Assignment

- VUID-RuntimeSpirv-OpCooperativeMatrixLoadNV-06324
  For OpCooperativeMatrixLoadNV and OpCooperativeMatrixStoreNV instructions, the Pointer
  and Stride operands must be aligned to at least the lesser of 16 bytes or the natural
  alignment of a row or column (depending on ColumnMajor) of the matrix (where the
natural alignment is the number of columns/rows multiplied by the component size)

- **VUID-RuntimeSpirv-MeshNV-07113**
  For mesh shaders using the MeshNV Execution Model the OutputVertices OpExecutionMode must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesNV::maxMeshOutputVertices

- **VUID-RuntimeSpirv-MeshNV-07114**
  For mesh shaders using the MeshNV Execution Model the OutputPrimitivesNV OpExecutionMode must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesNV::maxMeshOutputPrimitives

- **VUID-RuntimeSpirv-MeshEXT-07115**
  For mesh shaders using the MeshEXT Execution Model the OutputVertices OpExecutionMode must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshOutputVertices

- **VUID-RuntimeSpirv-MeshEXT-07332**
  For mesh shaders using the MeshEXT Execution Model the “Vertex Count” operand of OpSetMeshOutputsEXT must be less than or equal to OutputVertices OpExecutionMode

- **VUID-RuntimeSpirv-MeshEXT-07116**
  For mesh shaders using the MeshEXT Execution Model the OutputPrimitivesEXT OpExecutionMode must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshOutputPrimitives

- **VUID-RuntimeSpirv-MeshEXT-07333**
  For mesh shaders using the MeshEXT Execution Model the “Primitive Count” operand of OpSetMeshOutputsEXT must be less than or equal to OutputPrimitivesEXT OpExecutionMode

- **VUID-RuntimeSpirv-TaskEXT-07117**
  In task shaders using the TaskEXT Execution Model OpEmitMeshTasksEXT must be called exactly once under dynamically uniform conditions

- **VUID-RuntimeSpirv-TaskEXT-07118**
  In mesh shaders using the MeshEXT Execution Model OpSetMeshOutputsEXT must be called at most once under dynamically uniform conditions

- **VUID-RuntimeSpirv-TaskEXT-07291**
  In task shaders using the TaskEXT Execution Model the x size in LocalSize or LocalSizeId must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesEXT::maxTaskWorkGroupSize[0]

- **VUID-RuntimeSpirv-TaskEXT-07292**
  In task shaders using the TaskEXT Execution Model the y size in LocalSize or LocalSizeId must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesEXT::maxTaskWorkGroupSize[1]

- **VUID-RuntimeSpirv-TaskEXT-07293**
  In task shaders using the TaskEXT Execution Model the z size in LocalSize or LocalSizeId must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesEXT::maxTaskWorkGroupSize[2]

- **VUID-RuntimeSpirv-TaskEXT-07294**
  In task shaders using the TaskEXT Execution Model the product of x size, y size, and z size in
LocalSize or LocalSizeId must be less than or equal to
VkPhysicalDeviceMeshShaderPropertiesEXT::maxTaskWorkGroupInvocations

- VUID-RuntimeSpirv-MeshEXT-07295
  For mesh shaders using the MeshEXT Execution Model the x size in LocalSize or LocalSizeId
  must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupSize[0]

- VUID-RuntimeSpirv-MeshEXT-07296
  For mesh shaders using the MeshEXT Execution Model the y size in LocalSize or LocalSizeId
  must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupSize[1]

- VUID-RuntimeSpirv-MeshEXT-07297
  For mesh shaders using the MeshEXT Execution Model the z size in LocalSize or LocalSizeId
  must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupSize[2]

- VUID-RuntimeSpirv-MeshEXT-07298
  For mesh shaders using the MeshEXT Execution Model the product of x size, y size, and z size
  in LocalSize or LocalSizeId must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupInvocations

- VUID-RuntimeSpirv-TaskEXT-07299
  In task shaders using the TaskEXT Execution Model the value of the “Group Count X” operand of
  OpEmitMeshTasksEXT must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupCount[0]

- VUID-RuntimeSpirv-TaskEXT-07300
  In task shaders using the TaskEXT Execution Model the value of the “Group Count Y” operand of
  OpEmitMeshTasksEXT must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupCount[1]

- VUID-RuntimeSpirv-TaskEXT-07301
  In task shaders using the TaskEXT Execution Model the value of the “Group Count Z” operand of
  OpEmitMeshTasksEXT must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupCount[2]

- VUID-RuntimeSpirv-TaskEXT-07302
  In task shaders using the TaskEXT Execution Model the product of the “Group Count” operands of
  OpEmitMeshTasksEXT must be less than or equal to VkPhysicalDeviceMeshShaderPropertiesEXT::maxMeshWorkGroupTotalCount

- VUID-RuntimeSpirv-maxMeshSharedMemorySize-08754
  The sum of size in bytes for variables and padding in the Workgroup Storage Class in the
  MeshEXT Execution Model must be less than or equal to maxMeshSharedMemorySize

- VUID-RuntimeSpirv-maxMeshPayloadAndSharedMemorySize-08755
  The sum of size in bytes for variables and padding in the TaskPayloadWorkgroupEXT or
  Workgroup Storage Class in the MeshEXT Execution Model must be less than or equal to
  maxMeshPayloadAndSharedMemorySize

- VUID-RuntimeSpirv-maxMeshOutputMemorySize-08756
  The sum of size in bytes for variables in the Output Storage Class in the MeshEXT Execution
Model must be less than or equal to maxMeshOutputMemorySize according to the formula in Mesh Shader Output

- VUID-RuntimeSpirv-maxMeshPayloadAndOutputMemorySize-08757
  The sum of size in bytes for variables and in the TaskPayloadWorkgroupEXT or Output Storage Class in the MeshEXT Execution Model must be less than or equal to maxMeshPayloadAndOutputMemorySize according to the formula in Mesh Shader Output

- VUID-RuntimeSpirv-maxTaskPayloadSize-08758
  The sum of size in bytes for variables and in the TaskPayloadWorkgroupEXT Storage Class in the TaskEXT Execution Model must be less than or equal to maxTaskPayloadSize

- VUID-RuntimeSpirv-maxTaskSharedMemorySize-08760
  The sum of size in bytes for variables and padding in the TaskPayloadWorkgroupEXT or Workgroup Storage Class in the TaskEXT Execution Model must be less than or equal to maxTaskSharedMemorySize

- VUID-RuntimeSpirv-maxTaskPayloadAndSharedMemorySize-08760
  The sum of size in bytes for variables and padding in the TaskPayloadWorkgroupEXT or Workgroup Storage Class in the TaskEXT Execution Model must be less than or equal to maxTaskPayloadAndSharedMemorySize

- VUID-RuntimeSpirv-OpCooperativeMatrixLoadKHR-08986
  For OpCooperativeMatrixLoadKHR and OpCooperativeMatrixStoreKHR instructions, the Pointer and Stride operands must be aligned to at least the lesser of 16 bytes or the natural alignment of a row or column (depending on ColumnMajor) of the matrix (where the natural alignment is the number of columns/rows multiplied by the component size).

- VUID-RuntimeSpirv-shaderSampleRateInterpolationFunctions-06325
  If the VK_KHR_portability_subset extension is enabled, and VkPhysicalDevicePortabilitySubsetFeaturesKHR::shaderSampleRateInterpolationFunctions is VK_FALSE, then GLSL.std.450 fragment interpolation functions are not supported by the implementation and OpCapability must not be set to InterpolationFunction

- VUID-RuntimeSpirv-tessellationShader-06326
  If tessellationShader is enabled, and the VK_KHR_portability_subset extension is enabled, and VkPhysicalDevicePortabilitySubsetFeaturesKHR::tessellationIsolines is VK_FALSE, then OpExecutionMode must not be set to Isolines

- VUID-RuntimeSpirv-tessellationShader-06327
  If tessellationShader is enabled, and the VK_KHR_portability_subset extension is enabled, and VkPhysicalDevicePortabilitySubsetFeaturesKHR::tessellationPointMode is VK_FALSE, then OpExecutionMode must not be set to PointMode

- VUID-RuntimeSpirv-storageBuffer8BitAccess-06328
  If storageBuffer8BitAccess is VK_FALSE, then objects containing an 8-bit integer element must not have Storage Class of StorageBuffer, ShaderRecordBufferKHR, or PhysicalStorageBuffer

- VUID-RuntimeSpirv-uniformAndStorageBuffer8BitAccess-06329
  If uniformAndStorageBuffer8BitAccess is VK_FALSE, then objects in the Uniform Storage Class with the Block decoration must not have an 8-bit integer member

- VUID-RuntimeSpirv-storagePushConstant8-06330
  If storagePushConstant8 is VK_FALSE, then objects containing an 8-bit integer element must
not have Storage Class of PushConstant

• VUID-RuntimeSpirv-storageBuffer16BitAccess-06331
  If storageBuffer16BitAccess is VK_FALSE, then objects containing 16-bit integer or 16-bit floating-point elements must not have Storage Class of StorageBuffer, ShaderRecordBufferKHR, or PhysicalStorageBuffer

• VUID-RuntimeSpirv-uniformAndStorageBuffer16BitAccess-06332
  If uniformAndStorageBuffer16BitAccess is VK_FALSE, then objects in the Uniform Storage Class with the Block decoration must not have 16-bit integer or 16-bit floating-point members

• VUID-RuntimeSpirv-storagePushConstant16-06333
  If storagePushConstant16 is VK_FALSE, then objects containing 16-bit integer or 16-bit floating-point elements must not have Storage Class of PushConstant

• VUID-RuntimeSpirv-storageInputOutput16-06334
  If storageInputOutput16 is VK_FALSE, then objects containing 16-bit integer or 16-bit floating-point elements must not have Storage Class of Input or Output

• VUID-RuntimeSpirv-None-06337
  shaderBufferFloat16Atomics, or shaderBufferFloat16AtomicAdd, or shaderBufferFloat16AtomicMinMax, or shaderSharedFloat16Atomics, or shaderSharedFloat16AtomicAdd, or shaderSharedFloat16AtomicMinMax must be enabled for 16-bit floating point atomic operations

• VUID-RuntimeSpirv-None-06338
  shaderBufferFloat32Atomics, or shaderBufferFloat32AtomicAdd, or shaderSharedFloat32Atomics, or shaderSharedFloat32AtomicAdd, or shaderImageFloat32Atomics, or shaderImageFloat32AtomicAdd or shaderImageFloat32AtomicMinMax, or shaderSharedFloat32AtomicMinMax, or shaderImageFloat32AtomicMinMax must be enabled for 32-bit floating point atomic operations

• VUID-RuntimeSpirv-None-06339
  shaderBufferFloat64Atomics, or shaderBufferFloat64AtomicAdd, or shaderSharedFloat64Atomics, or shaderSharedFloat64AtomicAdd, or shaderBufferFloat64AtomicMinMax, or shaderSharedFloat64AtomicMinMax, must be enabled for 64-bit floating point atomic operations

• VUID-RuntimeSpirv-NonWritable-06340
  If fragmentStoresAndAtomics is not enabled, then all storage image, storage texel buffer, and storage buffer variables in the fragment stage must be decorated with the NonWritable decoration

• VUID-RuntimeSpirv-NonWritable-06341
  If vertexPipelineStoresAndAtomics is not enabled, then all storage image, storage texel buffer, and storage buffer variables in the vertex, tessellation, and geometry stages must be decorated with the NonWritable decoration

• VUID-RuntimeSpirv-NonWritable-06342
  If subgroupQuadOperationsInAllStages is VK_FALSE, then quad subgroup operations must not be used except for in fragment and compute stages

• VUID-RuntimeSpirv-None-06343
Group operations with subgroup scope must not be used if the shader stage is not in subgroupSupportedStages

- VUID-RuntimeSpirv-Offset-06344
  The first element of the Offset operand of InterpolateAtOffset must be greater than or equal to:
  \[ \text{frag}_{\text{width}} \times \text{minInterpolationOffset} \]
  where \(\text{frag}_{\text{width}}\) is the width of the current fragment in pixels

- VUID-RuntimeSpirv-Offset-06345
  The first element of the Offset operand of InterpolateAtOffset must be less than or equal to:
  \[ \text{frag}_{\text{width}} \times (\text{maxInterpolationOffset} + \text{ULP}) - \text{ULP} \]
  where \(\text{frag}_{\text{width}}\) is the width of the current fragment in pixels and \(\text{ULP} = 1 / 2^{\text{subPixelInterpolationOffsetBits}}\)

- VUID-RuntimeSpirv-Offset-06346
  The second element of the Offset operand of InterpolateAtOffset must be greater than or equal to:
  \[ \text{frag}_{\text{height}} \times \text{minInterpolationOffset} \]
  where \(\text{frag}_{\text{height}}\) is the height of the current fragment in pixels

- VUID-RuntimeSpirv-Offset-06347
  The second element of the Offset operand of InterpolateAtOffset must be less than or equal to:
  \[ \text{frag}_{\text{height}} \times (\text{maxInterpolationOffset} + \text{ULP}) - \text{ULP} \]
  where \(\text{frag}_{\text{height}}\) is the height of the current fragment in pixels and \(\text{ULP} = 1 / 2^{\text{subPixelInterpolationOffsetBits}}\).

- VUID-RuntimeSpirv-OpRayQueryInitializeKHR-06348
  For OpRayQueryInitializeKHR instructions, all components of the RayOrigin and RayDirection operands must be finite floating-point values

- VUID-RuntimeSpirv-OpRayQueryInitializeKHR-06349
  For OpRayQueryInitializeKHR instructions, the RayTmin and RayTmax operands must be non-negative floating-point values

- VUID-RuntimeSpirv-OpRayQueryInitializeKHR-06350
  For OpRayQueryInitializeKHR instructions, the RayTmin operand must be less than or equal to the RayTmax operand

- VUID-RuntimeSpirv-OpRayQueryInitializeKHR-06351
  For OpRayQueryInitializeKHR instructions, RayOrigin, RayDirection, RayTmin, and RayTmax operands must not contain NaNs

- VUID-RuntimeSpirv-OpRayQueryInitializeKHR-06352
  For OpRayQueryInitializeKHR instructions, Acceleration Structure must be an acceleration structure built as a top-level acceleration structure

- VUID-RuntimeSpirv-OpRayQueryInitializeKHR-06889
  For OpRayQueryInitializeKHR instructions, the Rayflags operand must not contain both SkipTrianglesKHR and SkipAABBsKHR

- VUID-RuntimeSpirv-OpRayQueryInitializeKHR-06890
For `OpRayQueryInitializeKHR` instructions, the `Rayflags` operand **must** not contain more than one of `SkipTrianglesKHR`, `CullBackFacingTrianglesKHR`, and `CullFrontFacingTrianglesKHR`.

- **VUID/RuntimeSpirv-OpRayQueryInitializeKHR-06891**
  For `OpRayQueryInitializeKHR` instructions, the `Rayflags` operand **must** not contain more than one of `OpaqueKHR`, `NoOpaqueKHR`, `CullOpaqueKHR`, and `CullNoOpaqueKHR`.

- **VUID/RuntimeSpirv-OpRayQueryGenerateIntersectionKHR-06353**
  For `OpRayQueryGenerateIntersectionKHR` instructions, `Hit T` **must** satisfy the condition $\text{RayTmin} \leq \text{Hit T} \leq \text{RayTmax}$, where $\text{RayTmin}$ is equal to the value returned by `OpRayQueryGetRayTMinKHR` with the same ray query object, and $\text{RayTmax}$ is equal to the value of `OpRayQueryGetIntersectionTKHR` for the current committed intersection with the same ray query object.

- **VUID/RuntimeSpirv-OpRayQueryGenerateIntersectionKHR-06354**
  For `OpRayQueryGenerateIntersectionKHR` instructions, Acceleration Structure **must** not be built with `VK_BUILD_ACCELERATION_STRUCTURE_MOTION_BIT_NV` in flags.

- **VUID/RuntimeSpirv-flags-08761**
  For `OpRayQueryGetIntersectionTriangleVertexPositionsKHR` instructions, Acceleration Structure **must** have been built with `VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_DATA_ACCESS_KHR` in flags.

- **VUID/RuntimeSpirv-OpTraceRayKHR-06355**
  For `OpTraceRayKHR` instructions, all components of the `RayOrigin` and `RayDirection` operands **must** be finite floating-point values.

- **VUID/RuntimeSpirv-OpTraceRayKHR-06356**
  For `OpTraceRayKHR` instructions, the `RayTmin` and `RayTmax` operands **must** be non-negative floating-point values.

- **VUID/RuntimeSpirv-OpTraceRayKHR-06552**
  For `OpTraceRayKHR` instructions, the `Rayflags` operand **must** not contain both `SkipTrianglesKHR` and `SkipAABBsKHR`.

- **VUID/RuntimeSpirv-OpTraceRayKHR-06554**
  For `OpTraceRayKHR` instructions, if the `Rayflags` operand contains `SkipAABBsKHR`, the pipeline **must** not have been created with `VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR` set.

- **VUID/RuntimeSpirv-OpTraceRayKHR-06555**
  For `OpTraceRayKHR` instructions, if the `Rayflags` operand contains `SkipTrianglesKHR`, the pipeline **must** not have been created with `VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR` set.

- **VUID/RuntimeSpirv-OpTraceRayKHR-06357**
  For `OpTraceRayKHR` instructions, if the `Rayflags` operand contains `SkipTrianglesKHR`, the pipeline **must** not have been created with `VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR` set.
For **OpTraceRayKHR** instructions, the **RayTmin** operand **must** be less than or equal to the **RayTmax** operand.

- **VUID-RuntimeSpirv-OpTraceRayKHR-06358**
  For **OpTraceRayKHR** instructions, **RayOrigin**, **RayDirection**, **RayTmin**, and **RayTmax** operands **must** not contain NaNs.

- **VUID-RuntimeSpirv-OpTraceRayKHR-06359**
  For **OpTraceRayKHR** instructions, **Acceleration Structure** **must** be an acceleration structure built as a **top-level acceleration structure**.

- **VUID-RuntimeSpirv-OpReportIntersectionKHR-06998**
  The value of the “Hit Kind” operand of **OpReportIntersectionKHR** **must** be in the range [0,127].

- **VUID-RuntimeSpirv-OpTraceRayKHR-06360**
  For **OpTraceRayKHR** instructions, if **Acceleration Structure** was built with **VK_BUILD_ACCELERATION_STRUCTURE_MOTION_BIT_NV** in flags, the pipeline **must** have been created with **VK_PIPELINE_CREATE_RAY_TRACING_ALLOW_MOTION_BIT_NV** set.

- **VUID-RuntimeSpirv-OpTraceRayMotionNV-06361**
  For **OpTraceRayMotionNV** instructions, all components of the **RayOrigin** and **RayDirection** operands **must** be finite floating-point values.

- **VUID-RuntimeSpirv-OpTraceRayMotionNV-06362**
  For **OpTraceRayMotionNV** instructions, the **RayTmin** and **RayTmax** operands **must** be non-negative floating-point values.

- **VUID-RuntimeSpirv-OpTraceRayMotionNV-06363**
  For **OpTraceRayMotionNV** instructions, the **RayTmin** operand **must** be less than or equal to the **RayTmax** operand.

- **VUID-RuntimeSpirv-OpTraceRayMotionNV-06364**
  For **OpTraceRayMotionNV** instructions, **RayOrigin**, **RayDirection**, **RayTmin**, and **RayTmax** operands **must** not contain NaNs.

- **VUID-RuntimeSpirv-OpTraceRayMotionNV-06365**
  For **OpTraceRayMotionNV** instructions, **Acceleration Structure** **must** be an acceleration structure built as a **top-level acceleration structure** with **VK_BUILD_ACCELERATION_STRUCTURE_MOTION_BIT_NV** in flags.

- **VUID-RuntimeSpirv-OpTraceRayMotionNV-06366**
  For **OpTraceRayMotionNV** instructions the **time** operand **must** be between 0.0 and 1.0.

- **VUID-RuntimeSpirv-OpTraceRayMotionNV-06367**
  For **OpTraceRayMotionNV** instructions the pipeline **must** have been created with **VK_PIPELINE_CREATE_RAY_TRACING_ALLOW_MOTION_BIT_NV** set.

- **VUID-RuntimeSpirv-OpHitObjectTraceRayMotionNV-07704**
  For **OpHitObjectTraceRayMotionNV** instructions, if **Acceleration Structure** was built with **VK_BUILD_ACCELERATION_STRUCTURE_MOTION_BIT_NV** in flags, the pipeline **must** have been created with **VK_PIPELINE_CREATE_RAY_TRACING_ALLOW_MOTION_BIT_NV** set.

- **VUID-RuntimeSpirv-OpHitObjectTraceRayNV-07705**
  For **OpHitObjectTraceRayNV** and **OpHitObjectTraceRayMotionNV** instructions, all components of the **RayOrigin** and **RayDirection** operands **must** be finite floating-point values.
For `OpHitObjectTraceRayNV` and `OpHitObjectTraceRayMotionNV` instructions, the `RayTmin` and `RayTmax` operands **must** be non-negative floating-point values.

For `OpHitObjectTraceRayNV` and `OpHitObjectTraceRayMotionNV` instructions, the `RayTmin` operand **must** be less than or equal to the `RayTmax` operand.

For `OpHitObjectTraceRayNV` and `OpHitObjectTraceRayMotionNV` instructions, `RayOrigin`, `RayDirection`, `RayTmin`, and `RayTmax` operands **must** not contain NaNs.

For `OpHitObjectTraceRayMotionNV` instructions, `Acceleration Structure` **must** be an acceleration structure built as a top-level acceleration structure with `VK_BUILD_ACCELERATION_STRUCTURE_MOTION_BIT_NV` in flags.

For `OpHitObjectTraceRayNV` and `OpHitObjectTraceRayMotionNV` instructions the `time` operand **must** be between 0.0 and 1.0.

For `OpHitObjectTraceRayMotionNV` instructions the pipeline **must** have been created with `VK_PIPELINE_CREATE_RAY_TRACING_ALLOW_MOTION_BIT_NV` set.

For `OpHitObjectTraceRayNV` and `OpHitObjectTraceRayMotionNV` instructions, the `Rayflags` operand **must** not contain both `SkipTrianglesKHR` and `SkipAABBsKHR`.

For `OpHitObjectTraceRayNV` and `OpHitObjectTraceRayMotionNV` instructions, the `Rayflags` operand **must** not contain more than one of `SkipTrianglesKHR`, `CullBackFacingTrianglesKHR`, and `CullFrontFacingTrianglesKHR`.

For `OpHitObjectTraceRayNV` and `OpHitObjectTraceRayMotionNV` instructions, the `Rayflags` operand **must** not contain more than one of `OpaqueKHR`, `NoOpaqueKHR`, `CullOpaqueKHR`, and `CullNoOpaqueKHR`.

For `OpHitObjectTraceRayNV` and `OpHitObjectTraceRayMotionNV` instructions, if the `Rayflags` operand contains `SkipTrianglesKHR`, the pipeline **must** not have been created with `VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR` set.

For `OpHitObjectTraceRayNV` and `OpHitObjectTraceRayMotionNV` instructions, if the `Rayflags` operand contains `SkipAABBsKHR`, the pipeline **must** not have been created with `VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR` set.

In compute shaders using the `GLCompute Execution Model` the `x` size in `LocalSize` or `LocalSizeId` **must** be less than or equal to `VkPhysicalDeviceLimits::maxComputeWorkGroupSize[0]`.

For `OpHitObjectTraceRayNV` and `OpHitObjectTraceRayMotionNV` instructions, if the `Rayflags` operand contains `SkipTrianglesKHR`, the pipeline **must** not have been created with `VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR` set.

For `OpHitObjectTraceRayNV` and `OpHitObjectTraceRayMotionNV` instructions, if the `Rayflags` operand contains `SkipAABBsKHR`, the pipeline **must** not have been created with `VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR` set.

For `OpHitObjectTraceRayNV` and `OpHitObjectTraceRayMotionNV` instructions, if the `Rayflags` operand contains `SkipTrianglesKHR`, the pipeline **must** not have been created with `VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR` set.

For `OpHitObjectTraceRayNV` and `OpHitObjectTraceRayMotionNV` instructions, if the `Rayflags` operand contains `SkipAABBsKHR`, the pipeline **must** not have been created with `VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR` set.
In compute shaders using the **GLCompute Execution Model** the \( y \) size in `LocalSize` or `LocalSizeId` **must** be less than or equal to `VkPhysicalDeviceLimits::maxComputeWorkGroupSize`[1]

- **VUID-RuntimeSpirv-z-06431**
  In compute shaders using the **GLCompute Execution Model** the \( z \) size in `LocalSize` or `LocalSizeId` **must** be less than or equal to `VkPhysicalDeviceLimits::maxComputeWorkGroupSize`[2]

- **VUID-RuntimeSpirv-x-06432**
  In compute shaders using the **GLCompute Execution Model** the product of \( x \) size, \( y \) size, and \( z \) size in `LocalSize` or `LocalSizeId` **must** be less than or equal to `VkPhysicalDeviceLimits::maxComputeWorkGroupInvocations`

- **VUID-RuntimeSpirv-LocalSizeId-06434**
  If `Execution Mode LocalSizeId` is used, **maintenance4** **must** be enabled

- **VUID-RuntimeSpirv-maintenance4-06817**
  If `maintenance4` is not enabled, any `OpTypeVector` output interface variables **must** not have a higher `Component Count` than a matching `OpTypeVector` input interface variable

- **VUID-RuntimeSpirv-OpEntryPoint-08743**
  Any **user-defined variables** shared between the `OpEntryPoint` of two shader stages, and declared with `Input` as its `Storage Class` for the subsequent shader stage, **must** have all `Location` slots and `Component` words declared in the preceding shader stage's `OpEntryPoint` with `Output` as the `Storage Class`

- **VUID-RuntimeSpirv-OpEntryPoint-07754**
  Any **user-defined variables** between the `OpEntryPoint` of two shader stages **must** have the same type and width for each `Component`

- **VUID-RuntimeSpirv-OpVariable-08746**
  Any `OpVariable`, `Block`-decorated `OpTypeStruct`, or `Block`-decorated `OpTypeStruct` members shared between the `OpEntryPoint` of two shader stages **must** have matching decorations as defined in `interface matching`

- **VUID-RuntimeSpirv-Workgroup-06530**
  The sum of size in bytes for variables and `padding` in the `Workgroup Storage Class` in the **GLCompute Execution Model** **must** be less than or equal to `maxComputeSharedMemorySize`

- **VUID-RuntimeSpirv-shaderZeroInitializeWorkgroupMemory-06372**
  If `shaderZeroInitializeWorkgroupMemory` is not enabled, any `OpVariable` with `Workgroup` as its `Storage Class` **must** not have an `Initializer` operand

- **VUID-RuntimeSpirv-OpImage-06376**
  If an `OpImage*Gather` operation has an image operand of `Offset`, `ConstOffset`, or `ConstOffsets` the offset value **must** be greater than or equal to `minTexelGatherOffset`

- **VUID-RuntimeSpirv-OpImage-06377**
  If an `OpImage*Gather` operation has an image operand of `Offset`, `ConstOffset`, or `ConstOffsets` the offset value **must** be less than or equal to `maxTexelGatherOffset`

- **VUID-RuntimeSpirv-OpImageSample-06435**
  If an `OpImageSample*` or `OpImageFetch*` operation has an image operand of `ConstOffset` then the offset value **must** be greater than or equal to `minTexelOffset`
• VUID-RuntimeSpirv-OpImageSample-06436
  If an OpImageSample* or OpImageFetch* operation has an image operand of ConstOffset then the offset value must be less than or equal to maxTexelOffset.

• VUID-RuntimeSpirv-samples-08725
  If an OpTypeImage has an MS operand 0, its bound image must have been created with VkImageCreateInfo::samples as VK_SAMPLE_COUNT_1_BIT.

• VUID-RuntimeSpirv-samples-08726
  If an OpTypeImage has an MS operand 1, its bound image must not have been created with VkImageCreateInfo::samples as VK_SAMPLE_COUNT_1_BIT.

• VUID-RuntimeSpirv-SampleRateShading-06378
  If the subpass description contains VK_SUBPASS_DESCRIPTION_FRAGMENT_REGION_BIT_QCOM, then the SPIR-V fragment shader Capability SampleRateShading must not be enabled.

• VUID-RuntimeSpirv-SubgroupUniformControlFlowKHR-06379
  The Execution Mode SubgroupUniformControlFlowKHR must not be applied to an entry point unless shaderSubgroupUniformControlFlow is enabled and the corresponding shader stage bit is set in subgroup supportedStages and the entry point does not execute any invocation repack instructions.

• VUID-RuntimeSpirv-shaderEarlyAndLateFragmentTests-06767
  If shaderEarlyAndLateFragmentTests is not enabled, the EarlyAndLateFragmentTestsEXT Execution Mode must not be used.

• VUID-RuntimeSpirv-shaderEarlyAndLateFragmentTests-06768
  If shaderEarlyAndLateFragmentTests feature is not enabled, the StencilRefUnchangedFrontEXT Execution Mode must not be used.

• VUID-RuntimeSpirv-shaderEarlyAndLateFragmentTests-06769
  If shaderEarlyAndLateFragmentTests is not enabled, the StencilRefUnchangedBackEXT Execution Mode must not be used.

• VUID-RuntimeSpirv-shaderEarlyAndLateFragmentTests-06770
  If shaderEarlyAndLateFragmentTests is not enabled, the StencilRefGreaterFrontEXT Execution Mode must not be used.

• VUID-RuntimeSpirv-shaderEarlyAndLateFragmentTests-06771
  If shaderEarlyAndLateFragmentTests is not enabled, the StencilRefGreaterBackEXT Execution Mode must not be used.

• VUID-RuntimeSpirv-shaderEarlyAndLateFragmentTests-06772
  If shaderEarlyAndLateFragmentTests is not enabled, the StencilRefLessFrontEXT Execution Mode must not be used.

• VUID-RuntimeSpirv-shaderEarlyAndLateFragmentTests-06773
  If shaderEarlyAndLateFragmentTests is not enabled, the StencilRefLessBackEXT Execution Mode must not be used.

• VUID-RuntimeSpirv-OpImageWeightedSampleQCOM-06979
  If an OpImageWeightedSampleQCOM operation is used, then the Texture Sampled Image and Weight Image parameters must both be dynamically uniform for the quad.

• VUID-RuntimeSpirv-OpImageWeightedSampleQCOM-06980
  If an OpImageWeightedSampleQCOM operation is used, then the Weight Image parameter must.
be of Storage Class UniformConstant and type OpTypeImage with Depth=0, Dim=2D, Arrayed=1,
              MS=0, and Sampled=1

- VUID-RuntimeSpirv-OpImageWeightedSampleQCOM-06981
  If an OpImageWeightedSampleQCOM operation is used, then the Weight Image parameter must
  be decorated with WeightTextureQCOM

- VUID-RuntimeSpirv-OpImageBlockMatchSADQCOM-06982
  If an OpImageBlockMatchSADQCOM or OpImageBlockMatchSSDQCOM operation is used, then the
target sampled image, reference sampled image, and Block Size parameters must both be
dynamically uniform for the quad

- VUID-RuntimeSpirv-OpImageBlockMatchSSDQCOM-06983
  If an OpImageBlockMatchSSDQCOM or OpImageBlockMatchSADQCOM operation is used, then target
  sampled image and reference sampled image parameters must be of storage class
  UniformConstant and type OpTypeImage with Depth=0, Dim=2D, Arrayed=0, MS=0, and Sampled=1

- VUID-RuntimeSpirv-OpImageBlockMatchSSDQCOM-06984
  If an OpImageBlockMatchSSDQCOM or OpImageBlockMatchSADQCOM operation is used, then the
target sampled image and reference sampled image parameters must be decorated with
  BlockMatchTextureQCOM

- VUID-RuntimeSpirv-OpImageBlockMatchSSDQCOM-06985
  If an OpImageBlockMatchSSDQCOM or OpImageBlockMatchSADQCOM operation is used, then target
  sampled image and reference sampled image parameters must have been created using an
  identical sampler object

- VUID-RuntimeSpirv-OpImageBlockMatchSSDQCOM-06986
  If an OpImageBlockMatchSSDQCOM or OpImageBlockMatchSADQCOM operation is used, then target
  sampled image and reference sampled image parameters must have been created with a
  sampler object with unnormalizedCoordinates equal to VK_TRUE

- VUID-RuntimeSpirv-OpImageBlockMatchSSDQCOM-06987
  If an OpImageBlockMatchSSDQCOM or OpImageBlockMatchSADQCOM operation is used, then target
  sampled image and reference sampled image parameters must have been created with a
  sampler object with unnormalizedCoordinates equal to VK_TRUE

- VUID-RuntimeSpirv-OpImageBlockMatchSSDQCOM-06988
  If an OpImageBlockMatchSSDQCOM or OpImageBlockMatchSADQCOM operation is used, then Block
  Size less than or equal to maxBlockMatchRegion

- VUID-RuntimeSpirv-OpImageBoxFilterQCOM-06989
  If an OpImageBoxFilterQCOM operation is used, then Box Size.y must be equal to or greater
  than 1.0 and less than or equal to maxBoxFilterBlockSize.height

- VUID-RuntimeSpirv-OpImageBoxFilterQCOM-06990
  If an OpImageBoxFilterQCOM operation is used, then Sampled Texture Image and Box Size
  parameters must be dynamically uniform

- VUID-RuntimeSpirv-OpEntryPoint-08727
  Each OpEntryPoint must not have more than one variable decorated with InputAttachmentIndex per image aspect of the attachment image bound to it, either
  explicitly or implicitly as described by input attachment interface

- VUID-RuntimeSpirv-shaderTileImageColorReadAccess-08728
If shaderTileImageColorReadAccess is not enabled, OpColorAttachmentReadEXT operation must not be used

• VUID-RuntimeSpirv-shaderTileImageDepthReadAccess-08729
  If shaderTileImageDepthReadAccess is not enabled, OpDepthAttachmentReadEXT operation must not be used

• VUID-RuntimeSpirv-shaderTileImageStencilReadAccess-08730
  If shaderTileImageStencilReadAccess is not enabled, OpStencilAttachmentReadEXT operation must not be used

• VUID-RuntimeSpirv-minSampleShading-08731
  If sample shading is enabled and minSampleShading is 1.0, the sample operand of any OpColorAttachmentReadEXT, OpDepthAttachmentReadEXT, or OpStencilAttachmentReadEXT operation must evaluate to the value of the coverage index for any given fragment invocation

• VUID-RuntimeSpirv-minSampleShading-08732
  If sample shading is enabled and any of the OpColorAttachmentReadEXT, OpDepthAttachmentReadEXT, or OpStencilAttachmentReadEXT operations are used, then minSampleShading must be 1.0

• VUID-RuntimeSpirv-MeshEXT-09218
  In mesh shaders using the MeshEXT or MeshNV Execution Model and the OutputPoints Execution Mode, if maintenance5 is not enabled, and if the number of output points is greater than 0, a PointSize decorated variable must be written to for each output point

• VUID-RuntimeSpirv-maintenance5-09190
  If maintenance5 is enabled and a PointSize decorated variable is written to, all execution paths must write to a PointSize decorated variable

• VUID-RuntimeSpirv-ShaderEnqueueAMDX-09191
  The ShaderEnqueueAMDX capability must only be used in shaders with the GLCompute execution model

• VUID-RuntimeSpirv-NodePayloadAMDX-09192
  Variables in the NodePayloadAMDX storage class must only be declared in the GLCompute execution model

• VUID-RuntimeSpirv-maxExecutionGraphShaderPayloadSize-09193
  Variables declared in the NodePayloadAMDX storage class must not be larger than the maxExecutionGraphShaderPayloadSize limit

• VUID-RuntimeSpirv-maxExecutionGraphShaderPayloadSize-09194
  Variables declared in the NodeOutputPayloadAMDX storage class must not be larger than the maxExecutionGraphShaderPayloadSize limit

• VUID-RuntimeSpirv-maxExecutionGraphShaderPayloadSize-09195
  For a given entry point, the sum of the size of any variable in the NodePayloadAMDX storage class, and the combined size of all statically initialized variables in the NodeOutputPayloadAMDX storage class must not be greater than maxExecutionGraphShaderPayloadSize

• VUID-RuntimeSpirv-maxExecutionGraphShaderPayloadCount-09196
  Shaders must not statically initialize more than maxExecutionGraphShaderPayloadCount
variables in the `NodeOutputPayloadAMDX` storage class

- **VUID-RuntimeSpirv-maxExecutionGraphShaderOutputNodes-09197**
  Shaders **must** not include more than `maxExecutionGraphShaderOutputNodes` instances of `OpInitializeNodePayloadsAMDX`

- **VUID-RuntimeSpirv-OpImageBlockMatchWindow-09219**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` operation is used, then the target sampled image, reference sampled image, and Block Size parameters **must** both be *dynamically uniform* for the quad

- **VUID-RuntimeSpirv-OpImageBlockMatchWindow-09220**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` operation is used, then target sampled image and reference sampled image parameters **must** be of storage class `UniformConstant` and type `OpTypeImage` with `Depth=0, Dim=2D, Arrayed=0, MS=0, and Sampled=1`

- **VUID-RuntimeSpirv-OpImageBlockMatchWindow-09221**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` operation is used, then target sampled image and reference sampled image parameters **must** have been created using an identical sampler object

- **VUID-RuntimeSpirv-OpImageBlockMatchWindow-09222**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` operation is used, then target sampled image and reference sampled image parameters **must** have been created with a sampler object with `unnormalizedCoordinates equal to VK_TRUE`

- **VUID-RuntimeSpirv-OpImageBlockMatchWindow-09223**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` operation is used, then target sampled image and reference sampled image parameters **must** have been created with sampler object with `unnormalizedCoordinates equal to VK_TRUE`

- **VUID-RuntimeSpirv-OpImageBlockMatchWindow-09224**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` operation is used, then target sampled image and reference sampled image parameters **must** have been created with `Block Match Texture QCOM`

- **VUID-RuntimeSpirv-maxBlockMatchRegion-09225**
  If a `OpImageBlockMatchWindow*QCOM` or `OpImageBlockMatchGather*QCOM` operation is used, then Block Size less than or equal to `maxBlockMatchRegion`

- **VUID-RuntimeSpirv-pNext-09226**
  If a `OpImageBlockMatchWindow*QCOM` operation is used, then target sampled image **must** have been created using a sampler object that included `VkSamplerBlockMatchWindowCreateInfoQCOM` in the `pNext` chain.

**Precision and Operation of SPIR-V Instructions**

The following rules apply to half, single, and double-precision floating point instructions:

- Positive and negative infinities and positive and negative zeros are generated as dictated by [IEEE 754](https://en.wikipedia.org/wiki/IEEE_754), but subject to the precisions allowed in the following table.

- Dividing a non-zero by a zero results in the appropriately signed [IEEE 754](https://en.wikipedia.org/wiki/IEEE_754) infinity.
• Signaling NaNs are not required to be generated and exceptions are never raised. Signaling NaNs may be converted to quiet NaNs values by any floating point instruction.

• By default, the implementation may perform optimizations on half, single, or double-precision floating-point instructions that ignore sign of a zero, or assume that arguments and results are not NaNs or infinities. If the entry point is declared with the SignedZeroInfNanPreserve Execution Mode, then NaNs, infinities, and the sign of zero must not be ignored.


• Denormalized values are supported.

  ◦ By default, any half, single, or double-precision denormalized value input into a shader or potentially generated by any instruction (except those listed above) or any extended instructions for GLSL in a shader may be flushed to zero.

  ◦ If the entry point is declared with the DenormFlushToZero Execution Mode then for the affected instructions the denormalized result must be flushed to zero and the denormalized operands may be flushed to zero. Denormalized values obtained via unpacking an integer into a vector of values with smaller bit width and interpreting those values as floating-point numbers must be flushed to zero.


The precision of double-precision instructions is at least that of single precision.

The precision of individual operations is defined in Precision of Individual Operations. Subject to the constraints below, however, implementations may reorder or combine operations, resulting in expressions exhibiting different precisions than might be expected from the constituent operations.

**Evaluation of Expressions**

Implementations may rearrange floating-point operations using any of the mathematical properties governing the expressions in precise arithmetic, even where the floating-point operations do not share these properties. This includes, but is not limited to, associativity and distributivity, and may involve a different number of rounding steps than would occur if the operations were not rearranged. In shaders that use the SignedZeroInfNanPreserve Execution Mode the values must be preserved if they are generated after any rearrangement but the Execution Mode does not change which rearrangements are valid. This rearrangement can be prevented for particular operations by using the NoContraction decoration.

**Note**

For example, in the absence of the NoContraction decoration implementations are allowed to implement \( a + b - a \) and \( \frac{a \times b}{a} \) as \( b \). The SignedZeroInfNanPreserve does not prevent these transformations, even though they may overflow to infinity or NaN when evaluated in floating-point.

If the NoContraction decoration is applied then operations may not be rearranged, so, for example, \( a + a - a \) must account for possible overflow to infinity. If infinities are not preserved then the expression may be replaced with \( a \), since the replacement is exact when overflow does not occur and infinities may be replaced with undefined values. If both NoContraction and SignedZeroInfNanPreserve are used then the result must be infinity for sufficiently large \( a \).

**Precision of Individual Operations**

The precision of individual operations is defined either in terms of rounding (correctly rounded), as an error bound in ULP, or as inherited from a formula as follows:

**Correctly Rounded**

Operations described as “correctly rounded” will return the infinitely precise result, \( x \), rounded so as to be representable in floating-point. The rounding mode is not specified, unless the entry point is declared with the RoundingModeRTE or the RoundingModeRTZ Execution Mode. These execution modes affect only correctly rounded SPIR-V instructions. These execution modes do not affect OpQuantizeToF16. If the rounding mode is not specified then this rounding is implementation specific, subject to the following rules. If \( x \) is exactly representable then \( x \) will be returned. Otherwise, either the floating-point value closest to and no less than \( x \) or the value closest to and no greater than \( x \) will be returned.
Where an error bound of \( n \) ULP (units in the last place) is given, for an operation with infinitely precise result \( x \) the value returned \textbf{must} be in the range \([x - n \times \text{ulp}(x), x + n \times \text{ulp}(x)]\). The function \text{ulp}(x) is defined as follows:

If there exist non-equal, finite floating-point numbers \( a \) and \( b \) such that \( a \leq x \leq b \) then \text{ulp}(x) is the minimum possible distance between such numbers, \( \text{ulp}(x) = \min_a, b |b - a| \). If such numbers do not exist then \text{ulp}(x) is defined to be the difference between the two non-equal, finite floating-point numbers nearest to \( x \).

Where the range of allowed return values includes any value of magnitude larger than that of the largest representable finite floating-point number, operations \textbf{may}, additionally, return either an infinity of the appropriate sign or the finite number with the largest magnitude of the appropriate sign. If the infinitely precise result of the operation is not mathematically defined then the value returned is undefined.

\textit{Inherited From …}

Where an operation’s precision is described as being inherited from a formula, the result returned \textbf{must} be at least as accurate as the result of computing an approximation to \( x \) using a formula equivalent to the given formula applied to the supplied inputs. Specifically, the formula given may be transformed using the mathematical associativity, commutativity and distributivity of the operators involved to yield an equivalent formula. The SPIR-V precision rules, when applied to each such formula and the given input values, define a range of permitted values. If NaN is one of the permitted values then the operation may return any result, otherwise let the largest permitted value in any of the ranges be \( F_{\text{max}} \) and the smallest be \( F_{\text{min}} \). The operation \textbf{must} return a value in the range \([x - E, x + E]\) where \( E = \max(|x - F_{\text{min}}|, |x - F_{\text{max}}|) \). If the entry point is declared with the \texttt{DenormFlushToZero} execution mode, then any intermediate denormal value(s) while evaluating the formula \textbf{may} be flushed to zero. Denormal final results \textbf{must} be flushed to zero. If the entry point is declared with the \texttt{DenormPreserve Execution Mode}, then denormals \textbf{must} be preserved throughout the formula.

For half- (16 bit) and single- (32 bit) precision instructions, precisions are \textbf{required} to be at least as follows:

\begin{table}[h]
\centering
\caption{Precision of core SPIR-V Instructions}
\begin{tabular}{|l|l|l|}
\hline
\textbf{Instruction} & \textbf{Single precision, unless decorated with RelaxedPrecision} & \textbf{Half precision} \\
\hline
\texttt{OpFAdd} & Correctly rounded. &  \\
\texttt{OpFSub} & Correctly rounded. &  \\
\texttt{OpDot(x, y)} & Inherited from \( \sum_{i=0}^{n-1} x_i \times y_i \). &  \\
\texttt{OpFOrdEqual, OpFUnordEqual} & Correct result. &  \\
\hline
\end{tabular}
\end{table}
<table>
<thead>
<tr>
<th>Instruction</th>
<th>Single precision, unless decorated with RelaxedPrecision</th>
<th>Half precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>OpFOrdLessThan, OpFUnordLessThan</td>
<td>Correct result.</td>
<td></td>
</tr>
<tr>
<td>OpFOrdGreaterThan, OpFUnordGreaterThan</td>
<td>Correct result.</td>
<td></td>
</tr>
<tr>
<td>OpFOrdGreaterThanEqual, OpFUnordGreaterThanEqual</td>
<td>Correct result.</td>
<td></td>
</tr>
<tr>
<td>OpFDiv(x,y)</td>
<td>2.5 ULP for $</td>
<td>y</td>
</tr>
<tr>
<td>OpFRem(x,y)</td>
<td>Inherited from $x - y \times \text{trunc}(x/y)$.</td>
<td></td>
</tr>
<tr>
<td>OpFMod(x,y)</td>
<td>Inherited from $x - y \times \text{floor}(x/y)$.</td>
<td></td>
</tr>
<tr>
<td>conversions between types</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
</tbody>
</table>

**Note**

The OpFRem and OpFMod instructions use cheap approximations of remainder, and the error can be large due to the discontinuity in trunc() and floor(). This can produce mathematically unexpected results in some cases, such as FMod(x,x) computing x rather than 0, and can also cause the result to have a different sign than the infinitely precise result.

Table 91. Precision of GLSL.std.450 Instructions

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Single precision, unless decorated with RelaxedPrecision</th>
<th>Half precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>fma()</td>
<td>Inherited from OpFMul followed by OpFAdd.</td>
<td></td>
</tr>
<tr>
<td>exp(x), exp2(x)</td>
<td>$3 + 2 \times</td>
<td>x</td>
</tr>
<tr>
<td>log(), log2()</td>
<td>3 ULP outside the range $[0.5, 2.0]$. Absolute error $&lt; 2^{-21}$ inside the range $[0.5, 2.0]$.</td>
<td>3 ULP outside the range $[0.5, 2.0]$. Absolute error $&lt; 2^{-7}$ inside the range $[0.5, 2.0]$.</td>
</tr>
<tr>
<td>pow(x, y)</td>
<td>Inherited from exp2($y \times \log2(x)$).</td>
<td></td>
</tr>
<tr>
<td>sqrt()</td>
<td>Inherited from 1.0 / inversesqrt().</td>
<td></td>
</tr>
<tr>
<td>inversesqrt()</td>
<td>2 ULP.</td>
<td></td>
</tr>
<tr>
<td>radians(x)</td>
<td>Inherited from $x \times C_{\frac{\pi}{180}}$, where $C_{\frac{\pi}{180}}$ is a correctly rounded approximation to $\frac{\pi}{180}$.</td>
<td></td>
</tr>
<tr>
<td>degrees(x)</td>
<td>Inherited from $x \times C_{180 \cdot \frac{\pi}{180}}$, where $C_{180 \cdot \frac{\pi}{180}}$ is a correctly rounded approximation to $\frac{180}{\pi}$.</td>
<td></td>
</tr>
<tr>
<td>Instruction</td>
<td>Single precision, unless decorated with RelaxedPrecision</td>
<td>Half precision</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------------------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>sin()</td>
<td>Absolute error $\leq 2^{-11}$ inside the range $[-n, n]$.</td>
<td>Absolute error $\leq 2^{-7}$ inside the range $[-n, n]$.</td>
</tr>
<tr>
<td>cos()</td>
<td>Absolute error $\leq 2^{-11}$ inside the range $[-n, n]$.</td>
<td>Absolute error $\leq 2^{-7}$ inside the range $[-n, n]$.</td>
</tr>
<tr>
<td>tan()</td>
<td>Inherited from $\frac{\sin()}{\cos()}$.</td>
<td></td>
</tr>
<tr>
<td>asin(x)</td>
<td>Inherited from $\arctan2(x, \sqrt{1.0 - x \times x})$.</td>
<td></td>
</tr>
<tr>
<td>acos(x)</td>
<td>Inherited from $\arctan2(\sqrt{1.0 - x \times x}, x)$.</td>
<td></td>
</tr>
<tr>
<td>atan(), atan2()</td>
<td>$4096$ ULP</td>
<td>$5$ ULP.</td>
</tr>
<tr>
<td>sinh(x)</td>
<td>Inherited from $(e^x - e^{-x}) \times 0.5$.</td>
<td></td>
</tr>
<tr>
<td>cosh(x)</td>
<td>Inherited from $(e^x + e^{-x}) \times 0.5$.</td>
<td></td>
</tr>
<tr>
<td>tanh()</td>
<td>Inherited from $\frac{\sinh()}{\cosh()}$</td>
<td></td>
</tr>
<tr>
<td>asinh(x)</td>
<td>Inherited from $\log(x + \sqrt{x \times x + 1.0})$.</td>
<td></td>
</tr>
<tr>
<td>acosh(x)</td>
<td>Inherited from $\log(x + \sqrt{x \times x - 1.0})$.</td>
<td></td>
</tr>
<tr>
<td>tanh()</td>
<td>Inherited from $\log\left(\frac{1 + \sqrt{1 + 4x}}{2}\right) \times 0.5$.</td>
<td></td>
</tr>
<tr>
<td>frexp()</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>ldexp()</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>length(x)</td>
<td>Inherited from $\sqrt{\text{dot}(x, x)}$.</td>
<td></td>
</tr>
<tr>
<td>distance(x, y)</td>
<td>Inherited from $\text{length}(x - y)$.</td>
<td></td>
</tr>
<tr>
<td>cross(x, y)</td>
<td>Inherited from $\text{OpSub}(\text{OpFMul}, \text{OpFMul})$.</td>
<td></td>
</tr>
<tr>
<td>normalize(x)</td>
<td>Inherited from $x \times \text{inversesqrt}(\text{dot}(x, x))$.</td>
<td></td>
</tr>
<tr>
<td>faceforward(N, I, NRef)</td>
<td>Inherited from $\text{dot}(N\text{Ref}, I) &lt; 0.0 ? N : -N$.</td>
<td></td>
</tr>
<tr>
<td>reflect(x, y)</td>
<td>Inherited from $x - 2.0 \times \text{dot}(y, x) \times y$.</td>
<td></td>
</tr>
<tr>
<td>refract(I, N, eta)</td>
<td>Inherited from $k &lt; 0.0 ? 0.0 : \text{eta} \times 1 - \text{eta} \times \text{dot}(N, I) + \sqrt{k}) \times N$, where $k = 1 - \text{eta} \times \text{eta} \times (1.0 - \text{dot}(N, I) \times \text{dot}(N, I))$.</td>
<td></td>
</tr>
<tr>
<td>round</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>roundEven</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>trunc</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>fabs</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>fsign</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>floor</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>ceil</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>fract</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>modf</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
</tbody>
</table>
### Instruction

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Single precision, unless decorated with RelaxedPrecision</th>
<th>Half precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>fmin</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>fmax</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>fclamp</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>fmix(x, y, a)</td>
<td>Inherited from $x \times (1.0 - a) + y \times a$.</td>
<td></td>
</tr>
<tr>
<td>step</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>smoothStep(edge0, edge1, x)</td>
<td>Inherited from $t \times t \times (3.0 - 2.0 \times t)$, where $t = \text{clamp}(\frac{x - \text{edge0}}{\text{edge1} - \text{edge0}}, 0.0, 1.0)$.</td>
<td></td>
</tr>
<tr>
<td>nmin</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>nmax</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
<tr>
<td>nclamp</td>
<td>Correctly rounded.</td>
<td></td>
</tr>
</tbody>
</table>

GLSL.std.450 extended instructions specifically defined in terms of the above instructions inherit the above errors. GLSL.std.450 extended instructions not listed above and not defined in terms of the above have undefined precision.

For the OpSRem and OpSMod instructions, if either operand is negative the result is undefined.

#### Note

While the OpSRem and OpSMod instructions are supported by the Vulkan environment, they require non-negative values and thus do not enable additional functionality beyond what OpUMod provides.

OpCooperativeMatrixMulAddNV performs its operations in an implementation-dependent order and internal precision.

OpCooperativeMatrixMulAddKHR performs its operations in an implementation-dependent order and internal precision.

### Signedness of SPIR-V Image Accesses

SPIR-V associates a signedness with all integer image accesses. This is required in certain parts of the SPIR-V and the Vulkan image access pipeline to ensure defined results. The signedness is determined from a combination of the access instruction's Image Operands and the underlying image's Sampled Type as follows:

1. If the instruction's Image Operands contains the SignExtend operand then the access is signed.
2. If the instruction's Image Operands contains the ZeroExtend operand then the access is unsigned.
3. Otherwise, the image accesses signedness matches that of the Sampled Type of the OpTypeImage being accessed.
Image Format and Type Matching

When specifying the Image Format of an OpTypeImage, the converted bit width and type, as shown in the table below, must match the Sampled Type. The signedness must match the signedness of any access to the image.

Note
Formatted accesses are always converted from a shader readable type to the resource's format or vice versa via Format Conversion for reads and Texel Output Format Conversion for writes. As such, the bit width and format below do not necessarily match 1:1 with what might be expected for some formats.

For a given Image Format, the Sampled Type must be the type described in the Type column of the below table, with its Literal Width set to that in the Bit Width column. Every access that is made to the image must have a signedness equal to that in the Signedness column (where applicable).

<table>
<thead>
<tr>
<th>Image Format</th>
<th>Type-Declaration instructions</th>
<th>Bit Width</th>
<th>Signedness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>Any</td>
<td>Any</td>
<td>Any</td>
</tr>
<tr>
<td>Rgba32f</td>
<td>OpTypeFloat</td>
<td>32</td>
<td>N/A</td>
</tr>
<tr>
<td>Rg32f</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R32f</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rgba16f</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rg16f</td>
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<td></td>
<td></td>
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<tr>
<td>R16f</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rgba16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rg16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rgba16Snorm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rg16Snorm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R16Snorm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rgb10A2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R11fG11fB10f</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rgba8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rg8</td>
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<td>R8</td>
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</tr>
<tr>
<td>Rgba8Snorm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rg8Snorm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R8Snorm</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Type-Declaration instructions**

<table>
<thead>
<tr>
<th>SPIR-V Image Format</th>
<th>Type-Declaration instructions</th>
<th>Bit Width</th>
<th>Signedness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rgba32i</td>
<td>OpTypeInt</td>
<td>32</td>
<td>1</td>
</tr>
<tr>
<td>Rg32i</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R32i</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rgba16i</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rg16i</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R16i</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rgba8i</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rg8i</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R8i</td>
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</tr>
<tr>
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<td></td>
<td>0</td>
</tr>
<tr>
<td>Rg32ui</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R32ui</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rgba16ui</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rg16ui</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R16ui</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rgba8ui</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rg8ui</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R8ui</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R64i</td>
<td>OpTypeInt</td>
<td>64</td>
<td>1</td>
</tr>
<tr>
<td>R64ui</td>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

The SPIR-V Type is defined by an instruction in SPIR-V, declared with the Type-Declaration Instruction, Bit Width, and Signedness from above.

### Compatibility Between SPIR-V Image Formats And Vulkan Formats

SPIR-V Image Format values are compatible with VkFormat values as defined below:

Table 92. SPIR-V and Vulkan Image Format Compatibility

<table>
<thead>
<tr>
<th>SPIR-V Image Format</th>
<th>Compatible Vulkan Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>Any</td>
</tr>
<tr>
<td>R8</td>
<td>VK_FORMAT_R8_UNORM</td>
</tr>
<tr>
<td>R8Snorm</td>
<td>VK_FORMAT_R8_SNORM</td>
</tr>
<tr>
<td>R8ui</td>
<td>VK_FORMAT_R8_UINT</td>
</tr>
<tr>
<td>R8i</td>
<td>VK_FORMAT_R8_SINT</td>
</tr>
<tr>
<td>Rg8</td>
<td>VK_FORMAT_R8G8_UNORM</td>
</tr>
<tr>
<td>Rg8Snorm</td>
<td>VK_FORMAT_R8G8_SNORM</td>
</tr>
<tr>
<td>SPIR-V Image Format</td>
<td>Compatible Vulkan Format</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Rg8ui</td>
<td>VK_FORMAT_R8G8_UINT</td>
</tr>
<tr>
<td>Rg8i</td>
<td>VK_FORMAT_R8G8_SINT</td>
</tr>
<tr>
<td>Rgba8</td>
<td>VK_FORMAT_R8G8B8B8_PIX</td>
</tr>
<tr>
<td>Rgba8Snorm</td>
<td>VK_FORMAT_R8G8B8B8_SNORM</td>
</tr>
<tr>
<td>Rgba8ui</td>
<td>VK_FORMAT_R8G8B8B8_PIX</td>
</tr>
<tr>
<td>Rgba8i</td>
<td>VK_FORMAT_R8G8B8B8_PIX</td>
</tr>
<tr>
<td>Rgb10A2</td>
<td>VK_FORMAT_A2B10G10R10_PIX</td>
</tr>
<tr>
<td>Rgb10A2ui</td>
<td>VK_FORMAT_A2B10G10R10_PIX</td>
</tr>
<tr>
<td>R16</td>
<td>VK_FORMAT_R16_PIX</td>
</tr>
<tr>
<td>R16Snorm</td>
<td>VK_FORMAT_R16_PIX</td>
</tr>
<tr>
<td>R16ui</td>
<td>VK_FORMAT_R16_PIX</td>
</tr>
<tr>
<td>R16i</td>
<td>VK_FORMAT_R16_PIX</td>
</tr>
<tr>
<td>R16f</td>
<td>VK_FORMAT_R16_PIX</td>
</tr>
<tr>
<td>Rg16</td>
<td>VK_FORMAT_R16_PIX</td>
</tr>
<tr>
<td>Rg16Snorm</td>
<td>VK_FORMAT_R16_PIX</td>
</tr>
<tr>
<td>Rg16ui</td>
<td>VK_FORMAT_R16_PIX</td>
</tr>
<tr>
<td>Rg16i</td>
<td>VK_FORMAT_R16_PIX</td>
</tr>
<tr>
<td>Rg16f</td>
<td>VK_FORMAT_R16_PIX</td>
</tr>
<tr>
<td>Rgba16</td>
<td>VK_FORMAT_R16B16B16B16_PIX</td>
</tr>
<tr>
<td>Rgba16Snorm</td>
<td>VK_FORMAT_R16B16B16B16_SNORM</td>
</tr>
<tr>
<td>Rgba16ui</td>
<td>VK_FORMAT_R16B16B16B16_PIX</td>
</tr>
<tr>
<td>Rgba16i</td>
<td>VK_FORMAT_R16B16B16B16_PIX</td>
</tr>
<tr>
<td>Rgba16f</td>
<td>VK_FORMAT_R16B16B16B16_PIX</td>
</tr>
<tr>
<td>R32ui</td>
<td>VK_FORMAT_R32_PIX</td>
</tr>
<tr>
<td>R32i</td>
<td>VK_FORMAT_R32_PIX</td>
</tr>
<tr>
<td>R32f</td>
<td>VK_FORMAT_R32_PIX</td>
</tr>
<tr>
<td>Rg32ui</td>
<td>VK_FORMAT_R32G32_PIX</td>
</tr>
<tr>
<td>Rg32i</td>
<td>VK_FORMAT_R32G32_PIX</td>
</tr>
<tr>
<td>Rg32f</td>
<td>VK_FORMAT_R32G32_PIX</td>
</tr>
<tr>
<td>Rgba32ui</td>
<td>VK_FORMAT_R32G32B32B32_PIX</td>
</tr>
<tr>
<td>Rgba32i</td>
<td>VK_FORMAT_R32G32B32B32_PIX</td>
</tr>
<tr>
<td>Rgba32f</td>
<td>VK_FORMAT_R32G32B32B32_PIX</td>
</tr>
<tr>
<td>R64ui</td>
<td>VK_FORMAT_R64_PIX</td>
</tr>
<tr>
<td>R64i</td>
<td>VK_FORMAT_R64_PIX</td>
</tr>
<tr>
<td>R11fG11fB10f</td>
<td>VK_FORMAT_B10G11R11_UFLOAT_PACK32</td>
</tr>
</tbody>
</table>

**Ray Query Precision and Operation**

The values returned by `OpRayQueryGetIntersectionTriangleVertexPositionsKHR` are transformed by...
the geometry transform, which is performed at standard floating point precision, but without a specifically defined order of floating point operations to perform the matrix multiplication.
Appendix B: Memory Model

**Note**
This memory model describes synchronizations provided by all implementations; however, some of the synchronizations defined require extra features to be supported by the implementation. See `VkPhysicalDeviceVulkanMemoryModelFeatures`.

**Agent**

*Operation* is a general term for any task that is executed on the system.

**Note**
An operation is by definition something that is executed. Thus if an instruction is skipped due to control flow, it does not constitute an operation.

Each operation is executed by a particular *agent*. Possible agents include each shader invocation, each host thread, and each fixed-function stage of the pipeline.

**Memory Location**

A *memory location* identifies unique storage for 8 bits of data. Memory operations access a *set of memory locations* consisting of one or more memory locations at a time, e.g. an operation accessing a 32-bit integer in memory would read/write a set of four memory locations. Memory operations that access whole aggregates *may* access any padding bytes between elements or members, but no padding bytes at the end of the aggregate. Two sets of memory locations *overlap* if the intersection of their sets of memory locations is non-empty. A memory operation *must* not affect memory at a memory location not within its set of memory locations.

Memory locations for buffers and images are explicitly allocated in `VkDeviceMemory` objects, and are implicitly allocated for SPIR-V variables in each shader invocation.

Variables with *Workgroup* storage class that point to a block-decorated type share a set of memory locations.

**Allocation**

The values stored in newly allocated memory locations are determined by a SPIR-V variable’s initializer, if present, or else are undefined. At the time an allocation is created there have been no memory operations to any of its memory locations. The initialization is not considered to be a memory operation.

**Note**
For tessellation control shader output variables, a consequence of initialization not being considered a memory operation is that some implementations may need to...
Insert a barrier between the initialization of the output variables and any reads of those variables.

**Memory Operation**

For an operation \( A \) and memory location \( M \):

- \( A \) reads \( M \) if and only if the data stored in \( M \) is an input to \( A \).
- \( A \) writes \( M \) if and only if the data output from \( A \) is stored to \( M \).
- \( A \) accesses \( M \) if and only if it either reads or writes (or both) \( M \).

*Note*

A write whose value is the same as what was already in those memory locations is still considered to be a write and has all the same effects.

**Reference**

A *reference* is an object that a particular agent can use to access a set of memory locations. On the host, a reference is a host virtual address. On the device, a reference is:

- The descriptor that a variable is bound to, for variables in Image, Uniform, or StorageBuffer storage classes. If the variable is an array (or array of arrays, etc.) then each element of the array may be a unique reference.
- The address range for a buffer in PhysicalStorageBuffer storage class, where the base of the address range is queried with \( \text{vkGetBufferDeviceAddress} \) and the length of the range is the size of the buffer.
- A single common reference for all variables with Workgroup storage class that point to a block-decorated type.
- The variable itself for non-block-decorated type variables in Workgroup storage class.
- The variable itself for variables in other storage classes.

Two memory accesses through distinct references may require availability and visibility operations as defined below.

**Program-Order**

A *dynamic instance* of an instruction is defined in SPIR-V (https://registry.khronos.org/spir-v/specs/unified1/SPIRV.html#DynamicInstance) as a way of referring to a particular execution of a static instruction. Program-order is an ordering on dynamic instances of instructions executed by a single shader invocation:

- (Basic block): If instructions \( A \) and \( B \) are in the same basic block, and \( A \) is listed in the module before \( B \), then the \( n \)'th dynamic instance of \( A \) is program-ordered before the \( n \)'th dynamic instance of \( B \).
• (Branch): The dynamic instance of a branch or switch instruction is program-ordered before the
dynamic instance of the OpLabel instruction to which it transfers control.

• (Call entry): The dynamic instance of an OpFunctionCall instruction is program-ordered before
the dynamic instances of the OpFunctionParameter instructions and the body of the called
function.

• (Call exit): The dynamic instance of the instruction following an OpFunctionCall instruction is
program-ordered after the dynamic instance of the return instruction executed by the called
function.

• (Transitive Closure): If dynamic instance A of any instruction is program-ordered before
dynamic instance B of any instruction and B is program-ordered before dynamic instance C of
any instruction then A is program-ordered before C.

• (Complete definition): No other dynamic instances are program-ordered.

For instructions executed on the host, the source language defines the program-order relation (e.g.
as “sequenced-before”).

**Shader Call Related**

Shader-call-related is an equivalence relation on invocations defined as the symmetric and
transitive closure of:

• A is shader-call-related to B if A is created by an invocation repack instruction executed by B.

**Shader Call Order**

Shader-call-order is a partial order on dynamic instances of instructions executed by invocations
that are shader-call-related:

• (Program order): If dynamic instance A is program-ordered before B, then A is shader-call-ordered before B.

• (Shader call entry): If A is a dynamic instance of an invocation repack instruction and B is a
dynamic instance executed by an invocation that is created by A, then A is shader-call-ordered before B.

• (Shader call exit): If A is a dynamic instance of an invocation repack instruction, B is the next
dynamic instance executed by the same invocation, and C is a dynamic instance executed by an
invocation that is created by A, then C is shader-call-ordered before B.

• (Transitive closure): If A is shader-call-ordered-before B and B is shader-call-ordered-before C,
then A is shader-call-ordered-before C.

• (Complete definition): No other dynamic instances are shader-call-ordered.

**Scope**

Atomic and barrier instructions include scopes which identify sets of shader invocations that must
obey the requested ordering and atomicity rules of the operation, as defined below.
The various scopes are described in detail in the Shaders chapter.

Atomic Operation

An atomic operation on the device is any SPIR-V operation whose name begins with \texttt{OpAtomic}. An atomic operation on the host is any operation performed with an \texttt{std::atomic} typed object.

Each atomic operation has a memory scope and a semantics. Informally, the scope determines which other agents it is atomic with respect to, and the semantics constrains its ordering against other memory accesses. Device atomic operations have explicit scopes and semantics. Each host atomic operation implicitly uses the \texttt{CrossDevice} scope, and uses a memory semantics equivalent to a C++ \texttt{std::memory\_order} value of relaxed, acquire, release, acq\_rel, or seq\_cst.

Two atomic operations A and B are potentially-mutually-ordered if and only if all of the following are true:

- They access the same set of memory locations.
- They use the same reference.
- A is in the instance of B's memory scope.
- B is in the instance of A's memory scope.
- A and B are not the same operation (irreflexive).

Two atomic operations A and B are mutually-ordered if and only if they are potentially-mutually-ordered and any of the following are true:

- A and B are both device operations.
- A and B are both host operations.
- A is a device operation, B is a host operation, and the implementation supports concurrent host- and device-atomics.

\textbf{Note}

If two atomic operations are not mutually-ordered, and if their sets of memory locations overlap, then each must be synchronized against the other as if they were non-atomic operations.

Scoped Modification Order

For a given atomic write A, all atomic writes that are mutually-ordered with A occur in an order known as A's scoped modification order. A's scoped modification order relates no other operations.

\textbf{Note}

Invocations outside the instance of A's memory scope may observe the values at A's set of memory locations becoming visible to it in an order that disagrees with the scoped modification order.
Note
It is valid to have non-atomic operations or atomics in a different scope instance to the same set of memory locations, as long as they are synchronized against each other as if they were non-atomic (if they are not, it is treated as a data race). That means this definition of A’s scoped modification order could include atomic operations that occur much later, after intervening non-atomics. That is a bit non-intuitive, but it helps to keep this definition simple and non-circular.

Memory Semantics

Non-atomic memory operations, by default, may be observed by one agent in a different order than they were written by another agent.

Atomics and some synchronization operations include memory semantics, which are flags that constrain the order in which other memory accesses (including non-atomic memory accesses and availability and visibility operations) performed by the same agent can be observed by other agents, or can observe accesses by other agents.

Device instructions that include semantics are OpAtomic*, OpControlBarrier, OpMemoryBarrier, and OpMemoryNamedBarrier. Host instructions that include semantics are some std::atomic methods and memory fences.

SPIR-V supports the following memory semantics:

- Relaxed: No constraints on order of other memory accesses.
- Acquire: A memory read with this semantic performs an acquire operation. A memory barrier with this semantic is an acquire barrier.
- Release: A memory write with this semantic performs a release operation. A memory barrier with this semantic is a release barrier.
- AcquireRelease: A memory read-modify-write operation with this semantic performs both an acquire operation and a release operation, and inherits the limitations on ordering from both of those operations. A memory barrier with this semantic is both a release and acquire barrier.

Note
SPIR-V does not support “consume” semantics on the device.

The memory semantics operand also includes storage class semantics which indicate which storage classes are constrained by the synchronization. SPIR-V storage class semantics include:

- UniformMemory
- WorkgroupMemory
- ImageMemory
- OutputMemory

Each SPIR-V memory operation accesses a single storage class. Semantics in synchronization
operations can include a combination of storage classes.

The UniformMemory storage class semantic applies to accesses to memory in the PhysicalStorageBuffer, ShaderRecordBufferKHR, Uniform and StorageBuffer storage classes. The WorkgroupMemory storage class semantic applies to accesses to memory in the Workgroup storage class. The ImageMemory storage class semantic applies to accesses to memory in the Image storage class. The OutputMemory storage class semantic applies to accesses to memory in the Output storage class.

**Note**
Informally, these constraints limit how memory operations can be reordered, and these limits apply not only to the order of accesses as performed in the agent that executes the instruction, but also to the order the effects of writes become visible to all other agents within the same instance of the instruction’s memory scope.

**Note**
Release and acquire operations in different threads can act as synchronization operations, to guarantee that writes that happened before the release are visible after the acquire. (This is not a formal definition, just an Informative forward reference.)

**Note**
The OutputMemory storage class semantic is only useful in tessellation control shaders, which is the only execution model where output variables are shared between invocations.

The memory semantics operand can also include availability and visibility flags, which apply availability and visibility operations as described in availability and visibility. The availability/visibility flags are:

- **MakeAvailable**: Semantics must be Release or AcquireRelease. Performs an availability operation before the release operation or barrier.
- **MakeVisible**: Semantics must be Acquire or AcquireRelease. Performs a visibility operation after the acquire operation or barrier.

The specifics of these operations are defined in Availability and Visibility Semantics.

Host atomic operations may support a different list of memory semantics and synchronization operations, depending on the host architecture and source language.

### Release Sequence

After an atomic operation A performs a release operation on a set of memory locations M, the release sequence headed by A is the longest continuous subsequence of A's scoped modification order that consists of:

- the atomic operation A as its first element
• atomic read-modify-write operations on M by any agent

**Note**
The atomics in the last bullet **must** be mutually-ordered with A by virtue of being in A's scoped modification order.

**Note**
This intentionally omits “atomic writes to M performed by the same agent that performed A”, which is present in the corresponding C++ definition.

**Synchronizes-With**

*Synchronizes-with* is a relation between operations, where each operation is either an atomic operation or a memory barrier (aka fence on the host).

If A and B are atomic operations, then A synchronizes-with B if and only if all of the following are true:

- A performs a release operation
- B performs an acquire operation
- A and B are mutually-ordered
- B reads a value written by A or by an operation in the release sequence headed by A

*OpControlBarrier, OpMemoryBarrier, and OpMemoryNamedBarrier* are *memory barrier* instructions in SPIR-V.

If A is a release barrier and B is an atomic operation that performs an acquire operation, then A synchronizes-with B if and only if all of the following are true:

- there exists an atomic write X (with any memory semantics)
- A is program-ordered before X
- X and B are mutually-ordered
- B reads a value written by X or by an operation in the release sequence headed by X
  - If X is relaxed, it is still considered to head a hypothetical release sequence for this rule
- A and B are in the instance of each other's memory scopes
- X's storage class is in A's semantics.

If A is an atomic operation that performs a release operation and B is an acquire barrier, then A synchronizes-with B if and only if all of the following are true:

- there exists an atomic read X (with any memory semantics)
- X is program-ordered before B
- X and A are mutually-ordered
• X reads a value written by A or by an operation in the release sequence headed by A
• A and B are in the instance of each other's memory scopes
• X's storage class is in B's semantics.

If A is a release barrier and B is an acquire barrier, then A synchronizes-with B if all of the following are true:

• there exists an atomic write X (with any memory semantics)
• A is program-ordered before X
• there exists an atomic read Y (with any memory semantics)
• Y is program-ordered before B
• X and Y are mutually-ordered
• Y reads the value written by X or by an operation in the release sequence headed by X
  ◦ If X is relaxed, it is still considered to head a hypothetical release sequence for this rule
• A and B are in the instance of each other's memory scopes
• X's and Y's storage class is in A's and B's semantics.
  ◦ NOTE: X and Y must have the same storage class, because they are mutually ordered.

If A is a release barrier, B is an acquire barrier, and C is a control barrier (where A can equal C, and B can equal C), then A synchronizes-with B if all of the following are true:

• A is program-ordered before (or equals) C
• C is program-ordered before (or equals) B
• A and B are in the instance of each other's memory scopes
• A and B are in the instance of C's execution scope

Note
This is similar to the barrier-barrier synchronization above, but with a control barrier filling the role of the relaxed atomics.

Let F be an ordering of fragment shader invocations, such that invocation $F_1$ is ordered before invocation $F_2$ if and only if $F_1$ and $F_2$ overlap as described in Fragment Shader Interlock and $F_1$ executes the interlocked code before $F_2$.

If A is an OpEndInvocationInterlockEXT instruction and B is an OpBeginInvocationInterlockEXT instruction, then A synchronizes-with B if the agent that executes A is ordered before the agent that executes B in F. A and B are both considered to have FragmentInterlock memory scope and semantics of UniformMemory and ImageMemory, and A is considered to have Release semantics and B is considered to have Acquire semantics.

Note
OpBeginInvocationInterlockEXT and OpBeginInvocationInterlockEXT do not perform implicit availability or visibility operations. Usually, shaders using fragment
shader interlock will declare the relevant resources as **coherent** to get implicit per-instruction availability and visibility operations.

If A is a release barrier and B is an acquire barrier, then A synchronizes-with B if all of the following are true:

- A is shader-call-ordered-before B
- A and B are in the instance of each other's memory scopes

No other release and acquire barriers synchronize-with each other.

**System-Synchronizes-With**

*System-synchronizes-with* is a relation between arbitrary operations on the device or host. Certain operations system-synchronize-with each other, which informally means the first operation occurs before the second and that the synchronization is performed without using application-visible memory accesses.

If there is an *execution dependency* between two operations A and B, then the operation in the first synchronization scope system-synchronizes-with the operation in the second synchronization scope.

---

*Note*

This covers all Vulkan synchronization primitives, including device operations executing before a synchronization primitive is signaled, wait operations happening before subsequent device operations, signal operations happening before host operations that wait on them, and host operations happening before `vkQueueSubmit`. The list is spread throughout the synchronization chapter, and is not repeated here.

System-synchronizes-with implicitly includes all storage class semantics and has **CrossDevice** scope.

If A system-synchronizes-with B, we also say A is **system-synchronized-before** B and B is **system-synchronized-after** A.

**Private vs. Non-Private**

By default, non-atomic memory operations are treated as **private**, meaning such a memory operation is not intended to be used for communication with other agents. Memory operations with the NonPrivatePointer/NonPrivateTexel bit set are treated as **non-private**, and are intended to be used for communication with other agents.

More precisely, for private memory operations to be **Location-Ordered** between distinct agents requires using system-synchronizes-with rather than shader-based synchronization. Non-private memory operations still obey program-order.

Atomic operations are always considered non-private.
**Inter-Thread-Happens-Before**

Let SC be a non-empty set of storage class semantics. Then (using template syntax) operation \(A\) \(\text{inter-thread-happens-before<SC>}\) operation \(B\) if and only if any of the following is true:

- A system-synchronizes-with \(B\)
- A synchronizes-with \(B\), and both \(A\) and \(B\) have all of \(SC\) in their semantics
- A is an operation on memory in a storage class in \(SC\) or that has all of \(SC\) in its semantics, \(B\) is a release barrier or release atomic with all of \(SC\) in its semantics, and \(A\) is program-ordered before \(B\)
- A is an acquire barrier or acquire atomic with all of \(SC\) in its semantics, \(B\) is an operation on memory in a storage class in \(SC\) or that has all of \(SC\) in its semantics, and \(A\) is program-ordered before \(B\)
- \(A\) and \(B\) are both host operations and \(A\) inter-thread-happens-before \(B\) as defined in the host language specification
- \(A\) inter-thread-happens-before<\(SC\)> some \(X\) and \(X\) inter-thread-happens-before<\(SC\)> \(B\)

**Happens-Before**

Operation \(A\) \(\text{happens-before}\) operation \(B\) if and only if any of the following is true:

- \(A\) is program-ordered before \(B\)
- \(A\) inter-thread-happens-before<\(SC\)> \(B\) for some set of storage classes \(SC\)

\(\text{Happens-after}\) is defined similarly.

**Note**

Unlike C++, happens-before is not always sufficient for a write to be visible to a read. Additional availability and visibility operations may be required for writes to be visible-to other memory accesses.

**Note**

Happens-before is not transitive, but each of program-order and inter-thread-happens-before<\(SC\)> are transitive. These can be thought of as covering the “single-threaded” case and the “multi-threaded” case, and it is not necessary (and not valid) to form chains between the two.

**Availability and Visibility**

Availability and visibility are states of a write operation, which (informally) track how far the write has permeated the system, i.e. which agents and references are able to observe the write. Availability state is per memory domain. Visibility state is per (agent,reference) pair. Availability and visibility states are per-memory location for each write.
Memory domains are named according to the agents whose memory accesses use the domain. Domains used by shader invocations are organized hierarchically into multiple smaller memory domains which correspond to the different scopes. Each memory domain is considered the dual of a scope, and vice versa. The memory domains defined in Vulkan include:

- **host** - accessible by host agents
- **device** - accessible by all device agents for a particular device
- **shader** - accessible by shader agents for a particular device, corresponding to the Device scope
- **queue family instance** - accessible by shader agents in a single queue family, corresponding to the QueueFamily scope.
- **fragment interlock instance** - accessible by fragment shader agents that overlap, corresponding to the FragmentInterlock scope.
- **shader call instance** - accessible by shader agents that are shader-call-related, corresponding to the ShaderCallKHR scope.
- **workgroup instance** - accessible by shader agents in the same workgroup, corresponding to the Workgroup scope.
- **subgroup instance** - accessible by shader agents in the same subgroup, corresponding to the Subgroup scope.

The memory domains are nested in the order listed above, except for shader call instance domain, with memory domains later in the list nested in the domains earlier in the list. The shader call instance domain is at an implementation-dependent location in the list, and is nested according to that location. The shader call instance domain is not broader than the queue family instance domain.

**Note**

Memory domains do not correspond to storage classes or device-local and host-local VkDeviceMemory allocations, rather they indicate whether a write can be made visible only to agents in the same subgroup, same workgroup, overlapping fragment shader invocation, shader-call-related ray tracing invocation, in any shader invocation, or anywhere on the device, or host. The shader, queue family instance, fragment interlock instance, shader call instance, workgroup instance, and subgroup instance domains are only used for shader-based availability/visibility operations, in other cases writes can be made available from/visible to the shader via the device domain.

Availability operations, visibility operations, and memory domain operations alter the state of the write operations that happen-before them, and which are included in their source scope to be available or visible to their destination scope.

- For an availability operation, the source scope is a set of (agent,reference,memory location) tuples, and the destination scope is a set of memory domains.
- For a memory domain operation, the source scope is a memory domain and the destination scope is a memory domain.
- For a visibility operation, the source scope is a set of memory domains and the destination scope is a set of memory domains.
scope is a set of \((\text{agent,reference,}\text{memory location})\) tuples.

How the scopes are determined depends on the specific operation. Availability and memory domain operations expand the set of memory domains to which the write is available. Visibility operations expand the set of \((\text{agent,reference,}\text{memory location})\) tuples to which the write is visible.

Recall that availability and visibility states are per-memory location, and let \(W\) be a write operation to one or more locations performed by agent A via reference R. Let \(L\) be one of the locations written. \((W,L)\) (the write \(W\) to \(L\)), is initially not available to any memory domain and only visible to \((A,R,L)\). An availability operation \(AV\) that happens-after \(W\) and that includes \((A,R,L)\) in its source scope makes \((W,L)\) available to the memory domains in its destination scope.

A memory domain operation \(DOM\) that happens-after \(AV\) and for which \((W,L)\) is available in the source scope makes \((W,L)\) available in the destination memory domain.

A visibility operation \(VIS\) that happens-after \(AV\) (or \(DOM\)) and for which \((W,L)\) is available in any domain in the source scope makes \((W,L)\) visible to all \((\text{agent,reference,}\text{L})\) tuples included in its destination scope.

If write \(W_2\) happens-after \(W\), and their sets of memory locations overlap, then \(W\) will not be available/visible to all agents/references for those memory locations that overlap (and future \(AV/DOM/VIS\) ops cannot revive \(W\)’s write to those locations).

Availability, memory domain, and visibility operations are treated like other non-atomic memory accesses for the purpose of memory semantics, meaning they can be ordered by release-acquire sequences or memory barriers.

An availability chain is a sequence of availability operations to increasingly broad memory domains, where element \(N+1\) of the chain is performed in the dual scope instance of the destination memory domain of element \(N\) and element \(N\) happens-before element \(N+1\). An example is an availability operation with destination scope of the workgroup instance domain that happens-before an availability operation to the shader domain performed by an invocation in the same workgroup. An availability chain \(AVC\) that happens-after \(W\) and that includes \((A,R,L)\) in the source scope makes \((W,L)\) available to the memory domains in its final destination scope. An availability chain with a single element is just the availability operation.

Similarly, a visibility chain is a sequence of visibility operations from increasingly narrow memory domains, where element \(N\) of the chain is performed in the dual scope instance of the source memory domain of element \(N+1\) and element \(N\) happens-before element \(N+1\). An example is a visibility operation with source scope of the shader domain that happens-before a visibility operation with source scope of the workgroup instance domain performed by an invocation in the same workgroup. A visibility chain \(VISC\) that happens-after \(AVC\) (or \(DOM\)) and for which \((W,L)\) is available in any domain in the source scope makes \((W,L)\) visible to all \((\text{agent,reference,}\text{L})\) tuples included in its final destination scope. A visibility chain with a single element is just the visibility operation.

**Availability, Visibility, and Domain Operations**

The following operations generate availability, visibility, and domain operations. When multiple
availability/visibility/domain operations are described, they are system-synchronized-with each other in the order listed.

An operation that performs a memory dependency generates:

- If the source access mask includes `VK_ACCESS_HOST_WRITE_BIT`, then the dependency includes a memory domain operation from host domain to device domain.
- An availability operation with source scope of all writes in the first *access scope* of the dependency and a destination scope of the device domain.
- A visibility operation with source scope of the device domain and destination scope of the second access scope of the dependency.
- If the destination access mask includes `VK_ACCESS_HOST_READ_BIT` or `VK_ACCESS_HOST_WRITE_BIT`, then the dependency includes a memory domain operation from device domain to host domain.

`vkFlushMappedMemoryRanges` performs an availability operation, with a source scope of (agents,references) = (all host threads, all mapped memory ranges passed to the command), and destination scope of the host domain.

`vkInvalidateMappedMemoryRanges` performs a visibility operation, with a source scope of the host domain and a destination scope of (agents,references) = (all host threads, all mapped memory ranges passed to the command).

`vkQueueSubmit` performs a memory domain operation from host to device, and a visibility operation with source scope of the device domain and destination scope of all agents and references on the device.

**Availability and Visibility Semantics**

A memory barrier or atomic operation via agent A that includes MakeAvailable in its semantics performs an availability operation whose source scope includes agent A and all references in the storage classes in that instruction’s storage class semantics, and all memory locations, and whose destination scope is a set of memory domains selected as specified below. The implicit availability operation is program-ordered between the barrier or atomic and all other operations program-ordered before the barrier or atomic.

A memory barrier or atomic operation via agent A that includes MakeVisible in its semantics performs a visibility operation whose source scope is a set of memory domains selected as specified below, and whose destination scope includes agent A and all references in the storage classes in that instruction’s storage class semantics, and all memory locations. The implicit visibility operation is program-ordered between the barrier or atomic and all other operations program-ordered after the barrier or atomic.

The memory domains are selected based on the memory scope of the instruction as follows:

- **Device** scope uses the shader domain
- **QueueFamily** scope uses the queue family instance domain
- **FragmentInterlock** scope uses the fragment interlock instance domain
• **ShaderCallKHR** scope uses the shader call instance domain

• **Workgroup** scope uses the workgroup instance domain

• **Subgroup** uses the subgroup instance domain

• **Invocation** perform no availability/visibility operations.

When an availability operation performed by an agent A includes a memory domain D in its destination scope, where D corresponds to scope instance S, it also includes the memory domains that correspond to each smaller scope instance S’ that is a subset of S and that includes A. Similarly for visibility operations.

### Per-Instruction Availability and Visibility Semantics

A memory write instruction that includes MakePointerAvailable, or an image write instruction that includes MakeTexelAvailable, performs an availability operation whose source scope includes the agent and reference used to perform the write and the memory locations written by the instruction, and whose destination scope is a set of memory domains selected by the Scope operand specified in Availability and Visibility Semantics. The implicit availability operation is program-ordered between the write and all other operations program-ordered after the write.

A memory read instruction that includes MakePointerVisible, or an image read instruction that includes MakeTexelVisible, performs a visibility operation whose source scope is a set of memory domains selected by the Scope operand as specified in Availability and Visibility Semantics, and whose destination scope includes the agent and reference used to perform the read and the memory locations read by the instruction. The implicit visibility operation is program-ordered between read and all other operations program-ordered before the read.

**Note**

Although reads with per-instruction visibility only perform visibility ops from the shader or fragment interlock instance or shader call instance or workgroup instance or subgroup instance domain, they will also see writes that were made visible via the device domain, i.e. those writes previously performed by non-shader agents and made visible via API commands.

**Note**

It is expected that all invocations in a subgroup execute on the same processor with the same path to memory, and thus availability and visibility operations with subgroup scope can be expected to be “free”.

### Location-Ordered

Let X and Y be memory accesses to overlapping sets of memory locations M, where X \(!=\ Y. Let (A_X,R \_X) be the agent and reference used for X, and (A_Y,R \_Y) be the agent and reference used for Y. For now, let “-→” denote happens-before and “-→\_rcpo” denote the reflexive closure of program-ordered before.

If D1 and D2 are different memory domains, then let DOM(D1,D2) be a memory domain operation from D1 to D2. Otherwise, let DOM(D,D) be a placeholder such that X→DOM(D,D)→Y if and only if
X → Y.

X is location-ordered before Y for a location L in M if and only if any of the following is true:

- $A_X = A_Y$ and $R_X = R_Y$ and $X → Y$
  
  ◦ NOTE: this case means no availability/visibility ops are required when it is the same (agent,reference).

- X is a read, both X and Y are non-private, and $X → Y$

- X is a read, and X (transitively) system-synchronizes with Y

- If $R_X = R_Y$ and $A_X$ and $A_Y$ access a common memory domain D (e.g. are in the same workgroup instance if D is the workgroup instance domain), and both X and Y are non-private:
  
  ◦ X is a write, Y is a write, $AVC(A_X,R_X,D,L)$ is an availability chain making $(X,L)$ available to domain D, and $X → rcpo AVC(A_X,R_X,D,L) → Y$

  ◦ X is a write, Y is a read, $AVC(A_X,R_X,D,L)$ is an availability chain making $(X,L)$ available to domain D, $VISC(A_Y,R_Y,D,L)$ is a visibility chain making writes to L available in domain D visible to Y, and $X → rcpo AVC(A_X,R_X,D,L) → VISC(A_Y,R_Y,D,L) → rcpo Y$

  ◦ If $VkPhysicalDeviceVulkanMemoryModelFeatures::vulkanMemoryModelAvailabilityVisibilityChains$ is $VK_FALSE$, then AVC and VISC must each only have a single element in the chain, in each sub-bullet above.

- Let $D_X$ and $D_Y$ each be either the device domain or the host domain, depending on whether $A_X$ and $A_Y$ execute on the device or host:
  
  ◦ X is a write and Y is a write, and $X → AV(A_X,R_X,D_X,L) → DOM(D_X,D_Y) → Y$

  ◦ X is a write and Y is a read, and $X → AV(A_X,R_X,D_X,L) → DOM(D_X,D_Y) → VIS(A_Y,R_Y,D_Y,L) → Y$

Note

The final bullet (synchronization through device/host domain) requires API-level synchronization operations, since the device/host domains are not accessible via shader instructions. And “device domain” is not to be confused with “device scope”, which synchronizes through the “shader domain”.

Data Race

Let X and Y be operations that access overlapping sets of memory locations M, where X != Y, and at least one of X and Y is a write, and X and Y are not mutually-ordered atomic operations. If there does not exist a location-ordered relation between X and Y for each location in M, then there is a data race.

Applications must ensure that no data races occur during the execution of their application.

Note

Data races can only occur due to instructions that are actually executed. For example, an instruction skipped due to control flow must not contribute to a data race.
Visible-To

Let X be a write and Y be a read whose sets of memory locations overlap, and let M be the set of memory locations that overlap. Let \( M_x \) be a non-empty subset of M. Then X is visible-to Y for memory locations \( M_x \) if and only if all of the following are true:

- X is location-ordered before Y for each location L in \( M_x \).
- There does not exist another write Z to any location L in \( M_x \) such that X is location-ordered before Z for location L and Z is location-ordered before Y for location L.

If X is visible-to Y, then Y reads the value written by X for locations \( M_x \).

Note

It is possible for there to be a write between X and Y that overwrites a subset of the memory locations, but the remaining memory locations (\( M_x \)) will still be visible-to Y.

Acyclicity

Reads-from is a relation between operations, where the first operation is a write, the second operation is a read, and the second operation reads the value written by the first operation. From-reads is a relation between operations, where the first operation is a read, the second operation is a write, and the first operation reads a value written earlier than the second operation in the second operation’s scoped modification order (or the first operation reads from the initial value, and the second operation is any write to the same locations).

Then the implementation must guarantee that no cycles exist in the union of the following relations:

- location-ordered
- scoped modification order (over all atomic writes)
- reads-from
- from-reads

Note

This is a “consistency” axiom, which informally guarantees that sequences of operations cannot violate causality.

Scoped Modification Order Coherence

Let A and B be mutually-ordered atomic operations, where A is location-ordered before B. Then the following rules are a consequence of acyclicity:

- If A and B are both reads and A does not read the initial value, then the write that A takes its value from must be earlier in its own scoped modification order than (or the same as) the write that B takes its value from (no cycles between location-order, reads-from, and from-reads).
• If A is a read and B is a write and A does not read the initial value, then A **must** take its value from a write earlier than B in B's scoped modification order (no cycles between location-order, scope modification order, and reads-from).

• If A is a write and B is a read, then B **must** take its value from A or a write later than A in A's scoped modification order (no cycles between location-order, scoped modification order, and from-reads).

• If A and B are both writes, then A **must** be earlier than B in A's scoped modification order (no cycles between location-order and scoped modification order).

• If A is a write and B is a read-modify-write and B reads the value written by A, then B comes immediately after A in A's scoped modification order (no cycles between scoped modification order and from-reads).

**Shader I/O**

If a shader invocation A in a shader stage other than *Vertex* performs a memory read operation X from an object in storage class CallableDataKHR, IncomingCallableDataKHR, RayPayloadKHR, HitAttributeKHR, IncomingRayPayloadKHR, or Input, then X is system-synchronized-after all writes to the corresponding CallableDataKHR, IncomingCallableDataKHR, RayPayloadKHR, HitAttributeKHR, IncomingRayPayloadKHR, or Output storage variable(s) in the shader invocation(s) that contribute to generating invocation A, and those writes are all visible-to X.

**Note**

It is not necessary for the upstream shader invocations to have completed execution, they only need to have generated the output that is being read.

**Deallocation**

A call to **vkFreeMemory** **must** happen-after all memory operations on all memory locations in that VkDeviceMemory object.

**Note**

Normally, device memory operations in a given queue are synchronized with **vkFreeMemory** by having a host thread wait on a fence signaled by that queue, and the wait happens-before the call to **vkFreeMemory** on the host.

The deallocation of SPIR-V variables is managed by the system and happens-after all operations on those variables.

**Descriptions (Informative)**

This subsection offers more easily understandable consequences of the memory model for app/compiler developers.

Let SC be the storage class(es) specified by a release or acquire operation or barrier.
• An atomic write with release semantics must not be reordered against any read or write to SC that is program-ordered before it (regardless of the storage class the atomic is in).

• An atomic read with acquire semantics must not be reordered against any read or write to SC that is program-ordered after it (regardless of the storage class the atomic is in).

• Any write to SC program-ordered after a release barrier must not be reordered against any read or write to SC program-ordered before that barrier.

• Any read from SC program-ordered before an acquire barrier must not be reordered against any read or write to SC program-ordered after the barrier.

A control barrier (even if it has no memory semantics) must not be reordered against any memory barriers.

This memory model allows memory accesses with and without availability and visibility operations, as well as atomic operations, all to be performed on the same memory location. This is critical to allow it to reason about memory that is reused in multiple ways, e.g. across the lifetime of different shader invocations or draw calls. While GLSL (and legacy SPIR-V) applies the “coherent” decoration to variables (for historical reasons), this model treats each memory access instruction as having optional implicit availability/visibility operations. GLSL to SPIR-V compilers should map all (non-atomic) operations on a coherent variable to Make(Pointer, Texel){Available}{Visible} flags in this model.

Atomic operations implicitly have availability/visibility operations, and the scope of those operations is taken from the atomic operation's scope.

**Tessellation Output Ordering**

For SPIR-V that uses the Vulkan Memory Model, the `OutputMemory` storage class is used to synchronize accesses to tessellation control output variables. For legacy SPIR-V that does not enable the Vulkan Memory Model via `OpMemoryModel`, tessellation outputs can be ordered using a control barrier with no particular memory scope or semantics, as defined below.

Let X and Y be memory operations performed by shader invocations A\textsubscript{x} and A\textsubscript{y}. Operation X is **tessellation-output-ordered** before operation Y if and only if all of the following are true:

- There is a dynamic instance of an `OpControlBarrier` instruction C such that X is program-ordered before C in A\textsubscript{x} and C is program-ordered before Y in A\textsubscript{y}.

- A\textsubscript{x} and A\textsubscript{y} are in the same instance of C's execution scope.

If shader invocations A\textsubscript{x} and A\textsubscript{y} in the TessellationControl execution model execute memory operations X and Y, respectively, on the `Output` storage class, and X is tessellation-output-ordered before Y with a scope of `Workgroup`, then X is location-ordered before Y, and if X is a write and Y is a read then X is visible-to Y.

**Cooperative Matrix Memory Access**

For each dynamic instance of a cooperative matrix load or store instruction (`OpCooperativeMatrixLoadNV` or `OpCooperativeMatrixStoreNV`), a single implementation-dependent
invocation within the instance of the matrix’s scope performs a non-atomic load or store (respectively) to each memory location that is defined to be accessed by the instruction.
Appendix C: Compressed Image Formats

The compressed texture formats used by Vulkan are described in the specifically identified sections of the Khronos Data Format Specification, version 1.3.

Unless otherwise described, the quantities encoded in these compressed formats are treated as normalized, unsigned values.

Those formats listed as sRGB-encoded have in-memory representations of R, G and B components which are nonlinearly-encoded as R', G', and B'; any alpha component is unchanged. As part of filtering, the nonlinear R', G', and B' values are converted to linear R, G, and B components; any alpha component is unchanged. The conversion between linear and nonlinear encoding is performed as described in the “KHR_DF_TRANSFER_SRGB” section of the Khronos Data Format Specification.
Block-Compressed Image Formats

BC1, BC2 and BC3 formats are described in “S3TC Compressed Texture Image Formats” chapter of the Khronos Data Format Specification. BC4 and BC5 are described in the “RGTC Compressed Texture Image Formats” chapter. BC6H and BC7 are described in the “BPTC Compressed Texture Image Formats” chapter.

Table 93. Mapping of Vulkan BC formats to descriptions

<table>
<thead>
<tr>
<th>VkFormat</th>
<th>Khronos Data Format Specification description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_FORMAT_BC1_RGB_UNORM_BLOCK</td>
<td>BC1 with no alpha</td>
</tr>
<tr>
<td>VK_FORMAT_BC1_RGB_SRGB_BLOCK</td>
<td>BC1 with no alpha, sRGB-encoded</td>
</tr>
<tr>
<td>VK_FORMAT_BC1_RGBA_UNORM_BLOCK</td>
<td>BC1 with alpha</td>
</tr>
<tr>
<td>VK_FORMAT_BC1_RGBA_SRGB_BLOCK</td>
<td>BC1 with alpha, sRGB-encoded</td>
</tr>
<tr>
<td>VK_FORMAT_BC2_UNORM_BLOCK</td>
<td>BC2</td>
</tr>
<tr>
<td>VK_FORMAT_BC2_SRGB_BLOCK</td>
<td>BC2, sRGB-encoded</td>
</tr>
<tr>
<td>VK_FORMAT_BC3_UNORM_BLOCK</td>
<td>BC3</td>
</tr>
<tr>
<td>VK_FORMAT_BC3_SRGB_BLOCK</td>
<td>BC3, sRGB-encoded</td>
</tr>
<tr>
<td>Formats described in the “S3TC Compressed Texture Image Formats” chapter</td>
<td></td>
</tr>
<tr>
<td>VK_FORMAT_BC4_UNORM_BLOCK</td>
<td>BC4 unsigned</td>
</tr>
<tr>
<td>VK_FORMAT_BC4_SNORM_BLOCK</td>
<td>BC4 signed</td>
</tr>
<tr>
<td>VK_FORMAT_BC5_UNORM_BLOCK</td>
<td>BC5 unsigned</td>
</tr>
<tr>
<td>VK_FORMAT_BC5_SNORM_BLOCK</td>
<td>BC5 signed</td>
</tr>
<tr>
<td>Formats described in the “RGTC Compressed Texture Image Formats” chapter</td>
<td></td>
</tr>
<tr>
<td>VK_FORMAT_BC6H_UFLOAT_BLOCK</td>
<td>BC6H (unsigned version)</td>
</tr>
<tr>
<td>VK_FORMAT_BC6H_SFLOAT_BLOCK</td>
<td>BC6H (signed version)</td>
</tr>
<tr>
<td>VK_FORMAT_BC7_UNORM_BLOCK</td>
<td>BC7</td>
</tr>
<tr>
<td>VK_FORMAT_BC7_SRGB_BLOCK</td>
<td>BC7, sRGB-encoded</td>
</tr>
</tbody>
</table>
ETC Compressed Image Formats

The following formats are described in the “ETC2 Compressed Texture Image Formats” chapter of the [Khronos Data Format Specification](https://www.khronos.org/doc健身房).

<table>
<thead>
<tr>
<th>VkFormat</th>
<th>Khronos Data Format Specification description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_FORMAT_ETC2_R8G8B8_UNORM_BLOCK</td>
<td>RGB ETC2</td>
</tr>
<tr>
<td>VK_FORMAT_ETC2_R8G8B8_SRGB_BLOCK</td>
<td>RGB ETC2 with sRGB encoding</td>
</tr>
<tr>
<td>VK_FORMAT_ETC2_R8G8B8A1_UNORM_BLOCK</td>
<td>RGB ETC2 with punch-through alpha</td>
</tr>
<tr>
<td>VK_FORMAT_ETC2_R8G8B8A1_SRGB_BLOCK</td>
<td>RGB ETC2 with punch-through alpha and sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ETC2_R8G8B8A8_UNORM_BLOCK</td>
<td>RGBA ETC2</td>
</tr>
<tr>
<td>VK_FORMAT_ETC2_R8G8B8A8_SRGB_BLOCK</td>
<td>RGBA ETC2 with sRGB encoding</td>
</tr>
<tr>
<td>VK_FORMAT_EAC_R11_UNORM_BLOCK</td>
<td>Unsigned R11 EAC</td>
</tr>
<tr>
<td>VK_FORMAT_EAC_R11_SNORM_BLOCK</td>
<td>Signed R11 EAC</td>
</tr>
<tr>
<td>VK_FORMAT_EAC_R11G11_UNORM_BLOCK</td>
<td>Unsigned RG11 EAC</td>
</tr>
<tr>
<td>VK_FORMAT_EAC_R11G11_SNORM_BLOCK</td>
<td>Signed RG11 EAC</td>
</tr>
</tbody>
</table>
### ASTC Compressed Image Formats

ASTC formats are described in the “ASTC Compressed Texture Image Formats” chapter of the Khronos Data Format Specification.

#### Table 95. Mapping of Vulkan ASTC formats to descriptions

<table>
<thead>
<tr>
<th>VkFormat</th>
<th>Compressed texel block dimensions</th>
<th>Requested mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_FORMAT_ASTC_4x4_UNORM_BLOCK</td>
<td>4 × 4</td>
<td>Linear LDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_4x4_SRGB_BLOCK</td>
<td>4 × 4</td>
<td>sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_5x4_UNORM_BLOCK</td>
<td>5 × 4</td>
<td>Linear LDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_5x4_SRGB_BLOCK</td>
<td>5 × 4</td>
<td>sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_5x5_UNORM_BLOCK</td>
<td>5 × 5</td>
<td>Linear LDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_5x5_SRGB_BLOCK</td>
<td>5 × 5</td>
<td>sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_6x5_UNORM_BLOCK</td>
<td>6 × 5</td>
<td>Linear LDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_6x5_SRGB_BLOCK</td>
<td>6 × 5</td>
<td>sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_6x6_UNORM_BLOCK</td>
<td>6 × 6</td>
<td>Linear LDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_6x6_SRGB_BLOCK</td>
<td>6 × 6</td>
<td>sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_8x5_UNORM_BLOCK</td>
<td>8 × 5</td>
<td>Linear LDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_8x5_SRGB_BLOCK</td>
<td>8 × 5</td>
<td>sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_8x6_UNORM_BLOCK</td>
<td>8 × 6</td>
<td>Linear LDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_8x6_SRGB_BLOCK</td>
<td>8 × 6</td>
<td>sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_8x8_UNORM_BLOCK</td>
<td>8 × 8</td>
<td>Linear LDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_8x8_SRGB_BLOCK</td>
<td>8 × 8</td>
<td>sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_10x5_UNORM_BLOCK</td>
<td>10 × 5</td>
<td>Linear LDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_10x5_SRGB_BLOCK</td>
<td>10 × 5</td>
<td>sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_10x6_UNORM_BLOCK</td>
<td>10 × 6</td>
<td>Linear LDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_10x6_SRGB_BLOCK</td>
<td>10 × 6</td>
<td>sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_10x8_UNORM_BLOCK</td>
<td>10 × 8</td>
<td>Linear LDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_10x8_SRGB_BLOCK</td>
<td>10 × 8</td>
<td>sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_10x10_UNORM_BLOCK</td>
<td>10 × 10</td>
<td>Linear LDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_10x10_SRGB_BLOCK</td>
<td>10 × 10</td>
<td>sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_12x10_UNORM_BLOCK</td>
<td>12 × 10</td>
<td>Linear LDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_12x10_SRGB_BLOCK</td>
<td>12 × 10</td>
<td>sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_12x12_UNORM_BLOCK</td>
<td>12 × 12</td>
<td>Linear LDR</td>
</tr>
<tr>
<td>VkFormat</td>
<td>Compressed texel block dimensions</td>
<td>Requested mode</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>----------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_12x12_SRGB_BLOCK</td>
<td>12 x 12</td>
<td>sRGB</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_4x4_SFLOAT_BLOCK</td>
<td>4 x 4</td>
<td>HDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_5x4_SFLOAT_BLOCK</td>
<td>5 x 4</td>
<td>HDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_5x5_SFLOAT_BLOCK</td>
<td>5 x 5</td>
<td>HDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_6x5_SFLOAT_BLOCK</td>
<td>6 x 5</td>
<td>HDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_6x6_SFLOAT_BLOCK</td>
<td>6 x 6</td>
<td>HDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_8x5_SFLOAT_BLOCK</td>
<td>8 x 5</td>
<td>HDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_8x6_SFLOAT_BLOCK</td>
<td>8 x 6</td>
<td>HDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_8x8_SFLOAT_BLOCK</td>
<td>8 x 8</td>
<td>HDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_10x5_SFLOAT_BLOCK</td>
<td>10 x 5</td>
<td>HDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_10x6_SFLOAT_BLOCK</td>
<td>10 x 6</td>
<td>HDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_10x8_SFLOAT_BLOCK</td>
<td>10 x 8</td>
<td>HDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_10x10_SFLOAT_BLOCK</td>
<td>10 x 10</td>
<td>HDR</td>
</tr>
<tr>
<td>VK_FORMAT_ASTC_12x12_SFLOAT_BLOCK</td>
<td>12 x 12</td>
<td>HDR</td>
</tr>
</tbody>
</table>

ASTC textures containing HDR block encodings **should** be passed to the API using an ASTC SFLOAT texture format.

**Note**
An HDR block in a texture passed using a LDR UNORM format will return the appropriate ASTC error color if the implementation supports only the ASTC LDR profile, but may result in either the error color or a decompressed HDR color if the implementation supports HDR decoding.

**ASTC decode mode**

If the `VK_EXT_astc_decode_mode` extension is enabled, the decode mode is determined as follows:

<table>
<thead>
<tr>
<th>VkFormat</th>
<th>Decoding mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_FORMAT_R16G16B16A16_SFLOAT</td>
<td>decode_float16</td>
</tr>
<tr>
<td>VK_FORMAT_R8G8B8A8_UNORM</td>
<td>decode_unorm8</td>
</tr>
<tr>
<td>VK_FORMAT_E5B9G9R9_UFLOAT_PACK32</td>
<td>decode_rgb9e5</td>
</tr>
</tbody>
</table>

Otherwise, the ASTC decode mode is decode_float16.
Note that an implementation **may** use HDR mode when linear LDR mode is requested unless the decode mode is decode_unorm8.
PVRTC Compressed Image Formats

PVRTC formats are described in the “PVRTC Compressed Texture Image Formats” chapter of the Khronos Data Format Specification.

### Table 97. Mapping of Vulkan PVRTC formats to descriptions

<table>
<thead>
<tr>
<th>VkFormat</th>
<th>Compressed texel block dimensions</th>
<th>sRGB-encoded</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_FORMAT_PVRTC1_2BPP_UNORM_BLOCK_IMG</td>
<td>$8 \times 4$</td>
<td>No</td>
</tr>
<tr>
<td>VK_FORMAT_PVRTC1_4BPP_UNORM_BLOCK_IMG</td>
<td>$4 \times 4$</td>
<td>No</td>
</tr>
<tr>
<td>VK_FORMAT_PVRTC2_2BPP_UNORM_BLOCK_IMG</td>
<td>$8 \times 4$</td>
<td>No</td>
</tr>
<tr>
<td>VK_FORMAT_PVRTC2_4BPP_UNORM_BLOCK_IMG</td>
<td>$4 \times 4$</td>
<td>No</td>
</tr>
<tr>
<td>VK_FORMAT_PVRTC1_2BPP_SRGB_BLOCK_IMG</td>
<td>$8 \times 4$</td>
<td>Yes</td>
</tr>
<tr>
<td>VK_FORMAT_PVRTC1_4BPP_SRGB_BLOCK_IMG</td>
<td>$4 \times 4$</td>
<td>Yes</td>
</tr>
<tr>
<td>VK_FORMAT_PVRTC2_2BPP_SRGB_BLOCK_IMG</td>
<td>$8 \times 4$</td>
<td>Yes</td>
</tr>
<tr>
<td>VK_FORMAT_PVRTC2_4BPP_SRGB_BLOCK_IMG</td>
<td>$4 \times 4$</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Appendix D: Core Revisions (Informative)

New minor versions of the Vulkan API are defined periodically by the Khronos Vulkan Working Group. These consist of some amount of additional functionality added to the core API, potentially including both new functionality and functionality promoted from extensions.

It is possible to build the specification for earlier versions, but to aid readability of the latest versions, this appendix gives an overview of the changes as compared to earlier versions.

Version 1.3

Vulkan Version 1.3 promoted a number of key extensions into the core API:

- VK_KHR_copy_commands2
- VK_KHR_dynamic_rendering
- VK_KHR_format_feature_flags2
- VK_KHR_maintenance4
- VK_KHR_shader_integer_dot_product
- VK_KHR_shader_non_semantic_info
- VK_KHR_shader_terminate_invocation
- VK_KHR_synchronization2
- VK_KHR_zero_initialize_workgroup_memory
- VK_EXT_4444_formats
- VK_EXT_extended_dynamic_state
- VK_EXT_extended_dynamic_state2
- VK_EXT_image_robustness
- VK_EXT_inline_uniform_block
- VK_EXT_pipeline_creation_cache_control
- VK_EXT_pipeline_creation_feedback
- VK_EXT_private_data
- VK_EXT_shader_demote_to_helper_invocation
- VK_EXT_subgroup_size_control
- VK_EXT_texel_buffer_alignment
- VK_EXT_texture_compression_astc_hdr
- VK_EXT_tooling_info
- VK_EXT_ycbcr_2plane_444_formats
All differences in behavior between these extensions and the corresponding Vulkan 1.3 functionality are summarized below.

**Differences relative to **VK_EXT_4444 Formats**

If the VK_EXT_4444 Formats extension is not supported, support for all formats defined by it are optional in Vulkan 1.3. There are no members in the VkPhysicalDeviceVulkan13Features structure corresponding to the VkPhysicalDevice4444FormatsFeaturesEXT structure.

**Differences relative to VK_EXT_extended_dynamic_state**

All dynamic state enumerants and entry points defined by VK_EXT_extended_dynamic_state are required in Vulkan 1.3. There are no members in the VkPhysicalDeviceVulkan13Features structure corresponding to the VkPhysicalDeviceExtendedDynamicStateFeaturesEXT structure.

**Differences relative to VK_EXT_extended_dynamic_state2**

The optional dynamic state enumerants and entry points defined by VK_EXT_extended_dynamic_state2 for patch control points and logic op are not promoted in Vulkan 1.3. There are no members in the VkPhysicalDeviceVulkan13Features structure corresponding to the VkPhysicalDeviceExtendedDynamicState2FeaturesEXT structure.

**Differences relative to VK_EXT_texel_buffer_alignment**

The more specific alignment requirements defined by VkPhysicalDeviceTexelBufferAlignmentProperties are required in Vulkan 1.3. There are no members in the VkPhysicalDeviceVulkan13Features structure corresponding to the VkPhysicalDeviceTexelBufferAlignmentFeaturesEXT structure. The texelBufferAlignment feature is enabled if using a Vulkan 1.3 instance.

**Differences relative to VK_EXT_texture_compression_astc_hdr**

If the VK_EXT_texture_compression_astc_hdr extension is not supported, support for all formats defined by it are optional in Vulkan 1.3. The textureCompressionASTC_HDR member of VkPhysicalDeviceVulkan13Features indicates whether a Vulkan 1.3 implementation supports these formats.

**Differences relative to VK_EXT_ycbcr_2plane_444_formats**

If the VK_EXT_ycbcr_2plane_444_formats extension is not supported, support for all formats defined by it are optional in Vulkan 1.3. There are no members in the VkPhysicalDeviceVulkan13Features structure corresponding to the VkPhysicalDeviceYcbcr2Plane444FormatsFeaturesEXT structure.

**Additional Vulkan 1.3 Feature Support**

In addition to the promoted extensions described above, Vulkan 1.3 added required support for:

- SPIR-V version 1.6
SPIR-V 1.6 deprecates (but does not remove) the WorkgroupSize decoration.

- The bufferDeviceAddress feature which indicates support for accessing memory in shaders as storage buffers via vkGetBufferDeviceAddress.
- The vulkanMemoryModel and vulkanMemoryModelDeviceScope features, which indicate support for the corresponding Vulkan Memory Model capabilities.
- The maxInlineUniformTotalSize limit is added to provide the total size of all inline uniform block bindings in a pipeline layout.

### New Macros

- VK_API_VERSION_1_3

### New Base Types

- VkFlags64

### New Object Types

- VkPrivateDataSlot

### New Commands

- vkCmdBeginRendering
- vkCmdBindVertexBuffers2
- vkCmdBlitImage2
- vkCmdCopyBuffer2
- vkCmdCopyBufferToImage2
- vkCmdCopyImage2
- vkCmdCopyImageToBuffer2
- vkCmdEndRendering
- vkCmdPipelineBarrier2
- vkCmdResetEvent2
- vkCmdResolveImage2
- vkCmdSetCullMode
- vkCmdSetDepthBiasEnable
- vkCmdSetDepthBoundsTestEnable
- vkCmdSetDepthCompareOp
- vkCmdSetDepthTestEnable
- vkCmdSetDepthWriteEnable
- vkCmdSetEvent2
• vkCmdSetFrontFace
• vkCmdSetPrimitiveRestartEnable
• vkCmdSetPrimitiveTopology
• vkCmdSetRasterizerDiscardEnable
• vkCmdSetScissorWithCount
• vkCmdSetStencilOp
• vkCmdSetStencilTestEnable
• vkCmdSetViewportWithCount
• vkCmdWaitEvents2
• vkCmdWriteTimestamp2
• vkCreatePrivateDataSlot
• vkDestroyPrivateDataSlot
• vkGetDeviceBufferMemoryRequirements
• vkGetDeviceImageMemoryRequirements
• vkGetDeviceImageSparseMemoryRequirements
• vkGetPhysicalDeviceToolProperties
• vkGetPrivateData
• vkQueueSubmit2
• vkSetPrivateData
• vkSetPrivateData

New Structures

• VkBlitImageInfo2
• VkBufferCopy2
• VkBufferImageCopy2
• VkBufferMemoryBarrier2
• VkCommandBufferSubmitInfo
• VkCopyBufferInfo2
• VkCopyBufferToImageInfo2
• VkCopyImageInfo2
• VkCopyImageToBufferInfo2
• VkDependencyInfo
• VkDeviceBufferMemoryRequirements
• VkDeviceImageMemoryRequirements
• VkImageBlit2
• VkImageCopy2
- VkImageMemoryBarrier2
- VkImageResolve2
- VkPhysicalDeviceToolProperties
- VkPipelineCreationFeedback
- VkPrivateDataSlotCreateInfo
- VkRenderingAttachmentCreateInfo
- VkRenderingInfo
- VkResolveImageInfo2
- VkSemaphoreSubmitInfo
- VkSubmitInfo2
- Extending VkCommandBufferInheritanceInfo:
  - VkCommandBufferInheritanceRenderingInfo
- Extending VkDescriptorPoolCreateInfo:
  - VkDescriptorPoolInlineUniformBlockCreateInfo
- Extending VkDeviceCreateInfo:
  - VkDevicePrivateDataCreateInfo
- Extending VkFormatProperties2:
  - VkFormatProperties3
- Extending VkGraphicsPipelineCreateInfo:
  - VkPipelineRenderingCreateInfo
- Extending VkGraphicsPipelineCreateInfo, VkComputePipelineCreateInfo, VkRayTracingPipelineCreateInfoNV, VkRayTracingPipelineCreateInfoKHR, VkExecutionGraphPipelineCreateInfoAMDX:
  - VkPipelineCreationFeedbackCreateInfo
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceDynamicRenderingFeatures
  - VkPhysicalDeviceImageRobustnessFeatures
  - VkPhysicalDeviceInlineUniformBlockFeatures
  - VkPhysicalDeviceMaintenance4Features
  - VkPhysicalDevicePipelineCreationCacheControlFeatures
  - VkPhysicalDevicePrivateDataFeatures
  - VkPhysicalDeviceShaderDemoteToHelperInvocationFeatures
  - VkPhysicalDeviceShaderIntegerDotProductFeatures
  - VkPhysicalDeviceShaderTerminateInvocationFeatures
  - VkPhysicalDeviceSubgroupSizeControlFeatures
- VkPhysicalDeviceSynchronization2Features
- VkPhysicalDeviceTextureCompressionASTCHDRFeatures
- VkPhysicalDeviceVulkan13Features
- VkPhysicalDeviceZeroInitializeWorkgroupMemoryFeatures

- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceInlineUniformBlockProperties
  - VkPhysicalDeviceMaintenance4Properties
  - VkPhysicalDeviceShaderIntegerDotProductProperties
  - VkPhysicalDeviceSubgroupSizeControlProperties
  - VkPhysicalDeviceTexelBufferAlignmentProperties
  - VkPhysicalDeviceVulkan13Properties

- Extending VkPipelineShaderStageCreateInfo, VkShaderCreateInfoEXT:
  - VkPipelineShaderStageRequiredSubgroupSizeCreateInfo

- Extending VkSubpassDependency2:
  - VkMemoryBarrier2

- Extending VkWriteDescriptorSet:
  - VkWriteDescriptorSetInlineUniformBlock

**New Enums**

- VkAccessFlagBits2
- VkFormatFeatureFlagBits2
- VkPipelineCreationFeedbackFlagBits
- VkPipelineStageFlagBits2
- VkRenderingFlagBits
- VkSubmitFlagBits
- VkToolPurposeFlagBits

**New Bitmasks**

- VkAccessFlags2
- VkFormatFeatureFlags2
- VkPipelineCreationFeedbackFlags
- VkPipelineStageFlags2
- VkPrivateDataSlotCreateFlags
- VkRenderingFlags
- VkSubmitFlags
• VkToolPurposeFlags

New Enum Constants

• Extending VkAccessFlagBits:
  ◦ VK_ACCESS_NONE

• Extending VkAttachmentStoreOp:
  ◦ VK_ATTACHMENT_STORE_OP_NONE

• Extending VkDescriptorType:
  ◦ VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK

• Extending VkDynamicState:
  ◦ VK_DYNAMIC_STATE_CULL_MODE
  ◦ VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE
  ◦ VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE
  ◦ VK_DYNAMIC_STATE_DEPTH_COMPARE_OP
  ◦ VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE
  ◦ VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE
  ◦ VK_DYNAMIC_STATE_FRONT_FACE
  ◦ VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE
  ◦ VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY
  ◦ VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE
  ◦ VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT
  ◦ VK_DYNAMIC_STATE_STENCIL_OP
  ◦ VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE
  ◦ VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE
  ◦ VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT

• Extending VkEventCreateFlagBits:
  ◦ VK_EVENT_CREATE_DEVICE_ONLY_BIT

• Extending VkFormat:
  ◦ VK_FORMAT_A4B4G4R4_UNORM_PACK16
  ◦ VK_FORMAT_A4R4G4B4_UNORM_PACK16
  ◦ VK_FORMAT_ASTC_10x10_SFLOAT_BLOCK
  ◦ VK_FORMAT_ASTC_10x5_SFLOAT_BLOCK
  ◦ VK_FORMAT_ASTC_10x6_SFLOAT_BLOCK
  ◦ VK_FORMAT_ASTC_10x8_SFLOAT_BLOCK
  ◦ VK_FORMAT_ASTC_12x10_SFLOAT_BLOCK
• Extending `VkImageAspectFlagBits`:
  - `VK_IMAGE_ASPECT_NONE`

• Extending `VkImageLayout`:
  - `VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL`
  - `VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL`

• Extending `VkObjectType`:
  - `VK_OBJECT_TYPE_PRIVATE_DATA_SLOT`

• Extending `VkPipelineCacheCreateFlagBits`:
  - `VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT`

• Extending `VkPipelineCreateFlagBits`:
  - `VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT`
  - `VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT`

• Extending `VkPipelineShaderStageCreateFlagBits`:
  - `VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT`
  - `VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT`

• Extending `VkPipelineStageFlagBits`:
  - `VK_PIPELINE_STAGE_NONE`

• Extending `VkResult`:
  - `VK_PIPELINE_COMPILE_REQUIRED`

• Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_BLIT_IMAGE_INFO_2`
  - `VK_STRUCTURE_TYPE_BUFFER_COPY_2`
VK_STRUCTURE_TYPE_BUFFER_IMAGE_COPY_2
VK_STRUCTURE_TYPE_BUFFER_MEMORY_BARRIER_2
VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_RENDERING_INFO
VK_STRUCTURE_TYPE_COMMAND_BUFFER_SUBMIT_INFO
VK_STRUCTURE_TYPE_COPY_BUFFER_INFO_2
VK_STRUCTURE_TYPE_COPY_BUFFER_TO_IMAGE_INFO_2
VK_STRUCTURE_TYPE_COPY_IMAGE_INFO_2
VK_STRUCTURE_TYPE_COPY_IMAGE_TO_BUFFER_INFO_2
VK_STRUCTURE_TYPE_DEPENDENCY_INFO
VK_STRUCTURE_TYPE_DESCRIPTOR_POOL_INLINE_UNIFORM_BLOCK_CREATE_INFO
VK_STRUCTURE_TYPE_DEVICE_BUFFER_MEMORY_REQUIREMENTS
VK_STRUCTURE_TYPE_DEVICE_IMAGE_MEMORY_REQUIREMENTS
VK_STRUCTURE_TYPE_DEVICE_PRIVATE_DATA_CREATE_INFO
VK_STRUCTURE_TYPE_FORMAT_PROPERTIES_3
VK_STRUCTURE_TYPE_IMAGE_BLIT_2
VK_STRUCTURE_TYPE_IMAGE_COPY_2
VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER_2
VK_STRUCTURE_TYPE_IMAGE_RESOLVE_2
VK_STRUCTURE_TYPE_MEMORY_BARRIER_2
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DYNAMIC_RENDERING_FEATURES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_ROBUSTNESS_FEATURES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INLINE_UNIFORM_BLOCK_FEATURES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INLINE_UNIFORM_BLOCK_PROPERTIES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_4_FEATURES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_4_PROPERTIES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_CREATION_CACHE_CONTROL_FEATURES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRIVATE_DATA_FEATURES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_DEMOTE_TO_HELPER_INVOCATION_FEATURES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_INTEGER_DOT_PRODUCT_FEATURES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_INTEGER_DOT_PRODUCT_PROPERTIES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_TERMINATE_INVOCATION_FEATURES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBGROUP_SIZE_CONTROL_FEATURES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBGROUP_SIZE_CONTROL_PROPERTIES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SYNCHRONIZATION_2_FEATURES
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXEL_BUFFER_ALIGNMENT_PROPERTIES
• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXTURE_COMPRESSION_ASTC_HDR_FEATURES
• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TOOL_PROPERTIES
• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_3_FEATURES
• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_3_PROPERTIES
• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ZERO_INITIALIZE_WORKGROUP_MEMORY_FEATURES
• VK_STRUCTURE_TYPE_PIPELINE_CREATION_FEEDBACK_CREATE_INFO
• VK_STRUCTURE_TYPE_PIPELINE_RENDERING_CREATE_INFO
• VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_REQUIRED_SUBGROUP_SIZE_CREATE_INFO
• VK_STRUCTURE_TYPE_PRIVATE_DATA_SLOT_CREATE_INFO
• VK_STRUCTURE_TYPE_RENDERING_ATTACHMENT_INFO
• VK_STRUCTURE_TYPE_RENDERING_INFO
• VK_STRUCTURE_TYPE_RESOLVE_IMAGE_INFO_2
• VK_STRUCTURE_TYPE_SEMAPHORE_SUBMIT_INFO
• VK_STRUCTURE_TYPE_SUBMIT_INFO_2
• VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET_INLINE_UNIFORM_BLOCK

Version 1.2

Vulkan Version 1.2 promoted a number of key extensions into the core API:

• VK_KHR_8bit_storage
• VK_KHR_buffer_device_address
• VK_KHR_create_renderpass2
• VK_KHR_depth_stencil_resolve
• VK_KHR_draw_indirect_count
• VK_KHR_driver_properties
• VK_KHR_image_format_list
• VK_KHR_imageless_framebuffer
• VK_KHR_sampler_mirror_clamp_to_edge
• VK_KHR_separate_depth_stencil_layouts
• VK_KHR_shader_atomic_int64
• VK_KHR_shader_float16_int8
• VK_KHR_shader_float_controls
• VK_KHR_shader_subgroup_extended_types
• VK_KHR_spirv_1_4
• VK_KHR_timeline_semaphore
• VK_KHR_uniform_buffer_standard_layout
• VK_KHR_vulkan_memory_model
• VK_EXT_descriptor_indexing
• VK_EXT_host_query_reset
• VK_EXT_sampler_filter_minmax
• VK_EXT_scalar_block_layout
• VK_EXT_separate_stencil_usage
• VK_EXT_shader_viewport_index_layer

All differences in behavior between these extensions and the corresponding Vulkan 1.2 functionality are summarized below.

Differences relative to **VK_KHR_8bit_storage**

If the **VK_KHR_8bit_storage** extension is not supported, support for the SPIR-V storageBuffer8BitAccess capability in shader modules is optional. Support for this feature is defined by *VkPhysicalDeviceVulkan12Features::storageBuffer8BitAccess* when queried via *vkGetPhysicalDeviceFeatures2*.

Differences relative to **VK_KHR_draw_indirect_count**

If the **VK_KHR_draw_indirect_count** extension is not supported, support for the entry points *vkCmdDrawIndirectCount* and *vkCmdDrawIndexedIndirectCount* is optional. Support for this feature is defined by *VkPhysicalDeviceVulkan12Features::drawIndirectCount* when queried via *vkGetPhysicalDeviceFeatures2*.

Differences relative to **VK_KHR_sampler_mirror_clamp_to_edge**

If the **VK_KHR_sampler_mirror_clamp_to_edge** extension is not supported, support for the *VkSamplerAddressMode VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE* is optional. Support for this feature is defined by *VkPhysicalDeviceVulkan12Features::samplerMirrorClampToEdge* when queried via *vkGetPhysicalDeviceFeatures2*.

Differences relative to **VK_EXT_descriptor_indexing**

If the **VK_EXT_descriptor_indexing** extension is not supported, support for the descriptorIndexing feature is optional. Support for this feature is defined by *VkPhysicalDeviceVulkan12Features::descriptorIndexing* when queried via *vkGetPhysicalDeviceFeatures2*.

Differences relative to **VK_EXT_scalar_block_layout**

If the **VK_EXT_scalar_block_layout** extension is not supported, support for the scalarBlockLayout feature is optional. Support for this feature is defined by *VkPhysicalDeviceVulkan12Features::scalarBlockLayout* when queried via *vkGetPhysicalDeviceFeatures2*.
Differences relative to **VK_EXT_shader_viewport_index_layer**

The **ShaderViewportIndexLayerEXT** SPIR-V capability was replaced with the **ShaderViewportIndex** and **ShaderLayer** capabilities. Declaring both is equivalent to declaring **ShaderViewportIndexLayerEXT**. If the **VK_EXT_shader_viewport_index_layer** extension is not supported, support for the **ShaderViewportIndexLayerEXT** SPIR-V capability is optional. Support for this feature is defined by **VkPhysicalDeviceVulkan12Features::shaderOutputViewportIndex** and **VkPhysicalDeviceVulkan12Features::shaderOutputLayer** when queried via **vkGetPhysicalDeviceFeatures2**.

Differences relative to **VK_KHR_buffer_device_address**

If the **VK_KHR_buffer_device_address** extension is not supported, support for the **bufferDeviceAddress** feature is optional. Support for this feature is defined by **VkPhysicalDeviceVulkan12Features::bufferDeviceAddress** when queried via **vkGetPhysicalDeviceFeatures2**.

Differences relative to **VK_KHR_shader_atomic_int64**

If the **VK_KHR_shader_atomic_int64** extension is not supported, support for the **shaderBufferInt64Atomics** feature is optional. Support for this feature is defined by **VkPhysicalDeviceVulkan12Features::shaderBufferInt64Atomics** when queried via **vkGetPhysicalDeviceFeatures2**.

Differences relative to **VK_KHR_shader_float16_int8**

If the **VK_KHR_shader_float16_int8** extension is not supported, support for the **shaderFloat16** and **shaderInt8** features is optional. Support for these features are defined by **VkPhysicalDeviceVulkan12Features::shaderFloat16** and **VkPhysicalDeviceVulkan12Features::shaderInt8** when queried via **vkGetPhysicalDeviceFeatures2**.

Differences relative to **VK_KHR_vulkan_memory_model**

If the **VK_KHR_vulkan_memory_model** extension is not supported, support for the **vulkanMemoryModel** feature is optional. Support for this feature is defined by **VkPhysicalDeviceVulkan12Features::vulkanMemoryModel** when queried via **vkGetPhysicalDeviceFeatures2**.

**Additional Vulkan 1.2 Feature Support**

In addition to the promoted extensions described above, Vulkan 1.2 added support for:

- SPIR-V version 1.4.
- SPIR-V version 1.5.
- The **samplerMirrorClampToEdge** feature which indicates whether the implementation supports the **VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE** sampler address mode.
- The **ShaderNonUniform** capability in SPIR-V version 1.5.
- The **shaderOutputViewportIndex** feature which indicates that the **ShaderViewportIndex** capability can be used.
• The shaderOutputLayer feature which indicates that the ShaderLayer capability can be used.

• The subgroupBroadcastDynamicId feature which allows the “Id” operand of OpGroupNonUniformBroadcast to be dynamically uniform within a subgroup, and the “Index” operand of OpGroupNonUniformQuadBroadcast to be dynamically uniform within a derivative group, in shader modules of version 1.5 or higher.

• The drawIndirectCount feature which indicates whether the vkCmdDrawIndirectCount and vkCmdDrawIndexedIndirectCount functions can be used.

• The descriptorIndexing feature which indicates the implementation supports the minimum number of descriptor indexing features as defined in the Feature Requirements section.

• The samplerFilterMinmax feature which indicates whether the implementation supports the minimum number of image formats that support the VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_MINMAX_BIT feature bit as defined by the filterMinmaxSingleComponentFormats property minimum requirements.

• The framebufferIntegerColorSampleCounts limit which indicates the color sample counts that are supported for all framebuffer color attachments with integer formats.

New Macros

• VK_API_VERSION_1_2

New Commands

• vkCmdBeginRenderPass2
• vkCmdDrawIndexedIndirectCount
• vkCmdDrawIndirectCount
• vkCmdEndRenderPass2
• vkCmdNextSubpass2
• vkCreateRenderPass2
• vkGetBufferDeviceAddress
• vkGetBufferOpaqueCaptureAddress
• vkGetDeviceMemoryOpaqueCaptureAddress
• vkGetSemaphoreCounterValue
• vkResetQueryPool
• vkSignalSemaphore
• vkWaitSemaphores

New Structures

• VkAttachmentDescription2
• VkAttachmentReference2
• VkBufferDeviceAddressInfo
• VkConformanceVersion
• VkDeviceMemoryOpaqueCaptureAddressInfo
• VkFramebufferAttachmentImageInfo
• VkRenderPassCreateInfo2
• VkSemaphoreSignalInfo
• VkSemaphoreWaitInfo
• VkSubpassBeginInfo
• VkSubpassDependency2
• VkSubpassDescription2
• VkSubpassEndInfo
• Extending VkAttachmentDescription2:
  ◦ VkAttachmentDescriptionStencilLayout
• Extending VkAttachmentReference2:
  ◦ VkAttachmentReferenceStencilLayout
• Extending VkBufferCreateInfo:
  ◦ VkBufferOpaqueCaptureAddressCreateInfo
• Extending VkDescriptorSetAllocateInfo:
  ◦ VkDescriptorSetVariableDescriptorCountAllocateInfo
• Extending VkDescriptorSetLayoutCreateInfo:
  ◦ VkDescriptorSetLayoutBindingFlagsCreateInfo
• Extending VkDescriptorSetLayoutSupport:
  ◦ VkDescriptorSetVariableDescriptorCountLayoutSupport
• Extending VkFramebufferCreateInfo:
  ◦ VkFramebufferAttachmentsCreateInfo
• Extending VkImageCreateInfo, VkPhysicalDeviceImageFormatInfo2:
  ◦ VkImageStencilUsageCreateInfo
• Extending VkImageCreateInfo, VkPhysicalDeviceImageFormatInfo2, VkSwapchainCreateInfoKHR:
  ◦ VkImageFormatListCreateInfo
• Extending VkMemoryAllocateInfo:
  ◦ VkMemoryOpaqueCaptureAddressAllocateInfo
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDevice8BitStorageFeatures
  ◦ VkPhysicalDeviceBufferDeviceAddressFeatures
  ◦ VkPhysicalDeviceDescriptorIndexingFeatures
• `VkPhysicalDeviceHostQueryResetFeatures`
• `VkPhysicalDeviceImagelessFramebufferFeatures`
• `VkPhysicalDeviceScalarBlockLayoutFeatures`
• `VkPhysicalDeviceSeparateDepthStencilLayoutsFeatures`
• `VkPhysicalDeviceShaderAtomicInt64Features`
• `VkPhysicalDeviceShaderFloat16Int8Features`
• `VkPhysicalDeviceShaderSubgroupExtendedTypesFeatures`
• `VkPhysicalDeviceTimelineSemaphoreFeatures`
• `VkPhysicalDeviceUniformBufferStandardLayoutFeatures`
• `VkPhysicalDeviceVulkan11Features`
• `VkPhysicalDeviceVulkan12Features`
• `VkPhysicalDeviceVulkanMemoryModelFeatures`

• **Extending `VkPhysicalDeviceProperties2`**:
  • `VkPhysicalDeviceDepthStencilResolveProperties`
  • `VkPhysicalDeviceDescriptorIndexingProperties`
  • `VkPhysicalDeviceDriverProperties`
  • `VkPhysicalDeviceFloatControlsProperties`
  • `VkPhysicalDeviceSamplerFilterMinmaxProperties`
  • `VkPhysicalDeviceTimelineSemaphoreProperties`
  • `VkPhysicalDeviceVulkan11Properties`
  • `VkPhysicalDeviceVulkan12Properties`

• **Extending `VkRenderPassBeginInfo`**:
  • `VkRenderPassAttachmentBeginInfo`

• **Extending `VkSamplerCreateInfo`**:
  • `VkSamplerReductionModeCreateInfo`

• **Extending `VkSemaphoreCreateInfo`**, `VkPhysicalDeviceExternalSemaphoreInfo`:
  • `VkSemaphoreTypeCreateInfo`

• **Extending `VkSubmitInfo`, `VkBindSparseInfo`**:
  • `VkTimelineSemaphoreSubmitInfo`

• **Extending `VkSubpassDescription2`**:
  • `VkSubpassDescriptionDepthStencilResolve`

**New Enums**

• `VkDescriptorBindingFlagBits`
• `VkDriverId`
• VkResolveModeFlagBits
• VkSamplerReductionMode
• VkSemaphoreType
• VkSemaphoreWaitFlagBits
• VkShaderFloatControlsIndependence

New Bitmasks

• VkDescriptorBindingFlags
• VkResolveModeFlags
• VkSemaphoreWaitFlags

New Enum Constants

• VK_MAX_DRIVER_INFO_SIZE
• VK_MAX_DRIVER_NAME_SIZE

Extending VkBufferCreateFlagBits:
  ◦ VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT

Extending VkBufferUsageFlagBits:
  ◦ VK_BUFFER_USAGE_SHADER_DEVICE_ADDRESS_BIT

Extending VkDescriptorPoolCreateFlagBits:
  ◦ VK_DESCRIPTOR_POOL_CREATE_UPDATE_AFTER_BIND_BIT

Extending VkDescriptorSetLayoutCreateFlagBits:
  ◦ VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT

Extending VkFormatFeatureFlagBits:
  ◦ VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_MINMAX_BIT

Extending VkFramebufferCreateFlagBits:
  ◦ VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT

Extending VkImageLayout:
  ◦ VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL
  ◦ VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL
  ◦ VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL
  ◦ VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL

Extending VkMemoryAllocateFlagBits:
  ◦ VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT
  ◦ VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT

Extending VkResult:
- VK_ERROR_FRAGMENTATION
- VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS

**Extending VkSamplerAddressMode:**
- VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE

**Extending VkStructureType:**
- VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_2
- VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_STENCIL_LAYOUT
- VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_2
- VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_STENCIL_LAYOUT
- VK_STRUCTURE_TYPE_BUFFER_DEVICE_ADDRESS_INFO
- VK_STRUCTURE_TYPE_BUFFER_OPAQUE_CAPTURE_ADDRESS_CREATE_INFO
- VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_BINDING_FLAGS_CREATE_INFO
- VK_STRUCTURE_TYPE_DESCRIPTOR_SET_VARIABLE_DESCRIPTOR_COUNT_ALLOCATE_INFO
- VK_STRUCTURE_TYPE_DESCRIPTOR_SET_VARIABLE_DESCRIPTOR_COUNT_LAYOUT_SUPPORT
- VK_STRUCTURE_TYPE_DEVICE_MEMORY_OPAQUE_CAPTURE_ADDRESS_INFO
- VK_STRUCTURE_TYPE_FRAMEBUFFER_ATTACHMENTS_CREATE_INFO
- VK_STRUCTURE_TYPE_FRAMEBUFFER_ATTACHMENT_IMAGE_INFO
- VK_STRUCTURE_TYPE_IMAGE_FORMAT_LIST_CREATE_INFO
- VK_STRUCTURE_TYPE_IMAGE_STENCIL_USAGE_CREATE_INFO
- VK_STRUCTURE_TYPE_MEMORY_OPAQUE_CAPTURE_ADDRESS_ALLOCATE_INFO
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_8BIT_STORAGE_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BUFFER_DEVICE_ADDRESS_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_STENCIL_RESOLVE_PROPERTIES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_INDEXING_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_INDEXING_PROPERTIES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DRIVER_PROPERTIES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FLOAT_CONTROLS_PROPERTIES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_HOST_QUERY_RESET_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGELESS_FRAMEBUFFER_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SAMPLER_FILTER_MINMAX_PROPERTIES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SCALAR_BLOCK_LAYOUT_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SEPARATE_DEPTH_STENCIL_LAYOUTS_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ATOMIC_INT64_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_FLOAT16_INT8_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_SUBGROUP_EXTENDED_TYPES_FEATURES
• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TIMELINE_SEMAPHORE_FEATURES
• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TIMELINE_SEMAPHORE_PROPERTIES
• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_UNIFORM_BUFFER_STANDARD_LAYOUT_FEATURES
• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_1_FEATURES
• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_1_PROPERTIES
• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_2_FEATURES
• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_1_2_PROPERTIES
• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_MEMORY_MODEL_FEATURES
• VK_STRUCTURE_TYPE_RENDER_PASS_ATTACHMENT_BEGIN_INFO
• VK_STRUCTURE_TYPE_RENDER_PASS_CREATE_INFO_2
• VK_STRUCTURE_TYPE_SAMPLER_REDUCTION_MODE_CREATE_INFO
• VK_STRUCTURE_TYPE_SEMAPHORE_SIGNAL_INFO
• VK_STRUCTURE_TYPE_SEMAPHORE_TYPE_CREATE_INFO
• VK_STRUCTURE_TYPE_SEMAPHORE_WAIT_INFO
• VK_STRUCTURE_TYPE_SUBPASS_BEGIN_INFO
• VK_STRUCTURE_TYPE_SUBPASS_DEPENDENCY_2
• VK_STRUCTURE_TYPE_SUBPASS_DESCRIPTION_2
• VK_STRUCTURE_TYPE_SUBPASS_DESCRIPTION_DEPTH_STENCIL_RESOLVE
• VK_STRUCTURE_TYPE_SUBPASS_END_INFO
• VK_STRUCTURE_TYPE_TIMELINE_SEMAPHORE_SUBMIT_INFO

Version 1.1

Vulkan Version 1.1 promoted a number of key extensions into the core API:

- VK_KHR_16bit_storage
- VK_KHR_bind_memory2
- VK_KHR_dedicated_allocation
- VK_KHR_descriptor_update_template
- VK_KHR_device_group
- VK_KHR_device_group_creation
- VK_KHR_external_fence
- VK_KHR_external_fence_capabilities
- VK_KHR_external_memory
- VK_KHR_external_memory_capabilities
VK_KHR_external_semaphore
VK_KHR_external_semaphore_capabilities
VK_KHR_get_memory_requirements2
VK_KHR_get_physical_device_properties2
VK_KHR_maintenance1
VK_KHR_maintenance2
VK_KHR_maintenance3
VK_KHR_multiview
VK_KHR_relaxed_block_layout
VK_KHR_sampler_ycbcr_conversion
VK_KHR_shader_draw_parameters
VK_KHR_storage_buffer_storage_class
VK_KHR_variable_pointers

All differences in behavior between these extensions and the corresponding Vulkan 1.1 functionality are summarized below.

Differences relative to VK_KHR_16bit_storage

If the VK_KHR_16bit_storage extension is not supported, support for the storageBuffer16BitAccess feature is optional. Support for this feature is defined by VkPhysicalDevice16BitStorageFeatures::storageBuffer16BitAccess or VkPhysicalDeviceVulkan11Features::storageBuffer16BitAccess when queried via vkGetPhysicalDeviceFeatures2.

Differences relative to VK_KHR_sampler_ycbcr_conversion

If the VK_KHR_sampler_ycbcr_conversion extension is not supported, support for the samplerYcbcrConversion feature is optional. Support for this feature is defined by VkPhysicalDeviceSamplerYcbcrConversionFeatures::samplerYcbcrConversion or VkPhysicalDeviceVulkan11Features::samplerYcbcrConversion when queried via vkGetPhysicalDeviceFeatures2.

Differences relative to VK_KHR_shader_draw_parameters

If the VK_KHR_shader_draw_parameters extension is not supported, support for the SPV_KHR_shader_draw_parameters SPIR-V extension is optional. Support for this feature is defined by VkPhysicalDeviceShaderDrawParametersFeatures::shaderDrawParameters or VkPhysicalDeviceVulkan11Features::shaderDrawParameters when queried via vkGetPhysicalDeviceFeatures2.
Differences relative to **VK_KHR_variable_pointers**

If the `VK_KHR_variable_pointers` extension is not supported, support for the `variablePointersStorageBuffer` feature is optional. Support for this feature is defined by `VkPhysicalDeviceVariablePointersFeatures::variablePointersStorageBuffer` or `VkPhysicalDeviceVulkan11Features::variablePointersStorageBuffer` when queried via `vkGetPhysicalDeviceFeatures2`.

**Additional Vulkan 1.1 Feature Support**

In addition to the promoted extensions described above, Vulkan 1.1 added support for:

- The **group operations** and **subgroup scope**.
- The **protected memory** feature.
- A new command to enumerate the instance version: `vkEnumerateInstanceVersion`.
- The **VkPhysicalDeviceShaderDrawParametersFeatures** feature query struct (where the `VK_KHR_shader_draw_parameters` extension did not have one).

**New Macros**

- `VK_API_VERSION_1_1`

**New Object Types**

- `VkDescriptorUpdateTemplate`
- `VkSamplerYcbcrConversion`

**New Commands**

- `vkBindBufferMemory2`
- `vkBindImageMemory2`
- `vkCmdDispatchBase`
- `vkCmdSetDeviceMask`
- `vkCreateDescriptorUpdateTemplate`
- `vkCreateSamplerYcbcrConversion`
- `vkDestroyDescriptorUpdateTemplate`
- `vkDestroySamplerYcbcrConversion`
- `vkEnumerateInstanceVersion`
- `vkEnumeratePhysicalDeviceGroups`
- `vkGetBufferMemoryRequirements2`
- `vkGetDescriptorSetLayoutSupport`
- `vkGetDeviceGroupPeerMemoryFeatures`
• vkGetDeviceQueue2
• vkGetImageMemoryRequirements2
• vkGetImageSparseMemoryRequirements2
• vkGetPhysicalDeviceExternalBufferProperties
• vkGetPhysicalDeviceExternalFenceProperties
• vkGetPhysicalDeviceExternalSemaphoreProperties
• vkGetPhysicalDeviceFeatures2
• vkGetPhysicalDeviceFormatProperties2
• vkGetPhysicalDeviceImageFormatProperties2
• vkGetPhysicalDeviceMemoryProperties2
• vkGetPhysicalDeviceProperties2
• vkGetPhysicalDeviceQueueFamilyProperties2
• vkGetPhysicalDeviceSparseImageFormatProperties2
• vkTrimCommandPool
• vkUpdateDescriptorSetWithTemplate

New Structures

• VkBindBufferMemoryInfo
• VkBindImageMemoryInfo
• VkBufferMemoryRequirementsInfo2
• VkDescriptorSetLayoutSupport
• VkDescriptorUpdateTemplateCreateInfo
• VkDescriptorUpdateTemplateEntry
• VkDeviceQueueInfo2
• VkExternalBufferProperties
• VkExternalFenceProperties
• VkExternalMemoryProperties
• VkExternalSemaphoreProperties
• VkFormatProperties2
• VkImageFormatProperties2
• VkImageMemoryRequirementsInfo2
• VkImageSparseMemoryRequirementsInfo2
• VkInputAttachmentAspectReference
• VkMemoryRequirements2
• VkPhysicalDeviceExternalBufferInfo
• VkPhysicalDeviceExternalFenceInfo
• VkPhysicalDeviceExternalSemaphoreInfo
• VkPhysicalDeviceGroupProperties
• VkPhysicalDeviceImageFormatInfo2
• VkPhysicalDeviceMemoryProperties2
• VkPhysicalDeviceProperties2
• VkPhysicalDeviceSparseImageFormatInfo2
• VkQueueFamilyProperties2
• VkSamplerYcbcrConversionCreateInfo
• VkSparseImageFormatProperties2
• VkSparseImageMemoryRequirements2
• Extending VkBindBufferMemoryInfo:
  ◦ VkBindBufferMemoryDeviceGroupInfo
• Extending VkBindImageMemoryInfo:
  ◦ VkBindImageMemoryDeviceGroupInfo
  ◦ VkBindImagePlaneMemoryInfo
• Extending VkBindSparseInfo:
  ◦ VkDeviceGroupBindSparseInfo
• Extending VkBufferCreateInfo:
  ◦ VkExternalMemoryBufferCreateInfo
• Extending VkCommandBufferBeginInfo:
  ◦ VkDeviceGroupCommandBufferBeginInfo
• Extending VkDeviceCreateInfo:
  ◦ VkDeviceGroupDeviceCreateInfo
  ◦ VkPhysicalDeviceFeatures2
• Extending VkFenceCreateInfo:
  ◦ VkExportFenceCreateInfo
• Extending VkImageCreateInfo:
  ◦ VkExternalMemoryImageCreateInfo
• Extending VkImageFormatProperties2:
  ◦ VkExternalImageFormatProperties
  ◦ VkSamplerYcbcrConversionImageFormatProperties
• Extending VkImageMemoryRequirementsInfo2:
  ◦ VkImagePlaneMemoryRequirementsInfo
• Extending VkImageViewCreateInfo:
• Extending `VkMemoryAllocateInfo`:
  ◦ `VkExportMemoryAllocateInfo`
  ◦ `VkMemoryAllocateFlagsInfo`
  ◦ `VkMemoryDedicatedAllocateInfo`

• Extending `VkMemoryRequirements2`:
  ◦ `VkMemoryDedicatedRequirements`

• Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  ◦ `VkPhysicalDevice16BitStorageFeatures`
  ◦ `VkPhysicalDeviceMultiviewFeatures`
  ◦ `VkPhysicalDeviceProtectedMemoryFeatures`
  ◦ `VkPhysicalDeviceSamplerYcbcrConversionFeatures`
  ◦ `VkPhysicalDeviceShaderDrawParameterFeatures`
  ◦ `VkPhysicalDeviceShaderDrawParametersFeatures`
  ◦ `VkPhysicalDeviceVariablePointerFeatures`
  ◦ `VkPhysicalDeviceVariablePointersFeatures`

• Extending `VkPhysicalDeviceImageFormatInfo2`:
  ◦ `VkPhysicalDeviceExternalImageFormatInfo`

• Extending `VkPhysicalDeviceProperties2`:
  ◦ `VkPhysicalDeviceIDProperties`
  ◦ `VkPhysicalDeviceMaintenance3Properties`
  ◦ `VkPhysicalDeviceMultiviewProperties`
  ◦ `VkPhysicalDevicePointClippingProperties`
  ◦ `VkPhysicalDeviceProtectedMemoryProperties`
  ◦ `VkPhysicalDeviceSubgroupProperties`

• Extending `VkPipelineTessellationStateCreateInfo`:
  ◦ `VkPipelineTessellationDomainOriginStateCreateInfo`

• Extending `VkRenderPassBeginInfo, VkRenderingInfo`:
  ◦ `VkDeviceGroupRenderPassBeginInfo`

• Extending `VkRenderPassCreateInfo`:
  ◦ `VkRenderPassInputAttachmentAspectCreateInfo`
  ◦ `VkRenderPassMultiviewCreateInfo`

• Extending `VkSamplerCreateInfo, VkImageViewCreateInfo`:
  ◦ `VkSamplerYcbcrConversionInfo`

• Extending `VkSemaphoreCreateInfo`
- **VkExportSemaphoreCreateInfo**
- **Extending VkSubmitInfo:**
  - **VkDeviceGroupSubmitInfo**
  - **VkProtectedSubmitInfo**

### New Enums

- **VkChromaLocation**
- **VkDescriptorUpdateTemplateType**
- **VkDeviceQueueCreateFlagBits**
- **VkExternalFenceFeatureFlagBits**
- **VkExternalFenceHandleTypeFlagBits**
- **VkExternalMemoryFeatureFlagBits**
- **VkExternalMemoryHandleTypeFlagBits**
- **VkExternalSemaphoreFeatureFlagBits**
- **VkExternalSemaphoreHandleTypeFlagBits**
- **VkFenceImportFlagBits**
- **VkMemoryAllocateFlagBits**
- **VkPeerMemoryFeatureFlagBits**
- **VkPointClippingBehavior**
- **VkSamplerYcbcrModelConversion**
- **VkSamplerYcbcrRange**
- **VkSemaphoreImportFlagBits**
- **VkSubgroupFeatureFlagBits**
- **VkTessellationDomainOrigin**

### New Bitmasks

- **VkCommandPoolTrimFlags**
- **VkDescriptorUpdateTemplateCreateFlags**
- **VkExternalFenceFeatureFlags**
- **VkExternalFenceHandleTypeFlags**
- **VkExternalMemoryFeatureFlags**
- **VkExternalMemoryHandleTypeFlags**
- **VkExternalSemaphoreFeatureFlags**
- **VkExternalSemaphoreHandleTypeFlags**
- **VkFenceImportFlags**
• VkMemoryAllocateFlags
• VkPeerMemoryFeatureFlags
• VkSemaphoreImportFlags
• VkSubgroupFeatureFlags

New Enum Constants

• VK_LUID_SIZE
• VK_MAX_DEVICE_GROUP_SIZE
• VK_QUEUE_FAMILY_EXTERNAL

Extending VkBufferCreateFlagBits:
  ◦ VK_BUFFER_CREATE_PROTECTED_BIT

Extending VkCommandPoolCreateFlagBits:
  ◦ VK_COMMAND_POOL_CREATE_PROTECTED_BIT

Extending VkDependencyFlagBits:
  ◦ VK_DEPENDENCY_DEVICE_GROUP_BIT
  ◦ VK_DEPENDENCY_VIEW_LOCAL_BIT

Extending VkDeviceQueueCreateFlagBits:
  ◦ VK_DEVICE_QUEUE_CREATE_PROTECTED_BIT

Extending VkFormat:
  ◦ VK_FORMAT_B10X6G10X6R10X6G10X6_422_UNORM_4PACK16
  ◦ VK_FORMAT_B12X4G12X4R12X4G12X4_422_UNORM_4PACK16
  ◦ VK_FORMAT_B16G16R16G16_422_UNORM
  ◦ VK_FORMAT_B8G8R8G8_422_UNORM
  ◦ VK_FORMAT_G10X6B10X6G10X6R10X6_422_UNORM_4PACK16
  ◦ VK_FORMAT_G10X6_B10X6R10X6_2PLANE_420_UNORM_3PACK16
  ◦ VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_420_UNORM_3PACK16
  ◦ VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_444_UNORM_3PACK16
  ◦ VK_FORMAT_G12X4B12X4G12X4R12X4_422_UNORM_4PACK16
  ◦ VK_FORMAT_G12X4_B12X4R12X4_2PLANE_420_UNORM_3PACK16
  ◦ VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_420_UNORM_3PACK16
  ◦ VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_422_UNORM_3PACK16
  ◦ VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_444_UNORM_3PACK16
  ◦ VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_422_UNORM_3PACK16
• Extending VkFormatFeatureFlagBits:
  ◦ VK_FORMAT_FEATURE_COSITED_CHROMA_SAMPLES_BIT
  ◦ VK_FORMAT_FEATURE_DISJOINT_BIT
  ◦ VK_FORMAT_FEATURE_MIDPOINT_CHROMA_SAMPLES_BIT
  ◦ VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_BIT
  ◦ VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_FORCEABLE_BIT
  ◦ VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_LINEAR_FILTER_BIT
  ◦ VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_SEPARATE_RECONSTRUCTION_FILTER_BIT
  ◦ VK_FORMAT_FEATURE_TRANSFER_DST_BIT
  ◦ VK_FORMAT_FEATURE_TRANSFER_SRC_BIT

• Extending VkImageAspectFlagBits:
  ◦ VK_IMAGE_ASPECT_PLANE_0_BIT
  ◦ VK_IMAGE_ASPECT_PLANE_1_BIT
  ◦ VK_IMAGE_ASPECT_PLANE_2_BIT

• Extending VkImageCreateFlagBits:
  ◦ VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT
- `VK_IMAGE_CREATE_ALIAS_BIT`
- `VK_IMAGE_CREATE_BLOCK_TEXEL_VIEW_COMPATIBLE_BIT`
- `VK_IMAGE_CREATE_DISJOINT_BIT`
- `VK_IMAGE_CREATE_EXTENDED_USAGE_BIT`
- `VK_IMAGE_CREATE_PROTECTED_BIT`
- `VK_IMAGE_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT`

**Extending `VkImageLayout`:**
- `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL`
- `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL`

**Extending `VkMemoryHeapFlagBits`:**
- `VK_MEMORY_HEAP_MULTI_INSTANCE_BIT`

**Extending `VkMemoryPropertyFlagBits`:**
- `VK_MEMORY_PROPERTY_PROTECTED_BIT`

**Extending `VkObjectType`:**
- `VK_OBJECT_TYPE_DESCRIPTOR_UPDATE_TEMPLATE`
- `VK_OBJECT_TYPE_SAMPLER_YCBCR_CONVERSION`

**Extending `VkPipelineCreateFlagBits`:**
- `VK_PIPELINE_CREATE_DISPATCH_BASE`
- `VK_PIPELINE_CREATE_DISPATCH_BASE_BIT`
- `VK_PIPELINE_CREATE_VIEW_INDEX_FROM_DEVICE_INDEX_BIT`

**Extending `VkQueueFlagBits`:**
- `VK_QUEUE_PROTECTED_BIT`

**Extending `VkResult`:**
- `VK_ERROR_INVALID_EXTERNAL_HANDLE`
- `VK_ERROR_OUT_OF_POOL_MEMORY`

**Extending `VkStructureType`:**
- `VK_STRUCTURE_TYPE_BIND_BUFFER_MEMORY_DEVICE_GROUP_INFO`
- `VK_STRUCTURE_TYPE_BIND_BUFFER_MEMORY_INFO`
- `VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_DEVICE_GROUP_INFO`
- `VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_INFO`
- `VK_STRUCTURE_TYPE_BIND_IMAGE_PLANE_MEMORY_INFO`
- `VK_STRUCTURE_TYPE_BUFFER_MEMORY_REQUIREMENTS_INFO_2`
- `VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_SUPPORT`
- `VK_STRUCTURE_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_CREATE_INFO`
- `VK_STRUCTURE_TYPE_DEVICE_GROUP_BIND_SPARSE_INFO`
- VK_STRUCTURE_TYPE_DEVICE_GROUP_COMMAND_BUFFER_BEGIN_INFO
- VK_STRUCTURE_TYPE_DEVICE_GROUP_DEVICE_CREATE_INFO
- VK_STRUCTURE_TYPE_DEVICE_GROUP_RENDER_PASS_BEGIN_INFO
- VK_STRUCTURE_TYPE_DEVICE_GROUP_SUBMIT_INFO
- VK_STRUCTURE_TYPE_DEVICE_QUEUE_INFO_2
- VK_STRUCTURE_TYPE_EXPORT_FENCE_CREATE_INFO
- VK_STRUCTURE_TYPE_EXPORT_MEMORY_ALLOCATE_INFO
- VK_STRUCTURE_TYPE_EXPORT_SEMAPHORE_CREATE_INFO
- VK_STRUCTURE_TYPE_EXTERNAL_BUFFER_PROPERTIES
- VK_STRUCTURE_TYPE_EXTERNAL_FENCE_PROPERTIES
- VK_STRUCTURE_TYPE_EXTERNAL_IMAGE_FORMAT_PROPERTIES
- VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_BUFFER_CREATE_INFO
- VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_IMAGE_CREATE_INFO
- VK_STRUCTURE_TYPE_EXTERNAL_SEMAPHORE_PROPERTIES
- VK_STRUCTURE_TYPE_FORMAT_PROPERTIES_2
- VK_STRUCTURE_TYPE_IMAGE_FORMAT_PROPERTIES_2
- VK_STRUCTURE_TYPE_IMAGE_MEMORY_REQUIREMENTS_INFO_2
- VK_STRUCTURE_TYPE_IMAGE_PLANE_MEMORY_REQUIREMENTS_INFO
- VK_STRUCTURE_TYPE_IMAGE_SPARSE_MEMORY_REQUIREMENTS_INFO_2
- VK_STRUCTURE_TYPE_IMAGE_VIEW_USAGE_CREATE_INFO
- VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_FLAGS_INFO
- VK_STRUCTURE_TYPE_MEMORY_DEDICATED_ALLOCATE_INFO
- VK_STRUCTURE_TYPE_MEMORY_DEDICATED_REQUIREMENTS
- VK_STRUCTURE_TYPE_MEMORY_REQUIREMENTS_2
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_16BIT_STORAGE_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_BUFFER_INFO
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_FENCE_INFO
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_IMAGE_FORMAT_INFO
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_SEMAPHORE_INFO
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FEATURES_2
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GROUP_PROPERTIES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ID_PROPERTIES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_FORMAT_INFO_2
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_3_PROPERTIES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_PROPERTIES_2
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_PROPERTIES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_POINT_CLIPPING_PROPERTIES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PROPERTIES_2
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PROTECTED_MEMORY_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PROTECTED_MEMORY_PROPERTIES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SAMPLER_YCBCR_CONVERSION_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_DRAW_PARAMETERS_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_DRAW_PARAMETER_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SPARSE_IMAGE_FORMAT_INFO_2
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBGROUP_PROPERTIES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VARIABLE_POINTERS_FEATURES
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VARIABLE_POINTER_FEATURES
- VK_STRUCTURE_TYPE_PIPELINE_TESSELLATION_DOMAIN_ORIGIN_STATE_CREATE_INFO
- VK_STRUCTURE_TYPE_PROTECTED_SUBMIT_INFO
- VK_STRUCTURE_TYPE_QUEUE_FAMILY_PROPERTIES_2
- VK_STRUCTURE_TYPE_RENDER_PASS_INPUT_ATTACHMENT_ASPECT_CREATE_INFO
- VK_STRUCTURE_TYPE_RENDER_PASS_MULTIVIEW_CREATE_INFO
- VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_CREATE_INFO
- VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_IMAGE_FORMAT_PROPERTIES
- VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_INFO
- VK_STRUCTURE_TYPE_SPARSE_IMAGE_FORMAT_PROPERTIES_2
- VK_STRUCTURE_TYPE_SPARSE_IMAGE_MEMORY_REQUIREMENTS_2

**Version 1.0**

Vulkan Version 1.0 was the initial release of the Vulkan API.

**New Macros**

- VK_API_VERSION
- VK_API_VERSION_1_0
- VK_API_VERSION_MAJOR
- VK_API_VERSION_MINOR
- VK_API_VERSION_PATCH
- VK_API_VERSION_VARIANT
- VK_DEFINE_HANDLE
• VK_DEFINE_NON_DISPATCHABLE_HANDLE
• VK_HEADER_VERSION
• VK_HEADER_VERSION_COMPLETE
• VK_MAKE_API_VERSION
• VK_MAKE_VERSION
• VK_NULL_HANDLE
• VK_USE_64_BIT_PTR_DEFINES
• VK_VERSION_MAJOR
• VK_VERSION_MINOR
• VK_VERSION_PATCH

New Base Types

• VkBool32
• VkDeviceAddress
• VkDeviceSize
• VkFlags
• VkSampleMask

New Object Types

• VkBuffer
• VkBufferView
• VkCommandBuffer
• VkCommandPool
• VkDescriptorPool
• VkDescriptorSet
• VkDescriptorSetLayout
• VkDevice
• VkDeviceMemory
• VkEvent
• VkFence
• VkFramebuffer
• VkImage
• VkImageView
• VkInstance
• VkPhysicalDevice
• VkPipeline
• VkPipelineCache
• VkPipelineLayout
• VkQueryPool
• VkQueue
• VkRenderPass
• VkSampler
• VkSemaphore
• VkShaderModule

New Commands

• vkAllocateCommandBuffers
• vkAllocateDescriptorSets
• vkAllocateMemory
• vkBeginCommandBuffer
• vkBindBufferMemory
• vkBindImageMemory
• vkCmdBeginQuery
• vkCmdBeginRenderPass
• vkCmdBindDescriptorSets
• vkCmdBindIndexBuffer
• vkCmdBindPipeline
• vkCmdBindVertexBuffers
• vkCmdBlitImage
• vkCmdClearAttachments
• vkCmdClearColorImage
• vkCmdClearColorImage
• vkCmdCopyBuffer
• vkCmdCopyBufferToImage
• vkCmdCopyImage
• vkCmdCopyImageToBuffer
• vkCmdCopyQueryPoolResults
• vkCmdDispatch
• vkCmdDispatchIndirect
• vkCmdDraw
- vkCmdDrawIndexed
- vkCmdDrawIndexedIndirect
- vkCmdDrawIndirect
- vkCmdEndQuery
- vkCmdEndRenderPass
- vkCmdExecuteCommands
- vkCmdFillBuffer
- vkCmdNextSubpass
- vkCmdPipelineBarrier
- vkCmdPushConstants
- vkCmdResetEvent
- vkCmdResetQueryPool
- vkCmdResolveImage
- vkCmdSetBlendConstants
- vkCmdSetDepthBias
- vkCmdSetDepthBounds
- vkCmdSetEvent
- vkCmdSetLineWidth
- vkCmdSetScissor
- vkCmdSetStencilCompareMask
- vkCmdSetStencilReference
- vkCmdSetStencilWriteMask
- vkCmdSetViewport
- vkCmdUpdateBuffer
- vkCmdWaitEvents
- vkCmdWriteTimestamp
- vkCreateBuffer
- vkCreateBufferView
- vkCreateCommandPool
- vkCreateComputePipelines
- vkCreateDescriptorPool
- vkCreateDescriptorSetLayout
- vkCreateDevice
- vkCreateEvent
- vkCreateFence
- vkCreateFramebuffer
- vkCreateGraphicsPipelines
- vkCreateImage
- vkCreateImageView
- vkCreateInstance
- vkCreatePipelineCache
- vkCreatePipelineLayout
- vkCreateQueryPool
- vkCreateRenderPass
- vkCreateSampler
- vkCreateSemaphore
- vkCreateShaderModule
- vkDestroyBuffer
- vkDestroyBufferView
- vkDestroyCommandPool
- vkDestroyDescriptorPool
- vkDestroyDescriptorSetLayout
- vkDestroyDevice
- vkDestroyEvent
- vkDestroyFence
- vkDestroyFramebuffer
- vkDestroyImage
- vkDestroyImageView
- vkDestroyInstance
- vkDestroyPipeline
- vkDestroyPipelineCache
- vkDestroyPipelineLayout
- vkDestroyQueryPool
- vkDestroyRenderPass
- vkDestroySampler
- vkDestroySemaphore
- vkDestroyShaderModule
- vkDeviceWaitIdle
- vkEndCommandBuffer
- vkEnumerateDeviceExtensionProperties
- vkEnumerateDeviceLayerProperties
- vkEnumerateInstanceExtensionProperties
- vkEnumerateInstanceLayerProperties
- vkEnumeratePhysicalDevices
- vkFlushMappedMemoryRanges
- vkFreeCommandBuffers
- vkFreeDescriptorSets
- vkFreeMemory
- vkGetBufferMemoryRequirements
- vkGetDeviceMemoryCommitment
- vkGetDeviceProcAddr
- vkGetDeviceQueue
- vkGetEventStatus
- vkGetFenceStatus
- vkGetImageMemoryRequirements
- vkGetImageSparseMemoryRequirements
- vkGetImageSubresourceLayout
- vkGetInstanceProcAddr
- vkGetPhysicalDeviceFeatures
- vkGetPhysicalDeviceFormatProperties
- vkGetPhysicalDeviceImageFormatProperties
- vkGetPhysicalDeviceMemoryProperties
- vkGetPhysicalDeviceProperties
- vkGetPhysicalDeviceQueueFamilyProperties
- vkGetPhysicalDeviceSparseImageFormatProperties
- vkGetPipelineCacheData
- vkGetQueryPoolResults
- vkGetRenderAreaGranularity
- vkInvalidateMappedMemoryRanges
- vkMapMemory
- vkMergePipelineCaches
- vkQueueBindSparse
- vkQueueSubmit
- vkQueueWaitIdle
- vkResetCommandBuffer
• vkResetCommandPool
• vkResetDescriptorPool
• vkResetEvent
• vkResetFences
• vkSetEvent
• vkUnmapMemory
• vkUpdateDescriptorSets
• vkWaitForFences

New Structures

• VkAllocationCallbacks
• VkApplicationInfo
• VkAttachmentDescription
• VkAttachmentReference
• VkBaseInStructure
• VkBaseOutStructure
• VkBindSparseInfo
• VkBufferCopy
• VkBufferCreateInfo
• VkBufferImageCopy
• VkBufferMemoryBarrier
• VkBufferViewCreateInfo
• VkClearAttachment
• VkClearDepthStencilValue
• VkClearRect
• VkCommandBufferAllocateInfo
• VkCommandBufferBeginInfo
• VkCommandBufferInheritanceInfo
• VkCommandPoolCreateInfo
• VkComponentMapping
• VkComputePipelineCreateInfo
• VkCopyDescriptorSet
• VkDescriptorBufferInfo
• VkDescriptorImageInfo
• VkDescriptorPoolCreateInfo
- VkDescriptorPoolSize
- VkDescriptorSetAllocateInfo
- VkDescriptorSetLayoutBinding
- VkDescriptorSetLayoutCreateInfo
- VkDeviceCreateInfo
- VkDeviceQueueCreateInfo
- VkDispatchIndirectCommand
- VkDrawIndexedIndirectCommand
- VkDrawIndirectCommand
- VkEventCreateInfo
- VkExtensionProperties
- VkExtent2D
- VkExtent3D
- VkFenceCreateInfo
- VkFormatProperties
- VkFramebufferCreateInfo
- VkGraphicsPipelineCreateInfo
- VkImageBlit
- VkImageCopy
- VkImageCreateInfo
- VkImageFormatProperties
- VkImageMemoryBarrier
- VkImageResolve
- VkImageSubresource
- VkImageSubresourceLayers
- VkImageSubresourceRange
- VkImageViewCreateInfo
- VkInstanceCreateInfo
- VkLayerProperties
- VkMappedMemoryRange
- VkMemoryAllocateInfo
- VkMemoryBarrier
- VkMemoryHeap
- VkMemoryRequirements
- VkMemoryType
• VkOffset2D
• VkOffset3D
• VkPhysicalDeviceFeatures
• VkPhysicalDeviceLimits
• VkPhysicalDeviceMemoryProperties
• VkPhysicalDeviceProperties
• VkPhysicalDeviceSparseProperties
• VkPipelineCacheCreateInfo
• VkPipelineCacheHeaderVersionOne
• VkPipelineColorBlendAttachmentState
• VkPipelineColorBlendStateCreateInfo
• VkPipelineDepthStencilStateCreateInfo
• VkPipelineDynamicStateCreateInfo
• VkPipelineInputAssemblyStateCreateInfo
• VkPipelineLayoutCreateInfo
• VkPipelineMultisampleStateCreateInfo
• VkPipelineRasterizationStateCreateInfo
• VkPipelineShaderStageCreateInfo
• VkPipelineTessellationStateCreateInfo
• VkPipelineVertexInputStateCreateInfo
• VkPipelineViewportStateCreateInfo
• VkPushConstantRange
• VkQueryPoolCreateInfo
• VkQueueFamilyProperties
• VkRect2D
• VkRenderPassBeginInfo
• VkRenderPassCreateInfo
• VkSamplerCreateInfo
• VkSemaphoreCreateInfo
• VkSparseBufferMemoryBindInfo
• VkSparseImageFormatProperties
• VkSparseImageMemoryBind
• VkSparseImageMemoryBindInfo
• VkSparseImageOpaqueMemoryBindInfo
• VkSparseImageMemoryRequirements
- VkSparseMemoryBind
- VkSpecializationInfo
- VkSpecializationMapEntry
- VkStencilOpState
- VkSubmitInfo
- VkSubpassDependency
- VkSubpassDescription
- VkSubresourceLayout
- VkVertexInputAttributeDescription
- VkVertexInputBindingDescription
- VkViewport
- VkWriteDescriptorSet

- ExtendingVkPipelineShaderStageCreateInfo:
  - VkShaderModuleCreateInfo

**New Unions**

- VkClearColorValue
- VkClearValue

**New Function Pointers**

- PFN_vkAllocationFunction
- PFN_vkFreeFunction
- PFN_vkInternalAllocationNotification
- PFN_vkInternalFreeNotification
- PFN_vkReallocationFunction
- PFN_vkVoidFunction

**New Enums**

- VkAccessFlagBits
- VkAttachmentDescriptionFlagBits
- VkAttachmentLoadOp
- VkAttachmentStoreOp
- VkBlendFactor
- VkBlendOp
- VkBorderColor
- VkBufferCreateFlagBits
- VkBufferUsageFlagBits
- VkColorComponentFlagBits
- VkCommandBufferLevel
- VkCommandBufferResetFlagBits
- VkCommandBufferUsageFlagBits
- VkCommandPoolCreateFlagBits
- VkCommandPoolResetFlagBits
- VkCompareOp
- VkComponentSwizzle
- VkCullModeFlagBits
- VkDependencyFlagBits
- VkDescriptorPoolCreateFlagBits
- VkDescriptorSetLayoutCreateFlagBits
- VkDescriptorType
- VkDynamicState
- VkEventCreateFlagBits
- VkFenceCreateFlagBits
- VkFilter
- VkFormat
- VkFormatFeatureFlagBits
- VkFramebufferCreateFlagBits
- VkFrontFace
- VkImageAspectFlagBits
- VkImageCreateFlagBits
- VkImageLayout
- VkImageTiling
- VkImageType
- VkImageUsageFlagBits
- VkImageViewCreateFlagBits
- VkImageViewType
- VkIndexType
- VkInstanceCreateFlagBits
- VkInternalAllocationType
- VkLogicOp
- VkMemoryHeapFlagBits
- VkMemoryPropertyFlagBits
- VkObjectType
- VkPhysicalDeviceType
- VkPipelineBindPoint
- VkPipelineCacheHeaderVersion
- VkPipelineCreateFlagBits
- VkPipelineShaderStageCreateFlagBits
- VkPipelineStageFlagBits
- VkPolygonMode
- VkPrimitiveTopology
- VkQueryControlFlagBits
- VkQueryPipelineStatisticFlagBits
- VkQueryResultFlagBits
- VkQueryType
- VkQueueFlagBits
- VkRenderPassCreateFlagBits
- VkResult
- VkSampleCountFlagBits
- VkSamplerAddressMode
- VkSamplerCreateFlagBits
- VkSamplerMipmapMode
- VkShaderStageFlagBits
- VkSharingMode
- VkSparseImageFormatFlagBits
- VkSparseMemoryBindFlagBits
- VkStencilFaceFlagBits
- VkStencilOp
- VkStructureType
- VkSubpassContents
- VkSubpassDescriptionFlagBits
- VkSystemAllocationScope
- VkVendorId
- VkVertexInputRate
New Bitmasks

- VkAccessFlags
- VkAttachmentDescriptionFlags
- VkBufferCreateFlags
- VkBufferUsageFlags
- VkBufferViewCreateFlags
- VkColorComponentFlags
- VkCommandBufferResetFlags
- VkCommandBufferUsageFlags
- VkCommandPoolCreateFlags
- VkCommandPoolResetFlags
- VkCullModeFlags
- VkDependencyFlags
- VkDescriptorPoolCreateFlags
- VkDescriptorPoolResetFlags
- VkDescriptorSetLayoutCreateFlags
- VkDeviceCreateFlags
- VkDeviceQueueCreateFlags
- VkEventCreateFlags
- VkFenceCreateFlags
- VkFormatFeatureFlags
- VkFramebufferCreateFlags
- VkImageAspectFlags
- VkImageCreateFlags
- VkImageUsageFlags
- VkImageViewCreateFlags
- VkInstanceCreateFlags
- VkMemoryHeapFlags
- VkMemoryMapFlags
- VkMemoryPropertyFlags
- VkPipelineCacheCreateFlags
- VkPipelineColorBlendStateCreateFlags
- VkPipelineCreateFlags
- VkPipelineDepthStencilStateCreateFlags
• VkPipelineDynamicStateCreateFlags
• VkPipelineInputAssemblyStateCreateFlags
• VkPipelineLayoutCreateFlags
• VkPipelineMultisampleStateCreateFlags
• VkPipelineRasterizationStateCreateFlags
• VkPipelineShaderStageCreateFlags
• VkPipelineStageFlags
• VkPipelineTessellationStateCreateFlags
• VkPipelineVertexInputStateCreateFlags
• VkPipelineViewportStateCreateFlags
• VkQueryControlFlags
• VkQueryPipelineStatisticFlags
• VkQueryPoolCreateFlags
• VkQueryResultFlags
• VkQueueFlags
• VkRenderPassCreateFlags
• VkSampleCountFlags
• VkSamplerCreateFlags
• VkSemaphoreCreateFlags
• VkShaderModuleCreateFlags
• VkShaderStageFlags
• VkSparseImageFormatFlags
• VkSparseMemoryBindFlags
• VkStencilFaceFlags
• VkSubpassDescriptionFlags

**New Headers**

• vk_platform

**New Enum Constants**

• VK_ATTACHMENT_UNUSED
• VK_FALSE
• VK_LOD_CLAMP_NONE
• VK_MAX_DESCRIPTION_SIZE
• VK_MAX_EXTENSION_NAME_SIZE
• VK_MAX_MEMORY_HEAPS
• VK_MAX_MEMORY_TYPES
• VK_MAX_PHYSICAL_DEVICE_NAME_SIZE
• VK_QUEUE_FAMILY_IGNORED
• VK_REMAINING_ARRAY LAYERS
• VK_REMAINING_MIP_LEVELS
• VK_SUBPASS_EXTERNAL
• VK_TRUE
• VK_UUID_SIZE
• VK_WHOLE_SIZE
Appendix E: Layers & Extensions (Informative)

Extensions to the Vulkan API can be defined by authors, groups of authors, and the Khronos Vulkan Working Group. In order not to compromise the readability of the Vulkan Specification, the core Specification does not incorporate most extensions. The online Registry of extensions is available at URL

https://registry.khronos.org/vulkan/

and allows generating versions of the Specification incorporating different extensions.

Authors creating extensions and layers must follow the mandatory procedures described in the Vulkan Documentation and Extensions document when creating extensions and layers.

The remainder of this appendix documents a set of extensions chosen when this document was built. Versions of the Specification published in the Registry include:

- Core API + mandatory extensions required of all Vulkan implementations.
- Core API + all registered and published Khronos (KHR) extensions.
- Core API + all registered and published extensions.

Extensions are grouped as Khronos KHR, multivendor EXT, and then alphabetically by author ID. Within each group, extensions are listed in alphabetical order by their name.

Extension Dependencies

Extensions which have dependencies on specific core versions or on other extensions will list such dependencies.

For core versions, the specified version must be supported at runtime. All extensions implicitly require support for Vulkan 1.0.

For a device extension, use of any device-level functionality defined by that extension requires that any extensions that extension depends on be enabled.

For any extension, use of any instance-level functionality defined by that extension requires only that any extensions that extension depends on be supported at runtime.

List of Current Extensions

- VK_KHR_acceleration_structure
- VK_KHR_android_surface
- VK_KHR_cooperative_matrix
- VK_KHR_deferred_host_operations
• VK_KHR_display
• VK_KHR_display_swapchain
• VK_KHR_external_fence_fd
• VK_KHR_external_fence_win32
• VK_KHR_external_memory_fd
• VK_KHR_external_memory_win32
• VK_KHR_external_semaphore_fd
• VK_KHR_external_semaphore_win32
• VK_KHR_fragment_shader_barycentric
• VK_KHR_fragment_shading_rate
• VK_KHR_get_display_properties2
• VK_KHR_get_surface_capabilities2
• VK_KHR_global_priority
• VK_KHR_incremental_present
• VK_KHR_maintenance5
• VK_KHR_map_memory2
• VK_KHR_performance_query
• VK_KHR_pipeline_executable_properties
• VK_KHR_pipeline_library
• VK_KHR_portability_enumeration
• VK_KHR_present_id
• VK_KHR_present_wait
• VK_KHR_push_descriptor
• VK_KHR_ray_query
• VK_KHR_ray_tracing_maintenance1
• VK_KHR_ray_tracing_pipeline
• VK_KHR_ray_tracing_position_fetch
• VK_KHR_shader_clock
• VK_KHR_shader_subgroup_uniform_control_flow
• VK_KHR_shared_presentable_image
• VK_KHR_surface
• VK_KHR_surface_protectedCapabilities
• VK_KHR_swapchain
• VK_KHR_swapchain_mutable_format
• VK_KHR_video_decode_h264
• VK_KHR_video_decode_h265
• VK_KHR_video_decode_queue
• VK_KHR_video_queue
• VK_KHR_wayland_surface
• VK_KHR_win32_keyed_mutex
• VK_KHR_win32_surface
• VK_KHR_workgroup_memory_explicit_layout
• VK_KHR_xcb_surface
• VK_KHR_xlib_surface
• VK_EXT_acquire_drm_display
• VK_EXT_acquire_xlib_display
• VK_EXT_astc_decode_mode
• VK_EXT_attachment_feedback_loop_dynamic_state
• VK_EXT_attachment_feedback_loop_layout
• VK_EXT_blend_operation_advanced
• VK_EXT_border_color_swizzle
• VK_EXT_calibrated_timestamps
• VK_EXT_color_write_enable
• VK_EXT_conditional_rendering
• VK_EXT_conservative_rasterization
• VK_EXT_custom_border_color
• VK_EXT_debug_utils
• VK_EXT_depth_bias_control
• VK_EXT_depth_clamp_zero_one
• VK_EXT_depth_clip_control
• VK_EXT_depth_clip_enable
• VK_EXT_depth_range_unrestricted
• VK_EXT_descriptor_buffer
• VK_EXT_device_address_binding_report
• VK_EXT_device_fault
• VK_EXT_device_memory_report
• VK_EXT_direct_mode_display
• VK_EXT_directfb_surface
• VK_EXT_discard_rectangles
• VK_EXT_display_control
• VK_EXT_display_surface_counter
• VK_EXT_dynamicrendering_unused_attachments
• VK_EXT_extended_dynamic_state3
• VK_EXT_external_memory_acquire_unmodified
• VK_EXT_external_memory_dma_buf
• VK_EXT_external_memory_host
• VK_EXT_filter_cubic
• VK_EXT_fragment_density_map
• VK_EXT_fragment_density_map2
• VK_EXT_fragment_shader_interlock
• VK_EXT_frame_boundary
• VK_EXT_full_screen_exclusive
• VK_EXT_graphics_pipeline_library
• VK_EXT_hdr_metadata
• VK_EXT_headless_surface
• VK_EXT_host_image_copy
• VK_EXT_image_2d_view_of_3d
• VK_EXT_image_compression_control
• VK_EXT_image_compression_control_swapchain
• VK_EXT_image_drm_format_modifier
• VK_EXT_image_sliced_view_of_3d
• VK_EXT_image_view_min_lod
• VK_EXT_index_type_uint8
• VK_EXT_legacy_dithering
• VK_EXT_line_rasterization
• VK_EXT_load_store_op_none
• VK_EXT_memory_budget
• VK_EXT_memory_priority
• VK_EXT_mesh_shader
• VK_EXT_metal_objects
• VK_EXT_metal_surface
• VK_EXT_multi_draw
• VK_EXT_multisampled_render_to_single_sampled
• VK_EXT_mutable_descriptor_type
• VK_EXT_non_seamless_cube_map
- VK_EXT_opacity_micromap
- VK_EXT_pageable_device_local_memory
- VK_EXT_pci_bus_info
- VK_EXT_physical_device_drm
- VK_EXT_pipeline_library_group_handles
- VK_EXT_pipeline_properties
- VK_EXT_pipeline_protected_access
- VK_EXT_pipeline_robustness
- VK_EXT_post_depth_coverage
- VK_EXT_primitive_topology_list_restart
- VK_EXT_primitives_generated_query
- VK_EXT_provoking_vertex
- VK_EXT_queue_family_foreign
- VK_EXT_rasterization_order_attachment_access
- VK_EXT_rgba10x6_formats
- VK_EXT_robustness2
- VK_EXT_sample_locations
- VK_EXT_shader_atomic_float
- VK_EXT_shader_atomic_float2
- VK_EXT_shader_image_atomic_int64
- VK_EXT_shader_module_identifier
- VK_EXT_shader_object
- VK_EXT_shader_stencil_export
- VK_EXT_shader_tile_image
- VK_EXT_subpass_merge_feedback
- VK_EXT_surface_maintenance1
- VK_EXT_swapchain_colorspace
- VK_EXT_swapchain_maintenance1
- VK_EXT_transform_feedback
- VK_EXT_validation_cache
- VK_EXT_validation_features
- VK_EXT_vertex_attribute_divisor
- VK_EXT_vertex_input_dynamic_state
- VK_EXT_ycbcr_image_arrays
- VK_AMD_buffer_marker
• VK_INTEL_performance_query
• VK_INTEL_shader_integer_functions2
• VK_LUNARG_direct_driver_loading
• VK_MSFT_layered_driver
• VK_NN_vi_surface
• VK_NV_acquire_winrt_display
• VK_NV_clip_space_w_scaling
• VK_NV_compute_shader_derivatives
• VK_NV Cooperative_matrix
• VK_NV_copy_memory_indirect
• VK_NV_corner_sampled_image
• VK_NV_coverage_reduction_mode
• VK_NV_dedicated_allocation_image_aliasing
• VK_NV_descriptor_pool_overallocation
• VK_NV_device_diagnostic_checkpoints
• VK_NV_device_diagnostics_config
• VK_NV_device_generated_commands
• VK_NV_device_generated_commands_compute
• VK_NV_external_memory_rdma
• VK_NV_fill_rectangle
• VK_NV_fragment_coverage_to_color
• VK_NV_fragment_shading_rate_enums
• VK_NV_framebuffer_mixed_samples
• VK_NV_geometry_shader_passsthrough
• VK_NV_inherited_viewport_scissor
• VK_NV_linear_color_attachment
• VK_NV_low_latency
• VK_NV_memory_decompression
• VK_NV_mesh_shader
• VK_NV_optical_flow
• VK_NV_present_barrier
• VK_NV_ray_tracing
• VK_NV_ray_tracing_invocation_reorder
• VK_NV_ray_tracing_motion_blur
• VK_NV_representative_fragment_test
• VK_NV_sample_mask_override_coverage
• VK_NV_scissor-exclusive
• VK_NV_shader_image_footprint
• VK_NV_shader_sm_builtins
• VK_NV_shader_subgroup_partitioned
• VK_NV_shading_rate_image
• VK_NV_viewport_array2
• VK_NV_viewport_swizzle
• VK_NVX_binary_import
• VK_NVX_image_view_handle
• VK_NVX_multiview_per_view_attributes
• VK_QCOM_filter_cubic_clamp
• VK_QCOM_filter_cubic_weights
• VK_QCOM_fragment_density_map_offset
• VK_QCOM_image_processing
• VK_QCOM_image_processing2
• VK_QCOM_multiview_per_view_render_areas
• VK_QCOM_multiview_per_view_viewports
• VK_QCOM_render_pass_shader_resolve
• VK_QCOM_render_pass_store_ops
• VK_QCOM_render_pass_transform
• VK_QCOM_rotated_copy_commands
• VK_QCOM_tile_properties
• VK_QCOM_ycbcr_degamma
• VK_QNX_external_memory_screen_buffer
• VK_QNX_screen_surface
• VK_SEC_amigo_profiling
• VK_VALVE_descriptor_set_host_mapping
VK_KHR_acceleration_structure

Name String
VK_KHR_acceleration_structure

Extension Type
Device extension

Registered Extension Number
151

Revision
13

Ratification Status
Ratified

Extension and Version Dependencies
Version 1.1
and
VK_EXT_descriptor_indexing
and
VK_KHR_buffer_device_address
and
VK_KHR_deferred_host_operations

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2021-09-30

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Description

In order to be efficient, rendering techniques such as ray tracing need a quick way to identify which primitives may be intersected by a ray traversing the geometries. Acceleration structures are the most common way to represent the geometry spatially sorted, in order to quickly identify such potential intersections.

This extension adds new functionalities:

- Acceleration structure objects and build commands
- Structures to describe geometry inputs to acceleration structure builds
- Acceleration structure copy commands

New Object Types

- VkAccelerationStructureKHR

New Commands

- vkBuildAccelerationStructuresKHR
- vkCmdBuildAccelerationStructuresIndirectKHR
- vkCmdBuildAccelerationStructuresKHR
- vkCmdCopyAccelerationStructureKHR
- vkCmdCopyAccelerationStructureToMemoryKHR
- vkCmdCopyMemoryToAccelerationStructureKHR
- vkCmdWriteAccelerationStructuresPropertiesKHR
- vkCopyAccelerationStructureKHR
- vkCopyAccelerationStructureToMemoryKHR
- vkCopyMemoryToAccelerationStructureKHR
- vkCreateAccelerationStructureKHR
- vkDestroyAccelerationStructureKHR
- vkGetAccelerationStructureBuildSizesKHR
- vkGetAccelerationStructureDeviceAddressKHR
- vkGetDeviceAccelerationStructureCompatibilityKHR
- vkWriteAccelerationStructuresPropertiesKHR

New Structures

- VkAabbPositionsKHR
- VkAccelerationStructureBuildGeometryInfoKHR
- VkAccelerationStructureBuildRangeInfoKHR
- `VkAccelerationStructureBuildSizesInfoKHR`
- `VkAccelerationStructureCreateInfoKHR`
- `VkAccelerationStructureDeviceAddressInfoKHR`
- `VkAccelerationStructureGeometryAabbsDataKHR`
- `VkAccelerationStructureGeometryInstancesDataKHR`
- `VkAccelerationStructureGeometryKHR`
- `VkAccelerationStructureGeometryTrianglesDataKHR`
- `VkAccelerationStructureInstanceKHR`
- `VkAccelerationStructureVersionInfoKHR`
- `VkCopyAccelerationStructureInfoKHR`
- `VkCopyAccelerationStructureToDeviceMemoryInfoKHR`
- `VkCopyMemoryToDeviceAccelerationStructureInfoKHR`
- `VkTransformMatrixKHR`

**Extending** `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
- `VkPhysicalDeviceAccelerationStructureFeaturesKHR`

**Extending** `VkPhysicalDeviceProperties2`:
- `VkPhysicalDeviceAccelerationStructurePropertiesKHR`

**Extending** `VkWriteDescriptorSet`:
- `VkWriteDescriptorSetAccelerationStructureKHR`

**New Unions**
- `VkAccelerationStructureGeometryDataKHR`
- `VkDeviceOrHostAddressConstKHR`
- `VkDeviceOrHostAddressKHR`

**New Enums**
- `VkAccelerationStructureBuildTypeKHR`
- `VkAccelerationStructureCompatibilityKHR`
- `VkAccelerationStructureCreateFlagBitsKHR`
- `VkAccelerationStructureTypeKHR`
- `VkBuildAccelerationStructureFlagBitsKHR`
- `VkBuildAccelerationStructureModeKHR`
- `VkCopyAccelerationStructureModeKHR`
- `VkGeometryFlagBitsKHR`
- `VkGeometryInstanceFlagBitsKHR`
- `VkGeometryFlagBitsKHR`
• VkGeometryTypeKHR

New Bitmasks

• VkAccelerationStructureCreateFlagsKHR
• VkBuildAccelerationStructureFlagsKHR
• VkGeometryFlagsKHR
• VkGeometryInstanceFlagsKHR

New Enum Constants

• VK_KHR_ACCELERATION_STRUCTURE_EXTENSION_NAME
• VK_KHR_ACCELERATION_STRUCTURE_SPEC_VERSION

Extending VkAccessFlagBits:

◦ VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_KHR
◦ VK_ACCESS_ACCELERATION_STRUCTURE_WRITE_BIT_KHR

Extending VkBufferUsageFlagBits:

◦ VK_BUFFER_USAGE_ACCELERATION_STRUCTURE_BUILD_INPUT_READ_ONLY_BIT_KHR
◦ VK_BUFFER_USAGE_ACCELERATION_STRUCTURE_STORAGE_BIT_KHR

Extending VkDescriptorType:

◦ VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_KHR

Extending VkFormatFeatureFlagBits:

◦ VK_FORMAT_FEATURE_ACCELERATION_STRUCTURE_VERTEX_BUFFER_BIT_KHR

Extending VkIndexType:

◦ VK_INDEX_TYPE_NONE_KHR

Extending VkObjectType:

◦ VK_OBJECT_TYPE_ACCELERATION_STRUCTURE_KHR

Extending VkPipelineStageFlagBits:

◦ VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR

Extending VkQueryType:

◦ VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_KHR
◦ VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_SIZE_KHR

Extending VkStructureType:

◦ VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_BUILD_GEOMETRY_INFO_KHR
◦ VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_BUILD_SIZES_INFO_KHR
◦ VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_CREATE_INFO_KHR
◦ VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_DEVICE_ADDRESS_INFO_KHR
If VK_EXT_debug_report is supported:

- Extending VkDebugReportObjectTypeEXT:
  - VK_DEBUG_REPORT_OBJECT_TYPE_ACCELERATION_STRUCTURE_KHR_EXT

If VK_KHR_format_feature_flags2 is supported:

- Extending VkFormatFeatureFlagBits2:
  - VK_FORMAT_FEATURE_2_ACCELERATION_STRUCTURE_VERTEX_BUFFER_BIT_KHR

Issues

(1) How does this extension differ from VK_NV_ray_tracing?

DISCUSSION:

The following is a summary of the main functional differences between VK_KHR_acceleration_structure and VK_NV_ray_tracing:

- added acceleration structure serialization / deserialization
  (VK_COPY_ACCELERATION_STRUCTURE_MODE_SERIALIZE_KHR,
   VK_COPY_ACCELERATION_STRUCTURE_MODE_DESERIALIZE_KHR,
   vkCmdCopyAccelerationStructureToMemoryKHR,
   vkCmdCopyMemoryToAccelerationStructureKHR)
- added inactive primitives and instances
- added VkPhysicalDeviceAccelerationStructureFeaturesKHR structure
- added indirect and batched acceleration structure builds
  (vkCmdBuildAccelerationStructuresIndirectKHR)
- added host acceleration structure commands
- reworked geometry structures so they could be better shared between device, host, and indirect builds
• explicitly made VkAccelerationStructureKHR use device addresses
• added acceleration structure compatibility check function (vkGetDeviceAccelerationStructureCompatibilityKHR)
• add parameter for requesting memory requirements for host and/or device build
• added format feature for acceleration structure build vertex formats (VK_FORMAT_FEATURE_ACCELERATION_STRUCTURE_VERTEX_BUFFER_BIT_KHR)

(2) Can you give a more detailed comparison of differences and similarities between VK_NV_ray_tracing and VK_KHR_acceleration_structure?

DISCUSSION:

The following is a more detailed comparison of which commands, structures, and enums are aliased, changed, or removed.

• Aliased functionality — enums, structures, and commands that are considered equivalent:
  ◦ VkGeometryTypeNV ↔ VkGeometryTypeKHR
  ◦ VkAccelerationStructureTypeNV ↔ VkAccelerationStructureTypeKHR
  ◦ VkCopyAccelerationStructureModeNV ↔ VkCopyAccelerationStructureModeKHR
  ◦ VkGeometryFlagsNV ↔ VkGeometryFlagsKHR
  ◦ VkGeometryFlagBitsNV ↔ VkGeometryFlagBitsKHR
  ◦ VkGeometryInstanceFlagsNV ↔ VkGeometryInstanceFlagsKHR
  ◦ VkGeometryInstanceFlagBitsNV ↔ VkGeometryInstanceFlagBitsKHR
  ◦ VkBuildAccelerationStructureFlagsNV ↔ VkBuildAccelerationStructureFlagsKHR
  ◦ VkBuildAccelerationStructureFlagBitsNV ↔ VkBuildAccelerationStructureFlagBitsKHR
  ◦ VkTransformMatrixNV ↔ VkTransformMatrixKHR (added to VK_NV_ray_tracing for descriptive purposes)
  ◦ VkAabbPositionsNV ↔ VkAabbPositionsKHR (added to VK_NV_ray_tracing for descriptive purposes)
  ◦ VkAccelerationStructureInstanceNV ↔ VkAccelerationStructureInstanceKHR (added to VK_NV_ray_tracing for descriptive purposes)

• Changed enums, structures, and commands:
  ◦ renamed VK_GEOMETRY_INSTANCE_TRIANGLE_CULL_DISABLE_BIT_NV → VK_GEOMETRY_INSTANCE_TRIANGLE_FACING_CULL_DISABLE_BIT_KHR in VkGeometryInstanceFlagBitsKHR
  ◦ VkGeometryTrianglesNV → VkAccelerationStructureGeometryTrianglesDataKHR (device or host address instead of buffer+offset)
  ◦ VkGeometryAABBNV → VkAccelerationStructureGeometryAabbsDataKHR (device or host address instead of buffer+offset)
  ◦ VkGeometryDataNV → VkAccelerationStructureGeometryDataKHR (union of triangle/aabbs/instances)
- **VkGeometryNV** → **VkAccelerationStructureGeometryKHR** (changed type of geometry)
- **VkAccelerationStructureCreateInfoNV** → **VkAccelerationStructureCreateInfoKHR** (reshuffle geometry layout/information)
- **VkPhysicalDeviceRayTracingPropertiesNV** → **VkPhysicalDeviceAccelerationStructurePropertiesKHR** (for acceleration structure properties, renamed `maxTriangleCount` to `maxPrimitiveCount`, added per stage and update after bind limits) and **VkPhysicalDeviceRayTracingPipelinePropertiesKHR** (for ray tracing pipeline properties)
- **VkAccelerationStructureMemoryRequirementsInfoNV** (deleted - replaced by allocating on top of **VkBuffer**)
- **VkWriteDescriptorSetAccelerationStructureNV** → **VkWriteDescriptorSetAccelerationStructureKHR** (different acceleration structure type)
- **vkCreateAccelerationStructureNV** → **vkCreateAccelerationStructureKHR** (device address, different geometry layout/information)
- **vkGetAccelerationStructureMemoryRequirementsNV** (deleted - replaced by allocating on top of **VkBuffer**)
- **vkCmdBuildAccelerationStructureNV** → **vkCmdBuildAccelerationStructuresKHR** (params moved to structs, layout differences)
- **vkCmdCopyAccelerationStructureNV** → **vkCmdCopyAccelerationStructureKHR** (params to struct, extendable)
- **vkGetAccelerationStructureHandleNV** → **vkGetAccelerationStructureDeviceAddressKHR** (device address instead of handle)
- **VkAccelerationStructureMemoryRequirementsTypeNV** → **size queries for scratch space moved to vkGetAccelerationStructureBuildSizesKHR**
- **vkDestroyAccelerationStructureNV** → **vkDestroyAccelerationStructureKHR** (different acceleration structure types)
- **vkCmdWriteAccelerationStructuresPropertiesNV** → **vkCmdWriteAccelerationStructuresPropertiesKHR** (different acceleration structure types)

- **Added enums, structures and commands:**
  - **VK_GEOMETRY_TYPE_INSTANCES_KHR** to **VkGeometryTypeKHR** enum
  - **VK_COPY_ACCELERATION_STRUCTURE_MODE_SERIALIZE_KHR, VK_COPY_ACCELERATION_STRUCTURE_MODE_DESERIALIZE_KHR** to **VkCopyAccelerationStructureModeKHR** enum
  - **VkPhysicalDeviceAccelerationStructureFeaturesKHR** structure
  - **VkAccelerationStructureBuildTypeKHR** enum
  - **VkBuildAccelerationStructureModeKHR** enum
  - **VkDeviceOrHostAddressKHR** and **VkDeviceOrHostAddressConstKHR** unions
  - **VkAccelerationStructureBuildRangeInfoKHR** struct
  - **VkAccelerationStructureGeometryInstancesDataKHR** struct
- VkAccelerationStructureDeviceAddressInfoKHR struct
- VkAccelerationStructureVersionInfoKHR struct
- VkStridedDeviceAddressRegionKHR struct
- VkCopyAccelerationStructureToMemoryInfoKHR struct
- VkCopyMemoryToAccelerationStructureInfoKHR struct
- VkCopyAccelerationStructureInfoKHR struct
- vkBuildAccelerationStructuresKHR command (host build)
- vkCopyAccelerationStructureKHR command (host copy)
- vkCopyAccelerationStructureToMemoryKHR (host serialize)
- vkCopyMemoryToAccelerationStructureKHR (host deserialize)
- vkWriteAccelerationStructuresPropertiesKHR (host properties)
- vkCmdCopyAccelerationStructureToMemoryKHR (device serialize)
- vkCmdCopyMemoryToAccelerationStructureKHR (device deserialize)
- vkGetDeviceAccelerationStructureCompatibilityKHR (serialization)

(3) What are the changes between the public provisional (VK_KHR_ray_tracing v8) release and the internal provisional (VK_KHR_ray_tracing v9) release?

- added geometryFlags to VkAccelerationStructureCreateGeometryTypeInfoKHR (later reworked to obsolete this)
- added minAccelerationStructureScratchOffsetAlignment property to VkPhysicalDeviceRayTracingPropertiesKHR
- fix naming and return enum from vkGetDeviceAccelerationStructureCompatibilityKHR
  - renamed VkAccelerationStructureVersionKHR to VkAccelerationStructureVersionInfoKHR
  - renamed VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_VERSION_KHR to VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_VERSION_INFO_KHR
  - removed VK_ERROR_INCOMPATIBLE_VERSION_KHR
  - added VkAccelerationStructureCompatibilityKHR enum
  - remove return value from vkGetDeviceAccelerationStructureCompatibilityKHR and added return enum parameter
- Require Vulkan 1.1
- added creation time capture and replay flags
  - added VkAccelerationStructureCreateFlagBitsKHR and VkAccelerationStructureCreateFlagsKHR
  - renamed the flags member of VkAccelerationStructureCreateInfoKHR to buildFlags (later removed) and added the createFlags member
- change vkCmdBuildAccelerationStructuresIndirectKHR to use buffer device address for indirect parameter
• make **VK_KHR_deferred_host_operations** an interaction instead of a required extension (later went back on this)

• renamed `VkAccelerationStructureBuildOffsetInfoKHR` to `VkAccelerationStructureBuildRangeInfoKHR`
  ◦ renamed the `ppOffsetInfos` parameter of `vkCmdBuildAccelerationStructuresKHR` to `ppBuildRangeInfos`

• Re-unify geometry description between build and create
  ◦ remove `VkAccelerationStructureCreateGeometryTypeInfoKHR` and `VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_CREATE_GEOMETRY_TYPE_INFO_KHR`
  ◦ added `VkAccelerationStructureCreateSizeInfoKHR` structure (later removed)
  ◦ change type of the `pGeometryInfos` member of `VkAccelerationStructureCreateInfoKHR` from `VkAccelerationStructureCreateGeometryTypeInfoKHR` to `VkAccelerationStructureGeometryKHR` (later removed)
  ◦ added `pCreateSizeInfos` member to `VkAccelerationStructureCreateInfoKHR` (later removed)

• Fix ppGeometries ambiguity, add pGeometries
  ◦ remove `geometryArrayOfPointers` member of `VkAccelerationStructureBuildGeometryInfoKHR`
  ◦ disambiguate two meanings of `ppGeometries` by explicitly adding `pGeometries` to the `VkAccelerationStructureBuildGeometryInfoKHR` structure and require one of them be **NULL**

• added **nullDescriptor** support for acceleration structures

• changed the **update** member of `VkAccelerationStructureBuildGeometryInfoKHR` from a bool to the **mode** `VkBuildAccelerationStructureModeKHR` enum which allows future extensibility in update types

• Clarify deferred host ops for pipeline creation
  ◦ `VkDeferredOperationKHR` is now a top-level parameter for `vkBuildAccelerationStructuresKHR`, `vkCreateRayTracingPipelinesKHR`, `vkCopyAccelerationStructureToMemoryKHR`, `vkCopyAccelerationStructureKHR`, and `vkCopyMemoryToAccelerationStructureKHR`
  ◦ removed `VkDeferredOperationInfoKHR` structure
  ◦ change deferred host creation/return parameter behavior such that the implementation can modify such parameters until the deferred host operation completes
  ◦ **VK_KHR_deferred_host_operations** is required again

• Change acceleration structure build to always be sized
  ◦ de-alias `VkAccelerationStructureMemoryRequirementsTypeNV` and `VkAccelerationStructureMemoryRequirementsTypeKHR`, and remove `VkAccelerationStructureMemoryRequirementsTypeKHR`
  ◦ add `vkGetAccelerationStructureBuildSizesKHR` command and `VkAccelerationStructureBuildSizesInfoKHR` structure and `VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_BUILD_SIZES_INFO_KHR` enum to query sizes for acceleration structures and scratch storage
• move size queries for scratch space to `vkGetAccelerationStructureBuildSizesKHR`
• remove `compactedSize`, `buildFlags`, `maxGeometryCount`, `pGeometryInfos`, `pCreateSizeInfos` members of `VkAccelerationStructureCreateInfoKHR` and add the `size` member
• add `maxVertex` member to `VkAccelerationStructureGeometryTrianglesDataKHR` structure
• remove `VkAccelerationStructureCreateInfoKHR` structure

(4) What are the changes between the internal provisional (VK_KHR_ray_tracing v9) release and the final (VK_KHR_acceleration_structure v11) release?

• refactor VK_KHR_ray_tracing into 3 extensions, enabling implementation flexibility and decoupling ray query support from ray pipelines:
  ◦ `VK_KHR_acceleration_structure` (for acceleration structure operations)
  ◦ `VK_KHR_ray_tracing_pipeline` (for ray tracing pipeline and shader stages)
  ◦ `VK_KHR_ray_query` (for ray queries in existing shader stages)
• clarify buffer usage flags for ray tracing
  ◦ `VK_BUFFER_USAGE_RAY_TRACING_BIT_NV` is left alone in `VK_NV_ray_tracing` (required on scratch and instanceData)
  ◦ `VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR` is added as an alias of `VK_BUFFER_USAGE_RAY_TRACING_BIT_NV` in `VK_KHR_ray_tracing_pipeline` and is required on shader binding table buffers
  ◦ `VK_BUFFER_USAGE_ACCELERATION_STRUCTURE_BUILD_INPUT_READ_ONLY_BIT_KHR` is added in `VK_KHR_acceleration_structure` for all vertex, index, transform, aabb, and instance buffer data referenced by device build commands
  ◦ `VK_BUFFER_USAGE_STORAGE_BUFFER_BIT` is used for scratchData
• add max primitive counts (`ppMaxPrimitiveCounts`) to `vkCmdBuildAccelerationStructuresIndirectKHR`
• Allocate acceleration structures from `VkBuffers` and add a mode to constrain the device address
  ◦ de-alias `VkBindAccelerationStructureMemoryInfoNV` and `vkBindAccelerationStructureMemoryNV`, and remove `VkAccelerationStructureMemoryRequirementsInfoKHR` and `vkGetAccelerationStructureMemoryRequirementsKHR`
  ◦ acceleration structures now take a `VkBuffer` and offset at creation time for memory placement
  ◦ add a new `VK_BUFFER_USAGE_ACCELERATION_STRUCTURE_STORAGE_BIT_KHR` buffer usage for such buffers
  ◦ add a new `VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR` acceleration structure type for layering
• move `VK_GEOMETRY_TYPE_INSTANCES_KHR` to main enum instead of being added via extension
• make build commands more consistent - all now build multiple acceleration structures and are named plurally (`vkCmdBuildAccelerationStructuresIndirectKHR, vkCmdBuildAccelerationStructuresKHR, vkBuildAccelerationStructuresKHR`)
• add interactions with `VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT` for acceleration structures, including a new feature `descriptorBindingAccelerationStructureUpdateAfterBind` and 3 new properties `maxPerStageDescriptorAccelerationStructures`, `maxPerStageDescriptorUpdateAfterBindAccelerationStructures`, `maxDescriptorSetUpdateAfterBindAccelerationStructures`

• extension is no longer provisional

• define synchronization requirements for builds, traces, and copies

• define synchronization requirements for AS build inputs and indirect build buffer

(5) What is `VK_ACCELERATION_STRUCTURE_TYPE_GENERIC_KHR` for?

**RESOLVED:** It is primarily intended for API layering. In DXR, the acceleration structure is basically just a buffer in a special layout, and you do not know at creation time whether it will be used as a top or bottom level acceleration structure. We thus added a generic acceleration structure type whose type is unknown at creation time, but is specified at build time instead. Applications which are written directly for Vulkan should not use it.

**Version History**

• Revision 1, 2019-12-05 (Members of the Vulkan Ray Tracing TSG)
  ◦ Internal revisions (forked from VK_NV_ray_tracing)

• Revision 2, 2019-12-20 (Daniel Koch, Eric Werness)
  ◦ Add const version of DeviceOrHostAddress (!3515)
  ◦ Add VU to clarify that only handles in the current pipeline are valid (!3518)
  ◦ Restore some missing VUs and add in-place update language (#1902, !3522)
  ◦ rename `VkAccelerationStructureInstanceKHR` member from accelerationStructure to accelerationStructureReference to better match its type (!3523)
  ◦ Allow `VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS` for pipeline creation if shader group handles cannot be reused (!3523)
  ◦ update documentation for the `VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS` error code and add missing documentation for new return codes from `VK_KHR_deferred_host_operations` (!3523)
  ◦ list new query types for `VK_KHR_ray_tracing` (!3523)
  ◦ Fix VU statements for `VkAccelerationStructureGeometryKHR` referring to correct union members and update to use more current wording (!3523)

• Revision 3, 2020-01-10 (Daniel Koch, Jon Leech, Christoph Kubisch)
  ◦ Fix 'instance of' and 'that/which contains/defines' markup issues (!3528)
  ◦ factor out `VK_KHR_pipeline_library` as stand-alone extension (!3540)
  ◦ Resolve Vulkan-hpp issues (!3543)
    ◦ add missing require for `VkGeometryInstanceFlagsKHR`
- de-alias VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_CREATE_INFO_NV since the KHR structure is no longer equivalent
- add len to pDataSize attribute for vkWriteAccelerationStructuresPropertiesKHR

Revision 4, 2020-01-23 (Daniel Koch, Eric Werness)
- Improve vkWriteAccelerationStructuresPropertiesKHR, add return value and VUs (#1947)
- Clarify language to allow multiple raygen shaders (#1959)
- Various editorial feedback (!3556)
- Add language to help deal with looped self-intersecting fans (#1901)
- Change vkCmdTraceRays{,Indirect}KHR args to pointers (!3559)
- Add scratch address validation language (#1941, !3551)
- Fix definition and add hierarchy information for shader call scope (#1977, !3571)

Revision 5, 2020-02-04 (Eric Werness, Jeff Bolz, Daniel Koch)
- remove vestigial accelerationStructureUUID (!3582)
- update definition of repack instructions and improve memory model interactions (#1910, #1913, !3584)
- Fix wrong sType for VkPhysicalDeviceRayTracingFeaturesKHR (#1988)
- Use provisional SPIR-V capabilities (#1987)
- require rayTraversalPrimitiveCulling if rayQuery is supported (#1927)
- Miss shaders do not have object parameters (!3592)
- Fix missing required types in XML (!3592)
- clarify matching conditions for update (!3592)
- add goal that host and device builds be similar (!3592)
- clarify that maxPrimitiveCount limit should apply to triangles and AABBs (!3592)
- Require alignment for instance arrayOfPointers (!3592)
- Zero is a valid value for instance flags (!3592)
- Add some alignment VUs that got lost in refactoring (!3592)
- Recommend TMin epsilon rather than culling (!3592)
- Get angle from dot product not cross product (!3592)
- Clarify that AH can access the payload and attributes (!3592)
- Match DXR behavior for inactive primitive definition (!3592)
- Use a more generic term than degenerate for inactive to avoid confusion (!3592)

Revision 6, 2020-02-20 (Daniel Koch)
- fix some dangling NV references (#1996)
- rename VkCmdTraceRaysIndirectCommandKHR to VkTraceRaysIndirectCommandKHR (!3607)
• update contributor list (#3611)
• use `uint64_t` instead of `VkAccelerationStructureReferenceKHR` in `VkAccelerationStructureInstanceKHR` (#2004)

• Revision 7, 2020-02-28 (Tobias Hector)
  • remove `HitTKHR` SPIR-V builtin (spirv/spirv-extensions#7)

• Revision 8, 2020-03-06 (Tobias Hector, Dae Kim, Daniel Koch, Jeff Bolz, Eric Werness)
  • explicitly state that `Tmax` is updated when new closest intersection is accepted (#2020,#3536)
  • Made references to min and max `t` values consistent (#3644)
  • finish enumerating differences relative to `VK_NV_ray_tracing` in issues (1) and (2) (#1974,#3642)
  • fix formatting in some math equations (#3642)
  • Restrict the `Hit Kind` operand of `OpReportIntersectionKHR` to 7-bits (spirv/spirv-extensions#8,#3646)
  • Say ray tracing 'should' be watertight (#2008,#3631)
  • Clarify memory requirements for ray tracing buffers (#2005,#3649)
  • Add callable size limits (#1997,#3652)

• Revision 9, 2020-04-15 (Eric Werness, Daniel Koch, Tobias Hector, Joshua Barczak)
  • Add geometry flags to acceleration structure creation (#3672)
  • add build scratch memory alignment (`minAccelerationStructureScratchOffsetAlignment`) (#2065,#3725)
  • fix naming and return enum from `vkGetDeviceAccelerationStructureCompatibilityKHR` (#2051,#3726)
  • require SPIR-V 1.4 (#2096,#3777)
  • added creation time capture/replay flags (#2104,#3774)
  • require Vulkan 1.1 (#2133,#3806)
  • use device addresses instead of `VkBuffers` for ray tracing commands (#2074,#3815)
  • add interactions with Vulkan 1.2 and `VK_KHR_vulkan_memory_model` (#2133,#3830)
  • make `VK_KHR_pipeline_library` an interaction instead of required (#2045,#2108,#3830)
  • make `VK_KHR_deferred_host_operations` an interaction instead of required (#2045,#3830)
  • removed `maxCallableSize` and added explicit stack size management for ray pipelines (#1997,#3817,#3772,#3844)
  • improved documentation for `VkAccelerationStructureVersionInfoKHR` (#2135,3835)
  • rename `VkAccelerationStructureBuildOffsetInfoKHR` to `VkAccelerationStructureBuildRangeInfoKHR` (#2058,#3754)
  • Re-unify geometry description between build and create (#3754)
  • Fix ppGeometries ambiguity, add pGeometries (#2032,#3811)
  • add interactions with `VK_EXT_robustness2` and allow nullDescriptor support for
acceleration structures (#1920, #3848)
◦ added future extensibility for AS updates (#2114, #3849)
◦ Fix VU for dispatchrays and add a limit on the size of the full grid (#2160, #3851)
◦ Add shaderGroupHandleAlignment property (#2180, #3875)
◦ Clarify deferred host ops for pipeline creation (#2067, #3813)
◦ Change acceleration structure build to always be sized (#2131, #2197, #2198, #3854, #3883, #3880)

• Revision 10, 2020-07-03 (Mathieu Robart, Daniel Koch, Eric Werness, Tobias Hector)
◦ Decomposition of the specification, from VK_KHR_ray_tracing to VK_KHR_acceleration_structure (#1918, #3912)
◦ clarify buffer usage flags for ray tracing (#2181, #3939)
◦ add max primitive counts to build indirect command (#2233, #3944)
◦ Allocate acceleration structures from VkBuffers and add a mode to constrain the device address (#2131, #3936)
◦ Move VK_GEOMETRY_TYPE_INSTANCES_KHR to main enum (#2243, #3952)
◦ make build commands more consistent (#2247, #3958)
◦ add interactions with UPDATE_AFTER_BIND (#2128, #3986)
◦ correct and expand build command VUs (#4020)
◦ fix copy command VUs (#4018)
◦ added various alignment requirements (#2229, #3943)
◦ fix valid usage for arrays of geometryCount items (#2198, #4010)
◦ define what is allowed to change on RTAS updates and relevant VUs (#2177, #3961)

• Revision 11, 2020-11-12 (Eric Werness, Josh Barczak, Daniel Koch, Tobias Hector)
◦ de-alias NV and KHR acceleration structure types and associated commands (#2271, #4035)
◦ specify alignment for host copy commands (#2273, #4037)
◦ document VK_FORMAT_FEATURE_ACCELERATION_STRUCTURE_VERTEX_BUFFER_BIT_KHR
◦ specify that acceleration structures are non-linear (#2289, #4068)
◦ add several missing VUs for strides, vertexFormat, and indexType (#2315, #4069)
◦ restore VUs for VkAccelerationStructureBuildGeometryInfoKHR (#2337, #4098)
◦ ban multi-instance memory for host operations (#2324, #4102)
◦ allow dstAccelerationStructure to be null for vkGetAccelerationStructureBuildSizesKHR (#2330, #4111)
◦ more build VU cleanup (#2138, #4130)
◦ specify host endianness for AS serialization (#2261, #4136)
◦ add invertible transform matrix VU (#1710, #4140)
◦ require geometryCount to be 1 for TLAS builds (#4145)
- improved validity conditions for build addresses (#4142)
- add single statement SPIR-V VUs, build limit VUs (!4158)
- document limits for vertex and aabb strides (#2390,#14184)
- specify that `VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_KHR` applies to AS copies (#2382,#4173)
- define sync for AS build inputs and indirect buffer (#2407,#4208)

**Revision 12, 2021-08-06 (Samuel Bourasseau)**
- rename `VK_GEOMETRY_INSTANCE_TRIANGLE_FRONT_COUNTERCLOCKWISE_BIT_KHR` to `VK_GEOMETRY_INSTANCE_TRIANGLE_FLIP_FACING_BIT_KHR` (keep previous as alias).
- Clarify description and add note.

**Revision 13, 2021-09-30 (Jon Leech)**
- Add interaction with `VK_KHR_format_feature_flags2` to `vk.xml`

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**VK_KHR_android_surface**

**Name String**

`VK_KHR_android_surface`

**Extension Type**

Instance extension

**Registered Extension Number**

9

**Revision**

6

**Ratification Status**

Ratified

**Extension and Version Dependencies**

`VK_KHR_surface`

**Contact**

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**Other Extension Metadata**

**Last Modified Date**

2016-01-14

**IP Status**

No known IP claims.
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Description

The `VK_KHR_android_surface` extension is an instance extension. It provides a mechanism to create a `VkSurfaceKHR` object (defined by the `VK_KHR_surface` extension) that refers to an `ANativeWindow`, Android's native surface type. The `ANativeWindow` represents the producer endpoint of any buffer queue, regardless of consumer endpoint. Common consumer endpoints for `ANativeWindows` are the system window compositor, video encoders, and application-specific compositors importing the images through a `SurfaceTexture`.

New Base Types

- `ANativeWindow`

New Commands

- `vkCreateAndroidSurfaceKHR`

New Structures

- `VkAndroidSurfaceCreateInfoKHR`

New Bitmasks

- `VkAndroidSurfaceCreateFlagsKHR`
New Enum Constants

- VK_KHR_ANDROID_SURFACE_EXTENSION_NAME
- VK_KHR_ANDROID_SURFACE_SPEC_VERSION

Extending VkStructureType:
- VK_STRUCTURE_TYPE_ANDROID_SURFACE_CREATE_INFO_KHR

Issues

1) Does Android need a way to query for compatibility between a particular physical device (and queue family?) and a specific Android display?

RESOLVED: No. Currently on Android, any physical device is expected to be able to present to the system compositor, and all queue families must support the necessary image layout transitions and synchronization operations.

Version History

- Revision 1, 2015-09-23 (Jesse Hall)
  ◦ Initial draft.
- Revision 2, 2015-10-26 (Ian Elliott)
  ◦ Renamed from VK_EXT_KHR_android_surface to VK_KHR_android_surface.
- Revision 3, 2015-11-03 (Daniel Rakos)
  ◦ Added allocation callbacks to surface creation function.
- Revision 4, 2015-11-10 (Jesse Hall)
  ◦ Removed VK_ERROR_INVALID_ANDROID_WINDOW_KHR.
- Revision 5, 2015-11-28 (Daniel Rakos)
  ◦ Updated the surface create function to take a pCreateInfo structure.
- Revision 6, 2016-01-14 (James Jones)
  ◦ Moved VK_ERROR_NATIVE_WINDOW_IN_USE_KHR from the VK_KHR_android_surface to the VK_KHR_surface extension.

VK_KHR_cooperative_matrix

Name String
- VK_KHR_cooperative_matrix

Extension Type
- Device extension

Registered Extension Number
- 507
This extension adds support for using cooperative matrix types in SPIR-V. Cooperative matrix types are medium-sized matrices that are primarily supported in compute shaders, where the storage for the matrix is spread across all invocations in some scope (usually a subgroup) and those invocations cooperate to efficiently perform matrix multiplies.

Cooperative matrix types are defined by the `SPV_KHR_cooperative_matrix` SPIR-V extension and can be used with the `GLSL_KHR_cooperative_matrix` GLSL extension.

This extension includes support for enumerating the matrix types and dimensions that are supported by the implementation.

**New Commands**

- `vkGetPhysicalDeviceCooperativeMatrixPropertiesKHR`
New Structures

- VkCooperativeMatrixPropertiesKHR
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceCooperativeMatrixFeaturesKHR
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceCooperativeMatrixPropertiesKHR

New Enums

- VkComponentTypeKHR
- VkScopeKHR

New Enum Constants

- VK_KHR_COOPERATIVE_MATRIX_EXTENSION_NAME
- VK_KHR_COOPERATIVE_MATRIX_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_COOPERATIVE_MATRIX_PROPERTIES_KHR
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COOPERATIVE_MATRIX_FEATURES_KHR
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COOPERATIVE_MATRIX_PROPERTIES_KHR

New SPIR-V Capabilities

- CooperativeMatrixKHR

Issues

Version History

- Revision 2, 2023-05-03 (Kevin Petit)
  - First KHR revision
- Revision 1, 2019-02-05 (Jeff Bolz)
  - NVIDIA vendor extension

VK_KHR_deferred_host_operations

Name String

VK_KHR_deferred_host_operations

Extension Type

Device extension
The VK_KHR_deferred_host_operations extension defines the infrastructure and usage patterns for deferrable commands, but does not specify any commands as deferrable. This is left to additional dependent extensions. Commands **must** not be deferred unless the deferral is specifically allowed by another extension which depends on VK_KHR_deferred_host_operations.

**New Object Types**

- VkDeferredOperationKHR
New Commands

- vkCreateDeferredOperationKHR
- vkDeferredOperationJoinKHR
- vkDestroyDeferredOperationKHR
- vkGetDeferredOperationMaxConcurrencyKHR
- vkGetDeferredOperationResultKHR

New Enum Constants

- VK_KHR_DEFERRED_HOST_OPERATIONS_EXTENSION_NAME
- VK_KHR_DEFERRED_HOST_OPERATIONS_SPEC_VERSION

Extending VkObjectType:
- VK_OBJECT_TYPE_DEFERRED_OPERATION_KHR

Extending VkResult:
- VK_OPERATION_DEFERRED_KHR
- VK_OPERATION_NOT_DEFERRED_KHR
- VK_THREAD_DONE_KHR
- VK_THREAD_IDLE_KHR

Code Examples

The following examples will illustrate the concept of deferrable operations using a hypothetical example. The command `vkDoSomethingExpensive` denotes a deferrable command.

The following example illustrates how a vulkan application might request deferral of an expensive operation:

```cpp
// create a deferred operation
VkDeferredOperationKHR hOp;
VkResult result = vkCreateDeferredOperationKHR(device, pCallbacks, &hOp);
assert(result == VK_SUCCESS);

result = vkDoSomethingExpensive(device, hOp, ...);
assert(result == VK_OPERATION_DEFERRED_KHR);

// operation was deferred. Execute it asynchronously
std::async::launch(
    [ hOp ] ( )
    {
        vkDeferredOperationJoinKHR(device, hOp);
        result = vkGetDeferredOperationResultKHR(device, hOp);
    }
);```

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The following example illustrates extracting concurrency from a single deferred operation:

```cpp
// create a deferred operation
VkDeferredOperationKHR hOp;
VkResult result = vkCreateDeferredOperationKHR(device, pCallbacks, &hOp);
assert(result == VK_SUCCESS);

result = vkDoSomethingExpensive(device, hOp, ...);
assert(result == VK_OPERATION_DEFERRED_KHR);

// Query the maximum amount of concurrency and clamp to the desired maximum
uint32_t numLaunches = std::min(vkGetDeferredOperationMaxConcurrencyKHR(device, hOp), maxThreads);

std::vector<std::future<void>> joins;
for (uint32_t i = 0; i < numLaunches; i++) {
    joins.emplace_back(std::async::launch([hOp] ()
    {
        vkDeferredOperationJoinKHR(device, hOp);
        // in a job system, a return of VK_THREAD_IDLE_KHR should queue another
        // job, but it is not functionally required
    }));
}

for (auto &f : joins) {
    f.get();
}

result = vkGetDeferredOperationResultKHR(device, hOp);

// deferred operation is now complete. 'result' indicates success or failure
vkDestroyDeferredOperationKHR(device, hOp, pCallbacks);
```

The following example shows a subroutine which guarantees completion of a deferred operation, in the presence of multiple worker threads, and returns the result of the operation.

```cpp
VkResult FinishDeferredOperation(VkDeferredOperationKHR hOp)
{
    ...
}
```
Issues

1. Should this extension have a VkPhysicalDevice*FeaturesKHR structure?

RESOLVED: No. This extension does not add any functionality on its own and requires a dependent extension to actually enable functionality and thus there is no value in adding a feature structure. If necessary, any dependent extension could add a feature boolean if it wanted to indicate that it is adding optional deferral support.
**Version History**

- **Revision 1**, 2019-12-05 (Josh Barczak, Daniel Koch)
  - Initial draft.
- **Revision 2**, 2020-03-06 (Daniel Koch, Tobias Hector)
  - Add missing VK_OBJECT_TYPE_DEFERRED_OPERATION_KHR enum
  - fix sample code
  - Clarified deferred operation parameter lifetimes (#2018,!3647)
- **Revision 3**, 2020-05-15 (Josh Barczak)
  - Clarify behavior of vkGetDeferredOperationMaxConcurrencyKHR, allowing it to return 0 if the operation is complete (#2036,!3850)
- **Revision 4**, 2020-11-12 (Tobias Hector, Daniel Koch)
  - Remove VkDeferredOperationInfoKHR and change return value semantics when deferred host operations are in use (#2067,3813)
  - clarify return value of vkGetDeferredOperationResultKHR (#2339,!4110)

**VK_KHR_display**

**Name String**

VK_KHR_display

**Extension Type**

Instance extension

**Registered Extension Number**

3

**Revision**

23

**Ratification Status**

Ratified

**Extension and Version Dependencies**

VK_KHR_surface

**Contact**

- James Jones [cubanismo](https://github.com/cubanismo)
- Norbert Nopper [FslNopper](https://github.com/FslNopper)

**Other Extension Metadata**

**Last Modified Date**

2017-03-13
IP Status
No known IP claims.

Contributors
• James Jones, NVIDIA
• Norbert Nopper, Freescale
• Jeff Vigil, Qualcomm
• Daniel Rakos, AMD

Description
This extension provides the API to enumerate displays and available modes on a given device.

New Object Types
• VkDisplayKHR
• VkDisplayModeKHR

New Commands
• vkCreateDisplayModeKHR
• vkCreateDisplayPlaneSurfaceKHR
• vkGetDisplayModePropertiesKHR
• vkGetDisplayPlaneCapabilitiesKHR
• vkGetDisplayPlaneSupportedDisplaysKHR
• vkGetPhysicalDeviceDisplayPlanePropertiesKHR
• vkGetPhysicalDeviceDisplayPropertiesKHR

New Structures
• VkDisplayModeCreateInfoKHR
• VkDisplayModeParametersKHR
• VkDisplayModePropertiesKHR
• VkDisplayPlaneCapabilitiesKHR
• VkDisplayPlanePropertiesKHR
• VkDisplayPropertiesKHR
• VkDisplaySurfaceCreateInfoKHR

New Enums
• VkDisplayPlaneAlphaFlagBitsKHR
New Bitmasks

- VkDisplayModeCreateFlagsKHR
- VkDisplayPlaneAlphaFlagsKHR
- VkDisplaySurfaceCreateFlagsKHR
- VkSurfaceTransformFlagsKHR

New Enum Constants

- VK_KHR_DISPLAY_EXTENSION_NAME
- VK_KHR_DISPLAY_SPEC_VERSION

Extending VkObjectType:
- VK_OBJECT_TYPE_DISPLAY_KHR
- VK_OBJECT_TYPE_DISPLAY_MODE_KHR

Extending VkStructureType:
- VK_STRUCTURE_TYPE_DISPLAY_MODE_CREATE_INFO_KHR
- VK_STRUCTURE_TYPE_DISPLAY_SURFACE_CREATE_INFO_KHR

Issues

1) Which properties of a mode should be fixed in the mode information vs. settable in some other function when setting the mode? E.g., do we need to double the size of the mode pool to include both stereo and non-stereo modes? YUV and RGB scanout even if they both take RGB input images? BGR vs. RGB input? etc.

PROPOSED RESOLUTION: Many modern displays support at most a handful of resolutions and timings natively. Other “modes” are expected to be supported using scaling hardware on the display engine or GPU. Other properties, such as rotation and mirroring should not require duplicating hardware modes just to express all combinations. Further, these properties may be implemented on a per-display or per-overlay granularity.

To avoid the exponential growth of modes as mutable properties are added, as was the case with EGLConfig/WGL pixel formats/GLXFBConfig, this specification should separate out hardware properties and configurable state into separate objects. Modes and overlay planes will express capabilities of the hardware, while a separate structure will allow applications to configure scaling, rotation, mirroring, color keys, LUT values, alpha masks, etc. for a given swapchain independent of the mode in use. Constraints on these settings will be established by properties of the immutable objects.

Note the resolution of this issue may affect issue 5 as well.

2) What properties of a display itself are useful?

PROPOSED RESOLUTION: This issue is too broad. It was meant to prompt general discussion, but resolving this issue amounts to completing this specification. All interesting properties should be
included. The issue will remain as a placeholder since removing it would make it hard to parse existing discussion notes that refer to issues by number.

3) How are multiple overlay planes within a display or mode enumerated?

**PROPOSED RESOLUTION:** They are referred to by an index. Each display will report the number of overlay planes it contains.

4) Should swapchains be created relative to a mode or a display?

**PROPOSED RESOLUTION:** When using this extension, swapchains are created relative to a mode and a plane. The mode implies the display object the swapchain will present to. If the specified mode is not the display’s current mode, the new mode will be applied when the first image is presented to the swapchain, and the default operating system mode, if any, will be restored when the swapchain is destroyed.

5) Should users query generic ranges from displays and construct their own modes explicitly using those constraints rather than querying a fixed set of modes (Most monitors only have one real “mode” these days, even though many support relatively arbitrary scaling, either on the monitor side or in the GPU display engine, making “modes” something of a relic/compatibility construct).

**PROPOSED RESOLUTION:** Expose both. Display information structures will expose a set of predefined modes, as well as any attributes necessary to construct a customized mode.

6) Is it fine if we return the display and display mode handles in the structure used to query their properties?

**PROPOSED RESOLUTION:** Yes.

7) Is there a possibility that not all displays of a device work with all of the present queues of a device? If yes, how do we determine which displays work with which present queues?

**PROPOSED RESOLUTION:** No known hardware has such limitations, but determining such limitations is supported automatically using the existing VK_KHR_surface and VK_KHR_swapchain query mechanisms.

8) Should all presentation need to be done relative to an overlay plane, or can a display mode + display be used alone to target an output?

**PROPOSED RESOLUTION:** Require specifying a plane explicitly.

9) Should displays have an associated window system display, such as an HDC or Display*?

**PROPOSED RESOLUTION:** No. Displays are independent of any windowing system in use on the system. Further, neither HDC nor Display* refer to a physical display object.

10) Are displays queried from a physical GPU or from a device instance?

**PROPOSED RESOLUTION:** Developers prefer to query modes directly from the physical GPU so they can use display information as an input to their device selection algorithms prior to device creation. This avoids the need to create placeholder device instances to enumerate displays.
This preference must be weighed against the extra initialization that must be done by driver vendors prior to device instance creation to support this usage.

11) Should displays and/or modes be dispatchable objects? If functions are to take displays, overlays, or modes as their first parameter, they must be dispatchable objects as defined in Khronos bug 13529. If they are not added to the list of dispatchable objects, functions operating on them must take some higher-level object as their first parameter. There is no performance case against making them dispatchable objects, but they would be the first extension objects to be dispatchable.

**PROPOSED RESOLUTION**: Do not make displays or modes dispatchable. They will dispatch based on their associated physical device.

12) Should hardware cursor capabilities be exposed?

**PROPOSED RESOLUTION**: Defer. This could be a separate extension on top of the base WSI specs.

if they are one physical display device to an end user, but may internally be implemented as two side-by-side displays using the same display engine (and sometimes cabling) resources as two physically separate display devices.

**RESOLVED**: Tiled displays will appear as a single display object in this API.

14) Should the raw EDID data be included in the display information?

**RESOLVED**: No. A future extension could be added which reports the EDID if necessary. This may be complicated by the outcome of issue 13.

15) Should min and max scaling factor capabilities of overlays be exposed?

**RESOLVED**: Yes. This is exposed indirectly by allowing applications to query the min/max position and extent of the source and destination regions from which image contents are fetched by the display engine when using a particular mode and overlay pair.

16) Should devices be able to expose planes that can be moved between displays? If so, how?

**RESOLVED**: Yes. Applications can determine which displays a given plane supports using `vkGetDisplayPlaneSupportedDisplaysKHR`.

17) Should there be a way to destroy display modes? If so, does it support destroying “built in” modes?

**RESOLVED**: Not in this extension. A future extension could add this functionality.

18) What should the lifetime of display and built-in display mode objects be?

**RESOLVED**: The lifetime of the instance. These objects cannot be destroyed. A future extension may be added to expose a way to destroy these objects and/or support display hotplug.

19) Should persistent mode for smart panels be enabled/disabled at swapchain creation time, or on a per-present basis.
RESOLVED: On a per-present basis.

Examples

Note
The example code for the VK_KHR_display and VK_KHR_display_swapchain extensions was removed from the appendix after revision 1.0.43. The display enumeration example code was ported to the cube demo that is shipped with the official Khronos SDK, and is being kept up-to-date in that location (see: https://github.com/KhronosGroup/Vulkan-Tools/blob/master/cube/cube.c).

Version History

• Revision 1, 2015-02-24 (James Jones)
  ◦ Initial draft
• Revision 2, 2015-03-12 (Norbert Nopper)
  ◦ Added overlay enumeration for a display.
• Revision 3, 2015-03-17 (Norbert Nopper)
  ◦ Fixed typos and namings as discussed in Bugzilla.
  ◦ Reordered and grouped functions.
  ◦ Added functions to query count of display, mode and overlay.
  ◦ Added native display handle, which may be needed on some platforms to create a native Window.
• Revision 4, 2015-03-18 (Norbert Nopper)
  ◦ Removed primary and virtualPostion members (see comment of James Jones in Bugzilla).
  ◦ Added native overlay handle to information structure.
  ◦ Replaced , with ; in struct.
• Revision 6, 2015-03-18 (Daniel Rakos)
  ◦ Added WSI extension suffix to all items.
  ◦ Made the whole API more “Vulkanish”.
  ◦ Replaced all functions with a single vkGetDisplayInfoKHR function to better match the rest of the API.
  ◦ Made the display, display mode, and overlay objects be first class objects, not subclasses of VkBaseObject as they do not support the common functions anyways.
  ◦ Renamed *Info structures to *Properties.
  ◦ Removed overlayIndex field from VkOverlayProperties as there is an implicit index already as a result of moving to a “Vulkanish” API.
  ◦ Displays are not get through device, but through physical GPU to match the rest of the Vulkan API. Also this is something ISVs explicitly requested.
• Added issue (6) and (7).

Revision 7, 2015-03-25 (James Jones)
• Added an issues section
• Added rotation and mirroring flags

Revision 8, 2015-03-25 (James Jones)
• Combined the duplicate issues sections introduced in last change.
• Added proposed resolutions to several issues.

Revision 9, 2015-04-01 (Daniel Rakos)
• Rebased extension against Vulkan 0.82.0

Revision 10, 2015-04-01 (James Jones)
• Added issues (10) and (11).
• Added more straw-man issue resolutions, and cleaned up the proposed resolution for issue (4).
• Updated the rotation and mirroring enums to have proper bitmask semantics.

Revision 11, 2015-04-15 (James Jones)
• Added proposed resolution for issues (1) and (2).
• Added issues (12), (13), (14), and (15)
• Removed pNativeHandle field from overlay structure.
• Fixed small compilation errors in example code.

Revision 12, 2015-07-29 (James Jones)
• Rewrote the guts of the extension against the latest WSI swapchain specifications and the latest Vulkan API.
• Address overlay planes by their index rather than an object handle and refer to them as “planes” rather than “overlays” to make it slightly clearer that even a display with no “overlays” still has at least one base “plane” that images can be displayed on.
• Updated most of the issues.
• Added an “extension type” section to the specification header.
• Reused the VK_EXT_KHR_surface surface transform enumerations rather than redefining them here.
• Updated the example code to use the new semantics.

Revision 13, 2015-08-21 (Ian Elliott)
• Renamed this extension and all of its enumerations, types, functions, etc. This makes it compliant with the proposed standard for Vulkan extensions.
• Switched from “revision” to “version”, including use of the VK_MAKE_VERSION macro in the header file.

Revision 14, 2015-09-01 (James Jones)
• Restore single-field revision number.
• Revision 15, 2015-09-08 (James Jones)
  ◦ Added alpha flags enum.
  ◦ Added premultiplied alpha support.
• Revision 16, 2015-09-08 (James Jones)
  ◦ Added description section to the spec.
  ◦ Added issues 16 - 18.
• Revision 17, 2015-10-02 (James Jones)
  ◦ Planes are now a property of the entire device rather than individual displays. This allows planes to be moved between multiple displays on devices that support it.
  ◦ Added a function to create a VkSurfaceKHR object describing a display plane and mode to align with the new per-platform surface creation conventions.
  ◦ Removed detailed mode timing data. It was agreed that the mode extents and refresh rate are sufficient for current use cases. Other information could be added back in as an extension if it is needed in the future.
  ◦ Added support for smart/persistent/buffered display devices.
• Revision 18, 2015-10-26 (Ian Elliott)
  ◦ Renamed from VK_EXT_KHR_display to VK_KHR_display.
• Revision 19, 2015-11-02 (James Jones)
  ◦ Updated example code to match revision 17 changes.
• Revision 20, 2015-11-03 (Daniel Rakos)
  ◦ Added allocation callbacks to creation functions.
• Revision 21, 2015-11-10 (Jesse Hall)
  ◦ Added VK_DISPLAY_PLANE_ALPHA_OPAQUE_BIT_KHR, and use VkDisplayPlaneAlphaFlagBitsKHR for VkDisplayPlanePropertiesKHR::alphaMode instead of VkDisplayPlaneAlphaFlagsKHR, since it only represents one mode.
  ◦ Added reserved flags bitmask to VkDisplayPlanePropertiesKHR.
  ◦ Use VkSurfaceTransformFlagBitsKHR instead of obsolete VkSurfaceTransformKHR.
  ◦ Renamed vkGetDisplayPlaneSupportedDisplaysKHR parameters for clarity.
• Revision 22, 2015-12-18 (James Jones)
  ◦ Added missing “planeIndex” parameter to vkGetDisplayPlaneSupportedDisplaysKHR()
• Revision 23, 2017-03-13 (James Jones)
  ◦ Closed all remaining issues. The specification and implementations have been shipping with the proposed resolutions for some time now.
  ◦ Removed the sample code and noted it has been integrated into the official Vulkan SDK cube demo.
VK_KHR_display_swapchain

Name String
    VK_KHR_display_swapchain

Extension Type
    Device extension

Registered Extension Number
    4

Revision
    10

Ratification Status
    Ratified

Extension and Version Dependencies
    VK_KHR_swapchain
    and
    VK_KHR_display

Contact
    • James Jones cubanismo

Other Extension Metadata

Last Modified Date
    2017-03-13

IP Status
    No known IP claims.

Contributors
    • James Jones, NVIDIA
    • Jeff Vigil, Qualcomm
    • Jesse Hall, Google

Description
    This extension provides an API to create a swapchain directly on a device's display without any underlying window system.

New Commands
    • vkCreateSharedSwapchainsKHR
New Structures

- Extending VkPresentInfoKHR:
  - VkDisplayPresentInfoKHR

New Enum Constants

- VK_KHR_DISPLAY_SWAPCHAIN_EXTENSION_NAME
- VK_KHR_DISPLAY_SWAPCHAIN_SPEC_VERSION

Extending VkResult:

- VK_ERROR_INCOMPATIBLE_DISPLAY_KHR

Extending VkStructureType:

- VK_STRUCTURE_TYPE_DISPLAY_PRESENT_INFO_KHR

Issues

1) Should swapchains sharing images each hold a reference to the images, or should it be up to the application to destroy the swapchains and images in an order that avoids the need for reference counting?

RESOLVED: Take a reference. The lifetime of presentable images is already complex enough.

2) Should the srcRect and dstRect parameters be specified as part of the presentation command, or at swapchain creation time?

RESOLVED: As part of the presentation command. This allows moving and scaling the image on the screen without the need to respecify the mode or create a new swapchain and presentable images.

3) Should srcRect and dstRect be specified as rects, or separate offset/extent values?

RESOLVED: As rects. Specifying them separately might make it easier for hardware to expose support for one but not the other, but in such cases applications must just take care to obey the reported capabilities and not use non-zero offsets or extents that require scaling, as appropriate.

4) How can applications create multiple swapchains that use the same images?

RESOLVED: By calling vkCreateSharedSwapchainsKHR.

An earlier resolution used vkCreateSwapchainKHR, chaining multiple VkSwapchainCreateInfoKHR structures through pNext. In order to allow each swapchain to also allow other extension structs, a level of indirection was used: VkSwapchainCreateInfoKHR::pNext pointed to a different structure, which had both sType and pNext members for additional extensions, and also had a pointer to the next VkSwapchainCreateInfoKHR structure. The number of swapchains to be created could only be found by walking this linked list of alternating structures, and the pSwapchains out parameter was reinterpreted to be an array of VkSwapchainKHR handles.

Another option considered was a method to specify a “shared” swapchain when creating a new swapchain, such that groups of swapchains using the same images could be built up one at a time.
This was deemed unusable because drivers need to know all of the displays an image will be used on when determining which internal formats and layouts to use for that image.

Examples

Note
The example code for the `VK_KHR_display` and `VK_KHR_display_swapchain` extensions was removed from the appendix after revision 1.0.43. The display swapchain creation example code was ported to the cube demo that is shipped with the official Khronos SDK, and is being kept up-to-date in that location (see: https://github.com/KhronosGroup/Vulkan-Tools/blob/master/cube/cube.c).

Version History

• Revision 1, 2015-07-29 (James Jones)
  ◦ Initial draft
• Revision 2, 2015-08-21 (Ian Elliott)
  ◦ Renamed this extension and all of its enumerations, types, functions, etc. This makes it compliant with the proposed standard for Vulkan extensions.
  ◦ Switched from “revision” to “version”, including use of the VK_MAKE_VERSION macro in the header file.
• Revision 3, 2015-09-01 (James Jones)
  ◦ Restore single-field revision number.
• Revision 4, 2015-09-08 (James Jones)
  ◦ Allow creating multiple swapchains that share the same images using a single call to `vkCreateSwapchainKHR()`.
• Revision 5, 2015-09-10 (Alon Or-bach)
  ◦ Removed underscores from SWAP_CHAIN in two enums.
• Revision 6, 2015-10-02 (James Jones)
  ◦ Added support for smart panels/buffered displays.
• Revision 7, 2015-10-26 (Ian Elliott)
  ◦ Renamed from `VK_EXT_KHR_display_swapchain` to `VK_KHR_display_swapchain`.
• Revision 8, 2015-11-03 (Daniel Rakos)
  ◦ Updated sample code based on the changes to `VK_KHR_swapchain`.
• Revision 9, 2015-11-10 (Jesse Hall)
  ◦ Replaced `VkDisplaySwapchainCreateInfoKHR` with `vkCreateSharedSwapchainsKHR`, changing resolution of issue #4.
• Revision 10, 2017-03-13 (James Jones)
  ◦ Closed all remaining issues. The specification and implementations have been shipping with the proposed resolutions for some time now.
- Removed the sample code and noted it has been integrated into the official Vulkan SDK cube demo.

**VK_KHR_external_fence_fd**

**Name String**

VK_KHR_external_fence_fd

**Extension Type**

Device extension

**Registered Extension Number**

116

**Revision**

1

**Ratification Status**

Ratified

**Extension and Version Dependencies**

- VK_KHR_external_fence
  - or
  - Version 1.1

**Contact**

- Jesse Hall  
  - critsec

**Other Extension Metadata**

**Last Modified Date**

2017-05-08

**IP Status**

No known IP claims.

**Contributors**

- Jesse Hall, Google
- James Jones, NVIDIA
- Jeff Juliano, NVIDIA
- Cass Everitt, Oculus
- Contributors to VK_KHR_external_semaphore_fd

**Description**

An application using external memory may wish to synchronize access to that memory using
fences. This extension enables an application to export fence payload to and import fence payload from POSIX file descriptors.

**New Commands**

- `vkGetFenceFdKHR`
- `vkImportFenceFdKHR`

**New Structures**

- `VkFenceGetFdInfoKHR`
- `VkImportFenceFdInfoKHR`

**New Enum Constants**

- `VK_KHR_EXTERNAL_FENCE_FD_EXTENSION_NAME`
- `VK_KHR_EXTERNAL_FENCE_FD_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_FENCE_GET_FD_INFO_KHR`
  - `VK_STRUCTURE_TYPE_IMPORT_FENCE_FD_INFO_KHR`

**Issues**

This extension borrows concepts, semantics, and language from `VK_KHR_external_semaphore_fd`. That extension's issues apply equally to this extension.

**Version History**

- Revision 1, 2017-05-08 (Jesse Hall)
  - Initial revision

**VK_KHR_external_fence_win32**

**Name String**

- `VK_KHR_external_fence_win32`

**Extension Type**

- Device extension

**Registered Extension Number**

- 115

**Revision**

- 1
Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_external_fence

Contact
• Jesse Hall @critsec

Other Extension Metadata

Last Modified Date
2017-05-08

IP Status
No known IP claims.

Contributors
• Jesse Hall, Google
• James Jones, NVIDIA
• Jeff Juliano, NVIDIA
• Cass Everitt, Oculus
• Contributors to VK_KHR_external_semaphore_win32

Description
An application using external memory may wish to synchronize access to that memory using fences. This extension enables an application to export fence payload to and import fence payload from Windows handles.

New Commands
• vkGetFenceWin32HandleKHR
• vkImportFenceWin32HandleKHR

New Structures
• VkFenceGetWin32HandleInfoKHR
• VkImportFenceWin32HandleInfoKHR
• Extending VkFenceCreateInfo:
  ◦ VkExportFenceWin32HandleInfoKHR

New Enum Constants
• VK_KHR_EXTERNAL_FENCE_WIN32_EXTENSION_NAME
Extending VkStructureType:

- VK_STRUCTURE_TYPE_EXPORT_FENCE_WIN32_HANDLE_INFO_KHR
- VK_STRUCTURE_TYPE_FENCE_GET_WIN32_HANDLE_INFO_KHR
- VK_STRUCTURE_TYPE_IMPORT_FENCE_WIN32_HANDLE_INFO_KHR

Issues

This extension borrows concepts, semantics, and language from VK_KHR_external_semaphore_win32. That extension’s issues apply equally to this extension.

1) Should D3D12 fence handle types be supported, like they are for semaphores?

**RESOLVED:** No. Doing so would require extending the fence signal and wait operations to provide values to signal / wait for, like VkD3D12FenceSubmitInfoKHR does. A D3D12 fence can be signaled by importing it into a VkSemaphore instead of a VkFence, and applications can check status or wait on the D3D12 fence using non-Vulkan APIs. The convenience of being able to do these operations on VkFence objects does not justify the extra API complexity.

Version History

- Revision 1, 2017-05-08 (Jesse Hall)
  - Initial revision

VK_KHR_external_memory_fd

Name String

VK_KHR_external_memory_fd

Extension Type

Device extension

Registered Extension Number

75

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

VK_KHR_external_memory
or

Version 1.1
Description
An application may wish to reference device memory in multiple Vulkan logical devices or instances, in multiple processes, and/or in multiple APIs. This extension enables an application to export POSIX file descriptor handles from Vulkan memory objects and to import Vulkan memory objects from POSIX file descriptor handles exported from other Vulkan memory objects or from similar resources in other APIs.

New Commands
• vkGetMemoryFdKHR
• vkGetMemoryFdPropertiesKHR

New Structures
• VkMemoryFdPropertiesKHR
• VkMemoryGetFdInfoKHR
• Extending VkMemoryAllocateInfo:
  ◦ VkImportMemoryFdInfoKHR

New Enum Constants
• VK_KHR_EXTERNAL_MEMORY_FD_EXTENSION_NAME
• VK_KHR_EXTERNAL_MEMORY_FD_SPEC_VERSION
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_IMPORT_MEMORY_FD_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_MEMORY_FD_PROPERTIES_KHR
  ◦ VK_STRUCTURE_TYPE_MEMORY_GET_FD_INFO_KHR
Issues

1) Does the application need to close the file descriptor returned by `vkGetMemoryFdKHR`?

**RESOLVED:** Yes, unless it is passed back in to a driver instance to import the memory. A successful get call transfers ownership of the file descriptor to the application, and a successful import transfers it back to the driver. Destroying the original memory object will not close the file descriptor or remove its reference to the underlying memory resource associated with it.

2) Do drivers ever need to expose multiple file descriptors per memory object?

**RESOLVED:** No. This would indicate there are actually multiple memory objects, rather than a single memory object.

3) How should the valid size and memory type for POSIX file descriptor memory handles created outside of Vulkan be specified?

**RESOLVED:** The valid memory types are queried directly from the external handle. The size will be specified by future extensions that introduce such external memory handle types.

Version History

- Revision 1, 2016-10-21 (James Jones)
  - Initial revision

**VK_KHR_external_memory_win32**

Name String

- `VK_KHR_external_memory_win32`

Extension Type

- Device extension

Registered Extension Number

- 74

Revision

- 1

Ratification Status

- Ratified

Extension and Version Dependencies

- `VK_KHR_external_memory`

Contact

- James Jones @cubanismo
Description

An application may wish to reference device memory in multiple Vulkan logical devices or instances, in multiple processes, and/or in multiple APIs. This extension enables an application to export Windows handles from Vulkan memory objects and to import Vulkan memory objects from Windows handles exported from other Vulkan memory objects or from similar resources in other APIs.

New Commands

- `vkGetMemoryWin32HandleKHR`
- `vkGetMemoryWin32HandlePropertiesKHR`

New Structures

- `VkMemoryGetWin32HandleInfoKHR`
- `VkMemoryWin32HandlePropertiesKHR`
- Extending `VkMemoryAllocateInfo`:
  - `VkExportMemoryWin32HandleInfoKHR`
  - `VkImportMemoryWin32HandleInfoKHR`

New Enum Constants

- `VK_KHR_EXTERNAL_MEMORY_WIN32_EXTENSION_NAME`
- `VK_KHR_EXTERNAL_MEMORY_WIN32_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_EXPORT_MEMORY_WIN32_HANDLE_INFO_KHR`
  - `VK_STRUCTURE_TYPE_IMPORT_MEMORY_WIN32_HANDLE_INFO_KHR`
  - `VK_STRUCTURE_TYPE_MEMORY_GET_WIN32_HANDLE_INFO_KHR`
  - `VK_STRUCTURE_TYPE_MEMORY_WIN32_HANDLE_PROPERTIES_KHR`
Issues

1) Do applications need to call `CloseHandle()` on the values returned from `vkGetMemoryWin32HandleKHR` when `handleType` is `VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT_KHR`?

**RESOLVED:** Yes, unless it is passed back in to another driver instance to import the object. A successful `get` call transfers ownership of the handle to the application. Destroying the memory object will not destroy the handle or the handle’s reference to the underlying memory resource.

2) Should the language regarding KMT/Windows 7 handles be moved to a separate extension so that it can be deprecated over time?

**RESOLVED:** No. Support for them can be deprecated by drivers if they choose, by no longer returning them in the supported handle types of the instance level queries.

3) How should the valid size and memory type for windows memory handles created outside of Vulkan be specified?

**RESOLVED:** The valid memory types are queried directly from the external handle. The size is determined by the associated image or buffer memory requirements for external handle types that require dedicated allocations, and by the size specified when creating the object from which the handle was exported for other external handle types.

Version History

- Revision 1, 2016-10-21 (James Jones)
  - Initial revision

**VK_KHR_external_semaphore_fd**

Name String

`VK_KHR_external_semaphore_fd`

Extension Type

Device extension

Registered Extension Number

80

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

`VK_KHR_external_semaphore` or
Description

An application using external memory may wish to synchronize access to that memory using semaphores. This extension enables an application to export semaphore payload to and import semaphore payload from POSIX file descriptors.

New Commands

- vkGetSemaphoreFdKHR
- vkImportSemaphoreFdKHR

New Structures

- VkImportSemaphoreFdInfoKHR
- VkSemaphoreGetFdInfoKHR

New Enum Constants

- VK_KHR_EXTERNAL_SEMAPHORE_FD_EXTENSION_NAME
- VK_KHR_EXTERNAL_SEMAPHORE_FD_SPEC_VERSION

Extending VkStructureType:
  - VK_STRUCTURE_TYPE_IMPORT_SEMAPHORE_FD_INFO_KHR
  - VK_STRUCTURE_TYPE_SEMAPHORE_GET_FD_INFO_KHR
Issues

1) Does the application need to close the file descriptor returned by `vkGetSemaphoreFdKHR`?

RESOLVED: Yes, unless it is passed back in to a driver instance to import the semaphore. A successful get call transfers ownership of the file descriptor to the application, and a successful import transfers it back to the driver. Destroying the original semaphore object will not close the file descriptor or remove its reference to the underlying semaphore resource associated with it.

Version History

- Revision 1, 2016-10-21 (Jesse Hall)
  - Initial revision

VK_KHR_external_semaphore_win32

Name String

VK_KHR_external_semaphore_win32

Extension Type

Device extension

Registered Extension Number

79

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

VK_KHR_external_semaphore

Contact

- James Jones  cubanismo

Other Extension Metadata

Last Modified Date

2016-10-21

IP Status

No known IP claims.

Contributors

- James Jones, NVIDIA
- Jeff Juliano, NVIDIA
Description

An application using external memory may wish to synchronize access to that memory using semaphores. This extension enables an application to export semaphore payload to and import semaphore payload from Windows handles.

New Commands

• `vkGetSemaphoreWin32HandleKHR`
• `vkImportSemaphoreWin32HandleKHR`

New Structures

• `VkImportSemaphoreWin32HandleInfoKHR`
• `VkSemaphoreGetWin32HandleInfoKHR`
• Extending `VkSemaphoreCreateInfo`:
  ◦ `VkExportSemaphoreWin32HandleInfoKHR`
• Extending `VkSubmitInfo`:
  ◦ `VkD3D12FenceSubmitInfoKHR`

New Enum Constants

• `VK_KHR_EXTERNAL_SEMAPHORE_WIN32_EXTENSION_NAME`
• `VK_KHR_EXTERNAL_SEMAPHORE_WIN32_SPEC_VERSION`
• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_D3D12_FENCE_SUBMIT_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_EXPORT_SEMAPHORE_WIN32_HANDLE_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_IMPORT_SEMAPHORE_WIN32_HANDLE_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_SEMAPHORE_GET_WIN32_HANDLE_INFO_KHR`

Issues

1) Do applications need to call `CloseHandle()` on the values returned from `vkGetSemaphoreWin32HandleKHR` when `handleType` is `VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_BIT_KHR`?

**RESOLVED:** Yes, unless it is passed back in to another driver instance to import the object. A successful get call transfers ownership of the handle to the application. Destroying the semaphore object will not destroy the handle or the handle's reference to the underlying semaphore resource.

2) Should the language regarding KMT/Windows 7 handles be moved to a separate extension so that it can be deprecated over time?
**RESOLVED:** No. Support for them can be deprecated by drivers if they choose, by no longer returning them in the supported handle types of the instance level queries.

3) Should applications be allowed to specify additional object attributes for shared handles?

**RESOLVED:** Yes. Applications will be allowed to provide similar attributes to those they would to any other handle creation API.

4) How do applications communicate the desired fence values to use with D3D12_FENCE-based Vulkan semaphores?

**RESOLVED:** There are a couple of options. The values for the signaled and reset states could be communicated up front when creating the object and remain static for the life of the Vulkan semaphore, or they could be specified using auxiliary structures when submitting semaphore signal and wait operations, similar to what is done with the keyed mutex extensions. The latter is more flexible and consistent with the keyed mutex usage, but the former is a much simpler API.

Since Vulkan tends to favor flexibility and consistency over simplicity, a new structure specifying D3D12 fence acquire and release values is added to the `vkQueueSubmit` function.

**Version History**

- Revision 1, 2016-10-21 (James Jones)
  - Initial revision

**VK_KHR_fragment_shader_barycentric**

**Name String**

`VK_KHR_fragment_shader_barycentric`

**Extension Type**

Device extension

**Registered Extension Number**

323

**Revision**

1

**Ratification Status**

Ratified

**Extension and Version Dependencies**

- `VK_KHR_get_physical_device_properties2`

**Contact**

- Stu Smith
Extension Proposal

VK_KHR_fragment_shader_barycentric

Other Extension Metadata

Last Modified Date

2022-03-10

IP Status

No known IP claims.

Interactions and External Dependencies

• This extension requires SPV_KHR_fragment_shader_barycentric
• This extension provides API support for GL_EXT_fragment_shader_barycentric

Contributors

• Stu Smith, AMD
• Tobias Hector, AMD
• Graeme Leese, Broadcom
• Jan-Harald Fredriksen, Arm
• Slawek Grajewski, Intel
• Pat Brown, NVIDIA
• Hans-Kristian Arntzen, Valve
• Contributors to the VK_NV_fragment_shader_barycentric specification

Description

This extension is based on the VK_NV_fragment_shader_barycentric extension, and adds support for the following SPIR-V extension in Vulkan:

• SPV_KHR_fragment_shader_barycentric

The extension provides access to three additional fragment shader variable decorations in SPIR-V:

• PerVertexKHR, which indicates that a fragment shader input will not have interpolated values, but instead must be accessed with an extra array index that identifies one of the vertices of the primitive producing the fragment
• BaryCoordKHR, which indicates that the variable is a three-component floating-point vector holding barycentric weights for the fragment produced using perspective interpolation
• BaryCoordNoPerspKHR, which indicates that the variable is a three-component floating-point vector holding barycentric weights for the fragment produced using linear interpolation

When using GLSL source-based shader languages, the following variables from GL_EXT_fragment_shader_barycentric map to these SPIR-V built-in decorations:
GLSL variables declared using the `pervertexEXT` GLSL qualifier are expected to be decorated with `PerVertexKHR` in SPIR-V.

**New Structures**

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceFragmentShaderBarycentricFeaturesKHR`
- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceFragmentShaderBarycentricPropertiesKHR`

**New Enum Constants**

- `VK_KHR_FRAGMENT_SHADER_BARYCENTRIC_EXTENSION_NAME`
- `VK_KHR_FRAGMENT_SHADER_BARYCENTRIC_SPEC_VERSION`

**Extending `VkStructureType`**:

- `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADER_BARYCENTRIC_FEATURES_KHR`
- `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADER_BARYCENTRIC_PROPERTIES_KHR`

**New Built-In Variables**

- `BaryCoordKHR`
- `BaryCoordNoPerspKHR`

**New SPIR-V Decorations**

- `PerVertexKHR`

**New SPIR-V Capabilities**

- `FragmentBarycentricKHR`

**Issues**

1) What are the interactions with MSAA and how are `BaryCoordKHR` and `BaryCoordNoPerspKHR` interpolated?

RESOLVED: The inputs decorated with `BaryCoordKHR` or `BaryCoordNoPerspKHR` may also be decorated with the `Centroid` or `Sample` qualifiers to specify interpolation, like any other fragment shader input. If `shaderSampleRateInterpolationFunctions` is enabled, the extended instructions `InterpolateAtCentroid`, `InterpolateAtOffset`, and `InterpolateAtSample` from the GLSL.std.450 may also be used with inputs decorated with `BaryCoordKHR` or `BaryCoordNoPerspKHR`. 
Version History

• Revision 1, 2022-03-10 (Stu Smith)
  ◦ Initial revision

VK_KHR_fragment_shading_rate

Name String

VK_KHR_fragment_shading_rate

Extension Type

Device extension

Registered Extension Number

227

Revision

2

Ratification Status

Ratified

Extension and Version Dependencies

  VK_KHR_create_renderpass2
  or
  Version 1.2
  and
  VK_KHR_get_physical_device_properties2
  or
  Version 1.1

Contact

• Tobias Hector

Extension Proposal

VK_KHR_fragment_shading_rate

Other Extension Metadata

Last Modified Date

2021-09-30

Interactions and External Dependencies

• This extension requires SPV_KHR_fragment_shading_rate.
• This extension provides API support for GL_EXT_fragment_shading_rate

Contributors

• Tobias Hector, AMD
Description

This extension adds the ability to change the rate at which fragments are shaded. Rather than the usual single fragment invocation for each pixel covered by a primitive, multiple pixels can be shaded by a single fragment shader invocation.

Up to three methods are available to the application to change the fragment shading rate:

• **Pipeline Fragment Shading Rate**, which allows the specification of a rate per-draw.
• **Primitive Fragment Shading Rate**, which allows the specification of a rate per primitive, specified during shading.
• **Attachment Fragment Shading Rate**, which allows the specification of a rate per-region of the framebuffer, specified in a specialized image attachment.

Additionally, these rates can all be specified and combined in order to adjust the overall detail in the image at each point.

This functionality can be used to focus shading efforts where higher levels of detail are needed in some parts of a scene compared to others. This can be particularly useful in high resolution rendering, or for XR contexts.

This extension also adds support for the **SPV_KHR_fragment_shading_rate** extension which enables setting the **primitive fragment shading rate**, and allows querying the final shading rate from a fragment shader.

New Commands

• `vkCmdSetFragmentShadingRateKHR`
• `vkGetPhysicalDeviceFragmentShadingRatesKHR`

New Structures

• `VkPhysicalDeviceFragmentShadingRateKHR`
• Extending `VkGraphicsPipelineCreateInfo`:
  ◦ `VkPipelineFragmentShadingRateStateCreateInfoKHR`
• Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  ◦ `VkPhysicalDeviceFragmentShadingRateFeaturesKHR`
• Extending `VkPhysicalDeviceProperties2`:
  ◦ `VkPhysicalDeviceFragmentShadingRatePropertiesKHR`
• Extending `VkSubpassDescription2`:
  ◦ `VkFragmentShadingRateAttachmentInfoKHR`

**New Enums**

• `VkFragmentShadingRateCombinerOpKHR`

**New Enum Constants**

• `VK_KHR_FRAGMENT_SHADING_RATE_EXTENSION_NAME`
• `VK_KHR_FRAGMENT_SHADING_RATE_SPEC_VERSION`

Extending `VkAccessFlagBits`:
  ◦ `VK_ACCESS_FRAGMENT_SHADING_RATE_ATTACHMENT_READ_BIT_KHR`

Extending `VkDynamicState`:
  ◦ `VK_DYNAMIC_STATE_FRAGMENT_SHADING_RATE_KHR`

Extending `VkFormatFeatureFlagBits`:
  ◦ `VK_FORMAT_FEATURE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`

Extending `VkImageLayout`:
  ◦ `VK_IMAGE_LAYOUT_FRAGMENT_SHADING_RATE_ATTACHMENT_OPTIMAL_KHR`

Extending `VkImageUsageFlagBits`:
  ◦ `VK_IMAGE_USAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`

Extending `VkPipelineStageFlagBits`:
  ◦ `VK_PIPELINE_STAGE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`

Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_FRAGMENT_SHADING_RATE_ATTACHMENT_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADING_RATE_FEATURES_KHR`
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADING_RATE_KHR`
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADING_RATE_PROPERTIES_KHR`
  ◦ `VK_STRUCTURE_TYPE_PIPELINE_FRAGMENT_SHADING_RATE_STATE_CREATE_INFO_KHR`

If `VK_KHR_format_feature_flags2` is supported:
• Extending VkFormatFeatureFlagBits2:
  ◦ VK_FORMAT_FEATURE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

Version History

• Revision 1, 2020-05-06 (Tobias Hector)
  ◦ Initial revision

• Revision 2, 2021-09-30 (Jon Leech)
  ◦ Add interaction with VK_KHR_format_feature_flags2 to vk.xml

VK_KHR_get_display_properties2

Name String
  VK_KHR_get_display_properties2

Extension Type
  Instance extension

Registered Extension Number
  122

Revision
  1

Ratification Status
  Ratified

Extension and Version Dependencies
  VK_KHR_display

Contact
  • James Jones cubanismo

Other Extension Metadata

Last Modified Date
  2017-02-21

IP Status
  No known IP claims.

Contributors
  • Ian Elliott, Google
  • James Jones, NVIDIA
Description
This extension provides new queries for device display properties and capabilities that can be easily extended by other extensions, without introducing any further queries. This extension can be considered the VK_KHR_display equivalent of the VK_KHR_get_physical_device_properties2 extension.

New Commands
- vkGetDisplayModeProperties2KHR
- vkGetDisplayPlaneCapabilities2KHR
- vkGetPhysicalDeviceDisplayPlaneProperties2KHR
- vkGetPhysicalDeviceDisplayProperties2KHR

New Structures
- VkDisplayModeProperties2KHR
- VkDisplayPlaneCapabilities2KHR
- VkDisplayPlaneInfo2KHR
- VkDisplayPlaneProperties2KHR
- VkDisplayProperties2KHR

New Enum Constants
- VK_KHR_GET_DISPLAY_PROPERTIES_2_EXTENSION_NAME
- VK_KHR_GET_DISPLAY_PROPERTIES_2_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_DISPLAY_MODE_PROPERTIES_2_KHR
  - VK_STRUCTURE_TYPE_DISPLAY_PLANE_CAPABILITIES_2_KHR
  - VK_STRUCTURE_TYPE_DISPLAY_PLANE_INFO_2_KHR
  - VK_STRUCTURE_TYPE_DISPLAY_PLANE_PROPERTIES_2_KHR
  - VK_STRUCTURE_TYPE_DISPLAY_PROPERTIES_2_KHR

Issues
1) What should this extension be named?

RESOLVED: VK_KHR_get_display_properties2. Other alternatives:
- VK_KHR_display2
- One extension, combined with VK_KHR_surface_capabilies2.

2) Should extensible input structs be added for these new functions:

RESOLVED:
• \texttt{vkGetPhysicalDeviceDisplayProperties2KHR}: No. The only current input is a \texttt{VkPhysicalDevice}. Other inputs would not make sense.

• \texttt{vkGetPhysicalDeviceDisplayPlaneProperties2KHR}: No. The only current input is a \texttt{VkPhysicalDevice}. Other inputs would not make sense.

• \texttt{vkGetDisplayModeProperties2KHR}: No. The only current inputs are a \texttt{VkPhysicalDevice} and a \texttt{VkDisplayModeKHR}. Other inputs would not make sense.

3) Should additional display query functions be extended?

**RESOLVED:**

• \texttt{vkGetDisplayPlaneSupportedDisplaysKHR}: No. Extensions should instead extend \texttt{vkGetDisplayPlaneCapabilitiesKHR}. 

**Version History**

• Revision 1, 2017-02-21 (James Jones)
  ◦ Initial draft.

**VK_KHR_get_surface_capabilities2**

**Name String**

\texttt{VK_KHR_get_surface_capabilities2}

**Extension Type**

Instance extension

**Registered Extension Number**

120

**Revision**

1

**Ratification Status**

Ratified

**Extension and Version Dependencies**

\texttt{VK_KHR_surface}

**Contact**

• James Jones \(\text{cubanismo}\)

**Other Extension Metadata**

**Last Modified Date**

2017-02-27
IP Status
No known IP claims.

Contributors
• Ian Elliott, Google
• James Jones, NVIDIA
• Alon Or-bach, Samsung

Description
This extension provides new queries for device surface capabilities that can be easily extended by other extensions, without introducing any further queries. This extension can be considered the VK_KHR_surface equivalent of the VK_KHR_get_physical_device_properties2 extension.

New Commands
• vkGetPhysicalDeviceSurfaceCapabilities2KHR
• vkGetPhysicalDeviceSurfaceFormats2KHR

New Structures
• VkPhysicalDeviceSurfaceInfo2KHR
• VkSurfaceCapabilities2KHR
• VkSurfaceFormat2KHR

New Enum Constants
• VK_KHR_GET_SURFACE_CAPABILITIES_2_EXTENSION_NAME
• VK_KHR_GET_SURFACE_CAPABILITIES_2_SPEC_VERSION
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SURFACE_INFO_2_KHR
  ◦ VK_STRUCTURE_TYPE_SURFACE_CAPABILITIES_2_KHR
  ◦ VK_STRUCTURE_TYPE_SURFACE_FORMAT_2_KHR

Issues
1) What should this extension be named?

RESOLVED: VK_KHR_get_surface_capabilities2. Other alternatives:
• VK_KHR_surface2
• One extension, combining a separate display-specific query extension.

2) Should additional WSI query functions be extended?
RESOLVED:

- *vkGetPhysicalDeviceSurfaceCapabilitiesKHR*: Yes. The need for this motivated the extension.
- *vkGetPhysicalDeviceSurfaceSupportKHR*: No. Currently only has boolean output. Extensions should instead extend *vkGetPhysicalDeviceSurfaceCapabilities2KHR*.
- *vkGetPhysicalDeviceSurfaceFormatsKHR*: Yes.
- *vkGetPhysicalDeviceSurfacePresentModesKHR*: No. Recent discussion concluded this introduced too much variability for applications to deal with. Extensions should instead extend *vkGetPhysicalDeviceSurfaceCapabilities2KHR*.
- *vkGetPhysicalDeviceXcbPresentationSupportKHR*: Not in this extension.

Version History

- Revision 1, 2017-02-27 (James Jones)
  - Initial draft.

**VK_KHR_global_priority**

**Name String**

*VK_KHR_global_priority*

**Extension Type**

- Device extension

**Registered Extension Number**

189

**Revision**

1

**Ratification Status**

- Ratified

**Extension and Version Dependencies**

*VK_KHR_get_physical_device_properties2*

**Contact**

- Tobias Hector [tobski](https://twitter.com/tobski)

**Other Extension Metadata**
Description

In Vulkan, users can specify device-scope queue priorities. In some cases it may be useful to extend this concept to a system-wide scope. This device extension allows applications to query the global queue priorities supported by a queue family, and then set a priority when creating queues. The default queue priority is `VK_QUEUE_GLOBAL_PRIORITY_MEDIUM_EXT`.

Implementations can report which global priority levels are treated differently by the implementation. It is intended primarily for use in system integration along with certain platform-specific priority enforcement rules.

The driver implementation will attempt to skew hardware resource allocation in favour of the higher-priority task. Therefore, higher-priority work may retain similar latency and throughput characteristics even if the system is congested with lower priority work.

The global priority level of a queue shall take precedence over the per-process queue priority (`VkDeviceQueueCreateInfo::pQueuePriorities`).

Abuse of this feature may result in starving the rest of the system from hardware resources. Therefore, the driver implementation may deny requests to acquire a priority above the default priority (`VK_QUEUE_GLOBAL_PRIORITY_MEDIUM_EXT`) if the caller does not have sufficient privileges. In this scenario `VK_ERROR_NOT_PERMITTED_EXT` is returned.

The driver implementation may fail the queue allocation request if resources required to complete the operation have been exhausted (either by the same process or a different process). In this scenario `VK_ERROR_INITIALIZATION_FAILED` is returned.

New Structures

- Extending `VkDeviceQueueCreateInfo`:
  - `VkDeviceQueueGlobalPriorityCreateInfoKHR`
- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDeviceGlobalPriorityQueryFeaturesKHR`
- Extending `VkQueueFamilyProperties2`:
  - `VkQueueFamilyGlobalPriorityPropertiesKHR`
New Enums

- VkQueueGlobalPriorityKHR

New Enum Constants

- VK_KHR_GLOBAL_PRIORITY_EXTENSION_NAME
- VK_KHR_GLOBAL_PRIORITY_SPEC_VERSION
- VK_MAX_GLOBAL_PRIORITY_SIZE_KHR

Extending VkResult:

- VK_ERROR_NOT_PERMITTED_KHR

Extending VkStructureType:

- VK_STRUCTURE_TYPE_DEVICE_QUEUE_GLOBAL_PRIORITY_CREATE_INFO_KHR
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GLOBAL_PRIORITY_QUERY_FEATURES_KHR
- VK_STRUCTURE_TYPE_QUEUE_FAMILY_GLOBAL_PRIORITY_PROPERTIES_KHR

Issues

1) Can we additionally query whether a caller is permitted to acquire a specific global queue priority in this extension?

**RESOLVED:** No. Whether a caller has enough privilege goes with the OS, and the Vulkan driver cannot really guarantee that the privilege will not change in between this query and the actual queue creation call.

2) If more than 1 queue using global priority is requested, is there a good way to know which queue is failing the device creation?

**RESOLVED:** No. There is not a good way at this moment, and it is also not quite actionable for the applications to know that because the information may not be accurate. Queue creation can fail because of runtime constraints like insufficient privilege or lack of resource, and the failure is not necessarily tied to that particular queue configuration requested.

Version History

- Revision 1, 2021-10-22 (Tobias Hector)
  - Initial draft

**VK_KHR_incremental_present**

Name String

VK_KHR_incremental_present

Extension Type

Device extension
This device extension extends `vkQueuePresentKHR`, from the `VK_KHR_swapchain` extension, allowing an application to specify a list of rectangular, modified regions of each image to present. This should be used in situations where an application is only changing a small portion of the presentable images within a swapchain, since it enables the presentation engine to avoid wasting time presenting parts of the surface that have not changed.

This extension is leveraged from the `EGL_KHR_swap_buffers_with_damage` extension.
New Structures

- VkPresentRegionKHR
- VkRectLayerKHR
- Extending VkPresentInfoKHR:
  - VkPresentRegionsKHR

New Enum Constants

- VK_KHR_INCREMENTAL_PRESENT_EXTENSION_NAME
- VK_KHR_INCREMENTAL_PRESENT_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PRESENT_REGIONS_KHR

Issues

1) How should we handle steroescopic-3D swapchains? We need to add a layer for each rectangle. One approach is to create another struct containing the VkRect2D plus layer, and have VkPresentRegionsKHR point to an array of that struct. Another approach is to have two parallel arrays, pRectangles and pLayers, where pRectangles[i] and pLayers[i] must be used together. Which approach should we use, and if the array of a new structure, what should that be called?

RESOLVED: Create a new structure, which is a VkRect2D plus a layer, and will be called VkRectLayerKHR.

2) Where is the origin of the VkRectLayerKHR?

RESOLVED: The upper left corner of the presentable image(s) of the swapchain, per the definition of framebuffer coordinates.

3) Does the rectangular region, VkRectLayerKHR, specify pixels of the swapchain's image(s), or of the surface?

RESOLVED: Of the image(s). Some presentation engines may scale the pixels of a swapchain's image(s) to the size of the surface. The size of the swapchain's image(s) will be consistent, where the size of the surface may vary over time.

4) What if all of the rectangles for a given swapchain contain a width and/or height of zero?

RESOLVED: The application is indicating that no pixels changed since the last present. The presentation engine may use such a hint and not update any pixels for the swapchain. However, all other semantics of vkQueuePresentKHR must still be honored, including waiting for semaphores to signal.

5) When the swapchain is created with VkSwapchainCreateInfoKHR::preTransform set to a value other than VK_SURFACE_TRANSFORM.IDENTITY_BIT_KHR, should the rectangular region, VkRectLayerKHR, be transformed to align with the preTransform?
RESOLVED: No. The rectangular region in VkRectLayerKHR should not be transformed. As such, it may not align with the extents of the swapchain’s image(s). It is the responsibility of the presentation engine to transform the rectangular region. This matches the behavior of the Android presentation engine, which set the precedent.

Version History

- Revision 1, 2016-11-02 (Ian Elliott)
  - Internal revisions
- Revision 2, 2021-03-18 (Ian Elliott)
  - Clarified alignment of rectangles for presentation engines that support transformed swapchains.

VK_KHR_maintenance5

Name String

VK_KHR_maintenance5

Extension Type

Device extension

Registered Extension Number

471

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

Version 1.1
  and
  VK_KHR_dynamic_rendering

Contact

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Extension Proposal

VK_KHR_maintenance5

Other Extension Metadata

Last Modified Date

2023-05-02
Interactions and External Dependencies

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Description

VK_KHR_maintenance5 adds a collection of minor features, none of which would warrant an entire extension of their own.

The new features are as follows:

- A new VK_FORMAT_A1B5G5R5_UNORM_PACK16_KHR format
- A new VK_FORMAT_A8_UNORM_KHR format
- A property to indicate that multisample coverage operations are performed after sample counting in EarlyFragmentTests mode
- Relax VkBufferView creation requirements by allowing subsets of the associated VkBuffer usage using VkBufferUsageFlags2CreateInfoKHR
- A new entry point vkCmdBindIndexBuffer2KHR, allowing a range of memory to be bound as an index buffer
- vkGetDeviceProcAddr must return NULL for supported core functions beyond the version requested by the application.
- A property to indicate that the sample mask test is performed after sample counting in EarlyFragmentTests mode
- vkCmdBindVertexBuffers2KHR now supports using VK_WHOLE_SIZE in the pSizes parameter.
- A default size of 1.0 is used if PointSize is not written
- Shader modules are deprecated - applications can now pass VkShaderModuleCreateInfo as a chained struct to pipeline creation via VkPipelineShaderStageCreateInfo
- A function vkGetRenderingAreaGranularityKHR to query the optimal render area for a dynamic rendering instance.
• A property to indicate that depth/stencil texturing operations with `VK_COMPONENT_SWIZZLE_ONE` have defined behavior

• Add `vkGetImageSubresourceLayout2KHR` and a new function `vkGetDeviceImageSubresourceLayoutKHR` to allow the application to query the image memory layout without having to create an image object and query it.

• Allow `VK_REMAINING_ARRAY LAYERS` as the `layerCount` member of `VkImageSubresourceLayers`

• Adds stronger guarantees for propagation of `VK_ERROR_DEVICE_LOST` return values

• A property to indicate whether `PointSize` controls the final rasterization of polygons if `polygon mode` is `VK_POLYGON_MODE_POINT`

• Two properties to indicate the non-strict line rasterization algorithm used

• Two new flags words `VkPipelineCreateFlagBits2KHR` and `VkBufferUsageFlagBits2KHR`

• Physical-device-level functions can now be called with any value in the valid range for a type beyond the defined enumerants, such that applications can avoid checking individual features, extensions, or versions before querying supported properties of a particular enumerant.

• Clarification that copies between images of any type are allowed, treating 1D images as 2D images with a height of 1.

### New Commands

• `vkCmdBindIndexBuffer2KHR`

• `vkGetDeviceImageSubresourceLayoutKHR`

• `vkGetImageSubresourceLayout2KHR`

• `vkGetRenderingAreaGranularityKHR`

### New Structures

• `VkDeviceImageSubresourceInfoKHR`

• `VkImageSubresource2KHR`

• `VkRenderingAreaInfoKHR`

• `VkSubresourceLayout2KHR`

• Extending `VkBufferViewCreateInfo`, `VkBufferCreateInfo`, `VkPhysicalDeviceExternalBufferInfo`, `VkDescriptorBufferBindingInfoEXT`:
  ◦ `VkBufferUsageFlags2CreateInfoKHR`

• Extending `VkComputePipelineCreateInfo`, `VkGraphicsPipelineCreateInfo`, `VkRayTracingPipelineCreateInfoNV`, `VkRayTracingPipelineCreateInfoKHR`:
  ◦ `VkPipelineCreateFlags2CreateInfoKHR`

• Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  ◦ `VkPhysicalDeviceMaintenance5FeaturesKHR`

• Extending `VkPhysicalDeviceProperties2`:
New Enums

- VkBufferUsageFlagBits2KHR
- VkPipelineCreateFlagBits2KHR

New Bitmasks

- VkBufferUsageFlags2KHR
- VkPipelineCreateFlags2KHR

New Enum Constants

- VK_KHR_MAINTENANCE_5_EXTENSION_NAME
- VK_KHR_MAINTENANCE_5_SPEC_VERSION

Extending VkFormat:

- VK_FORMAT_A1B5G5R5_UNORM_PACK16_KHR
- VK_FORMAT_A8_UNORM_KHR

Extending VkStructureType:

- VK_STRUCTURE_TYPE_BUFFER_USAGE_FLAGS_2_CREATE_INFO_KHR
- VK_STRUCTURE_TYPE_DEVICE_IMAGE_SUBRESOURCE_INFO_KHR
- VK_STRUCTURE_TYPE_IMAGE_SUBRESOURCE_2_KHR
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_5_FEATURES_KHR
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_5_PROPERTIES_KHR
- VK_STRUCTURE_TYPE_PIPELINE_CREATE_FLAGS_2_CREATE_INFO_KHR
- VK_STRUCTURE_TYPE_RENDERING_AREA_INFO_KHR
- VK_STRUCTURE_TYPE_SUBRESOURCE_LAYOUT_2_KHR

If VK_EXT_attachment_feedback_loop_layout is supported:

- Extending VkPipelineCreateFlagBits2KHR:
  - VK_PIPELINE_CREATE_2_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT
  - VK_PIPELINE_CREATE_2_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT

If VK_EXT_conditional_rendering is supported:

- Extending VkBufferUsageFlagBits2KHR:
  - VK_BUFFER_USAGE_2_CONDITIONAL_RENDERING_BIT_EXT

If VK_EXT_descriptor_buffer is supported:

- Extending VkBufferUsageFlagBits2KHR:
- **VK_BUFFER_USAGE_2_PUSH_DESCRIPTORs_DESCRIPTOR_BUFFER_BIT_EXT**
- **VK_BUFFER_USAGE_2_RESOURCE_DESCRIPTOR_BUFFER_BIT_EXT**
- **VK_BUFFER_USAGE_2_SAMPLER_DESCRIPTOR_BUFFER_BIT_EXT**

**Extending VkPipelineCreateFlagBits2KHR:**
- **VK_PIPELINE_CREATE_2_DESCRIPTOR_BUFFER_BIT_EXT**

If **VK_EXT_graphics_pipeline_library** is supported:

**Extending VkPipelineCreateFlagBits2KHR:**
- **VK_PIPELINE_CREATE_2_LINK_TIME_OPTIMIZATION_BIT_EXT**
- **VK_PIPELINE_CREATE_2_RETAIN_LINK_TIME_OPTIMIZATION_INFO_BIT_EXT**

If **VK_EXT_opacity_micromap** is supported:

**Extending VkBufferUsageFlagBits2KHR:**
- **VK_BUFFER_USAGE_2_MICROMAP_BUILD_INPUT_READ_ONLY_BIT_EXT**
- **VK_BUFFER_USAGE_2_MICROMAP_STORAGE_BIT_EXT**

**Extending VkPipelineCreateFlagBits2KHR:**
- **VK_PIPELINE_CREATE_2_RAY_TRACING_OPACITY_MICROMAP_BIT_EXT**

If **VK_EXT_pipeline_protected_access** is supported:

**Extending VkPipelineCreateFlagBits2KHR:**
- **VK_PIPELINE_CREATE_2_NO_PROTECTED_ACCESS_BIT_EXT**
- **VK_PIPELINE_CREATE_2_PROTECTED_ACCESS_ONLY_BIT_EXT**

If **VK_EXT_transform_feedback** is supported:

**Extending VkBufferUsageFlagBits2KHR:**
- **VK_BUFFER_USAGE_2_TRANSFORM_FEEDBACK_BUFFER_BIT_EXT**
- **VK_BUFFER_USAGE_2_TRANSFORM_FEEDBACK_COUNTER_BUFFER_BIT_EXT**

If **VK_KHR_acceleration_structure** is supported:

**Extending VkBufferUsageFlagBits2KHR:**
- **VK_BUFFER_USAGE_2_ACCELERATION_STRUCTURE_BUILD_INPUT_READ_ONLY_BIT_KHR**
- **VK_BUFFER_USAGE_2_ACCELERATION_STRUCTURE_STORAGE_BIT_KHR**

If **VK_KHR_dynamic_rendering** and **VK_EXT_fragment_density_map** is supported:

**Extending VkPipelineCreateFlagBits2KHR:**
- **VK_PIPELINE_CREATE_2_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT**

If **VK_KHR_dynamic_rendering** and **VK_KHR_fragment_shading_rate** is supported:
Extending `VkPipelineCreateFlagBits2KHR`:
  ◦ `VK_PIPELINE_CREATE_2_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`

If `VK_KHR_pipeline_executable_properties` is supported:

  Extending `VkPipelineCreateFlagBits2KHR`:
  ◦ `VK_PIPELINE_CREATE_2_CAPTURE_INTERNAL_REPRESENTATIONS_BIT_KHR`
  ◦ `VK_PIPELINE_CREATE_2_CAPTURE_STATISTICS_BIT_KHR`

If `VK_KHR_pipeline_library` is supported:

  Extending `VkPipelineCreateFlagBits2KHR`:
  ◦ `VK_PIPELINE_CREATE_2_LIBRARY_BIT_KHR`

If `VK_KHR_ray_tracing_pipeline` is supported:

  Extending `VkBufferUsageFlagBits2KHR`:
  ◦ `VK_BUFFER_USAGE_2_SHADER_BINDING_TABLE_BIT_KHR`

  Extending `VkPipelineCreateFlagBits2KHR`:
  ◦ `VK_PIPELINE_CREATE_2_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR`
  ◦ `VK_PIPELINE_CREATE_2_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR`
  ◦ `VK_PIPELINE_CREATE_2_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR`
  ◦ `VK_PIPELINE_CREATE_2_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR`
  ◦ `VK_PIPELINE_CREATE_2_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR`
  ◦ `VK_PIPELINE_CREATE_2_RAY_TRACING_SKIP_AABBS_BIT_KHR`
  ◦ `VK_PIPELINE_CREATE_2_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR`

If `VK_KHR_video_decode_queue` is supported:

  Extending `VkBufferUsageFlagBits2KHR`:
  ◦ `VK_BUFFER_USAGE_2_VIDEO_DECODE_DST_BIT_KHR`
  ◦ `VK_BUFFER_USAGE_2_VIDEO_DECODE_SRC_BIT_KHR`

If `VK_KHR_video_encode_queue` is supported:

  Extending `VkBufferUsageFlagBits2KHR`:
  ◦ `VK_BUFFER_USAGE_2_VIDEO_ENCODE_DST_BIT_KHR`
  ◦ `VK_BUFFER_USAGE_2_VIDEO_ENCODE_SRC_BIT_KHR`

If `VK_NV_device_generated_commands` is supported:

  Extending `VkPipelineCreateFlagBits2KHR`:
  ◦ `VK_PIPELINE_CREATE_2_INDIRECT_BINDABLE_BIT_NV`
If **VK_NV_displacement_micromap** is supported:

- Extending **VkPipelineCreateFlagBits2KHR**:
  - **VK_PIPELINE_CREATE_2_RAY_TRACING_DISPLACEMENT_MICROMAP_BIT_NV**

If **VK_NV_ray_tracing** is supported:

- Extending **VkBufferUsageFlagBits2KHR**:
  - **VK_BUFFER_USAGE_2_RAY_TRACING_BIT_NV**
- Extending **VkPipelineCreateFlagBits2KHR**:
  - **VK_PIPELINE_CREATE_2_DEFER_COMPILE_BIT_NV**

If **VK_NV_ray_tracing_motion_blur** is supported:

- Extending **VkPipelineCreateFlagBits2KHR**:
  - **VK_PIPELINE_CREATE_2_RAY_TRACING_ALLOW_MOTION_BIT_NV**

If **Version 1.1** or **VK_KHR_device_group** is supported:

- Extending **VkPipelineCreateFlagBits2KHR**:
  - **VK_PIPELINE_CREATE_2_DISPATCH_BASE_BIT_KHR**
  - **VK_PIPELINE_CREATE_2_VIEW_INDEX_FROM_DEVICE_INDEX_BIT_KHR**

If **Version 1.2** or **VK_KHR_buffer_device_address** or **VK_EXT_buffer_device_address** is supported:

- Extending **VkBufferUsageFlagBits2KHR**:
  - **VK_BUFFER_USAGE_2_SHADER_DEVICE_ADDRESS_BIT_KHR**

If **Version 1.3** or **VK_EXT_pipeline_creation_cache_control** is supported:

- Extending ** VkPipelineCreateFlagBits2KHR**:
  - **VK_PIPELINE_CREATE_2_EARLY_RETURN_ON_FAILURE_BIT_KHR**
  - **VK_PIPELINE_CREATE_2_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT_KHR**

**Issues**

None.

**Version History**

- Revision 1, 2022-12-12 (Stu Smith)
  - Initial revision

**VK_KHR_map_memory2**
Name String

VK_KHR_map_memory2

Extension Type

Device extension

Registered Extension Number

272

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

Contact

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Extension Proposal

VK_KHR_map_memory2

Other Extension Metadata

Last Modified Date

2023-03-14

Interactions and External Dependencies

• None

Contributors

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• Tobias Hector, AMD

Description

This extension provides extensible versions of the Vulkan memory map and unmap entry points. The new entry points are functionally identical to the core entry points, except that their parameters are specified using extensible structures that can be used to pass extension-specific information.

New Commands

• vkMapMemory2KHR

• vkUnmapMemory2KHR
New Structures

- VkMemoryMapInfoKHR
- VkMemoryUnmapInfoKHR

New Bitmasks

- VkMemoryUnmapFlagsKHR

New Enum Constants

- VK_KHR_MAP_MEMORY_2_EXTENSION_NAME
- VK_KHR_MAP_MEMORY_2_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_MEMORY_MAP_INFO_KHR
  - VK_STRUCTURE_TYPE_MEMORY_UNMAP_INFO_KHR

Version History

- Revision 0, 2022-08-03 (Faith Ekstrand)
  - Internal revisions
- Revision 1, 2023-03-14
  - Public release

VK_KHR_performance_query

Name String

VK_KHR_performance_query

Extension Type

Device extension

Registered Extension Number

117

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2
or
Version 1.1
Special Use

- Developer tools

Contact

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Other Extension Metadata

Last Modified Date

2019-10-08

IP Status

No known IP claims.

Contributors

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Description

The **VK_KHR_performance_query** extension adds a mechanism to allow querying of performance counters for use in applications and by profiling tools.

Each queue family *may* expose counters that *can* be enabled on a queue of that family. We extend **VkQueryType** to add a new query type for performance queries, and chain a structure on **VkQueryPoolCreateInfo** to specify the performance queries to enable.

New Commands

- `vkAcquireProfilingLockKHR`
- `vkEnumeratePhysicalDeviceQueueFamilyPerformanceQueryCountersKHR`
• vkGetPhysicalDeviceQueueFamilyPerformanceQueryPassesKHR
• vkReleaseProfilingLockKHR

**New Structures**

• VkAcquireProfilingLockInfoKHR
• VkPerformanceCounterDescriptionKHR
• VkPerformanceCounterKHR
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDevicePerformanceQueryFeaturesKHR
• Extending VkPhysicalDeviceProperties2:
  ◦ VkPhysicalDevicePerformanceQueryPropertiesKHR
• Extending VkQueryPoolCreateInfo:
  ◦ VkQueryPoolPerformanceCreateInfoKHR
• Extending VkSubmitInfo, VkSubmitInfo2:
  ◦ VkPerformanceQuerySubmitInfoKHR

**New Unions**

• VkPerformanceCounterResultKHR

**New Enums**

• VkAcquireProfilingLockFlagBitsKHR
• VkPerformanceCounterDescriptionFlagBitsKHR
• VkPerformanceCounterScopeKHR
• VkPerformanceCounterStorageKHR
• VkPerformanceCounterUnitKHR

**New Bitmasks**

• VkAcquireProfilingLockFlagsKHR
• VkPerformanceCounterDescriptionFlagsKHR

**New Enum Constants**

• VK_KHR_PERFORMANCE_QUERY_EXTENSION_NAME
• VK_KHR_PERFORMANCE_QUERY_SPEC_VERSION
• Extending VkQueryType:
  ◦ VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR
• Extending VkStructureType:
Issues

1) Should this extension include a mechanism to begin a query in command buffer A and end the query in command buffer B?

**RESOLVED** No - queries are tied to command buffer creation and thus have to be encapsulated within a single command buffer.

2) Should this extension include a mechanism to begin and end queries globally on the queue, not using the existing command buffer commands?

**RESOLVED** No - for the same reasoning as the resolution of 1).

3) Should this extension expose counters that require multiple passes?

**RESOLVED** Yes - users should re-submit a command buffer with the same commands in it multiple times, specifying the pass to count as the query parameter in VkPerformanceQuerySubmitInfoKHR.

4) How to handle counters across parallel workloads?

**RESOLVED** In the spirit of Vulkan, a counter description flag `VK_PERFORMANCE_COUNTER_DESCRIPTION_CONCURRENTLY_IMPACTED_BIT_KHR` denotes that the accuracy of a counter result is affected by parallel workloads.

5) How to handle secondary command buffers?

**RESOLVED** Secondary command buffers inherit any counter pass index specified in the parent primary command buffer. Note: this is no longer an issue after change from issue 10 resolution.

6) What commands does the profiling lock have to be held for?

**RESOLVED** For any command buffer that is being queried with a performance query pool, the profiling lock **must** be held while that command buffer is in the *recording, executable, or pending state*.

7) Should we support `vkCmdCopyQueryPoolResults`?

**RESOLVED** Yes.

8) Should we allow performance queries to interact with multiview?
9) Should a \texttt{queryCount > 1} be usable for performance queries?

**RESOLVED** Yes. Some vendors will have costly performance counter query pool creation, and would rather if a certain set of counters were to be used multiple times that a \texttt{queryCount > 1} can be used to amortize the instantiation cost.

10) Should we introduce an indirect mechanism to set the counter pass index?

**RESOLVED** Specify the counter pass index at submit time instead, to avoid requiring re-recording of command buffers when multiple counter passes are needed.

**Examples**

The following example shows how to find what performance counters a queue family supports, setup a query pool to record these performance counters, how to add the query pool to the command buffer to record information, and how to get the results from the query pool.

```c
// A previously created physical device
VkPhysicalDevice physicalDevice;

// One of the queue families our device supports
uint32_t queueFamilyIndex;

uint32_t counterCount;

// Get the count of counters supported
vkEnumeratePhysicalDeviceQueueFamilyPerformanceQueryCountersKHR(
    physicalDevice,
    queueFamilyIndex,
    &counterCount,
    NULL,
    NULL);

VkPerformanceCounterKHR* counters =
    malloc(sizeof(VkPerformanceCounterKHR) * counterCount);
VkPerformanceCounterDescriptionKHR* counterDescriptions =
    malloc(sizeof(VkPerformanceCounterDescriptionKHR) * counterCount);

// Get the counters supported
vkEnumeratePhysicalDeviceQueueFamilyPerformanceQueryCountersKHR(
    physicalDevice,
    queueFamilyIndex,
    &counterCount,
    counters,
    counterDescriptions);

// Try to enable the first 8 counters
uint32_t enabledCounters[8];
```
const uint32_t enabledCounterCount = min(counterCount, 8));

for (uint32_t i = 0; i < enabledCounterCount; i++) {
    enabledCounters[i] = i;
}

// A previously created device that had the performanceCounterQueryPools feature
// set to VK_TRUE
VkDevice device;

VkQueryPoolPerformanceCreateInfoKHR performanceQueryCreateInfo = {
    .sType = VK_STRUCTURE_TYPE_QUERY_POOL_PERFORMANCE_CREATE_INFO_KHR,
    .pNext = NULL,
    // Specify the queue family that this performance query is performed on
    .queueFamilyIndex = queueFamilyIndex,
    // The number of counters to enable
    .counterIndexCount = enabledCounterCount,
    // The array of indices of counters to enable
    .pCounterIndices = enabledCounters
};

// Get the number of passes our counters will require.
uint32_t numPasses;

vkGetPhysicalDeviceQueueFamilyPerformanceQueryPassesKHR(
    physicalDevice,
    &performanceQueryCreateInfo,
    &numPasses);

VkQueryPoolCreateInfo queryPoolCreateInfo = {
    .sType = VK_STRUCTURE_TYPE_QUERY_POOL_CREATE_INFO,
    .pNext = &performanceQueryCreateInfo,
    .flags = 0,
    // Using our new query type here
    .queryType = VK_QUERY_TYPE_PERFORMANCE_QUERY_KHR,
    .queryCount = 1,
    .pipelineStatistics = 0
};

VkQueryPool queryPool;

VkResult result = vkCreateQueryPool(
    device,
    &queryPoolCreateInfo,
    NULL,
    &queryPool);
assert(VK_SUCCESS == result);

// A queue from queueFamilyIndex
VkQueue queue;

// A command buffer we want to record counters on
VkCommandBuffer commandBuffer;

VkCommandBufferBeginInfo commandBufferBeginInfo = {
    .sType = VK_STRUCTURE_TYPE_COMMAND_BUFFER_BEGIN_INFO,
    .pNext = NULL,
    .flags = 0,
    .pInheritanceInfo = NULL
};

VkAcquireProfilingLockInfoKHR lockInfo = {
    .sType = VK_STRUCTURE_TYPE_ACQUIRE_PROFILING_LOCK_INFO_KHR,
    .pNext = NULL,
    .flags = 0,
    .timeout = UINT64_MAX // Wait forever for the lock
};

// Acquire the profiling lock before we record command buffers
// that will use performance queries
result = vkAcquireProfilingLockKHR(device, &lockInfo);

assert(VK_SUCCESS == result);

result = vkBeginCommandBuffer(commandBuffer, &commandBufferBeginInfo);

assert(VK_SUCCESS == result);

vkCmdResetQueryPool(
    commandBuffer,
    queryPool,
    0,
    1);

vkCmdBeginQuery(
    commandBuffer,
    queryPool,
    0,
    0);

// Perform the commands you want to get performance information on
// ...

// Perform a barrier to ensure all previous commands were complete before
// ending the query
vkCmdPipelineBarrier(
    commandBuffer,
    VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT,
    VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT,
    0,
    0,
    NULL,
    0,
    NULL,
    0,
    NULL);

vkCmdEndQuery(
    commandBuffer,
    queryPool,
    0);

result = vkEndCommandBuffer(commandBuffer);

assert(VK_SUCCESS == result);

for (uint32_t counterPass = 0; counterPass < numPasses; counterPass++) {
    VkPerformanceQuerySubmitInfoKHR performanceQuerySubmitInfo = {
        VK_STRUCTURE_TYPE_PERFORMANCE_QUERY_SUBMIT_INFO_KHR,
        NULL,
        counterPass
    };

    // Submit the command buffer and wait for its completion
    // ...
}

// Release the profiling lock after the command buffer is no longer in the
// pending state.
vkReleaseProfilingLockKHR(device);

result = vkResetCommandBuffer(commandBuffer, 0);

assert(VK_SUCCESS == result);

// Create an array to hold the results of all counters
VkPerformanceCounterResultKHR* recordedCounters = malloc(
    sizeof(VkPerformanceCounterResultKHR) * enabledCounterCount);

result = vkGetQueryPoolResults(
    device,
    queryPool,
    0,
    1,
    sizeof(VkPerformanceCounterResultKHR) * enabledCounterCount,
recordedCounters,
sizeof(VkPerformanceCounterResultKHR),
NULL);

// recordedCounters is filled with our counters, we will look at one for posterity
switch (counters[0].storage) {
    case VK_PERFORMANCE_COUNTER_STORAGE_INT32:
        // use recordCounters[0].int32 to get at the counter result!
        break;
    case VK_PERFORMANCE_COUNTER_STORAGE_INT64:
        // use recordCounters[0].int64 to get at the counter result!
        break;
    case VK_PERFORMANCE_COUNTER_STORAGE_UINT32:
        // use recordCounters[0].uint32 to get at the counter result!
        break;
    case VK_PERFORMANCE_COUNTER_STORAGE_UINT64:
        // use recordCounters[0].uint64 to get at the counter result!
        break;
    case VK_PERFORMANCE_COUNTER_STORAGE_FLOAT32:
        // use recordCounters[0].float32 to get at the counter result!
        break;
    case VK_PERFORMANCE_COUNTER_STORAGE_FLOAT64:
        // use recordCounters[0].float64 to get at the counter result!
        break;
}

Version History

• Revision 1, 2019-10-08

VK_KHR_pipeline_executable_properties

Name String

VK_KHR_pipeline_executable_properties

Extension Type

Device extension

Registered Extension Number

270

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2
Description

When a pipeline is created, its state and shaders are compiled into zero or more device-specific executables, which are used when executing commands against that pipeline. This extension adds a mechanism to query properties and statistics about the different executables produced by the pipeline compilation process. This is intended to be used by debugging and performance tools to allow them to provide more detailed information to the user. Certain compile time shader statistics provided through this extension may be useful to developers for debugging or performance analysis.

New Commands

- `vkGetPipelineExecutableInternalRepresentationsKHR`
- `vkGetPipelineExecutablePropertiesKHR`
New Structures

- VkPipelineExecutableInfoKHR
- VkPipelineExecutableInternalRepresentationKHR
- VkPipelineExecutablePropertiesKHR
- VkPipelineExecutableStatisticKHR
- VkPipelineInfoKHR

Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:

- VkPhysicalDevicePipelineExecutablePropertiesFeaturesKHR

New Unions

- VkPipelineExecutableStatisticValueKHR

New Enums

- VkPipelineExecutableStatisticFormatKHR

New Enum Constants

- VK_KHR_PIPELINE_EXECUTABLE_PROPERTIES_EXTENSION_NAME
- VK_KHR_PIPELINE_EXECUTABLE_PROPERTIES_SPEC_VERSION

Extending VkPipelineCreateFlagBits:

- VK_PIPELINE_CREATE_CAPTURE_INTERNAL_REPRESENTATIONS_BIT_KHR
- VK_PIPELINE_CREATE_CAPTURE_STATISTICS_BIT_KHR

Extending VkStructureType:

- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_EXECUTABLE_PROPERTIES_FEATURES_KHR
- VK_STRUCTURE_TYPE_PIPELINE_EXECUTABLE_INFO_KHR
- VK_STRUCTURE_TYPE_PIPELINE_EXECUTABLE_INTERNAL_REPRESENTATION_KHR
- VK_STRUCTURE_TYPE_PIPELINE_EXECUTABLE_PROPERTIES_KHR
- VK_STRUCTURE_TYPE_PIPELINE_EXECUTABLE_STATISTIC_KHR
- VK_STRUCTURE_TYPE_PIPELINE_INFO_KHR

Issues

1) What should we call the pieces of the pipeline which are produced by the compilation process and about which you can query properties and statistics?

**RESOLVED:** Call them “executables”. The name “binary” was used in early drafts of the extension but it was determined that “pipeline binary” could have a fairly broad meaning (such as a binary
serialized form of an entire pipeline) and was too big of a namespace for the very specific needs of this extension.

Version History

- Revision 1, 2019-05-28 (Faith Ekstrand)
  - Initial draft

**VK_KHR_pipeline_library**

Name String

VK_KHR_pipeline_library

Extension Type

Device extension

Registered Extension Number

291

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

Contact

- Christoph Kubisch pixeljetstream

Other Extension Metadata

Last Modified Date

2020-01-08

IP Status

No known IP claims.

Contributors

- See contributors to VK_KHR_ray_tracing_pipeline

Description

A pipeline library is a special pipeline that cannot be bound, instead it defines a set of shaders and shader groups which can be linked into other pipelines. This extension defines the infrastructure for pipeline libraries, but does not specify the creation or usage of pipeline libraries. This is left to additional dependent extensions.
New Structures

• Extending `VkGraphicsPipelineCreateInfo`:
  ◦ `VkPipelineLibraryCreateInfoKHR`

New Enum Constants

• `VK_KHR_PIPELINE_LIBRARY_EXTENSION_NAME`
• `VK_KHR_PIPELINE_LIBRARY_SPEC_VERSION`

Extending `VkPipelineCreateFlagBits`:

• `VK_PIPELINE_CREATE_LIBRARY_BIT_KHR`

Extending `VkStructureType`:

• `VK_STRUCTURE_TYPE_PIPELINE_LIBRARY_CREATE_INFO_KHR`

Version History

• Revision 1, 2020-01-08 (Christoph Kubisch)
  ◦ Initial draft.

`VK_KHR_portability_enumeration`

Name String

`VK_KHR_portability_enumeration`

Extension Type

Instance extension

Registered Extension Number

395

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

Contact

• Charles Giessen [charles-lunarg](mailto:charles-lunarg)

Other Extension Metadata

Last Modified Date

2021-06-02
IP Status
No known IP claims.

Interactions and External Dependencies
- Interacts with VK_KHR_portability_subset

Contributors
- Lenny Komow, LunarG
- Charles Giessen, LunarG

Description
This extension allows applications to control whether devices that expose the VK_KHR_portability_subset extension are included in the results of physical device enumeration. Since devices which support the VK_KHR_portability_subset extension are not fully conformant Vulkan implementations, the Vulkan loader does not report those devices unless the application explicitly asks for them. This prevents applications which may not be aware of non-conformant devices from accidentally using them, as any device which supports the VK_KHR_portability_subset extension mandates that the extension must be enabled if that device is used.

This extension is implemented in the loader.

New Enum Constants
- VK_KHR_PORTABILITY_ENUMERATION_EXTENSION_NAME
- VK_KHR_PORTABILITY_ENUMERATION_SPEC_VERSION
- Extending VkInstanceCreateFlagBits:
  - VK_INSTANCE_CREATE_ENUMERATE_PORTABILITY_BIT_KHR

Version History
- Revision 1, 2021-06-02 (Lenny Komow)
  - Initial version

VK_KHR_present_id

Name String
VK_KHR_present_id

Extension Type
Device extension

Registered Extension Number
295

Revision
1
Ratification Status
   Ratified

Extension and Version Dependencies
   VK_KHR_swapchain
   and
   VK_KHR_get_physical_device_properties2

Contact
   • Keith Packard @keithp

Other Extension Metadata

Last Modified Date
   2019-05-15

IP Status
   No known IP claims.

Contributors
   • Keith Packard, Valve
   • Ian Elliott, Google
   • Alon Or-bach, Samsung

Description
   This device extension allows an application that uses the VK_KHR_swapchain extension to provide an identifier for present operations on a swapchain. An application can use this to reference specific present operations in other extensions.

New Structures
   • Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
     ◦ VkPhysicalDevicePresentIdFeaturesKHR
   • Extending VkPresentInfoKHR:
     ◦ VkPresentIdKHR

New Enum Constants
   • VK_KHR_PRESENT_ID_EXTENSION_NAME
   • VK_KHR_PRESENT_ID_SPEC_VERSION
   • Extending VkStructureType:
     ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRESENT_ID_FEATURES_KHR
     ◦ VK_STRUCTURE_TYPE_PRESENT_ID_KHR
Issues
None.

Examples

Version History

• Revision 1, 2019-05-15 (Keith Packard)
  ◦ Initial version

VK_KHR_present_wait

Name String
VK_KHR_present_wait

Extension Type
Device extension

Registered Extension Number
249

Revision
1

Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_swapchain
and
VK_KHR_present_id

Contact
• Keith Packard keithp

Other Extension Metadata

Last Modified Date
2019-05-15

IP Status
No known IP claims.

Contributors
• Keith Packard, Valve
• Ian Elliott, Google
Description

This device extension allows an application that uses the VK_KHR_swapchain extension to wait for present operations to complete. An application can use this to monitor and control the pacing of the application by managing the number of outstanding images yet to be presented.

New Commands

• vkWaitForPresentKHR

New Structures

• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDevicePresentWaitFeaturesKHR

New Enum Constants

• VK_KHR_PRESENT_WAIT_EXTENSION_NAME
• VK_KHR_PRESENT_WAIT_SPEC_VERSION
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRESENT_WAIT_FEATURES_KHR

Issues

1) When does the wait finish?

**RESOLVED.** The wait will finish when the present is visible to the user. There is no requirement for any precise timing relationship between the presentation of the image to the user, but implementations should signal the wait as close as possible to the presentation of the first pixel in the new image to the user.

2) Should this use fences or other existing synchronization mechanism.

**RESOLVED.** Because display and rendering are often implemented in separate drivers, this extension will provide a separate synchronization API.

3) Should this extension share present identification with other extensions?

**RESOLVED.** Yes. A new extension, VK_KHR_present_id, should be created to provide a shared structure for presentation identifiers.

4) What happens when presentations complete out of order wrt calls to vkQueuePresent? This could happen if the semaphores for the presentations were ready out of order.

**OPTION A:** Require that when a PresentId is set that the driver ensure that images are always
presented in the order of calls to vkQueuePresent.

**OPTION B**: Finish both waits when the earliest present completes. This will complete the later present wait earlier than the actual presentation. This should be the easiest to implement as the driver need only track the largest present ID completed. This is also the ‘natural’ consequence of interpreting the existing vkWaitForPresentKHR specification.

**OPTION C**: Finish both waits when both have completed. This will complete the earlier presentation later than the actual presentation time. This is allowed by the current specification as there is no precise timing requirement for when the presentId value is updated. This requires slightly more complexity in the driver as it will need to track all outstanding presentId values.

**Examples**

**Version History**

- Revision 1, 2019-02-19 (Keith Packard)
  - Initial version

**VK_KHR_push_descriptor**

**Name String**

- VK_KHR_push_descriptor

**Extension Type**

- Device extension

**Registered Extension Number**

- 81

**Revision**

- 2

**Ratification Status**

- Ratified

**Extension and Version Dependencies**

- VK_KHR_get_physical_device_properties2

**Contact**

- Jeff Bolz Jeffbolznv

**Other Extension Metadata**

**Last Modified Date**

- 2017-09-12
IP Status
No known IP claims.

Contributors
• Jeff Bolz, NVIDIA
• Michael Worcester, Imagination Technologies

Description
This extension allows descriptors to be written into the command buffer, while the implementation is responsible for managing their memory. Push descriptors may enable easier porting from older APIs and in some cases can be more efficient than writing descriptors into descriptor sets.

New Commands
• `vkCmdPushDescriptorSetKHR`

If `VK_KHR_descriptor_update_template` is supported:
• `vkCmdPushDescriptorSetWithTemplateKHR`

If Version 1.1 is supported:
• `vkCmdPushDescriptorSetWithTemplateKHR`

New Structures
• Extending `VkPhysicalDeviceProperties2`:
  ○ `VkPhysicalDevicePushDescriptorPropertiesKHR`

New Enum Constants
• `VK_KHR_PUSH_DESCRIPTOR_EXTENSION_NAME`
• `VK_KHR_PUSH_DESCRIPTOR_SPEC_VERSION`
  Extending `VkDescriptorSetLayoutCreateFlagBits`:
  ○ `VK_DESCRIPTOR_SET_LAYOUT_CREATE_PUSH_DESCRIPTOR_BIT_KHR`
  Extending `VkStructureType`:
  ○ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PUSH_DESCRIPTOR_PROPERTIES_KHR`

If `VK_KHR_descriptor_update_template` is supported:

• Extending `VkDescriptorUpdateTemplateType`:
  ○ `VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_PUSH_DESCRIPTORS_KHR`

If Version 1.1 is supported:

• Extending `VkDescriptorUpdateTemplateType`:
**Version History**

- Revision 1, 2016-10-15 (Jeff Bolz)
  - Internal revisions
- Revision 2, 2017-09-12 (Tobias Hector)
  - Added interactions with Vulkan 1.1

**VK_KHR_ray_query**

**Name String**

VK_KHR_ray_query

**Extension Type**

Device extension

**Registered Extension Number**

349

**Revision**

1

**Ratification Status**

Ratified

**Extension and Version Dependencies**

- VK_KHR_spirv_1_4
- and
- VK_KHR_acceleration_structure

**Contact**

- Daniel Koch @dgkoch

**Other Extension Metadata**

**Last Modified Date**

2020-11-12

**Interactions and External Dependencies**

- This extension requires SPV_KHR_ray_query
- This extension provides API support for GLSL_EXT_ray_query

**Contributors**

- Matthäus Chajdas, AMD
- Greg Grebe, AMD
• Nicolai Hähnle, AMD
• Tobias Hector, AMD
• Dave Oldcorn, AMD
• Skyler Saleh, AMD
• Mathieu Robart, Arm
• Marius Bjorge, Arm
• Tom Olson, Arm
• Sebastian Tafuri, EA
• Henrik Rydgard, Embark
• Juan Cañada, Epic Games
• Patrick Kelly, Epic Games
• Yuriy O'Donnell, Epic Games
• Michael Doggett, Facebook/Oculus
• Andrew Garrard, Imagination
• Don Scorgie, Imagination
• Dae Kim, Imagination
• Joshua Barczak, Intel
• Slawek Grajewski, Intel
• Jeff Bolz, NVIDIA
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• Jon Leech, Khronos
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• Juul Joosten, OTOY
• Alex Bourd, Qualcomm
• Roman Larionov, Qualcomm
• David McAllister, Qualcomm
• Spencer Fricke, Samsung
• Lewis Gordon, Samsung
Description

Rasterization has been the dominant method to produce interactive graphics, but increasing performance of graphics hardware has made ray tracing a viable option for interactive rendering. Being able to integrate ray tracing with traditional rasterization makes it easier for applications to incrementally add ray traced effects to existing applications or to do hybrid approaches with rasterization for primary visibility and ray tracing for secondary queries.

Ray queries are available to all shader types, including graphics, compute and ray tracing pipelines. Ray queries are not able to launch additional shaders, instead returning traversal results to the calling shader.

This extension adds support for the following SPIR-V extension in Vulkan:

- SPV_KHR_ray_query

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceRayQueryFeaturesKHR

New Enum Constants

- VK_KHR_RAY_QUERY_EXTENSION_NAME
- VK_KHR_RAY_QUERY_SPEC_VERSION

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_QUERY_FEATURES_KHR

New SPIR-V Capabilities

- RayQueryKHR
- RayTraversalPrimitiveCullingKHR

Sample Code

Example of ray query in a GLSL shader, illustrating how to use ray queries to determine whether a given position (at ray origin) is in shadow or not, by tracing a ray towards the light, and checking for any intersections with geometry occluding the light.

```cpp
rayQueryEXT rq;
```
rayQueryInitializeEXT(rq, accStruct, gl_RayFlagsTerminateOnFirstHitEXT, cullMask, origin, tMin, direction, tMax);

// Traverse the acceleration structure and store information about the first intersection (if any)
rayQueryProceedEXT(rq);

if (rayQueryGetIntersectionTypeEXT(rq, true) == gl_RayQueryCommittedIntersectionNoneEXT) {
    // Not in shadow
}

Issues

(1) What are the changes between the public provisional (VK_KHR_ray_tracing v8) release and the final (VK_KHR_acceleration_structure v11 / VK_KHR_ray_query v1) release?

- refactor VK_KHR_ray_tracing into 3 extensions, enabling implementation flexibility and decoupling ray query support from ray pipelines:
  - VK_KHR_acceleration_structure (for acceleration structure operations)
  - VK_KHR_ray_tracing_pipeline (for ray tracing pipeline and shader stages)
  - VK_KHR_ray_query (for ray queries in existing shader stages)
- Update SPIRV capabilities to use RayQueryKHR
- extension is no longer provisional

Version History

- Revision 1, 2020-11-12 (Mathieu Robart, Daniel Koch, Andrew Garrard)
  - Decomposition of the specification, from VK_KHR_ray_tracing to VK_KHR_ray_query (#1918,!3912)
  - update to use RayQueryKHR SPIR-V capability
  - add numerical limits for ray parameters (#2235,!3960)
  - relax formula for ray intersection candidate determination (#2322,!*4080)
  - restrict traces to TLAS (#2239,!*4141)
  - require HitT to be in ray interval for OpRayQueryGenerateIntersectionKHR (#2359,!*4146)
  - add ray query shader stages for AS read bit (#2407,!*4203)

VK_KHR_ray_tracing_maintenance1

Name String

    VK_KHR_ray_tracing_maintenance1
Extension Type
Device extension

Registered Extension Number
387

Revision
1

Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_acceleration_structure

Contact
• Daniel Koch @dgkoch

Other Extension Metadata

Last Modified Date
2022-02-21

Interactions and External Dependencies
• This extension requires SPV_KHR_ray_cull_mask
• This extension provides API support for GLSL_EXT_ray_cull_mask
• Interacts with VK_KHR_ray_tracing_pipeline
• Interacts with VK_KHR_synchronization2

Contributors
• Stu Smith, AMD
• Tobias Hector, AMD
• Marius Bjorge, Arm
• Tom Olson, Arm
• Yuriy O’Donnell, Epic Games
• Yunpeng Zhu, Huawei
• Andrew Garrard, Imagination
• Dae Kim, Imagination
• Joshua Barczak, Intel
• Lionel Landwerlin, Intel
• Daniel Koch, NVIDIA
• Eric Werness, NVIDIA
Description

VK_KHR_ray_tracing_maintenance1 adds a collection of minor ray tracing features, none of which would warrant an entire extension of their own.

The new features are as follows:

- Adds support for the SPV_KHR_ray_cull_mask SPIR-V extension in Vulkan. This extension provides access to built-in CullMaskKHR shader variable which contains the value of the OpTrace* Cull Mask parameter. This new shader variable is accessible in the intersection, any-hit, closest-hit and miss shader stages.

- Adds support for a new pipeline stage and access mask built on top of VK_KHR_synchronization2:
  - VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR to specify execution of acceleration structure copy commands
  - VK_ACCESS_2_SHADER_BINDING_TABLE_READ_BIT_KHR to specify read access to a shader binding table in any shader pipeline stage

- Adds two new acceleration structure query parameters:
  - VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SIZE_KHR to query the acceleration structure size on the device timeline
  - VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_BOTTOM_LEVEL_POINTERS_KHR to query the number of bottom level acceleration structure pointers for serialization

- Adds an optional new indirect ray tracing dispatch command, vkCmdTraceRaysIndirect2KHR, which sources the shader binding table parameters as well as the dispatch dimensions from the device. The rayTracingPipelineTraceRaysIndirect2 feature indicates whether this functionality is supported.

New Commands

If VK_KHR_ray_tracing_pipeline is supported:

- vkCmdTraceRaysIndirect2KHR

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceRayTracingMaintenance1FeaturesKHR

If VK_KHR_ray_tracing_pipeline is supported:

- VkTraceRaysIndirectCommand2KHR

New Enum Constants

- VK_KHR_RAY_TRACING_MAINTENANCE_1_EXTENSION_NAME
• **VK_KHR_RAY_TRACING_MAINTENANCE_1_SPEC_VERSION**

• Extending **VkQueryType**:
  - **VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SERIALIZATION_BOTTOM_LEVEL_POINTERS_KHR**
  - **VK_QUERY_TYPE_ACCELERATION_STRUCTURE_SIZE_KHR**

• Extending **VkStructureType**:
  - **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_MAINTENANCE_1_FEATURES_KHR**

If **VK_KHR_synchronization2** is supported:

• Extending **VkPipelineStageFlagBits2**:
  - **VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_COPY_BIT_KHR**

If **VK_KHR_synchronization2** and **VK_KHR_ray_tracing_pipeline** is supported:

• Extending **VkAccessFlagBits2**:
  - **VK_ACCESS_2_SHADER_BINDING_TABLE_READ_BIT_KHR**

**New Built-In Variables**

• **CullMaskKHR**

**New SPIR-V Capabilities**

• **RayCullMaskKHR**

**Issues**

None Yet!

**Version History**

• Revision 1, 2022-02-21 (Members of the Vulkan Ray Tracing TSG)
  - internal revisions

**VK_KHR_ray_tracing_pipeline**

**Name String**

VK_KHR_ray_tracing_pipeline

**Extension Type**

Device extension

**Registered Extension Number**

348
Revision
1

Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_spirv_1_4
and
VK_KHR_acceleration_structure

Contact
• Daniel Koch dgkoch

Other Extension Metadata

Last Modified Date
2020-11-12

Interactions and External Dependencies
• This extension requires SPV_KHR_ray_tracing
• This extension provides API support for GLSL_EXT_ray_tracing
• This extension interacts with Vulkan 1.2 and VK_KHR_vulkan_memory_model, adding the shader-call-related relation of invocations, shader-call-order partial order of dynamic instances of instructions, and the ShaderCallKHR scope.
• This extension interacts with VK_KHR_pipeline_library, enabling pipeline libraries to be used with ray tracing pipelines and enabling usage of VkRayTracingPipelineInterfaceCreateInfoKHR.

Contributors
• Matthäus Chajdas, AMD
• Greg Grebe, AMD
• Nicolai Hähnle, AMD
• Tobias Hector, AMD
• Dave Oldcorn, AMD
• Skyler Saleh, AMD
• Mathieu Robart, Arm
• Marius Bjorge, Arm
• Tom Olson, Arm
• Sebastian Tafuri, EA
• Henrik Rydgard, Embark
• Juan Cañada, Epic Games
Description

Rasterization has been the dominant method to produce interactive graphics, but increasing performance of graphics hardware has made ray tracing a viable option for interactive rendering. Being able to integrate ray tracing with traditional rasterization makes it easier for applications to incrementally add ray traced effects to existing applications or to do hybrid approaches with rasterization for primary visibility and ray tracing for secondary queries.
To enable ray tracing, this extension adds a few different categories of new functionality:

- A new ray tracing pipeline type with new shader domains: ray generation, intersection, any-hit, closest hit, miss, and callable
- A shader binding indirection table to link shader groups with acceleration structure items
- Ray tracing commands which initiate the ray pipeline traversal and invocation of the various new shader domains depending on which traversal conditions are met

This extension adds support for the following SPIR-V extension in Vulkan:

- SPV_KHR_ray_tracing

**New Commands**

- vkCmdSetRayTracingPipelineStackSizeKHR
- vkCmdTraceRaysIndirectKHR
- vkCmdTraceRaysKHR
- vkCreateRayTracingPipelinesKHR
- vkGetRayTracingCaptureReplayShaderGroupHandlesKHR
- vkGetRayTracingShaderGroupHandlesKHR
- vkGetRayTracingShaderGroupStackSizeKHR

**New Structures**

- VkRayTracingPipelineCreateInfoKHR
- VkRayTracingPipelineInterfaceCreateInfoKHR
- VkRayTracingShaderGroupCreateInfoKHR
- VkStridedDeviceAddressRegionKHR
- VkTraceRaysIndirectCommandKHR
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceRayTracingPipelineFeaturesKHR
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceRayTracingPipelinePropertiesKHR

**New Enums**

- VkRayTracingShaderGroupTypeKHR
- VkShaderGroupShaderKHR

**New Enum Constants**

- VK_KHR_RAY_TRACING_PIPELINE_EXTENSION_NAME
• VK_KHR_RAY_TRACING_PIPELINE_SPEC_VERSION
• VK_SHADER_UNUSED_KHR

Extending VkBufferUsageFlagBits:
  ◦ VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR

Extending VkDynamicState:
  ◦ VK_DYNAMIC_STATE_RAY_TRACING_PIPELINE_STACK_SIZE_KHR

Extending VkPipelineBindPoint:
  ◦ VK_PIPELINE_BIND_POINT_RAY_TRACING_KHR

Extending VkPipelineCreateFlagBits:
  ◦ VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR
  ◦ VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR
  ◦ VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR
  ◦ VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR
  ◦ VK_PIPELINE_CREATE_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR
  ◦ VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR
  ◦ VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR

Extending VkPipelineStageFlagBits:
  ◦ VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR

Extending VkShaderStageFlagBits:
  ◦ VK_SHADER_STAGE_ANY_HIT_BIT_KHR
  ◦ VK_SHADER_STAGE_CALLABLE_BIT_KHR
  ◦ VK_SHADER_STAGE_CLOSEST_HIT_BIT_KHR
  ◦ VK_SHADER_STAGE_INTERSECTION_BIT_KHR
  ◦ VK_SHADER_STAGE_MISS_BIT_KHR
  ◦ VK_SHADER_STAGE_RAYGEN_BIT_KHR

Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_PIPELINE_FEATURES_KHR
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_PIPELINE_PROPERTIES_KHR
  ◦ VK_STRUCTURE_TYPE_RAY_TRACING_PIPELINE_CREATE_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_RAY_TRACING_PIPELINE_INTERFACE_CREATE_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_RAY_TRACING_SHADER_GROUP_CREATE_INFO_KHR

New or Modified Built-In Variables

• LaunchIdKHR
• LaunchSizeKHR
WorldRayOriginKHR
WorldRayDirectionKHR
ObjectRayOriginKHR
ObjectRayDirectionKHR
RayTminKHR
RayTmaxKHR
InstanceCustomIndexKHR
InstanceId
ObjectToWorldKHR
WorldToObjectKHR
HitKindKHR
IncomingRayFlagsKHR
RayGeometryIndexKHR
(modified)PrimitiveId

New SPIR-V Capabilities

- RayTracingKHR
- RayTraversalPrimitiveCullingKHR

Issues

(1) How does this extension differ from VK_NV_ray_tracing?

DISCUSSION:

The following is a summary of the main functional differences between VK_KHR_ray_tracing_pipeline and VK_NV_ray_tracing:

- added support for indirect ray tracing (vkCmdTraceRaysIndirectKHR)
- uses SPV_KHR_ray_tracing instead of SPV_NV_ray_tracing
  - refer to KHR SPIR-V enums instead of NV SPIR-V enums (which are functionally equivalent and aliased to the same values).
  - added RayGeometryIndexKHR built-in
- removed vkCompileDeferredNV compilation functionality and replaced with deferred host operations interactions for ray tracing
- added VkPhysicalDeviceRayTracingPipelineFeaturesKHR structure
- extended VkPhysicalDeviceRayTracingPipelinePropertiesKHR structure
  - renamed maxRecursionDepth to maxRayRecursionDepth and it has a minimum of 1 instead of 31
  - require shaderGroupHandleSize to be 32 bytes
added maxRayDispatchInvocationCount, shaderGroupHandleAlignment and maxRayHitAttributeSize

• reworked geometry structures so they could be better shared between device, host, and indirect builds

• changed SBT parameters to a structure and added size (VkStridedDeviceAddressRegionKHR)

• add parameter for requesting memory requirements for host and/or device build

• added pipeline library support for ray tracing

• added watertightness guarantees

• added no-null-shader pipeline flags (VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_*_SHADERS_BIT_KHR)

• added memory model interactions with ray tracing and define how subgroups work and can be repacked

(2) Can you give a more detailed comparison of differences and similarities between VK_NV_ray_tracing and VK_KHR_ray_tracing_pipeline?

DISCUSSION:

The following is a more detailed comparison of which commands, structures, and enums are aliased, changed, or removed.

• Aliased functionality — enums, structures, and commands that are considered equivalent:
  ◦ VkRayTracingShaderGroupTypeNV ↔ VkRayTracingShaderGroupTypeKHR
  ◦ vkGetRayTracingShaderGroupHandlesNV ↔ vkGetRayTracingShaderGroupHandlesKHR

• Changed enums, structures, and commands:
  ◦ VkRayTracingShaderGroupCreateInfoNV → VkRayTracingShaderGroupCreateInfoKHR (added pShaderGroupCaptureReplayHandle)
  ◦ VkRayTracingPipelineCreateInfoNV → VkRayTracingPipelineCreateInfoKHR (changed type of pGroups, added libraries, pLibraryInterface, and pDynamicState)
  ◦ VkPhysicalDeviceRayTracingPropertiesNV → VkPhysicalDeviceRayTracingPropertiesKHR (renamed maxTriangleCount to maxPrimitiveCount, added shaderGroupHandleCaptureReplaySize)
  ◦ vkCmdTraceRaysNV → vkCmdTraceRaysKHR (params to struct)
  ◦ vkCreateRayTracingPipelinesNV → vkCreateRayTracingPipelinesKHR (different struct, changed functionality)

• Added enums, structures and commands:
  ◦ VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_ANY_HIT_SHADERS_BIT_KHR
  ◦ VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_CLOSEST_HIT_SHADERS_BIT_KHR
  ◦ VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_MISS_SHADERS_BIT_KHR
  ◦ VK_PIPELINE_CREATE_RAY_TRACING_NO_NULL_INTERSECTION_SHADERS_BIT_KHR
  ◦ VK_PIPELINE_CREATE_RAY_TRACING_SKIP_TRIANGLES_BIT_KHR
  ◦ VK_PIPELINE_CREATE_RAY_TRACING_SKIP_AABBS_BIT_KHR to VkPipelineCreateFlagBits
  ◦ VkPhysicalDeviceRayTracingPipelineFeaturesKHR structure
- `VkDeviceOrHostAddressKHR` and `VkDeviceOrHostAddressConstKHR` unions
- `VkPipelineLibraryCreateInfoKHR` struct
- `VkRayTracingPipelineInterfaceCreateInfoKHR` struct
- `VkStridedDeviceAddressRegionKHR` struct
- `vkCmdTraceRaysIndirectKHR` command and `VkTraceRaysIndirectCommandKHR` struct
- `vkGetRayTracingCaptureReplayShaderGroupHandlesKHR` (shader group capture/replay)
- `vkCmdSetRayTracingPipelineStackSizeKHR` and `vkGetRayTracingShaderGroupStackSizeKHR` commands for stack size control

- Functionality removed:
  - `VK_PIPELINE_CREATE_DEFER_COMPILE_BIT_NV`
  - `vkCompileDeferredNV` command (replaced with `VK_KHR_deferred_host_operations`)

3) What are the changes between the public provisional (VK_KHR_ray_tracing v8) release and the internal provisional (VK_KHR_ray_tracing v9) release?

- Require Vulkan 1.1 and SPIR-V 1.4
- Added interactions with Vulkan 1.2 and `VK_KHR_vulkan_memory_model`
- added creation time capture and replay flags
  - added `VK_PIPELINE_CREATE_RAY_TRACING_SHADER_GROUP_HANDLE_CAPTURE_REPLAY_BIT_KHR` to `VkPipelineCreateFlagBits`
- replace `VkStridedBufferRegionKHR` with `VkStridedDeviceAddressRegionKHR` and change `vkCmdTraceRaysKHR`, `vkCmdTraceRaysIndirectKHR`, to take these for the shader binding table and use device addresses instead of buffers.
- require the shader binding table buffers to have the `VK_BUFFER_USAGE_RAY_TRACING_BIT_KHR` set
- make `VK_KHR_pipeline_library` an interaction instead of required extension
- rename the `libraries` member of `VkRayTracingPipelineCreateInfoKHR` to `pLibraryInfo` and make it a pointer
- make `VK_KHR_deferred_host_operations` an interaction instead of a required extension (later went back on this)
- added explicit stack size management for ray tracing pipelines
  - removed the `maxCallableSize` member of `VkRayTracingPipelineInterfaceCreateInfoKHR`
  - added the `pDynamicState` member to `VkRayTracingPipelineCreateInfoKHR`
  - added `VK_DYNAMIC_STATE_RAY_TRACING_PIPELINE_STACK_SIZE_KHR` dynamic state for ray tracing pipelines
  - added `vkGetRayTracingShaderGroupStackSizeKHR` and `vkCmdSetRayTracingPipelineStackSizeKHR` commands
  - added `VkShaderGroupShaderKHR` enum
- Added `maxRayDispatchInvocationCount` limit to `VkPhysicalDeviceRayTracingPipelinePropertiesKHR`
• Added shaderGroupHandleAlignment property to VkPhysicalDeviceRayTracingPipelinePropertiesKHR

• Added maxRayHitAttributeSize property to VkPhysicalDeviceRayTracingPipelinePropertiesKHR

• Clarify deferred host ops for pipeline creation
  ◦ VkDeferredOperationKHR is now a top-level parameter for vkCreateRayTracingPipelinesKHR
  ◦ removed VkDeferredOperationInfoKHR structure
  ◦ change deferred host creation/return parameter behavior such that the implementation can modify such parameters until the deferred host operation completes
  ◦ VK_KHR_deferred_host_operations is required again

(4) What are the changes between the internal provisional (VK_KHR_ray_tracing v9) release and the final (VK_KHR_acceleration_structure v11 / VK_KHR_ray_tracing_pipeline v1) release?

• refactor VK_KHR_ray_tracing into 3 extensions, enabling implementation flexibility and decoupling ray query support from ray pipelines:
  ◦ VK_KHR_acceleration_structure (for acceleration structure operations)
  ◦ VK_KHR_ray_tracing_pipeline (for ray tracing pipeline and shader stages)
  ◦ VK_KHR_ray_query (for ray queries in existing shader stages)

• Require Volatile for the following builtins in the ray generation, closest hit, miss, intersection, and callable shader stages:
  ◦ SubgroupSize, SubgroupLocalInvocationId, SubgroupEqMask, SubgroupGeMask, SubgroupGtMask, SubgroupLeMask, SubgroupLtMask
  ◦ SMIDNV, WarpIDNV

• clarify buffer usage flags for ray tracing
  ◦ VK_BUFFER_USAGE_SHADER_BINDING_TABLE_BIT_KHR is added as an alias of VK_BUFFER_USAGE_RAY_TRACING_BIT_NV and is required on shader binding table buffers
  ◦ VK_BUFFER_USAGE_STORAGE_BUFFER_BIT is used in VK_KHR_acceleration_structure for scratchData

• rename maxRecursionDepth to maxRayPipelineRecursionDepth (pipeline creation) and maxRayRecursionDepth (limit) to reduce confusion

• Add queryable maxRayHitAttributeSize limit and rename members of VkRayTracingPipelineInterfaceCreateInfoKHR to maxPipelineRayPayloadSize and maxPipelineRayHitAttributeSize for clarity

• Update SPIRV capabilities to use RayTracingKHR

• extension is no longer provisional

• define synchronization requirements for indirect trace rays and indirect buffer

(5) This extension adds gl_InstanceID for the intersection, any-hit, and closest hit shaders, but in KHR_vulkan_gsl, gl_InstanceID is replaced with gl_InstanceIndex. Which should be used for Vulkan in this extension?
RESOLVED: This extension uses gl_InstanceID and maps it to \texttt{InstanceId} in SPIR-V. It is acknowledged that this is different than other shader stages in Vulkan. There are two main reasons for the difference here:

- symmetry with \texttt{gl_PrimitiveID} which is also available in these shaders
- there is no “baseInstance” relevant for these shaders, and so ID makes it more obvious that this is zero-based.

(6) Why is \texttt{VK_KHR_pipeline_library} an interaction instead of a required dependency, particularly when the “Feature Requirements” section says it is required to be supported anyhow?

RESOLVED: If \texttt{VK_KHR_pipeline_library} were a required extension dependency, then every application would need to enable the extension whether or not they actually want to use the pipeline library functionality. Developers found this to be annoying and unfriendly behavior. We do wish to require all implementations to support it though, and thus it is listed in the feature requirements section.

Sample Code

Example ray generation GLSL shader

```glsl
#version 450 core
#extension GL_EXT_ray_tracing : require
layout(set = 0, binding = 0, rgba8) uniform image2D image;
layout(set = 0, binding = 1) uniform accelerationStructureEXT as;
layout(location = 0) rayPayloadEXT float payload;

void main()
{
    vec4 col = vec4(0, 0, 0, 1);

    vec3 origin = vec3(float(gl_LaunchIDEXT.x)/float(gl_LaunchSizeEXT.x),
                        float(gl_LaunchIDEXT.y)/float(gl_LaunchSizeEXT.y), 1.0);
    vec3 dir = vec3(0.0, 0.0, -1.0);

    traceRayEXT(as, 0, 0xff, 0, 1, origin, 0.0, dir, 1000.0, 0);

    col.y = payload;

    imageStore(image, ivec2(gl_LaunchIDEXT.xy), col);
}
```

Version History

- Revision 1, 2020-11-12 (Mathieu Robart, Daniel Koch, Eric Werness, Tobias Hector)
  - Decomposition of the specification, from \texttt{VK_KHR_ray_tracing} to \texttt{VK_KHR_ray_tracing_pipeline} (#1918, #3912)
  - require certain subgroup and \texttt{sm_shader_builtin} shader builtins to be decorated as volatile
in the ray generation, closest hit, miss, intersection, and callable stages (#1924,1954)
◦ clarify buffer usage flags for ray tracing (#2181,1939)
◦ rename maxRecursionDepth to maxRayPipelineRecursionDepth and maxRayRecursionDepth (#2203,1937)
◦ add queryable maxRayHitAttributeSize and rename members of VkRayTracingPipelineInterfaceCreateInfoKHR (#2102,1966)
◦ update to use RayTracingKHR SPIR-V capability
◦ add VUs for matching hit group type against geometry type (#2245,1994)
◦ require RayTMaxKHR be volatile in intersection shaders (#2268,1903)
◦ add numerical limits for ray parameters (#2235,1960)
◦ fix SBT indexing rules for device addresses (#2308,1979)
◦ relax formula for ray intersection candidate determination (#2322,1980)
◦ add more details on ShaderRecordBufferKHR variables (#2230,1983)
◦ clarify valid bits for InstanceCustomIndexKHR (GLSL/GLSL#19,19128)
◦ allow at most one IncomingRayPayloadKHR, IncomingCallableDataKHR, and HitAttributeKHR (!19129)
◦ add minimum for maxShaderGroupStride (#2353,1931)
◦ require VK_KHR_pipeline_library extension to be supported (#2348,1935)
◦ clarify meaning of 'geometry index' (#2272,1937)
◦ restrict traces to TLAS (#2239,1937)
◦ add note about maxPipelineRayPayloadSize (#2383,1972)
◦ do not require raygen shader in pipeline libraries (!19185)
◦ define sync for indirect trace rays and indirect buffer (#2407,1928)

**VK_KHR_ray_tracing_position_fetch**

**Name String**

VK_KHR_ray_tracing_position_fetch

**Extension Type**

Device extension

**Registered Extension Number**

482

**Revision**

1

**Ratification Status**

Ratified
Extension and Version Dependencies

VK_KHR_acceleration_structure

Contact

• Eric Werness

Extension Proposal

VK_KHR_ray_tracing_position_fetch

Other Extension Metadata

Last Modified Date

2023-02-17

Interactions and External Dependencies

• This extension requires SPV_KHR_ray_tracing_position_fetch
• This extension provides API support for GLSL_EXT_ray_tracing_position_fetch
• Interacts with VK_KHR_ray_tracing_pipeline
• Interacts with VK_KHR_ray_query

Contributors

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• Lionel Landwerlin, Intel
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• Yunpeng Zhu, Huawei Technologies
• Marius Bjorge, Arm
• Daniel Koch, NVIDIA

Description

VK_KHR_ray_tracing_position_fetch adds the ability to fetch the vertex positions in the shader from a hit triangle as stored in the acceleration structure.

An application adds VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_DATA_ACCESS_KHR to the acceleration structure at build time. Then, if the hit is a triangle geometry, the shader (any-hit or closest hit for ray pipelines or using ray query) can fetch the three, three-component vertex positions in object space, of the triangle which was hit.
New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceRayTracingPositionFetchFeaturesKHR`

New Enum Constants

- `VK_KHR_RAY_TRACING_POSITION_FETCH_EXTENSION_NAME`
- `VK_KHR_RAY_TRACING_POSITION_FETCH_SPEC_VERSION`

Extending `VkBuildAccelerationStructureFlagBitsKHR`:
  - `VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_DATA_ACCESS_KHR`

Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_POSITION_FETCH_FEATURES_KHR`

New Built-In Variables

- `HitTriangleVertexPositionsKHR`

New SPIR-V Capabilities

- `RayTracingPositionFetchKHR`

Issues

None Yet!

Version History

- Revision 1, 2023-02-17 (Eric Werness)
  - internal revisions

VK_KHR_shader_clock

Name String

- `VK_KHR_shader_clock`

Extension Type

- Device extension

Registered Extension Number

- 182

Revision

- 1
Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2
or
Version 1.1

Contact
• Aaron Hagan @ahagan

Other Extension Metadata

Last Modified Date
2019-4-25

IP Status
No known IP claims.

Interactions and External Dependencies
• This extension requires SPV_KHR_shader_clock.
• This extension provides API support for ARB_shader_clock and EXT_shader_realtime_clock

Contributors
• Aaron Hagan, AMD
• Daniel Koch, NVIDIA

Description
This extension advertises the SPIR-V ShaderClockKHR capability for Vulkan, which allows a shader to query a real-time or monotonically incrementing counter at the subgroup level or across the device level. The two valid SPIR-V scopes for OpReadClockKHR are Subgroup and Device.

When using GLSL source-based shading languages, the clockRealtime*EXT() timing functions map to the OpReadClockKHR instruction with a scope of Device, and the clock*ARB() timing functions map to the OpReadClockKHR instruction with a scope of Subgroup.

New Structures
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceShaderClockFeaturesKHR

New Enum Constants
• VK_KHR_SHADER_CLOCK_EXTENSION_NAME
• VK_KHR_SHADER_CLOCK_SPEC_VERSION
• Extending VkStructureType:
New SPIR-V Capabilities

- ShaderClockKHR

Version History

- Revision 1, 2019-4-25 (Aaron Hagan)
  - Initial revision

VK_KHR_shader_subgroup_uniform_control_flow

Name String

- VK_KHR_shader_subgroup_uniform_control_flow

Extension Type

- Device extension

Registered Extension Number

- 324

Revision

- 1

Ratification Status

- Ratified

Extension and Version Dependencies

Version 1.1

Contact

- Alan Baker alan-baker

Other Extension Metadata

Last Modified Date

- 2020-08-27

IP Status

- No known IP claims.

Interactions and External Dependencies

- Requires SPIR-V 1.3.
- This extension requires SPV_KHR_subgroup_uniform_control_flow
- This extension provides API support for GL_EXT_subgroupuniform_qualifier
Contributors

- Alan Baker, Google
- Jeff Bolz, NVIDIA

Description

This extension allows the use of the `SPV_KHR_subgroup_uniform_control_flow` SPIR-V extension in shader modules. `SPV_KHR_subgroup_uniform_control_flow` provides stronger guarantees that diverged subgroups will reconverge.

Developers should utilize this extension if they use subgroup operations to reduce the work performed by a uniform subgroup. This extension will guarantee that uniform subgroup will reconverge in the same manner as invocation groups (see “Uniform Control Flow” in the Khronos SPIR-V Specification).

New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceShaderSubgroupUniformControlFlowFeaturesKHR`

New Enum Constants

- `VK_KHR_SHADER_SUBGROUP_UNIFORM_CONTROL_FLOW_EXTENSION_NAME`
- `VK_KHR_SHADER_SUBGROUP_UNIFORM_CONTROL_FLOW_SPEC_VERSION`

- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_SUBGROUP_UNIFORM_CONTROL_FLOW_FEATURES_KHR`

Version History

- Revision 1, 2020-08-27 (Alan Baker)
  - Internal draft version

VK_KHR_shared_presentable_image

Name String

- `VK_KHR_shared_presentable_image`

Extension Type

- Device extension

Registered Extension Number

- 112

Revision

- 1
Ratification Status
Ratified

Extension and Version Dependencies

VK_KHR_swapchain
and
VK_KHR_get_surface_capabilities2
and
VK_KHR_get_physical_device_properties2
or
Version 1.1

Contact
• Alon Or-bach  alonorbach

Other Extension Metadata

Last Modified Date
2017-03-20

IP Status
No known IP claims.

Contributors
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• Tobias Hector, Imagination Technologies
• Graham Connor, Imagination Technologies
• Michael Worcester, Imagination Technologies
• Cass Everitt, Oculus
• Johannes Van Waveren, Oculus

Description
This extension extends VK_KHR_swapchain to enable creation of a shared presentable image. This allows the application to use the image while the presentation engine is accessing it, in order to reduce the latency between rendering and presentation.
New Commands

- vkGetSwapchainStatusKHR

New Structures

- Extending VkSurfaceCapabilities2KHR:
  - VkSharedPresentSurfaceCapabilitiesKHR

New Enum Constants

- VK_KHR_SHARED_PRESENTABLE_IMAGE_EXTENSION_NAME
- VK_KHR_SHARED_PRESENTABLE_IMAGE_SPEC_VERSION
- Extending VkImageLayout:
  - VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR
- Extending VkPresentModeKHR:
  - VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR
  - VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_SHARED_PRESENT_SURFACE_CAPABILITIES_KHR

Issues

1) Should we allow a Vulkan WSI swapchain to toggle between normal usage and shared presentation usage?

RESOLVED: No. WSI swapchains are typically recreated with new properties instead of having their properties changed. This can also save resources, assuming that fewer images are needed for shared presentation, and assuming that most VR applications do not need to switch between normal and shared usage.

2) Should we have a query for determining how the presentation engine refresh is triggered?

RESOLVED: Yes. This is done via which presentation modes a surface supports.

3) Should the object representing a shared presentable image be an extension of a VkSwapchainKHR or a separate object?

RESOLVED: Extension of a swapchain due to overlap in creation properties and to allow common functionality between shared and normal presentable images and swapchains.

4) What should we call the extension and the new structures it creates?

RESOLVED: Shared presentable image / shared present.

5) Should the `minImageCount` and `presentMode` values of the VkSwapchainCreateInfoKHR be ignored, or required to be compatible values?
6) What should the layout of the shared presentable image be?

**RESOLVED:** After acquiring the shared presentable image, the application must transition it to the `VK_IMAGE_LAYOUT_SHARED_PRESENT_KHR` layout prior to it being used. After this initial transition, any image usage that was requested during swapchain creation can be performed on the image without layout transitions being performed.

7) Do we need a new API for the trigger to refresh new content?

**RESOLVED:** `vkQueuePresentKHR` to act as API to trigger a refresh, as will allow combination with other compatible extensions to `vkQueuePresentKHR`.

8) How should an application detect a `VK_ERROR_OUT_OF_DATE_KHR` error on a swapchain using the `VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR` present mode?

**RESOLVED:** Introduce `vkGetSwapchainStatusKHR` to allow applications to query the status of a swapchain using a shared presentation mode.

9) What should subsequent calls to `vkQueuePresentKHR` for `VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR` swapchains be defined to do?

**RESOLVED:** State that implementations may use it as a hint for updated content.

10) Can the ownership of a shared presentable image be transferred to a different queue?

**RESOLVED:** No. It is not possible to transfer ownership of a shared presentable image obtained from a swapchain created using `VK_SHARING_MODE_EXCLUSIVE` after it has been presented.

11) How should `vkQueueSubmit` behave if a command buffer uses an image from a `VK_ERROR_OUT_OF_DATE_KHR` swapchain?

**RESOLVED:** `vkQueueSubmit` is expected to return the `VK_ERROR_DEVICE_LOST` error.

12) Can Vulkan provide any guarantee on the order of rendering, to enable beam chasing?

**RESOLVED:** This could be achieved via use of render passes to ensure strip rendering.

**Version History**

- Revision 1, 2017-03-20 (Alon Or-bach)
  - Internal revisions

**VK_KHR_surface**

Name String

- `VK_KHR_surface`
Extension Type
Instance extension

Registered Extension Number
1

Revision
25

Ratification Status
Ratified

Extension and Version Dependencies

Contact
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Other Extension Metadata

Last Modified Date
2016-08-25

IP Status
No known IP claims.

Contributors
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• Graham Sellers, AMD
• Jeff Vigil, Qualcomm
• Chia-I Wu, LunarG
• Faith Ekstrand, Intel

Description
The VK_KHR_surface extension is an instance extension. It introduces VkSurfaceKHR objects, which abstract native platform surface or window objects for use with Vulkan. It also provides a way to
determine whether a queue family in a physical device supports presenting to particular surface.

Separate extensions for each platform provide the mechanisms for creating `VkSurfaceKHR` objects, but once created they may be used in this and other platform-independent extensions, in particular the `VK_KHR_swapchain` extension.

**New Object Types**

- `VkSurfaceKHR`

**New Commands**

- `vkDestroySurfaceKHR`
- `vkGetPhysicalDeviceSurfaceCapabilitiesKHR`
- `vkGetPhysicalDeviceSurfaceFormatsKHR`
- `vkGetPhysicalDeviceSurfacePresentModesKHR`
- `vkGetPhysicalDeviceSurfaceSupportKHR`

**New Structures**

- `VkSurfaceCapabilitiesKHR`
- `VkSurfaceFormatKHR`

**New Enums**

- `VkColorSpaceKHR`
- `VkCompositeAlphaFlagBitsKHR`
- `VkPresentModeKHR`
- `VkSurfaceTransformFlagBitsKHR`

**New Bitmasks**

- `VkCompositeAlphaFlagsKHR`

**New Enum Constants**

- `VK_KHR_SURFACE_EXTENSION_NAME`
- `VK_KHR_SURFACE_SPEC_VERSION`

Extending `VkObjectType`:

- `VK_OBJECT_TYPE_SURFACE_KHR`

Extending `VkResult`:

- `VK_ERROR_NATIVE_WINDOW_IN_USE_KHR`
- `VK_ERROR_SURFACE_LOST_KHR`
Examples

Note
The example code for the VK_KHR_surface and VK_KHR_swapchain extensions was removed from the appendix after revision 1.0.29. This WSI example code was ported to the cube demo that is shipped with the official Khronos SDK, and is being kept up-to-date in that location (see: https://github.com/KhronosGroup/Vulkan-Tools/blob/master/cube/cube.c).

Issues

1) Should this extension include a method to query whether a physical device supports presenting to a specific window or native surface on a given platform?

**RESOLVED:** Yes. Without this, applications would need to create a device instance to determine whether a particular window can be presented to. Knowing that a device supports presentation to a platform in general is not sufficient, as a single machine might support multiple seats, or instances of the platform that each use different underlying physical devices. Additionally, on some platforms, such as the X Window System, different drivers and devices might be used for different windows depending on which section of the desktop they exist on.

2) Should the vkGetPhysicalDeviceSurfaceCapabilitiesKHR, vkGetPhysicalDeviceSurfaceFormatsKHR, and vkGetPhysicalDeviceSurfacePresentModesKHR functions be in this extension and operate on physical devices, rather than being in VK_KHR_swapchain (i.e. device extension) and being dependent on VkDevice?

**RESOLVED:** Yes. While it might be useful to depend on VkDevice (and therefore on enabled extensions and features) for the queries, Vulkan was released only with the VkPhysicalDevice versions. Many cases can be resolved by a Valid Usage statement, and/or by a separate pNext chain version of the query struct specific to a given extension or parameters, via extensible versions of the queries: vkGetPhysicalDeviceSurfacePresentModes2EXT, vkGetPhysicalDeviceSurfaceCapabilities2KHR, and vkGetPhysicalDeviceSurfaceFormats2KHR.

3) Should Vulkan support Xlib or XCB as the API for accessing the X Window System platform?

**RESOLVED:** Both. XCB is a more modern and efficient API, but Xlib usage is deeply ingrained in many applications and likely will remain in use for the foreseeable future. Not all drivers necessarily need to support both, but including both as options in the core specification will probably encourage support, which should in turn ease adoption of the Vulkan API in older codebases. Additionally, the performance improvements possible with XCB likely will not have a measurable impact on the performance of Vulkan presentation and other minimal window system interactions defined here.

4) Should the GBM platform be included in the list of platform enums?

**RESOLVED:** Deferred, and will be addressed with a platform-specific extension to be written in the future.
Version History

- Revision 1, 2015-05-20 (James Jones)
  - Initial draft, based on LunarG KHR spec, other KHR specs, patches attached to bugs.

- Revision 2, 2015-05-22 (Ian Elliott)
  - Created initial Description section.
  - Removed query for whether a platform requires the use of a queue for presentation, since it was decided that presentation will always be modeled as being part of the queue.
  - Fixed typos and other minor mistakes.

- Revision 3, 2015-05-26 (Ian Elliott)
  - Improved the Description section.

- Revision 4, 2015-05-27 (James Jones)
  - Fixed compilation errors in example code.

- Revision 5, 2015-06-01 (James Jones)
  - Added issues 1 and 2 and made related spec updates.

- Revision 6, 2015-06-01 (James Jones)
  - Merged the platform type mappings table previously removed from VK_KHR_swapchain with the platform description table in this spec.
  - Added issues 3 and 4 documenting choices made when building the initial list of native platforms supported.

- Revision 7, 2015-06-11 (Ian Elliott)
  - Updated table 1 per input from the KHR TSG.
  - Updated issue 4 (GBM) per discussion with Daniel Stone. He will create a platform-specific extension sometime in the future.

- Revision 8, 2015-06-17 (James Jones)
  - Updated enum-extending values using new convention.
  - Fixed the value of VK_SURFACE_PLATFORM_INFO_TYPE_SUPPORTED_KHR.

- Revision 9, 2015-06-17 (James Jones)
  - Rebased on Vulkan API version 126.

- Revision 10, 2015-06-18 (James Jones)
  - Marked issues 2 and 3 resolved.

- Revision 11, 2015-06-23 (Ian Elliott)
  - Examples now show use of function pointers for extension functions.
  - Eliminated extraneous whitespace.

- Revision 12, 2015-07-07 (Daniel Rakos)
  - Added error section describing when each error is expected to be reported.
- Replaced the term “queue node index” with “queue family index” in the spec as that is the agreed term to be used in the latest version of the core header and spec.
- Replaced bool32_t with VkBool32.

**Revision 13, 2015-08-06 (Daniel Rakos)**
- Updated spec against latest core API header version.

**Revision 14, 2015-08-20 (Ian Elliott)**
- Renamed this extension and all of its enumerations, types, functions, etc. This makes it compliant with the proposed standard for Vulkan extensions.
- Switched from “revision” to “version”, including use of the VK_MAKE_VERSION macro in the header file.
- Did miscellaneous cleanup, etc.

**Revision 15, 2015-08-20 (Ian Elliott—porting a 2015-07-29 change from James Jones)**
- Moved the surface transform enums here from VK_WSI_swapchain so they could be reused by VK_WSI_display.

**Revision 16, 2015-09-01 (James Jones)**
- Restore single-field revision number.

**Revision 17, 2015-09-01 (James Jones)**
- Fix example code compilation errors.

**Revision 18, 2015-09-26 (Jesse Hall)**
- Replaced VkSurfaceDescriptionKHR with the VkSurfaceKHR object, which is created via layered extensions. Added VkDestroySurfaceKHR.

**Revision 19, 2015-09-28 (Jesse Hall)**
- Renamed from VK_EXT_KHR_swapchain to VK_EXT_KHR_surface.

**Revision 20, 2015-09-30 (Jeff Vigil)**
- Add error result VK_ERROR_SURFACE_LOST_KHR.

**Revision 21, 2015-10-15 (Daniel Rakos)**
- Updated the resolution of issue #2 and include the surface capability queries in this extension.
- Renamed SurfaceProperties to SurfaceCapabilities as it better reflects that the values returned are the capabilities of the surface on a particular device.
- Other minor cleanup and consistency changes.

**Revision 22, 2015-10-26 (Ian Elliott)**
- Renamed from VK_EXT_KHR_surface to VK_KHR_surface.

**Revision 23, 2015-11-03 (Daniel Rakos)**
- Added allocation callbacks to vkDestroySurfaceKHR.

**Revision 24, 2015-11-10 (Jesse Hall)**
- Removed VkSurfaceTransformKHR. Use VkSurfaceTransformFlagBitsKHR instead.
• Rename VkSurfaceCapabilitiesKHR member maxImageArraySize to maxImageArrayLayers.

• Revision 25, 2016-01-14 (James Jones)
  ◦ Moved VK_ERROR_NATIVE_WINDOW_IN_USE_KHR from the VK_KHR_android_surface to the VK_KHR_surface extension.

• 2016-08-23 (Ian Elliott)
  ◦ Update the example code, to not have so many characters per line, and to split out a new example to show how to obtain function pointers.

• 2016-08-25 (Ian Elliott)
  ◦ A note was added at the beginning of the example code, stating that it will be removed from future versions of the appendix.

VK_KHR_surface_protected_capabilities

Name String
  VK_KHR_surface_protected_capabilities

Extension Type
  Instance extension

Registered Extension Number
  240

Revision
  1

Ratification Status
  Ratified

Extension and Version Dependencies
  Version 1.1
  and
  VK_KHR_get_surface_capabilities2

Contact
  • Sandeep Shinde @sashinde

Other Extension Metadata

Last Modified Date
  2018-12-18

IP Status
  No known IP claims.

Contributors
  • Sandeep Shinde, NVIDIA
Description

This extension extends VkSurfaceCapabilities2KHR, providing applications a way to query whether swapchains can be created with the VK_SWAPCHAIN_CREATE_PROTECTED_BIT_KHR flag set.

Vulkan 1.1 added (optional) support for protect memory and protected resources including buffers (VK_BUFFER_CREATE_PROTECTED_BIT), images (VK_IMAGE_CREATE_PROTECTED_BIT), and swapchains (VK_SWAPCHAIN_CREATE_PROTECTED_BIT_KHR). However, on implementations which support multiple windowing systems, not all window systems may be able to provide a protected display path.

This extension provides a way to query if a protected swapchain created for a surface (and thus a specific windowing system) can be displayed on screen. It extends the existing VkSurfaceCapabilities2KHR structure with a new VkSurfaceProtectedCapabilitiesKHR structure from which the application can obtain information about support for protected swapchain creation through vkGetPhysicalDeviceSurfaceCapabilities2KHR.

New Structures

- Extending VkSurfaceCapabilities2KHR:
  - VkSurfaceProtectedCapabilitiesKHR

New Enum Constants

- VK_KHR_SURFACE_PROTECTED_CAPABILITIES_EXTENSION_NAME
- VK_KHR_SURFACE_PROTECTED_CAPABILITIES_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_SURFACE_PROTECTED_CAPABILITIES_KHR

Version History

- Revision 1, 2018-12-18 (Sandeep Shinde, Daniel Koch)
  - Internal revisions.

VK_KHR_swapchain

Name String

VK_KHR_swapchain

Extension Type

Device extension

Registered Extension Number

2
Revision
70

Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_surface

Contact
• James Jones @cubanismo
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Other Extension Metadata

Last Modified Date
2017-10-06

IP Status
No known IP claims.

Interactions and External Dependencies
• Interacts with Vulkan 1.1

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• Jeff Vigil, Qualcomm
• Chia-I Wu, LunarG
• Faith Ekstrand, Intel
• Matthaeus G. Chajdas, AMD
• Ray Smith, ARM
Description

The **VK_KHR_swapchain** extension is the device-level companion to the **VK_KHR_surface** extension. It introduces **VkSwapchainKHR** objects, which provide the ability to present rendering results to a surface.

New Object Types

- **VkSwapchainKHR**

New Commands

- `vkAcquireNextImageKHR`
- `vkCreateSwapchainKHR`
- `vkDestroySwapchainKHR`
- `vkGetSwapchainImagesKHR`
- `vkQueuePresentKHR`

If **Version 1.1** is supported:

- `vkAcquireNextImage2KHR`
- `vkGetDeviceGroupPresentCapabilitiesKHR`
- `vkGetDeviceGroupSurfacePresentModesKHR`
- `vkGetPhysicalDevicePresentRectanglesKHR`

New Structures

- **VkPresentInfoKHR**
- **VkSwapchainCreateInfoKHR**

If **Version 1.1** is supported:

- **VkAcquireNextImageInfoKHR**
- **VkDeviceGroupPresentCapabilitiesKHR**
- Extending **VkBindImageMemoryInfo**:
  - **VkBindImageMemorySwapchainInfoKHR**
- Extending **VkImageCreateInfo**:
  - **VkImageSwapchainCreateInfoKHR**
- Extending **VkPresentInfoKHR**:
  - **VkDeviceGroupPresentInfoKHR**
- Extending **VkSwapchainCreateInfoKHR**:
  - **VkDeviceGroupSwapchainCreateInfoKHR**
New Enums

- VkSwapchainCreateFlagBitsKHR

If Version 1.1 is supported:

- VkDeviceGroupPresentModeFlagBitsKHR

New Bitmasks

- VkSwapchainCreateFlagsKHR

If Version 1.1 is supported:

- VkDeviceGroupPresentModeFlagsKHR

New Enum Constants

- VK_KHR_SWAPCHAIN_EXTENSION_NAME
- VK_KHR_SWAPCHAIN_SPEC_VERSION

Extending VkImageLayout:

- VK_IMAGE_LAYOUT_PRESENT_SRC_KHR

Extending VkObjectType:

- VK_OBJECT_TYPE_SWAPCHAIN_KHR

Extending VkResult:

- VK_ERROR_OUT_OF_DATE_KHR
- VK_SUBOPTIMAL_KHR

Extending VkStructureType:

- VK_STRUCTURE_TYPE_PRESENT_INFO_KHR
- VK_STRUCTURE_TYPE_SWAPCHAIN_CREATE_INFO_KHR

If Version 1.1 is supported:

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_ACQUIRE_NEXT_IMAGE_INFO_KHR
  - VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_SWAPCHAIN_INFO_KHR
  - VK_STRUCTURE_TYPE_DEVICE_GROUP_PRESENT_CAPABILITIES_KHR
  - VK_STRUCTURE_TYPE_DEVICE_GROUP_PRESENT_INFO_KHR
  - VK_STRUCTURE_TYPE_DEVICE_GROUP_SWAPCHAIN_CREATE_INFO_KHR
  - VK_STRUCTURE_TYPE_IMAGE_SWAPCHAIN_CREATE_INFO_KHR

- Extending VkSwapchainCreateFlagBitsKHR:
  - VK_SWAPCHAIN_CREATE_PROTECTED_BIT_KHR
**Issues**

1) Does this extension allow the application to specify the memory backing of the presentable images?

**RESOLVED:** No. Unlike standard images, the implementation will allocate the memory backing of the presentable image.

2) What operations are allowed on presentable images?

**RESOLVED:** This is determined by the image usage flags specified when creating the presentable image's swapchain.

3) Does this extension support MSAA presentable images?

**RESOLVED:** No. Presentable images are always single-sampled. Multi-sampled rendering must use regular images. To present the rendering results the application must manually resolve the multi-sampled image to a single-sampled presentable image prior to presentation.

4) Does this extension support stereo/multi-view presentable images?

**RESOLVED:** Yes. The number of views associated with a presentable image is determined by the imageArrayLayers specified when creating a swapchain. All presentable images in a given swapchain use the same array size.

5) Are the layers of stereo presentable images half-sized?

**RESOLVED:** No. The image extents always match those requested by the application.

6) Do the “present” and “acquire next image” commands operate on a queue? If not, do they need to include explicit semaphore objects to interlock them with queue operations?

**RESOLVED:** The present command operates on a queue. The image ownership operation it represents happens in order with other operations on the queue, so no explicit semaphore object is required to synchronize its actions.

Applications may want to acquire the next image in separate threads from those in which they manage their queue, or in multiple threads. To make such usage easier, the acquire next image command takes a semaphore to signal as a method of explicit synchronization. The application must later queue a wait for this semaphore before queuing execution of any commands using the image.

7) Does *vkAcquireNextImageKHR* block if no images are available?

**RESOLVED:** The command takes a timeout parameter. Special values for the timeout are 0, which makes the call a non-blocking operation, and * UINT64_MAX*, which blocks indefinitely. Values in between will block for up to the specified time. The call will return when an image becomes available or an error occurs. It may, but is not required to, return before the specified timeout expires if the swapchain becomes out of date.
8) Can multiple presents be queued using one `vkQueuePresentKHR` call?

**RESOLVED:** Yes. `VkPresentInfoKHR` contains a list of swapchains and corresponding image indices that will be presented. When supported, all presentations queued with a single `vkQueuePresentKHR` call will be applied atomically as one operation. The same swapchain must not appear in the list more than once. Later extensions may provide applications stronger guarantees of atomicity for such present operations, and/or allow them to query whether atomic presentation of a particular group of swapchains is possible.

9) How do the presentation and acquire next image functions notify the application the targeted surface has changed?

**RESOLVED:** Two new result codes are introduced for this purpose:

- **VK_SUBOPTIMAL_KHR** - Presentation will still succeed, subject to the window resize behavior, but the swapchain is no longer configured optimally for the surface it targets. Applications should query updated surface information and recreate their swapchain at the next convenient opportunity.

- **VK_ERROR_OUT_OF_DATE_KHR** - Failure. The swapchain is no longer compatible with the surface it targets. The application must query updated surface information and recreate the swapchain before presentation will succeed.

These can be returned by both `vkAcquireNextImageKHR` and `vkQueuePresentKHR`.

10) Does the `vkAcquireNextImageKHR` command return a semaphore to the application via an output parameter, or accept a semaphore to signal from the application as an object handle parameter?

**RESOLVED:** Accept a semaphore to signal as an object handle. This avoids the need to specify whether the application must destroy the semaphore or whether it is owned by the swapchain, and if the latter, what its lifetime is and whether it can be reused for other operations once it is received from `vkAcquireNextImageKHR`.

11) What types of swapchain queuing behavior should be exposed? Options include swap interval specification, mailbox/most recent vs. FIFO queue management, targeting specific vertical blank intervals or absolute times for a given present operation, and probably others. For some of these, whether they are specified at swapchain creation time or as per-present parameters needs to be decided as well.

**RESOLVED:** The base swapchain extension will expose 3 possible behaviors (of which, FIFO will always be supported):

- **Immediate present:** Does not wait for vertical blanking period to update the current image, likely resulting in visible tearing. No internal queue is used. Present requests are applied immediately.

- **Mailbox queue:** Waits for the next vertical blanking period to update the current image. No tearing should be observed. An internal single-entry queue is used to hold pending presentation requests. If the queue is full when a new presentation request is received, the new request replaces the existing entry, and any images associated with the prior entry become available for
reuse by the application.

- FIFO queue: Waits for the next vertical blanking period to update the current image. No tearing should be observed. An internal queue containing `numSwapchainImages - 1` entries is used to hold pending presentation requests. New requests are appended to the end of the queue, and one request is removed from the beginning of the queue and processed during each vertical blanking period in which the queue is non-empty.

Not all surfaces will support all of these modes, so the modes supported will be returned using a surface information query. All surfaces must support the FIFO queue mode. Applications must choose one of these modes up front when creating a swapchain. Switching modes can be accomplished by recreating the swapchain.

12) Can `VK_PRESENT_MODE_MAILBOX_KHR` provide non-blocking guarantees for `vkAcquireNextImageKHR`? If so, what is the proper criteria?

**RESOLVED:** Yes. The difficulty is not immediately obvious here. Naively, if at least 3 images are requested, mailbox mode should always have an image available for the application if the application does not own any images when the call to `vkAcquireNextImageKHR` was made. However, some presentation engines may have more than one “current” image, and would still need to block in some cases. The right requirement appears to be that if the application allocates the surface's minimum number of images + 1 then it is guaranteed non-blocking behavior when it does not currently own any images.

13) Is there a way to create and initialize a new swapchain for a surface that has generated a `VK_SUBOPTIMAL_KHR` return code while still using the old swapchain?

**RESOLVED:** Not as part of this specification. This could be useful to allow the application to create an “optimal” replacement swapchain and rebuild all its command buffers using it in a background thread at a low priority while continuing to use the “suboptimal” swapchain in the main thread. It could probably use the same “atomic replace” semantics proposed for recreating direct-to-device swapchains without incurring a mode switch. However, after discussion, it was determined some platforms probably could not support concurrent swapchains for the same surface though, so this will be left out of the base KHR extensions. A future extension could add this for platforms where it is supported.

14) Should there be a special value for `VkSurfaceCapabilitiesKHR::maxImageCount` to indicate there are no practical limits on the number of images in a swapchain?

**RESOLVED:** Yes. There will often be cases where there is no practical limit to the number of images in a swapchain other than the amount of available resources (i.e., memory) in the system. Trying to derive a hard limit from things like memory size is prone to failure. It is better in such cases to leave it to applications to figure such soft limits out via trial/failure iterations.

15) Should there be a special value for `VkSurfaceCapabilitiesKHR::currentExtent` to indicate the size of the platform surface is undefined?

**RESOLVED:** Yes. On some platforms (Wayland, for example), the surface size is defined by the images presented to it rather than the other way around.

16) Should there be a special value for `VkSurfaceCapabilitiesKHR::maxImageExtent` to indicate there
is no practical limit on the surface size?

**RESOLVED:** No. It seems unlikely such a system would exist. 0 could be used to indicate the platform places no limits on the extents beyond those imposed by Vulkan for normal images, but this query could just as easily return those same limits, so a special “unlimited” value does not seem useful for this field.

17) How should surface rotation and mirroring be exposed to applications? How do they specify rotation and mirroring transforms applied prior to presentation?

**RESOLVED:** Applications can query both the supported and current transforms of a surface. Both are specified relative to the device's “natural” display rotation and direction. The supported transforms indicate which orientations the presentation engine accepts images in. For example, a presentation engine that does not support transforming surfaces as part of presentation, and which is presenting to a surface that is displayed with a 90-degree rotation, would return only one supported transform bit: **VK_SURFACE_TRANSFORM_ROTATE_90_BIT_KHR**. Applications must transform their rendering by the transform they specify when creating the swapchain in `preTransform` field.

18) Can surfaces ever not support **VK_MIRROR_NONE**? Can they support vertical and horizontal mirroring simultaneously? Relatedly, should **VK_MIRROR_NONE_BIT** be zero, or bit one, and should applications be allowed to specify multiple pre and current mirror transform bits, or exactly one?

**RESOLVED:** Since some platforms may not support presenting with a transform other than the native window's current transform, and prerotation/mirroring are specified relative to the device's natural rotation and direction, rather than relative to the surface's current rotation and direction, it is necessary to express lack of support for no mirroring. To allow this, the **MIRROR_NONE** enum must occupy a bit in the flags. Since **MIRROR_NONE** must be a bit in the bitmask rather than a bitmask with no values set, allowing more than one bit to be set in the bitmask would make it possible to describe undefined transforms such as **VK_MIRROR_NONE_BIT | VK_MIRROR_HORIZONTAL_BIT**, or a transform that includes both “no mirroring” and “horizontal mirroring” simultaneously. Therefore, it is desirable to allow specifying all supported mirroring transforms using only one bit. The question then becomes, should there be a **VK_MIRROR_HORIZONTAL_AND_VERTICAL_BIT** to represent a simultaneous horizontal and vertical mirror transform? However, such a transform is equivalent to a 180 degree rotation, so presentation engines and applications that wish to support or use such a transform can express it through rotation instead. Therefore, 3 exclusive bits are sufficient to express all needed mirroring transforms.

19) Should support for sRGB be required?

**RESOLVED:** In the advent of UHD and HDR display devices, proper color space information is vital to the display pipeline represented by the swapchain. The app can discover the supported format/color-space pairs and select a pair most suited to its rendering needs. Currently only the sRGB color space is supported, future extensions may provide support for more color spaces. See issues 23 and 24.

20) Is there a mechanism to modify or replace an existing swapchain with one targeting the same surface?

**RESOLVED:** Yes. This is described above in the text.
21) Should there be a way to set prerotation and mirroring using native APIs when presenting using a Vulkan swapchain?

**RESOLVED:** Yes. The transforms that can be expressed in this extension are a subset of those possible on native platforms. If a platform exposes a method to specify the transform of presented images for a given surface using native methods and exposes more transforms or other properties for surfaces than Vulkan supports, it might be impossible, difficult, or inconvenient to set some of those properties using Vulkan KHR extensions and some using the native interfaces. To avoid overwriting properties set using native commands when presenting using a Vulkan swapchain, the application can set the pretransform to “inherit”, in which case the current native properties will be used, or if none are available, a platform-specific default will be used. Platforms that do not specify a reasonable default or do not provide native mechanisms to specify such transforms should not include the inherit bits in the `supportedTransforms` bitmask they return in `VkSurfaceCapabilitiesKHR`.

22) Should the content of presentable images be clipped by objects obscuring their target surface?

**RESOLVED:** Applications can choose which behavior they prefer. Allowing the content to be clipped could enable more efficient presentation methods on some platforms, but some applications might rely on the content of presentable images to perform techniques such as partial updates or motion blurs.

23) What is the purpose of specifying a `VkColorSpaceKHR` along with `VkFormat` when creating a swapchain?

**RESOLVED:** While Vulkan itself is color space agnostic (e.g. even the meaning of R, G, B and A can be freely defined by the rendering application), the swapchain eventually will have to present the images on a display device with specific color reproduction characteristics. If any color space transformations are necessary before an image can be displayed, the color space of the presented image must be known to the swapchain. A swapchain will only support a restricted set of color format and -space pairs. This set can be discovered via `vkGetPhysicalDeviceSurfaceFormatsKHR`. As it can be expected that most display devices support the sRGB color space, at least one format/color-space pair has to be exposed, where the color space is `VK_COLOR_SPACE_SRGB_NONLINEAR_KHR`.

24) How are sRGB formats and the sRGB color space related?

**RESOLVED:** While Vulkan exposes a number of SRGB texture formats, using such formats does not guarantee working in a specific color space. It merely means that the hardware can directly support applying the non-linear transfer functions defined by the sRGB standard color space when reading from or writing to images of those formats. Still, it is unlikely that a swapchain will expose a * _SRGB format along with any color space other than `VK_COLOR_SPACE_SRGB_NONLINEAR_KHR`. On the other hand, non-* _SRGB formats will be very likely exposed in pair with a SRGB color space. This means, the hardware will not apply any transfer function when reading from or writing to such images, yet they will still be presented on a device with sRGB display characteristics. In this case the application is responsible for applying the transfer function, for instance by using shader math.

25) How are the lifetimes of surfaces and swapchains targeting them related?
**RESOLVED:** A surface must outlive any swapchains targeting it. A `VkSurfaceKHR` owns the binding of the native window to the Vulkan driver.

26) How can the client control the way the alpha component of swapchain images is treated by the presentation engine during compositing?

**RESOLVED:** We should add new enum values to allow the client to negotiate with the presentation engine on how to treat image alpha values during the compositing process. Since not all platforms can practically control this through the Vulkan driver, a value of `VK_COMPOSITE_ALPHA_INHERIT_BIT_KHR` is provided like for surface transforms.

27) Is `vkCreateSwapchainKHR` the right function to return `VK_ERROR_NATIVE_WINDOW_IN_USE_KHR`, or should the various platform-specific `VkSurfaceKHR` factory functions catch this error earlier?

**RESOLVED:** For most platforms, the `VkSurfaceKHR` structure is a simple container holding the data that identifies a native window or other object representing a surface on a particular platform. For the surface factory functions to return this error, they would likely need to register a reference on the native objects with the native display server somehow, and ensure no other such references exist. Surfaces were not intended to be that heavyweight.

Swapchains are intended to be the objects that directly manipulate native windows and communicate with the native presentation mechanisms. Swapchains will already need to communicate with the native display server to negotiate allocation and/or presentation of presentable images for a native surface. Therefore, it makes more sense for swapchain creation to be the point at which native object exclusivity is enforced. Platforms may choose to enforce further restrictions on the number of `VkSurfaceKHR` objects that may be created for the same native window if such a requirement makes sense on a particular platform, but a global requirement is only sensible at the swapchain level.

### Examples

**Note**

The example code for the `VK_KHR_surface` and `VK_KHR_swapchain` extensions was removed from the appendix after revision 1.0.29. This WSI example code was ported to the cube demo that is shipped with the official Khronos SDK, and is being kept up-to-date in that location (see: [https://github.com/KhronosGroup/Vulkan-Tools/blob/master/cube/cube.c](https://github.com/KhronosGroup/Vulkan-Tools/blob/master/cube/cube.c)).

### Version History

- **Revision 1, 2015-05-20 (James Jones)**
  - Initial draft, based on LunarG KHR spec, other KHR specs, patches attached to bugs.
- **Revision 2, 2015-05-22 (Ian Elliott)**
  - Made many agreed-upon changes from 2015-05-21 KHR TSG meeting. This includes using only a queue for presentation, and having an explicit function to acquire the next image.
  - Fixed typos and other minor mistakes.
• Revision 3, 2015-05-26 (Ian Elliott)
  ◦ Improved the Description section.
  ◦ Added or resolved issues that were found in improving the Description. For example,
pSurfaceDescription is used consistently, instead of sometimes using pSurface.

• Revision 4, 2015-05-27 (James Jones)
  ◦ Fixed some grammatical errors and typos
  ◦ Filled in the description of imageUseFlags when creating a swapchain.
  ◦ Added a description of swapInterval.
  ◦ Replaced the paragraph describing the order of operations on a queue for image ownership
    and presentation.

• Revision 5, 2015-05-27 (James Jones)
  ◦ Imported relevant issues from the (abandoned) vk_wsi_persistent_swapchain_images
    extension.
  ◦ Added issues 6 and 7, regarding behavior of the acquire next image and present commands
    with respect to queues.
  ◦ Updated spec language and examples to align with proposed resolutions to issues 6 and 7.

• Revision 6, 2015-05-27 (James Jones)
  ◦ Added issue 8, regarding atomic presentation of multiple swapchains
  ◦ Updated spec language and examples to align with proposed resolution to issue 8.

• Revision 7, 2015-05-27 (James Jones)
  ◦ Fixed compilation errors in example code, and made related spec fixes.

• Revision 8, 2015-05-27 (James Jones)
  ◦ Added issue 9, and the related VK_SUBOPTIMAL_KHR result code.
  ◦ Renamed VK_OUT_OF_DATE_KHR to VK_ERROR_OUT_OF_DATE_KHR.

• Revision 9, 2015-05-27 (James Jones)
  ◦ Added inline proposed resolutions (marked with [JRJ]) to some XXX questions/issues. These
    should be moved to the issues section in a subsequent update if the proposals are adopted.

• Revision 10, 2015-05-28 (James Jones)
  ◦ Converted vkAcquireNextImageKHR back to a non-queue operation that uses a
    VkSemaphore object for explicit synchronization.
  ◦ Added issue 10 to determine whether vkAcquireNextImageKHR generates or returns
    semaphores, or whether it operates on a semaphore provided by the application.

• Revision 11, 2015-05-28 (James Jones)
  ◦ Marked issues 6, 7, and 8 resolved.
  ◦ Renamed VkSurfaceCapabilityPropertiesKHR to VkSurfacePropertiesKHR to better convey
    the mutable nature of the information it contains.

• Revision 12, 2015-05-28 (James Jones)
• Added issue 11 with a proposed resolution, and the related issue 12.
• Updated various sections of the spec to match the proposed resolution to issue 11.

Revision 13, 2015-06-01 (James Jones)
• Moved some structures to VK_EXT_KHR_swap_chain to resolve the specification’s issues 1 and 2.

Revision 14, 2015-06-01 (James Jones)
• Added code for example 4 demonstrating how an application might make use of the two different present and acquire next image KHR result codes.
• Added issue 13.

Revision 15, 2015-06-01 (James Jones)
• Added issues 14 - 16 and related spec language.
• Fixed some spelling errors.
• Added language describing the meaningful return values for vkAcquireNextImageKHR and vkQueuePresentKHR.

Revision 16, 2015-06-02 (James Jones)
• Added issues 17 and 18, as well as related spec language.
• Removed some erroneous text added by mistake in the last update.

Revision 17, 2015-06-15 (Ian Elliott)
• Changed special value from “-1” to “0” so that the data types can be unsigned.

Revision 18, 2015-06-15 (Ian Elliott)
• Clarified the values of VkSurfacePropertiesKHR::minImageCount and the timeout parameter of the vkAcquireNextImageKHR function.

Revision 19, 2015-06-17 (James Jones)
• Misc. cleanup. Removed resolved inline issues and fixed typos.
• Fixed clarification of VkSurfacePropertiesKHR::minImageCount made in version 18.
• Added a brief “Image Ownership” definition to the list of terms used in the spec.

Revision 20, 2015-06-17 (James Jones)
• Updated enum-extending values using new convention.

Revision 21, 2015-06-17 (James Jones)
• Added language describing how to use VK_IMAGE_LAYOUT_PRESENT_SOURCE_KHR.
• Cleaned up an XXX comment regarding the description of which queues vkQueuePresentKHR can be used on.

Revision 22, 2015-06-17 (James Jones)
• Rebased on Vulkan API version 126.

Revision 23, 2015-06-18 (James Jones)
• Updated language for issue 12 to read as a proposed resolution.
Marked issues 11, 12, 13, 16, and 17 resolved.
Temporarily added links to the relevant bugs under the remaining unresolved issues.
Added issues 19 and 20 as well as proposed resolutions.

• Revision 24, 2015-06-19 (Ian Elliott)
  Changed special value for VkSurfacePropertiesKHR::currentExtent back to “-1” from “0”. This value will never need to be unsigned, and “0” is actually a legal value.

• Revision 25, 2015-06-23 (Ian Elliott)
  Examples now show use of function pointers for extension functions.
  Eliminated extraneous whitespace.

• Revision 26, 2015-06-25 (Ian Elliott)
  Resolved Issues 9 & 10 per KHR TSG meeting.

• Revision 27, 2015-06-25 (James Jones)
  Added oldSwapchain member to VkSwapchainCreateInfoKHR.

• Revision 28, 2015-06-25 (James Jones)
  Added the “inherit” bits to the rotation and mirroring flags and the associated issue 21.

• Revision 29, 2015-06-25 (James Jones)
  Added the “clipped” flag to VkSwapchainCreateInfoKHR, and the associated issue 22.
  Specified that presenting an image does not modify it.

• Revision 30, 2015-06-25 (James Jones)
  Added language to the spec that clarifies the behavior of vkCreateSwapchainKHR() when the oldSwapchain field of VkSwapchainCreateInfoKHR is not NULL.

• Revision 31, 2015-06-26 (Ian Elliott)
  Example of new VkSwapchainCreateInfoKHR members, “oldSwapchain” and “clipped”.
  Example of using VkSurfacePropertiesKHR::{min|max}ImageCount to set VkSwapchainCreateInfoKHR::minImageCount.
  Rename vkGetSurfaceInfoKHR()'s 4th parameter to “pDataSize”, for consistency with other functions.
  Add macro with C-string name of extension (just to header file).

• Revision 32, 2015-06-26 (James Jones)
  Minor adjustments to the language describing the behavior of “oldSwapchain”
  Fixed the version date on my previous two updates.

• Revision 33, 2015-06-26 (Jesse Hall)
  Add usage flags to VkSwapchainCreateInfoKHR

• Revision 34, 2015-06-26 (Ian Elliott)
  Rename vkQueuePresentKHR()'s 2nd parameter to “pPresentInfo”, for consistency with other functions.
• Revision 35, 2015-06-26 (Faith Ekstrand)
  ◦ Merged the VkRotationFlagBitsKHR and VkMirrorFlagBitsKHR enums into a single
    VkSurfaceTransformFlagBitsKHR enum.

• Revision 36, 2015-06-26 (Faith Ekstrand)
  ◦ Added a VkSurfaceTransformKHR enum that is not a bitmask. Each value in
    VkSurfaceTransformKHR corresponds directly to one of the bits in
    VkSurfaceTransformFlagBitsKHR so transforming from one to the other is easy. Having a
    separate enum means that currentTransform and preTransform are now unambiguous by
    definition.

• Revision 37, 2015-06-29 (Ian Elliott)
  ◦ Corrected one of the signatures of vkAcquireNextImageKHR, which had the last two
    parameters switched from what it is elsewhere in the specification and header files.

• Revision 38, 2015-06-30 (Ian Elliott)
  ◦ Corrected a typo in description of the vkGetSwapchainInfoKHR() function.
  ◦ Corrected a typo in header file comment for VkPresentInfoKHR::sType.

• Revision 39, 2015-07-07 (Daniel Rakos)
  ◦ Added error section describing when each error is expected to be reported.
  ◦ Replaced bool32_t with VkBool32.

• Revision 40, 2015-07-10 (Ian Elliott)
  ◦ Updated to work with version 138 of the vulkan.h header. This includes declaring the
    VkSwapchainKHR type using the new VK_DEFINE_NONDISP_HANDLE macro, and no longer
    extending VkObjectType (which was eliminated).

• Revision 41 2015-07-09 (Mathias Heyer)
  ◦ Added color space language.

• Revision 42, 2015-07-10 (Daniel Rakos)
  ◦ Updated query mechanism to reflect the convention changes done in the core spec.
  ◦ Removed “queue” from the name of VK_STRUCTURE_TYPE_QUEUE_PRESENT_INFO_KHR to
    be consistent with the established naming convention.
  ◦ Removed reference to the no longer existing VkObjectType enum.

• Revision 43, 2015-07-17 (Daniel Rakos)
  ◦ Added support for concurrent sharing of swapchain images across queue families.
  ◦ Updated sample code based on recent changes

• Revision 44, 2015-07-27 (Ian Elliott)
  ◦ Noted that support for VK_PRESENT_MODE_FIFO_KHR is required. That is ICDs may
    optionally support IMMEDIATE and MAILBOX, but must support FIFO.

• Revision 45, 2015-08-07 (Ian Elliott)
  ◦ Corrected a typo in spec file (type and variable name had wrong case for the
    imageColorSpace member of the VkSwapchainCreateInfoKHR struct).
Corrected a typo in header file (last parameter in PFN_vkGetSurfacePropertiesKHR was missing “KHR” at the end of type: VkSurfacePropertiesKHR).

Revision 46, 2015-08-20 (Ian Elliott)

- Renamed this extension and all of its enumerations, types, functions, etc. This makes it compliant with the proposed standard for Vulkan extensions.
- Switched from “revision” to “version”, including use of the VK_MAKE_VERSION macro in the header file.
- Made improvements to several descriptions.
- Changed the status of several issues from PROPOSED to RESOLVED, leaving no unresolved issues.
- Resolved several TODOs, did miscellaneous cleanup, etc.

Revision 47, 2015-08-20 (Ian Elliott—porting a 2015-07-29 change from James Jones)

- Moved the surface transform enums to VK_WSI_swapchain so they could be reused by VK_WSI_display.

Revision 48, 2015-09-01 (James Jones)

- Various minor cleanups.

Revision 49, 2015-09-01 (James Jones)

- Restore single-field revision number.

Revision 50, 2015-09-01 (James Jones)

- Update Example #4 to include code that illustrates how to use the oldSwapchain field.

Revision 51, 2015-09-01 (James Jones)

- Fix example code compilation errors.

Revision 52, 2015-09-08 (Matthaeus G. Chajdas)

- Corrected a typo.

Revision 53, 2015-09-10 (Alon Or-bach)

- Removed underscore from SWAP_CHAIN left in VK_STRUCTURE_TYPE_SWAPCHAIN_CREATE_INFO_KHR.

Revision 54, 2015-09-11 (Jesse Hall)

- Described the execution and memory coherence requirements for image transitions to and from VK_IMAGE_LAYOUT_PRESENT_SOURCE_KHR.

Revision 55, 2015-09-11 (Ray Smith)

- Added errors for destroying and binding memory to presentable images

Revision 56, 2015-09-18 (James Jones)

- Added fence argument to vkAcquireNextImageKHR
- Added example of how to meter a host thread based on presentation rate.

Revision 57, 2015-09-26 (Jesse Hall)

- Replace VkSurfaceDescriptionKHR with VkSurfaceKHR.
• Added issue 25 with agreed resolution.

• Revision 58, 2015-09-28 (Jesse Hall)
  • Renamed from VK_EXT_KHR_device_swapchain to VK_EXT_KHR_swapchain.

• Revision 59, 2015-09-29 (Ian Elliott)
  • Changed vkDestroySwapchainKHR() to return void.

• Revision 60, 2015-10-01 (Jeff Vigil)
  • Added error result VK_ERROR_SURFACE_LOST_KHR.

• Revision 61, 2015-10-05 (Faith Ekstrand)
  • Added the VkCompositeAlpha enum and corresponding structure fields.

• Revision 62, 2015-10-12 (Daniel Rakos)
  • Added VK_PRESENT_MODE_FIFO_RELAXED_KHR.

• Revision 63, 2015-10-15 (Daniel Rakos)
  • Moved surface capability queries to VK_EXT_KHR_surface.

• Revision 64, 2015-10-26 (Ian Elliott)
  • Renamed from VK_EXT_KHR_swapchain to VK_KHR_swapchain.

• Revision 65, 2015-10-28 (Ian Elliott)
  • Added optional pResult member to VkPresentInfoKHR, so that per-swapchain results can be obtained from vkQueuePresentKHR().

• Revision 66, 2015-11-03 (Daniel Rakos)
  • Added allocation callbacks to create and destroy functions.
  • Updated resource transition language.
  • Updated sample code.

• Revision 67, 2015-11-10 (Jesse Hall)
  • Add reserved flags bitmask to VkSwapchainCreateInfoKHR.
  • Modify naming and member ordering to match API style conventions, and so the VkSwapchainCreateInfoKHR image property members mirror corresponding VkImageCreateInfo members but with an ‘image’ prefix.
  • Make VkPresentInfoKHR::pResults non-const; it is an output array parameter.
  • Make pPresentInfo parameter to vkQueuePresentKHR const.

• Revision 68, 2016-04-05 (Ian Elliott)
  • Moved the “validity” include for vkAcquireNextImage to be in its proper place, after the prototype and list of parameters.
  • Clarified language about presentable images, including how they are acquired, when applications can and cannot use them, etc. As part of this, removed language about “ownership” of presentable images, and replaced it with more-consistent language about presentable images being “acquired” by the application.

• 2016-08-23 (Ian Elliott)
Update the example code, to use the final API command names, to not have so many characters per line, and to split out a new example to show how to obtain function pointers. This code is more similar to the LunarG “cube” demo program.

- 2016-08-25 (Ian Elliott)
  - A note was added at the beginning of the example code, stating that it will be removed from future versions of the appendix.

- Revision 69, 2017-09-07 (Tobias Hector)
  - Added interactions with Vulkan 1.1

- Revision 70, 2017-10-06 (Ian Elliott)
  - Corrected interactions with Vulkan 1.1

**VK_KHR_swapchain_mutable_format**

**Name String**
- `VK_KHR_swapchain_mutable_format`

**Extension Type**
- Device extension

**Registered Extension Number**
- 201

**Revision**
- 1

**Ratification Status**
- Ratified

**Extension and Version Dependencies**
- `VK_KHR_swapchain`
  - `VK_KHR_maintenance2`
    - `Version 1.1`
  - `VK_KHR_image_format_list`
    - `Version 1.2`

**Contact**
- Daniel Rakos [drakos-amd](mailto:drakos-amd)

**Other Extension Metadata**
Description

This extension allows processing of swapchain images as different formats to that used by the window system, which is particularly useful for switching between sRGB and linear RGB formats.

It adds a new swapchain creation flag that enables creating image views from presentable images with a different format than the one used to create the swapchain.

New Enum Constants

- `VK_KHR_SWAPCHAIN_MUTABLE_FORMAT_EXTENSION_NAME`
- `VK_KHR_SWAPCHAIN_MUTABLE_FORMAT_SPEC_VERSION`
- Extending `VkSwapchainCreateInfoKHR`:
  - `VK_SWAPCHAIN_CREATE_MUTABLE_FORMAT_BIT_KHR`

Issues

1) Are there any new capabilities needed?

**RESOLVED**: No. It is expected that all implementations exposing this extension support swapchain image format mutability.

2) Do we need a separate `VK_SWAPCHAIN_CREATE_EXTENDED_USAGE_BIT_KHR`?

**RESOLVED**: No. This extension requires `VK_KHR_maintenance2` and presentable images of swapchains created with `VK_SWAPCHAIN_CREATE_MUTABLE_FORMAT_BIT_KHR` are created internally in a way equivalent to specifying both `VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT` and `VK_IMAGE_CREATE_EXTENDED_USAGE_BIT_KHR`.

3) Do we need a separate structure to allow specifying an image format list for swapchains?

**RESOLVED**: No. We simply use the same `VkImageFormatListCreateInfoKHR` structure introduced by `VK_KHR_image_format_list`. The structure is required to be included in the `pNext` chain of `VkSwapchainCreateInfoKHR` for swapchains created with `VK_SWAPCHAIN_CREATE_MUTABLE_FORMAT_BIT_KHR`.

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**Version History**

- Revision 1, 2018-03-28 (Daniel Rakos)
  - Internal revisions.

**VK_KHR_video_decode_h264**

**Name String**

`VK_KHR_video_decode_h264`

**Extension Type**

Device extension

**Registered Extension Number**

41

**Revision**

8

**Ratification Status**

Ratified

**Extension and Version Dependencies**

`VK_KHR_video_decode_queue`

**Contact**

- peter.fang@amd.com

**Extension Proposal**

`VK_KHR_video_decode_h264`

**Other Extension Metadata**

**Last Modified Date**

2022-09-29

**IP Status**

No known IP claims.

**Contributors**

- Ahmed Abdelkhalek, AMD
- Chunbo Chen, Intel
- HoHin Lau, AMD
- Jake Beju, AMD
- Peter Fang, AMD
- Ping Liu, Intel
Description

This extension builds upon the `VK_KHR_video_decode_queue` extension by adding support for decoding elementary video stream sequences compliant with the H.264/AVC video compression standard.

**Note**

This extension was promoted to `KHR` from the provisional extension `VK_EXT_video_decode_h264`.

New Structures

- Extending `VkVideoCapabilitiesKHR`:
  - `VkVideoDecodeH264CapabilitiesKHR`
- Extending `VkVideoDecodeInfoKHR`:
  - `VkVideoDecodeH264PictureInfoKHR`
- Extending `VkVideoProfileInfoKHR`, `VkQueryPoolCreateInfo`:
  - `VkVideoDecodeH264ProfileInfoKHR`
- Extending `VkVideoReferenceSlotInfoKHR`:
  - `VkVideoDecodeH264DpbSlotInfoKHR`
- Extending `VkVideoSessionParametersCreateInfoKHR`:
  - `VkVideoDecodeH264SessionParametersCreateInfoKHR`
- Extending `VkVideoSessionParametersUpdateInfoKHR`:
  - `VkVideoDecodeH264SessionParametersAddInfoKHR`

New Enums

- `VkVideoDecodeH264PictureLayoutFlagBitsKHR`

New Bitmasks

- `VkVideoDecodeH264PictureLayoutFlagsKHR`

New Enum Constants

- `VK_KHR_VIDEO_DECODE_H264_EXTENSION_NAME`
- `VK_KHR_VIDEO_DECODE_H264_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_VIDEO_DECODE_H264_CAPABILITIES_KHR`
• Extending VkVideoCodecOperationFlagBitsKHR:
  ◦ VK_VIDEO_CODEC_OPERATION_DECODE_H264_BIT_KHR

Version History

• Revision 1, 2018-6-11 (Peter Fang)
  ◦ Initial draft

• Revision 2, March 29 2021 (Tony Zlatinski)
  ◦ Spec and API Updates

• Revision 3, August 1 2021 (Srinath Kumarapuram)
  ◦ Rename VkVideoDecodeH264FieldLayoutFlagsEXT to VkVideoDecodeH264PictureLayoutFlagsEXT, VkVideoDecodeH264FieldLayoutFlagBitsEXT to VkVideoDecodeH264PictureLayoutFlagBitsEXT (along with the names of enumerants it defines), and VkVideoDecodeH264ProfileEXT.fieldLayout to VkVideoDecodeH264ProfileEXT.pictureLayout, following Vulkan naming conventions.

• Revision 4, 2022-03-16 (Ahmed Abdelkhalek)
  ◦ Relocate Std header version reporting/requesting from this extension to VK_KHR_video_queue extension.
  ◦ Remove the now empty VkVideoDecodeH264SessionCreateInfoEXT.

• Revision 5, 2022-03-31 (Ahmed Abdelkhalek)
  ◦ Use type StdVideoH264Level for VkVideoDecodeH264Capabilities.maxLevel

• Revision 6, 2022-08-09 (Daniel Rakos)
  ◦ Rename VkVideoDecodeH264ProfileEXT to VkVideoDecodeH264ProfileInfoEXT
  ◦ Rename VkVideoDecodeH264MvcEXT to VkVideoDecodeH264MvcInfoEXT

• Revision 7, 2022-09-18 (Daniel Rakos)
  ◦ Change type of VkVideoDecodeH264ProfileInfoEXT::pictureLayout to VkVideoDecodeH264PictureLayoutFlagBitsEXT
  ◦ Remove MVC support and related VkVideoDecodeH264MvcInfoEXT structure
  ◦ Rename spsStdCount, pSpsStd, ppsStdCount, and pPpsStd to stdSPSCount, pStdSPSs, stdPPSCount, and pStdPPSSs, respectively, in VkVideoDecodeH264SessionParametersAddInfoEXT
  ◦ Rename maxSpsStdCount and maxPpsStdCount to maxSPSCount and maxPPSCount, respectively, in VkVideoDecodeH264SessionParametersCreateInfoEXT
  ◦ Rename slicesCount and pSlicesDataOffsets to sliceCount and pSliceOffsets, respectively, in
• Revision 8, 2022-09-29 (Daniel Rakos)
  ◦ Change extension from EXT to KHR
  ◦ Extension is no longer provisional

VK_KHR_video_decode_h265

Name String
VK_KHR_video_decode_h265

Extension Type
Device extension

Registered Extension Number
188

Revision
7

Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_video_decode_queue

Contact
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Extension Proposal
VK_KHR_video_decode_h265

Other Extension Metadata

Last Modified Date
2022-11-14

IP Status
No known IP claims.

Contributors
• Ahmed Abdelkhalek, AMD
• HoHin Lau, AMD
• Jake Beju, AMD
• Peter Fang, AMD
• Ping Liu, Intel
Description

This extension builds upon the VK_KHR_video_decode_queue extension by adding support for decoding elementary video stream sequences compliant with the H.265/HEVC video compression standard.

Note

This extension was promoted to KHR from the provisional extension VK_EXT_video_decode_h265.

New Structures

- Extending VkVideoCapabilitiesKHR:
  - VkVideoDecodeH265CapabilitiesKHR
- Extending VkVideoDecodeInfoKHR:
  - VkVideoDecodeH265PictureInfoKHR
- Extending VkVideoProfileInfoKHR, VkQueryPoolCreateInfo:
  - VkVideoDecodeH265ProfileInfoKHR
- Extending VkVideoReferenceSlotInfoKHR:
  - VkVideoDecodeH265DpbSlotInfoKHR
- Extending VkVideoSessionParametersCreateInfoKHR:
  - VkVideoDecodeH265SessionParametersCreateInfoKHR
- Extending VkVideoSessionParametersUpdateInfoKHR:
  - VkVideoDecodeH265SessionParametersAddInfoKHR

New Enum Constants

- VK_KHR_VIDEO_DECODER_H265_EXTENSION_NAME
- VK_KHR_VIDEO_DECODER_H265_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_VIDEO_DECODER_H265_CAPABILITIES_KHR
  - VK_STRUCTURE_TYPE_VIDEO_DECODER_H265_DPB_SLOT_INFO_KHR
  - VK_STRUCTURE_TYPE_VIDEO_DECODER_H265_PICTURE_INFO_KHR
  - VK_STRUCTURE_TYPE_VIDEO_DECODER_H265_PROFILE_INFO_KHR
  - VK_STRUCTURE_TYPE_VIDEO_DECODER_H265_SESSION_PARAMETERS_ADD_INFO_KHR
  - VK_STRUCTURE_TYPE_VIDEO_DECODER_H265_SESSION_PARAMETERS_CREATE_INFO_KHR
• Extending VkVideoCodecOperationFlagBitsKHR:
  ◦ VK_VIDEO_CODEC_OPERATION_DECODE_H265_BIT_KHR

Version History

• Revision 1, 2018-6-11 (Peter Fang)
  ◦ Initial draft
• Revision 1.6, March 29 2021 (Tony Zlatinski)
  ◦ Spec and API updates.
• Revision 2, 2022-03-16 (Ahmed Abdelkhalek)
  ◦ Relocate Std header version reporting/requesting from this extension to VK_KHR_video_queue extension.
  ◦ Remove the now empty VkVideoDecodeH265SessionCreateInfoEXT.
• Revision 3, 2022-03-31 (Ahmed Abdelkhalek)
  ◦ Use type StdVideoH265Level for VkVideoDecodeH265Capabilities.maxLevel
• Revision 4, 2022-08-09 (Daniel Rakos)
  ◦ Rename VkVideoDecodeH265ProfileEXT to VkVideoDecodeH265ProfileInfoEXT
• Revision 5, 2022-09-18 (Daniel Rakos)
  ◦ Rename vpsStdCount, pVpsStd, spsStdCount, pSpsStd, ppsStdCount, and pPpsStd to stdVPSCount, pStdVPSs, stdSPSCount, pStdSPSs, stdPPSCount, and pStdPPSs, respectively, in VkVideoDecodeH265SessionParametersAddInfoEXT
  ◦ Rename maxVpsStdCount, maxSpsStdCount, and maxPpsStdCount to maxStdVPSCount, maxStdSPSCount, and maxStdPPSCount, respectively, in VkVideoDecodeH265SessionParametersCreateInfoEXT
  ◦ Rename slicesCount and pSlicesDataOffsets to sliceCount and pSliceOffsets, respectively, in VkVideoDecodeH265PictureInfoEXT
• Revision 6, 2022-11-14 (Daniel Rakos)
  ◦ Rename slice to sliceSegment in the APIs for better clarity
• Revision 7, 2022-11-14 (Daniel Rakos)
  ◦ Change extension from EXT to KHR
  ◦ Extension is no longer provisional

**VK_KHR_video_decode_queue**

Name String

VK_KHR_video_decode_queue

Extension Type

Device extension
Description

This extension builds upon the `VK_KHR_video_queue` extension by adding common APIs specific to video decoding and thus enabling implementations to expose queue families supporting video decode operations.

More specifically, it adds video decode specific capabilities and a new command buffer command that allows recording video decode operations against a video session.
This extension is to be used in conjunction with other codec specific video decode extensions that enable decoding video sequences of specific video compression standards.

**New Commands**

- `vkCmdDecodeVideoKHR`

**New Structures**

- `VkVideoDecodeInfoKHR`
- Extending `VkVideoCapabilitiesKHR`:
  - `VkVideoDecodeCapabilitiesKHR`
- Extending `VkVideoProfileInfoKHR, VkQueryPoolCreateInfo`:
  - `VkVideoDecodeUsageInfoKHR`

**New Enums**

- `VkVideoDecodeCapabilityFlagBitsKHR`
- `VkVideoDecodeUsageFlagBitsKHR`

**New Bitmasks**

- `VkVideoDecodeCapabilityFlagsKHR`
- `VkVideoDecodeFlagsKHR`
- `VkVideoDecodeUsageFlagsKHR`

**New Enum Constants**

- `VK_KHR_VIDEO_DECODE_QUEUE_EXTENSION_NAME`
- `VK_KHR_VIDEO_DECODE_QUEUE_SPEC_VERSION`
- Extending `VkAccessFlagBits2`:
  - `VK_ACCESS_2_VIDEO_DECODE_READ_BIT_KHR`
  - `VK_ACCESS_2_VIDEO_DECODE_WRITE_BIT_KHR`
- Extending `VkBufferUsageFlagBits`:
  - `VK_BUFFER_USAGE_VIDEO_DECODE_DST_BIT_KHR`
  - `VK_BUFFER_USAGE_VIDEO_DECODE_SRC_BIT_KHR`
- Extending `VkFormatFeatureFlagBits`:
  - `VK_FORMAT_FEATURE_VIDEO_DECODE_DPB_BIT_KHR`
  - `VK_FORMAT_FEATURE_VIDEO_DECODE_OUTPUT_BIT_KHR`
- Extending `VkImageLayout`:
  - `VK_IMAGE_LAYOUT_VIDEO_DECODE_DPB_KHR`
• **Extending** VkImageUsageFlagBits:
  ◦ VK_IMAGE_USAGE_VIDEO_DECODE_DPB_BIT_KHR
  ◦ VK_IMAGE_USAGE_VIDEO_DECODE_DST_BIT_KHR
  ◦ VK_IMAGE_USAGE_VIDEO_DECODE_SRC_BIT_KHR

• **Extending** VkPipelineStageFlagBits2:
  ◦ VK_PIPELINE_STAGE_2_VIDEO_DECODE_BIT_KHR

• **Extending** VkQueueFlagBits:
  ◦ VK_QUEUE_VIDEO_DECODE_BIT_KHR

• **Extending** VkStructureType:
  ◦ VK_STRUCTURE_TYPE_VIDEO_DECODE_CAPABILITIES_KHR
  ◦ VK_STRUCTURE_TYPE_VIDEO_DECODE_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_VIDEO_DECODE_USAGE_INFO_KHR

If **VK_KHR_format_feature_flags2** is supported:

• **Extending** VkFormatFeatureFlagBits2:
  ◦ VK_FORMAT_FEATURE_2_VIDEO_DECODE_DPB_BIT_KHR
  ◦ VK_FORMAT_FEATURE_2_VIDEO_DECODE_OUTPUT_BIT_KHR

**Version History**

• Revision 1, 2018-6-11 (Peter Fang)
  ◦ Initial draft

• Revision 1.5, Nov 09 2018 (Tony Zlatinski)
  ◦ API Updates

• Revision 1.6, Jan 08 2020 (Tony Zlatinski)
  ◦ API unify with the video_encode_queue spec

• Revision 1.7, March 29 2021 (Tony Zlatinski)
  ◦ Spec and API updates.

• Revision 2, September 30 2021 (Jon Leech)
  ◦ Add interaction with VK_KHR_format_feature_flags2 to vk.xml

• Revision 3, 2022-02-25 (Ahmed Abdelkhalek)
  ◦ Add VkVideoDecodeCapabilitiesKHR with new flags to report support for decode DPB and output coinciding in the same image, or in distinct images.

• Revision 4, 2022-03-31 (Ahmed Abdelkhalek)
  ◦ Remove redundant VkVideoDecodeInfoKHR.coded{Offset|Extent}
• Revision 5, 2022-07-18 (Daniel Rakos)
  ◦ Remove VkVideoDecodeFlagBitsKHR as it contains no defined flags for now

• Revision 6, 2022-08-12 (Daniel Rakos)
  ◦ Add VkVideoDecodeUsageInfoKHR structure and related flags

• Revision 7, 2022-09-29 (Daniel Rakos)
  ◦ Extension is no longer provisional

VK_KHR_video_queue

Name String
  VK_KHR_video_queue

Extension Type
  Device extension

Registered Extension Number
  24

Revision
  8

Ratification Status
  Ratified

Extension and Version Dependencies
  Version 1.1
  and
  VK_KHR_synchronization2

Contact
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Extension Proposal
  VK_KHR_video_queue

Other Extension Metadata

Last Modified Date
  2022-09-29

IP Status
  No known IP claims.

Contributors
  • Ahmed Abdelkhalek, AMD
  • George Hao, AMD
Description

This extension provides common APIs to enable exposing queue families with support for video codec operations by introducing the following new object types and related functionalities:

- Video session objects that represent and maintain the state needed to perform video codec operations.
- Video session parameters objects that act as a container for codec specific parameters.

In addition, it also introduces query commands that allow applications to determine video coding related capabilities, and command buffer commands that enable recording video coding operations against a video session.

This extension is to be used in conjunction with other extensions that enable specific video coding operations.

New Object Types

- `VkVideoSessionKHR`
- `VkVideoSessionParametersKHR`

New Commands

- `vkBindVideoSessionMemoryKHR`
- `vkCmdBeginVideoCodingKHR`
- `vkCmdControlVideoCodingKHR`
- `vkCmdEndVideoCodingKHR`
- `vkCreateVideoSessionKHR`
- `vkCreateVideoSessionParametersKHR`
- `vkDestroyVideoSessionKHR`
- `vkDestroyVideoSessionParametersKHR`
- `vkGetPhysicalDeviceVideoCapabilitiesKHR`
- `vkGetPhysicalDeviceVideoFormatPropertiesKHR`
- `vkGetVideoSessionMemoryRequirementsKHR`
- `vkUpdateVideoSessionParametersKHR`
New Structures

- VkBindVideoSessionMemoryInfoKHR
- VkPhysicalDeviceVideoFormatInfoKHR
- VkVideoBeginCodingInfoKHR
- VkVideoCapabilitiesKHR
- VkVideoCodingControlInfoKHR
- VkVideoEndCodingInfoKHR
- VkVideoFormatPropertiesKHR
- VkVideoPictureResourceInfoKHR
- VkVideoReferenceSlotInfoKHR
- VkVideoSessionCreateInfoKHR
- VkVideoSessionMemoryRequirementsKHR
- VkVideoSessionParametersCreateInfoKHR
- VkVideoSessionParametersUpdateInfoKHR
- Extending VkPhysicalDeviceImageFormatInfo2, VkPhysicalDeviceVideoFormatInfoKHR, VkImageCreateInfo, VkBufferCreateInfo:
  - VkVideoProfileListInfoKHR
- Extending VkQueryPoolCreateInfo:
  - VkVideoProfileInfoKHR
- Extending VkQueueFamilyProperties2:
  - VkQueueFamilyQueryResultStatusPropertiesKHR
  - VkQueueFamilyVideoPropertiesKHR

New Enums

- VkQueryResultStatusKHR
- VkVideoCapabilityFlagBitsKHR
- VkVideoChromaSubsamplingFlagBitsKHR
- VkVideoCodecOperationFlagBitsKHR
- VkVideoCodingControlFlagBitsKHR
- VkVideoComponentBitDepthFlagBitsKHR
- VkVideoSessionCreateFlagBitsKHR

New Bitmasks

- VkVideoBeginCodingFlagsKHR
- VkVideoCapabilityFlagsKHR

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• VkVideoChromaSubsamplingFlagsKHR
• VkVideoCodecOperationFlagsKHR
• VkVideoCodingControlFlagsKHR
• VkVideoComponentBitDepthFlagsKHR
• VkVideoEndCodingFlagsKHR
• VkVideoSessionCreateFlagsKHR
• VkVideoSessionParametersCreateFlagsKHR

New Enum Constants

• VK_KHR_VIDEO_QUEUE_EXTENSION_NAME
• VK_KHR_VIDEO_QUEUE_SPEC_VERSION

Extending VkObjectType:
  ◦ VK_OBJECT_TYPE_VIDEO_SESSION_KHR
  ◦ VK_OBJECT_TYPE_VIDEO_SESSION_PARAMETERS_KHR

Extending VkQueryResultFlagBits:
  ◦ VK_QUERY_RESULT_WITH_STATUS_BIT_KHR

Extending VkQueryType:
  ◦ VK_QUERY_TYPE_RESULT_STATUS_ONLY_KHR

Extending VkResult:
  ◦ VK_ERROR_IMAGE_USAGE_NOT_SUPPORTED_KHR
  ◦ VK_ERROR_VIDEO_PICTURE_LAYOUT_NOT_SUPPORTED_KHR
  ◦ VK_ERROR_VIDEO_PROFILE_CODEC_NOT_SUPPORTED_KHR
  ◦ VK_ERROR_VIDEO_PROFILE_FORMAT_NOT_SUPPORTED_KHR
  ◦ VK_ERROR_VIDEO_PROFILE_OPERATION_NOT_SUPPORTED_KHR
  ◦ VK_ERROR_VIDEO_STD_VERSION_NOT_SUPPORTED_KHR

Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_BIND_VIDEO_SESSION_MEMORY_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VIDEO_FORMAT_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_QUEUE_FAMILY_QUERY_RESULT_STATUS_PROPERTIES_KHR
  ◦ VK_STRUCTURE_TYPE_QUEUE_FAMILY_VIDEO_PROPERTIES_KHR
  ◦ VK_STRUCTURE_TYPE_VIDEO_BEGIN_CODING_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_VIDEO_CAPABILITIES_KHR
  ◦ VK_STRUCTURE_TYPE_VIDEO_CODING_CONTROL_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_VIDEO_END_CODING_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_VIDEO_FORMAT_PROPERTIES_KHR

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• VK_STRUCTURE_TYPE_VIDEO_PICTURE_RESOURCE_INFO_KHR
• VK_STRUCTURE_TYPE_VIDEO_PROFILE_INFO_KHR
• VK_STRUCTURE_TYPE_VIDEO_PROFILE_LIST_INFO_KHR
• VK_STRUCTURE_TYPE_VIDEO_REFERENCE_SLOT_INFO_KHR
• VK_STRUCTURE_TYPE_VIDEO_SESSION_CREATE_INFO_KHR
• VK_STRUCTURE_TYPE_VIDEO_SESSION_MEMORY_REQUIREMENTS_KHR
• VK_STRUCTURE_TYPE_VIDEO_SESSION_PARAMETERS_CREATE_INFO_KHR
• VK_STRUCTURE_TYPE_VIDEO_SESSION_PARAMETERS_UPDATE_INFO_KHR

Version History

• Revision 0.1, 2019-11-21 (Tony Zlatinski)
  ◦ Initial draft

• Revision 0.2, 2019-11-27 (Tony Zlatinski)
  ◦ Make vulkan video core common between decode and encode

• Revision 1, March 29 2021 (Tony Zlatinski)
  ◦ Spec and API updates.

• Revision 2, August 1 2021 (Srinath Kumarapuram)
  ◦ Rename VkVideoCapabilitiesFlagBitsKHR to VkVideoCapabilityFlagBitsKHR (along with the names of enumerants it defines) and VkVideoCapabilitiesFlagsKHR to VkVideoCapabilityFlagsKHR, following Vulkan naming conventions.

• Revision 3, 2022-03-16 (Ahmed Abdelkhalek)
  ◦ Relocate Std header version reporting/requesting from codec-operation specific extensions to this extension.
  ◦ Make Std header versions codec-operation specific instead of only codec-specific.

• Revision 4, 2022-05-30 (Daniel Rakos)
  ◦ Refactor the video format query APIs and related language
  ◦ Extend VkResult with video-specific error codes

• Revision 5, 2022-08-11 (Daniel Rakos)
  ◦ Add VkVideoSessionParametersCreateFlagsKHR
  ◦ Remove VkVideoCodingQualityPresetFlagsKHR
  ◦ Rename VkQueueFamilyQueryResultStatusProperties2KHR to VkQueueFamilyQueryResultStatusPropertiesKHR
  ◦ Rename VkVideoQueueFamilyProperties2KHR to VkQueueFamilyVideoPropertiesKHR
  ◦ Rename VkVideoProfileKHR to VkVideoProfileInfoKHR
  ◦ Rename VkVideoProfilesKHR to VkVideoProfileListInfoKHR
  ◦ Rename VkVideoGetMemoryPropertiesKHR to VkVideoSessionMemoryRequirementsKHR
Rename VkVideoBindMemoryKHR to VkBindVideoSessionMemoryInfoKHR

Fix pNext constness of VkPhysicalDeviceVideoFormatInfoKHR and VkVideoSessionMemoryRequirementsKHR

Fix incorrectly named value enums in bit enum types VkVideoCodecOperationFlagBitsKHR and VkVideoChromaSubsamplingFlagBitsKHR

Remove unnecessary default values from VkVideoSessionCreateFlagBitsKHR and VkVideoCodingControlFlagBitsKHR

Eliminate nested pointer in VkVideoSessionMemoryRequirementsKHR

Rename VkVideoPictureResourceKHR to VkVideoPictureResourceInfoKHR

Rename VkVideoReferenceSlotKHR to VkVideoReferenceSlotInfoKHR

• Revision 6, 2022-09-18 (Daniel Rakos)
  • Rename the maxReferencePicturesSlotsCount and maxReferencePicturesActiveCount fields of VkVideoCapabilitiesKHR and VkVideoSessionCreateInfoKHR to maxDpbSlots and maxActiveReferencePictures, respectively, to clarify their meaning
  • Rename capabilityFlags to flags in VkVideoCapabilitiesKHR
  • Rename videoPictureExtentGranularity to pictureAccessGranularity in VkVideoCapabilitiesKHR
  • Rename minExtent and maxExtent to minCodedExtent and maxCodedExtent, respectively, in VkVideoCapabilitiesKHR
  • Rename referencePicturesFormat to referencePictureFormat in VkVideoSessionCreateInfoKHR

• Revision 7, 2022-09-26 (Daniel Rakos)
  • Change type of VkVideoReferenceSlotInfoKHR::slotIndex from int8_t to int32_t

• Revision 8, 2022-09-29 (Daniel Rakos)
  • Extension is no longer provisional

**VK_KHR_wayland_surface**

**Name String**

   VK_KHR_wayland_surface

**Extension Type**

   Instance extension

**Registered Extension Number**

   7

**Revision**

   6

**Ratification Status**

   Ratified
Extension and Version Dependencies
VK_KHR_surface

Contact
• Jesse Hall @critsec
• Ian Elliott @ianelliottus

Other Extension Metadata

Last Modified Date
2015-11-28

IP Status
No known IP claims.

Contributors
• Patrick Doane, Blizzard
• Faith Ekstrand, Intel
• Ian Elliott, LunarG
• Courtney Goeltzenleuchter, LunarG
• Jesse Hall, Google
• James Jones, NVIDIA
• Antoine Labour, Google
• Jon Leech, Khronos
• David Mao, AMD
• Norbert Nopper, Freescale
• Alon Or-bach, Samsung
• Daniel Rakos, AMD
• Graham Sellers, AMD
• Ray Smith, ARM
• Jeff Vigil, Qualcomm
• Chia-I Wu, LunarG

Description
The VK_KHR_wayland_surface extension is an instance extension. It provides a mechanism to create a VkSurfaceKHR object (defined by the VK_KHR_surface extension) that refers to a Wayland wl_surface, as well as a query to determine support for rendering to a Wayland compositor.
New Commands

- vkCreateWaylandSurfaceKHR
- vkGetPhysicalDeviceWaylandPresentationSupportKHR

New Structures

- VkWaylandSurfaceCreateInfoKHR

New Bitmasks

- VkWaylandSurfaceCreateFlagsKHR

New Enum Constants

- VK_KHR_WAYLAND_SURFACE_EXTENSION_NAME
- VK_KHR_WAYLAND_SURFACE_SPEC_VERSION

Extending VkStructureType:

- VK_STRUCTURE_TYPE_WAYLAND_SURFACE_CREATE_INFO_KHR

Issues

1) Does Wayland need a way to query for compatibility between a particular physical device and a specific Wayland display? This would be a more general query than vkGetPhysicalDeviceSurfaceSupportKHR: if the Wayland-specific query returned VK_TRUE for a (VkPhysicalDevice, struct wl_display*) pair, then the physical device could be assumed to support presentation to any VkSurfaceKHR for surfaces on the display.

RESOLVED: Yes. vkGetPhysicalDeviceWaylandPresentationSupportKHR was added to address this issue.

2) Should we require surfaces created with vkCreateWaylandSurfaceKHR to support the VK_PRESENT_MODE_MAILBOX_KHR present mode?

RESOLVED: Yes. Wayland is an inherently mailbox window system and mailbox support is required for some Wayland compositor interactions to work as expected. While handling these interactions may be possible with VK_PRESENT_MODE_FIFO_KHR, it is much more difficult to do without deadlock and requiring all Wayland applications to be able to support implementations which only support VK_PRESENT_MODE_FIFO_KHR would be an onerous restriction on application developers.

Version History

- Revision 1, 2015-09-23 (Jesse Hall)
  ◦ Initial draft, based on the previous contents of VK_EXT_KHR_swapchain (later renamed VK_EXT_KHR_surface).
- Revision 2, 2015-10-02 (James Jones)
- Added vkGetPhysicalDeviceWaylandPresentationSupportKHR() to resolve issue #1.
- Adjusted wording of issue #1 to match the agreed-upon solution.
- Renamed “window” parameters to “surface” to match Wayland conventions.

- Revision 3, 2015-10-26 (Ian Elliott)
  - Renamed from VK_EXT_KHR_wayland_surface to VK_KHR_wayland_surface.

- Revision 4, 2015-11-03 (Daniel Rakos)
  - Added allocation callbacks to vkCreateWaylandSurfaceKHR.

- Revision 5, 2015-11-28 (Daniel Rakos)
  - Updated the surface create function to take a pCreateInfo structure.

- Revision 6, 2017-02-08 (Faith Ekstrand)
  - Added the requirement that implementations support VK_PRESENT_MODE_MAILBOX_KHR.
  - Added wording about interactions between vkQueuePresentKHR and the Wayland requests sent to the compositor.

**VK_KHR_win32_keyed_mutex**

**Name String**

VK_KHR_win32_keyed_mutex

**Extension Type**

Device extension

**Registered Extension Number**

76

**Revision**

1

**Ratification Status**

Ratified

**Extension and Version Dependencies**

VK_KHR_external_memory_win32

**Contact**

- Carsten Rohde crohde

**Other Extension Metadata**

**Last Modified Date**

2016-10-21

**IP Status**

No known IP claims.
Contributors

- James Jones, NVIDIA
- Jeff Juliano, NVIDIA
- Carsten Rohde, NVIDIA

Description

Applications that wish to import Direct3D 11 memory objects into the Vulkan API may wish to use the native keyed mutex mechanism to synchronize access to the memory between Vulkan and Direct3D. This extension provides a way for an application to access the keyed mutex associated with an imported Vulkan memory object when submitting command buffers to a queue.

New Structures

- Extending VkSubmitInfo, VkSubmitInfo2:
  - VkWin32KeyedMutexAcquireReleaseInfoKHR

New Enum Constants

- VK_KHR_WIN32_KEYED_MUTEX_EXTENSION_NAME
- VK_KHR_WIN32_KEYED_MUTEX_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_WIN32_KEYED_MUTEX_ACQUIRE_RELEASE_INFO_KHR

Version History

- Revision 1, 2016-10-21 (James Jones)
  - Initial revision

VK_KHR_win32_surface

Name String

VK_KHR_win32_surface

Extension Type

Instance extension

Registered Extension Number

10

Revision

6

Ratification Status

Ratified
Extension and Version Dependencies

VK_KHR_surface

Contact

- Jesse Hall (critsec)
- Ian Elliott (ianelliottus)

Other Extension Metadata

Last Modified Date

2017-04-24

IP Status

No known IP claims.

Contributors

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- Faith Ekstrand, Intel
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- Jesse Hall, Google
- James Jones, NVIDIA
- Antoine Labour, Google
- Jon Leech, Khronos
- David Mao, AMD
- Norbert Nopper, Freescale
- Alon Or-bach, Samsung
- Daniel Rakos, AMD
- Graham Sellers, AMD
- Ray Smith, ARM
- Jeff Vigil, Qualcomm
- Chia-I Wu, LunarG

Description

The VK_KHR_win32_surface extension is an instance extension. It provides a mechanism to create a VkSurfaceKHR object (defined by the VK_KHR_surface extension) that refers to a Win32 HWND, as well as a query to determine support for rendering to the windows desktop.
New Commands

- `vkCreateWin32SurfaceKHR`
- `vkGetPhysicalDeviceWin32PresentationSupportKHR`

New Structures

- `VkWin32SurfaceCreateInfoKHR`

New Bitmasks

- `VkWin32SurfaceCreateFlagsKHR`

New Enum Constants

- `VK_KHR_WIN32_SURFACE_EXTENSION_NAME`
- `VK_KHR_WIN32_SURFACE_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_WIN32_SURFACE_CREATE_INFO_KHR`

Issues

1) Does Win32 need a way to query for compatibility between a particular physical device and a specific screen? Compatibility between a physical device and a window generally only depends on what screen the window is on. However, there is not an obvious way to identify a screen without already having a window on the screen.

RESOLVED: No. While it may be useful, there is not a clear way to do this on Win32. However, a method was added to query support for presenting to the windows desktop as a whole.

2) If a native window object (HWND) is used by one graphics API, and then is later used by a different graphics API (one of which is Vulkan), can these uses interfere with each other?

RESOLVED: Yes.

Uses of a window object by multiple graphics APIs results in undefined behavior. Such behavior may succeed when using one Vulkan implementation but fail when using a different Vulkan implementation. Potential failures include:

- Creating then destroying a flip presentation model DXGI swapchain on a window object can prevent `vkCreateSwapchainKHR` from succeeding on the same window object.
- Creating then destroying a `VkSwapchainKHR` on a window object can prevent creation of a bitblt model DXGI swapchain on the same window object.
- Creating then destroying a `VkSwapchainKHR` on a window object can effectively `SetPixelFormat` to a different format than the format chosen by an OpenGL application.
- Creating then destroying a `VkSwapchainKHR` on a window object on one `VkPhysicalDevice` can prevent `vkCreateSwapchainKHR` from succeeding on the same window object, but on a
different \texttt{VkPhysicalDevice} that is associated with a different Vulkan ICD.

In all cases the problem can be worked around by creating a new window object.

Technical details include:

- Creating a DXGI swapchain over a window object can alter the object for the remainder of its lifetime. The alteration persists even after the DXGI swapchain has been destroyed. This alteration can make it impossible for a conformant Vulkan implementation to create a \texttt{VkSwapchainKHR} over the same window object. Mention of this alteration can be found in the remarks section of the MSDN documentation for \texttt{DXGI\_SWAP\_EFFECT}.

- Calling GDI's \texttt{SetPixelFormat} (needed by OpenGL's WGL layer) on a window object alters the object for the remainder of its lifetime. The MSDN documentation for \texttt{SetPixelFormat} explains that a window object's pixel format can be set only one time.

- Creating a \texttt{VkSwapchainKHR} over a window object can alter the object for its remaining lifetime. Either of the above alterations may occur as a side effect of \texttt{vkCreateSwapchainKHR}.

**Version History**

- Revision 1, 2015-09-23 (Jesse Hall)
  - Initial draft, based on the previous contents of VK\_EXT\_KHR\_swapchain (later renamed VK\_EXT\_KHR\_surface).

- Revision 2, 2015-10-02 (James Jones)
  - Added presentation support query for win32 desktops.

- Revision 3, 2015-10-26 (Ian Elliott)
  - Renamed from VK\_EXT\_KHR\_win32\_surface to VK\_KHR\_win32\_surface.

- Revision 4, 2015-11-03 (Daniel Rakos)
  - Added allocation callbacks to \texttt{vkCreateWin32SurfaceKHR}.

- Revision 5, 2015-11-28 (Daniel Rakos)
  - Updated the surface create function to take a \texttt{pCreateInfo} structure.

- Revision 6, 2017-04-24 (Jeff Juliano)
  - Add issue 2 addressing reuse of a native window object in a different Graphics API, or by a different Vulkan ICD.

**VK\_KHR\_workgroup\_memory\_explicit\_layout**

**Name String**

\texttt{VK\_KHR\_workgroup\_memory\_explicit\_layout}

**Extension Type**

Device extension
Registered Extension Number
337

Revision
1

Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2

Contact
• Caio Marcelo de Oliveira Filho cmarcelo

Other Extension Metadata

Last Modified Date
2020-06-01

IP Status
No known IP claims.

Interactions and External Dependencies
• This extension requires SPV_KHR_workgroup_memory_explicit_layout
• This extension provides API support for GL_EXT_shared_memory_block

Contributors
• Caio Marcelo de Oliveira Filho, Intel
• Jeff Bolz, NVIDIA
• Graeme Leese, Broadcom
• Faith Ekstrand, Intel
• Daniel Koch, NVIDIA

Description
This extension adds Vulkan support for the SPV_KHR_workgroup_memory_explicit_layout SPIR-V extension, which allows shaders to explicitly define the layout of Workgroup storage class memory and create aliases between variables from that storage class in a compute shader.

The aliasing feature allows different “views” on the same data, so the shader can bulk copy data from another storage class using one type (e.g. an array of large vectors), and then use the data with a more specific type. It also enables reducing the amount of workgroup memory consumed by allowing the shader to alias data whose lifetimes do not overlap.

The explicit layout support and some form of aliasing is also required for layering OpenCL on top of Vulkan.
New Structures

- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDeviceWorkgroupMemoryExplicitLayoutFeaturesKHR`

New Enum Constants

- `VK_KHR_WORKGROUP_MEMORY_EXPLICIT_LAYOUT_EXTENSION_NAME`
- `VK_KHR_WORKGROUP_MEMORY_EXPLICIT_LAYOUT_SPEC_VERSION`

- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_WORKGROUP_MEMORY_EXPLICIT_LAYOUT_FEATURES_KHR`

New SPIR-V Capabilities

- `WorkgroupMemoryExplicitLayoutKHR`
- `WorkgroupMemoryExplicitLayout8BitAccessKHR`
- `WorkgroupMemoryExplicitLayout16BitAccessKHR`

Version History

- Revision 1, 2020-06-01 (Caio Marcelo de Oliveira Filho)
  - Initial version

**VK_KHR xcb_surface**

Name String

- `VK_KHR xcb_surface`

Extension Type

- Instance extension

Registered Extension Number

- 6

Revision

- 6

Ratification Status

- Ratified

Extension and Version Dependencies

- `VK_KHR_surface`

Contact

- Jesse Hall [critsec](https://real-people.com/InTheRealWorld/4186)
Other Extension Metadata

Last Modified Date
2015-11-28

IP Status
No known IP claims.

Contributors
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• Jesse Hall, Google
• James Jones, NVIDIA
• Antoine Labour, Google
• Jon Leech, Khronos
• David Mao, AMD
• Norbert Nopper, Freescale
• Alon Or-bach, Samsung
• Daniel Rakos, AMD
• Graham Sellers, AMD
• Ray Smith, ARM
• Jeff Vigil, Qualcomm
• Chia-I Wu, LunarG

Description
The `VK_KHR_xcb_surface` extension is an instance extension. It provides a mechanism to create a `VkSurfaceKHR` object (defined by the `VK_KHR_surface` extension) that refers to an X11 Window, using the XCB client-side library, as well as a query to determine support for rendering via XCB.

New Commands
• `vkCreateXcbSurfaceKHR`
• `vkGetPhysicalDeviceXcbPresentationSupportKHR`

New Structures
• `VkXcbSurfaceCreateInfoKHR`
New Bitmasks

- VkXcbSurfaceCreateFlagsKHR

New Enum Constants

- VK_KHR_XCB_SURFACE_EXTENSION_NAME
- VK_KHR_XCB_SURFACE_SPEC_VERSION

Extending VkStructureType:
  - VK_STRUCTURE_TYPE_XCB_SURFACE_CREATE_INFO_KHR

Issues

1) Does XCB need a way to query for compatibility between a particular physical device and a specific screen? This would be a more general query than `vkGetPhysicalDeviceSurfaceSupportKHR`: If it returned `VK_TRUE`, then the physical device could be assumed to support presentation to any window on that screen.

**RESOLVED**: Yes, this is needed for toolkits that want to create a `VkDevice` before creating a window. To ensure the query is reliable, it must be made against a particular X visual rather than the screen in general.

Version History

- Revision 1, 2015-09-23 (Jesse Hall)
  - Initial draft, based on the previous contents of VK_EXT_KHR_swapchain (later renamed VK_EXT_KHR_surface).
- Revision 2, 2015-10-02 (James Jones)
  - Added presentation support query for an (xcb_connection_t*, xcb_visualid_t) pair.
  - Removed “root” parameter from CreateXcbSurfaceKHR(), as it is redundant when a window on the same screen is specified as well.
  - Adjusted wording of issue #1 and added agreed upon resolution.
- Revision 3, 2015-10-14 (Ian Elliott)
  - Removed “root” parameter from CreateXcbSurfaceKHR() in one more place.
- Revision 4, 2015-10-26 (Ian Elliott)
  - Renamed from VK_EXT_KHR_xcb_surface to VK_KHR_xcb_surface.
- Revision 5, 2015-10-23 (Daniel Rakos)
  - Added allocation callbacks to vkCreateXcbSurfaceKHR.
- Revision 6, 2015-11-28 (Daniel Rakos)
  - Updated the surface create function to take a pCreateInfo structure.
VK_KHR_xlib_surface

Name String
VK_KHR_xlib_surface

Extension Type
Instance extension

Registered Extension Number
5

Revision
6

Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_surface

Contact
• Jesse Hall ◌critsec
• Ian Elliott ◌ianelliottus

Other Extension Metadata

Last Modified Date
2015-11-28

IP Status
No known IP claims.

Contributors
• Patrick Doane, Blizzard
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• Ian Elliott, LunarG
• Courtney Goeltzenleuchter, LunarG
• Jesse Hall, Google
• James Jones, NVIDIA
• Antoine Labour, Google
• Jon Leech, Khronos
• David Mao, AMD
• Norbert Nopper, Freescale
• Alon Or-bach, Samsung
The **VK_KHR_xlib_surface** extension is an instance extension. It provides a mechanism to create a `VkSurfaceKHR` object (defined by the **VK_KHR_surface** extension) that refers to an X11 Window, using the Xlib client-side library, as well as a query to determine support for rendering via Xlib.

**New Commands**

- `vkCreateXlibSurfaceKHR`
- `vkGetPhysicalDeviceXlibPresentationSupportKHR`

**New Structures**

- `VkXlibSurfaceCreateInfoKHR`

**New Bitmasks**

- `VkXlibSurfaceCreateFlagsKHR`

**New Enum Constants**

- `VK_KHR_XLIB_SURFACE_EXTENSION_NAME`
- `VK_KHR_XLIB_SURFACE_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_XLIB_SURFACE_CREATE_INFO_KHR`

**Issues**

1) Does X11 need a way to query for compatibility between a particular physical device and a specific screen? This would be a more general query than `vkGetPhysicalDeviceSurfaceSupportKHR`; if it returned `VK_TRUE`, then the physical device could be assumed to support presentation to any window on that screen.

**RESOLVED**: Yes, this is needed for toolkits that want to create a `VkDevice` before creating a window. To ensure the query is reliable, it must be made against a particular X visual rather than the screen in general.
**Version History**

- Revision 1, 2015-09-23 (Jesse Hall)
  - Initial draft, based on the previous contents of VK_EXT_KHR_swapchain (later renamed VK_EXT_KHR_surface).

- Revision 2, 2015-10-02 (James Jones)
  - Added presentation support query for (Display*, VisualID) pair.
  - Removed “root” parameter from CreateXlibSurfaceKHR(), as it is redundant when a window on the same screen is specified as well.
  - Added appropriate X errors.
  - Adjusted wording of issue #1 and added agreed upon resolution.

- Revision 3, 2015-10-14 (Ian Elliott)
  - Renamed this extension from VK_EXT_KHR_x11_surface to VK_EXT_KHR_xlib_surface.

- Revision 4, 2015-10-26 (Ian Elliott)
  - Renamed from VK_EXT_KHR_xlib_surface to VK_KHR_xlib_surface.

- Revision 5, 2015-11-03 (Daniel Rakos)
  - Added allocation callbacks to vkCreateXlibSurfaceKHR.

- Revision 6, 2015-11-28 (Daniel Rakos)
  - Updated the surface create function to take a pCreateInfo structure.

**VK_EXT_acquire_drm_display**

**Name String**

VK_EXT_acquire_drm_display

**Extension Type**

Instance extension

**Registered Extension Number**

286

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

VK_EXT_direct_mode_display

**Contact**

- Drew DeVault sir@cmpwn.com
Other Extension Metadata

Last Modified Date
2021-06-09

IP Status
No known IP claims.

Contributors
• Simon Zeni, Status Holdings, Ltd.

Description
This extension allows an application to take exclusive control of a display using the Direct Rendering Manager (DRM) interface. When acquired, the display will be under full control of the application until the display is either released or the connector is unplugged.

New Commands
• vkAcquireDrmDisplayEXT
• vkGetDrmDisplayEXT

New Enum Constants
• VK_EXT_ACQUIRE_DRM_DISPLAY_EXTENSION_NAME
• VK_EXT_ACQUIRE_DRM_DISPLAY_SPEC_VERSION

Issues
None.

Version History
• Revision 1, 2021-05-11 (Simon Zeni)
  ◦ Initial draft

VK_EXT_acquire_xlib_display

Name String
VK_EXT_acquire_xlib_display

Extension Type
Instance extension

Registered Extension Number
90
Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_EXT_direct_mode_display

Contact

• James Jones cubanismo

Other Extension Metadata

Last Modified Date

2016-12-13

IP Status

No known IP claims.

Contributors

• Dave Airlie, Red Hat
• Pierre Boudier, NVIDIA
• James Jones, NVIDIA
• Damien Leone, NVIDIA
• Pierre-Loup Griffais, Valve
• Liam Middlebrook, NVIDIA
• Daniel Vetter, Intel

Description

This extension allows an application to take exclusive control on a display currently associated with an X11 screen. When control is acquired, the display will be deassociated from the X11 screen until control is released or the specified display connection is closed. Essentially, the X11 screen will behave as if the monitor has been unplugged until control is released.

New Commands

• vkAcquireXlibDisplayEXT
• vkGetRandROutputDisplayEXT

New Enum Constants

• VK_EXT_ACQUIRE_XLIB_DISPLAY_EXTENSION_NAME
• VK_EXT_ACQUIRE_XLIB_DISPLAY_SPEC_VERSION
Issues

1) Should `vkAcquireXlibDisplayEXT` take an RandR display ID, or a Vulkan display handle as input?

**RESOLVED:** A Vulkan display handle. Otherwise there would be no way to specify handles to displays that had been prevented from being included in the X11 display list by some native platform or vendor-specific mechanism.

2) How does an application figure out which RandR display corresponds to a Vulkan display?

**RESOLVED:** A new function, `vkGetRandROutputDisplayEXT`, is introduced for this purpose.

3) Should `vkGetRandROutputDisplayEXT` be part of this extension, or a general Vulkan / RandR or Vulkan / Xlib extension?

**RESOLVED:** To avoid yet another extension, include it in this extension.

Version History

- Revision 1, 2016-12-13 (James Jones)
  - Initial draft

VK_EXT_astc_decode_mode

**Name String**

`VK_EXT_astc_decode_mode`

**Extension Type**

Device extension

**Registered Extension Number**

68

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

- `VK_KHR_get_physical_device_properties2`
- or
- Version 1.1

**Contact**

- Jan-Harald Fredriksen 🌐janharaldfredriksen-arm
Other Extension Metadata

Last Modified Date
2018-08-07

Contributors
- Jan-Harald Fredriksen, Arm

Description

The existing specification requires that low dynamic range (LDR) ASTC textures are decompressed to FP16 values per component. In many cases, decompressing LDR textures to a lower precision intermediate result gives acceptable image quality. Source material for LDR textures is typically authored as 8-bit UNORM values, so decoding to FP16 values adds little value. On the other hand, reducing precision of the decoded result reduces the size of the decompressed data, potentially improving texture cache performance and saving power.

The goal of this extension is to enable this efficiency gain on existing ASTC texture data. This is achieved by giving the application the ability to select the intermediate decoding precision.

Three decoding options are provided:

- Decoding to `VK_FORMAT_R16G16B16A16_SFLOAT` precision: This is the default, and matches the required behavior in the core API.
- Decoding to `VK_FORMAT_R8G8B8A8_UNORM` precision: This is provided as an option in LDR mode.
- Decoding to `VK_FORMAT_E5B9G9R9_UFLOAT_PACK32` precision: This is provided as an option in both LDR and HDR mode. In this mode, negative values cannot be represented and are clamped to zero. The alpha component is ignored, and the results are as if alpha was 1.0. This decode mode is optional and support can be queried via the physical device properties.

New Structures

- Extending `VkImageViewCreateInfo`:
  - `VkImageViewASTCDecodeModeEXT`
- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceASTCDecodeFeaturesEXT`

New Enum Constants

- `VK_EXT_ASTC_DECODE_MODE_EXTENSION_NAME`
- `VK_EXT_ASTC_DECODE_MODE_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_IMAGE_VIEW_ASTC_DECODE_MODE_EXT`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ASTC_DECODE_FEATURES_EXT`
**Issues**

1) Are implementations allowed to decode at a higher precision than what is requested?

**RESOLUTION:** No.

If we allow this, then this extension could be exposed on all implementations that support ASTC. But developers would have no way of knowing what precision was actually used, and thus whether the image quality is sufficient at reduced precision.

2) Should the decode mode be image view state and/or sampler state?

**RESOLUTION:** Image view state only.

Some implementations treat the different decode modes as different texture formats.

**Example**

Create an image view that decodes to `VK_FORMAT_R8G8B8A8_UNORM` precision:

```c
VkImageViewASTCDecodeModeEXT decodeMode = {
    .sType = VK_STRUCTURE_TYPE_IMAGE_VIEW_ASTC_DECODE_MODE_EXT,
    .pNext = NULL,
    .decodeMode = VK_FORMAT_R8G8B8A8_UNORM
};

VkImageViewCreateInfo createInfo = {
    .sType = VK_STRUCTURE_TYPE_IMAGE_VIEW_CREATE_INFO,
    .pNext = &decodeMode,
    // flags, image, viewType set to application-desired values
    .format = VK_FORMAT_ASTC_8x8_UNORM_BLOCK,
    // components, subresourceRange set to application-desired values
};

VkImageView imageView;
VkResult result = vkCreateImageView( device,
    &createInfo,
    NULL,
    &imageView);
```

**Version History**

- Revision 1, 2018-08-07 (Jan-Harald Fredriksen)
VK_EXT_attachment_feedback_loop_dynamic_state

Name String
VK_EXT_attachment_feedback_loop_dynamic_state

Extension Type
Device extension

Registered Extension Number
525

Revision
1

Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2
and
VK_EXT_attachment_feedback_loop_layout

Contact
- Mike Blumenkrantz zmike

Extension Proposal
VK_EXT_attachment_feedback_loop_dynamic_state

Other Extension Metadata

Last Modified Date
2023-04-28

IP Status
No known IP claims.

Contributors
- Mike Blumenkrantz, Valve
- Daniel Story, Nintendo
- Stu Smith, AMD
- Samuel Pitoiset, Valve
- Ricardo Garcia, Igalia
Description

This extension adds support for setting attachment feedback loops dynamically on command buffers.

New Commands

• `vkCmdSetAttachmentFeedbackLoopEnableEXT`

New Structures

• Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  ◦ `VkPhysicalDeviceAttachmentFeedbackLoopDynamicStateFeaturesEXT`

New Enum Constants

• `VK_EXT_ATTACHMENT_FEEDBACK_LOOP_DYNAMIC_STATE_EXTENSION_NAME`
• `VK_EXT_ATTACHMENT_FEEDBACK_LOOP_DYNAMIC_STATE_SPEC_VERSION`
• Extending `VkDynamicState`:
  ◦ `VK_DYNAMIC_STATE_ATTACHMENT_FEEDBACK_LOOP_ENABLE_EXT`
• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ATTACHMENT_FEEDBACK_LOOP_DYNAMIC_STATE_FEATURES_EXT`

Version History

• Revision 1, 2023-04-28 (Mike Blumenkrantz)
  ◦ Initial revision

`VK_EXT_attachment_feedback_loop_layout`

Name String

`VK_EXT_attachment_feedback_loop_layout`

Extension Type

Device extension

Registered Extension Number

340

Revision

2

Ratification Status

Not ratified
Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Contact

• Joshua AshtonJoshua-Ashton

Extension Proposal

VK_EXT_attachment_feedback_loop_layout

Other Extension Metadata

Last Modified Date

2022-04-04

IP Status

No known IP claims.

Contributors

• Joshua Ashton, Valve
• Faith Ekstrand, Collabora
• Bas Nieuwenhuizen, Google
• Samuel Iglesias Gonsálvez, Igalia
• Ralph Potter, Samsung
• Jan-Harald Fredriksen, Arm
• Ricardo Garcia, Igalia

Description

This extension adds a new image layout, VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT, which allows applications to have an image layout in which they are able to both render to and sample/fetch from the same subresource of an image in a given render pass.

New Structures

• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceAttachmentFeedbackLoopLayoutFeaturesEXT

New Enum Constants

• VK_EXT_ATTACHMENT_FEEDBACK_LOOP_LAYOUT_EXTENSION_NAME
• VK_EXT_ATTACHMENT_FEEDBACK_LOOP_LAYOUT_SPEC_VERSION
• Extending VkDependencyFlagBits:
  ◦ VK_DEPENDENCY_FEEDBACK_LOOP_BIT_EXT
• Extending VkImageLayout:
• **VK_IMAGE_LAYOUT_ATTACHMENT_FEEDBACK_LOOP_OPTIMAL_EXT**

• **Extending VkImageUsageFlagBits:**
  - **VK_IMAGE_USAGE_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT**

• **Extending VkPipelineCreateFlagBits:**
  - **VK_PIPELINE_CREATE_COLOR_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT**
  - **VK_PIPELINE_CREATE_DEPTH_STENCIL_ATTACHMENT_FEEDBACK_LOOP_BIT_EXT**

• **Extending VkStructureType:**
  - **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ATTACHMENT_FEEDBACK_LOOP_LAYOUT_FEATURES_EXT**

### Version History

- **Revision 2, 2022-04-04 (Joshua Ashton):**
  - Renamed from VALVE to EXT.

- **Revision 1, 2021-03-09 (Joshua Ashton):**
  - Initial draft.

### VK_EXT_blend_operation_advanced

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### Extension and Version Dependencies

- **VK_KHR_get_physical_device_properties2**
  - or Version 1.1

### Contact

- Jeff Bolz [jeffbolznv](mailto:jeffbolznv)

### Other Extension Metadata
This extension adds a number of “advanced” blending operations that can be used to perform new color blending operations, many of which are more complex than the standard blend modes provided by unextended Vulkan. This extension requires different styles of usage, depending on the level of hardware support and the enabled features:

- If `VkPhysicalDeviceBlendOperationAdvancedFeaturesEXT::advancedBlendCoherentOperations` is `VK_FALSE`, the new blending operations are supported, but a memory dependency must separate each advanced blend operation on a given sample. `VK_ACCESS_COLOR_ATTACHMENT_READ_NONCOHERENT_BIT_EXT` is used to synchronize reads using advanced blend operations.

- If `VkPhysicalDeviceBlendOperationAdvancedFeaturesEXT::advancedBlendCoherentOperations` is `VK_TRUE`, advanced blend operations obey primitive order just like basic blend operations.

In unextended Vulkan, the set of blending operations is limited, and can be expressed very simply. The `VK_BLEND_OP_MIN` and `VK_BLEND_OP_MAX` blend operations simply compute component-wise minimums or maximums of source and destination color components. The `VK_BLEND_OP_ADD`, `VK_BLEND_OP_SUBTRACT`, and `VK_BLEND_OP_REVERSE_SUBTRACT` modes multiply the source and destination colors by source and destination factors and either add the two products together or subtract one from the other. This limited set of operations supports many common blending operations but precludes the use of more sophisticated transparency and blending operations commonly available in many dedicated imaging APIs.

This extension provides a number of new “advanced” blending operations. Unlike traditional blending operations using `VK_BLEND_OP_ADD`, these blending equations do not use source and destination factors specified by `VkBlendFactor`. Instead, each blend operation specifies a complete equation based on the source and destination colors. These new blend operations are used for both RGB and alpha components; they must not be used to perform separate RGB and alpha blending (via different values of color and alpha `VkBlendOp`).

These blending operations are performed using premultiplied colors, where RGB colors can be considered premultiplied or non-premultiplied by alpha, according to the `srcPremultiplied` and `dstPremultiplied` members of `VkPipelineColorBlendAdvancedStateCreateInfoEXT`. If a color is considered non-premultiplied, the (R,G,B) color components are multiplied by the alpha component prior to blending. For non-premultiplied color components in the range [0,1], the corresponding premultiplied color component would have values in the range [0 × A, 1 × A].

Many of these advanced blending equations are formulated where the result of blending source and destination colors with partial coverage have three separate contributions: from the portions covered by both the source and the destination, from the portion covered only by the source, and from the portion covered only by the destination. The blend parameter
VkPipelineColorBlendAdvancedStateCreateInfoEXT::blendOverlap can be used to specify a correlation between source and destination pixel coverage. If set to VK_BLEND_OVERLAP_CONJOINT_EXT, the source and destination are considered to have maximal overlap, as would be the case if drawing two objects on top of each other. If set to VK_BLEND_OVERLAP_DISJOINT_EXT, the source and destination are considered to have minimal overlap, as would be the case when rendering a complex polygon tessellated into individual non-intersecting triangles. If set to VK_BLEND_OVERLAP_UNCORRELATED_EXT, the source and destination coverage are assumed to have no spatial correlation within the pixel.

In addition to the coherency issues on implementations not supporting advancedBlendCoherentOperations, this extension has several limitations worth noting. First, the new blend operations have a limit on the number of color attachments they can be used with, as indicated by VkPhysicalDeviceBlendOperationAdvancedPropertiesEXT::advancedBlendMaxColorAttachments. Additionally, blending precision may be limited to 16-bit floating-point, which may result in a loss of precision and dynamic range for framebuffer formats with 32-bit floating-point components, and in a loss of precision for formats with 12- and 16-bit signed or unsigned normalized integer components.

### New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceBlendOperationAdvancedFeaturesEXT
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceBlendOperationAdvancedPropertiesEXT
- Extending VkPipelineColorBlendStateCreateInfo:
  - VkPipelineColorBlendAdvancedStateCreateInfoEXT

### New Enums

- VkBlendOverlapEXT

### New Enum Constants

- VK_EXT_BLEND_OPERATION_ADVANCED_EXTENSION_NAME
- VK_EXT_BLEND_OPERATION_ADVANCED_SPEC_VERSION
- Extending VkAccessFlagBits:
  - VK_ACCESS_COLOR_ATTACHMENT_READ_NONCOHERENT_BIT_EXT
- Extending VkBlendOp:
  - VK_BLEND_OP_BLUE_EXT
  - VK_BLEND_OP_COLORBURN_EXT
  - VK_BLEND_OP_COLORDODGE_EXT
  - VK_BLEND_OP_CONTRAST_EXT
  - VK_BLEND_OP_DARKEN_EXT

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VK_BLEND_OP_DIFFERENCE_EXT
VK_BLEND_OP_DST_ATOP_EXT
VK_BLEND_OP_DST_EXT
VK_BLEND_OP_DST_IN_EXT
VK_BLEND_OP_DST_OUT_EXT
VK_BLEND_OP_DST_OVER_EXT
VK_BLEND_OP_EXCLUSION_EXT
VK_BLEND_OP_GREEN_EXT
VK_BLEND_OP_HARDLIGHT_EXT
VK_BLEND_OP_HARDMIX_EXT
VK_BLEND_OP_HSL_COLOR_EXT
VK_BLEND_OP_HSL_HUE_EXT
VK_BLEND_OP_HSL_LUMINOSITY_EXT
VK_BLEND_OP_HSL_SATURATION_EXT
VK_BLEND_OP_INVERT_EXT
VK_BLEND_OP_INVERT_OVG_EXT
VK_BLEND_OP_INVERT_RGB_EXT
VK_BLEND_OP_LIGHTEN_EXT
VK_BLEND_OP_LINEARBURN_EXT
VK_BLEND_OP_LINEARDODGE_EXT
VK_BLEND_OP_LINEARLIGHT_EXT
VK_BLEND_OP_MINUS_CLAMPED_EXT
VK_BLEND_OP_MINUS_EXT
VK_BLEND_OP_MULTIPLY_EXT
VK_BLEND_OP_OVERLAY_EXT
VK_BLEND_OP_PINLIGHT_EXT
VK_BLEND_OP_PLUS_CLAMPED_ALPHA_EXT
VK_BLEND_OP_PLUS_CLAMPED_EXT
VK_BLEND_OP_PLUS_DARKER_EXT
VK_BLEND_OP_PLUS_EXT
VK_BLEND_OP_RED_EXT
VK_BLEND_OP_SCREEN_EXT
VK_BLEND_OP_SOFTLIGHT_EXT
VK_BLEND_OP_SRC_ATOP_EXT
VK_BLEND_OP_SRC_EXT
VK_BLEND_OP_SRC_IN_EXT
VK_BLEND_OP_SRC_OUT_EXT
VK_BLEND_OP_SRC_OVER_EXT
VK_BLEND_OP_VIVIDLIGHT_EXT
VK_BLEND_OP_XOR_EXT
VK_BLEND_OP_ZERO_EXT

Extending VkStructureType:

- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BLEND_OPERATION_ADVANCED_FEATURES_EXT
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BLEND_OPERATION_ADVANCED_PROPERTIES_EXT
- VK_STRUCTURE_TYPE_PIPELINE_COLOR_BLEND_ADVANCED_STATE_CREATE_INFO_EXT

Issues

None.

Version History

- Revision 1, 2017-06-12 (Jeff Bolz)
  - Internal revisions
- Revision 2, 2017-06-12 (Jeff Bolz)
  - Internal revisions

VK_EXT_border_color_swizzle

Name String

VK_EXT_border_color_swizzle

Extension Type

Device extension

Registered Extension Number

412

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

- VK_EXT_custom_border_color
**Special Uses**
- OpenGL / ES support
- D3D support

**Contact**
- Piers Daniell [pdaniell-nv](mailto:pdaniell-nv)

**Other Extension Metadata**

**Last Modified Date**
2021-10-12

**IP Status**
No known IP claims.

**Contributors**
- Graeme Leese, Broadcom
- Jan-Harald Fredriksen, Arm
- Ricardo Garcia, Igalia
- Shahbaz Youssefi, Google
- Stu Smith, AMD

**Description**

After the publication of VK_EXT_custom_border_color, it was discovered that some implementations had undefined behavior when combining a sampler that uses a custom border color with image views whose component mapping is not the identity mapping.

Since VK_EXT_custom_border_color has already shipped, this new extension VK_EXT_border_color_swizzle was created to define the interaction between custom border colors and non-identity image view swizzles, and provide a work-around for implementations that must pre-swizzle the sampler border color to match the image view component mapping it is combined with.

This extension also defines the behavior between samplers with an opaque black border color and image views with a non-identity component swizzle, which was previously left undefined.

**New Structures**

New Enum Constants

- VK_EXT_BORDER_COLOR_SWIZZLE_EXTENSION_NAME
- VK_EXT_BORDER_COLOR_SWIZZLE_SPEC_VERSION

Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BORDER_COLOR_SWIZZLE_FEATURES_EXT
  - VK_STRUCTURE_TYPE_SAMPLER_BORDER_COLOR_COMPONENT_MAPPING_CREATE_INFO_EXT

Issues

None.

Version History

- Revision 1, 2021-10-12 (Piers Daniell)
  - Internal revisions.

VK_EXT_calibrated_timestamps

Name String

VK_EXT_calibrated_timestamps

Extension Type

Device extension

Registered Extension Number

185

Revision

2

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2
  or
  Version 1.1

Contact

- Daniel Rakos drakos-amd

Extension Proposal

VK_EXT_calibrated_timestamps
Other Extension Metadata

Last Modified Date
2018-10-04

IP Status
No known IP claims.

Contributors
• Matthaeus G. Chajdas, AMD
• Alan Harrison, AMD
• Derrick Owens, AMD
• Daniel Rakos, AMD
• Faith Ekstrand, Intel
• Keith Packard, Valve

Description
This extension provides an interface to query calibrated timestamps obtained quasi simultaneously from two time domains.

New Commands

• `vkGetCalibratedTimestampsEXT`
• `vkGetPhysicalDeviceCalibrateableTimeDomainsEXT`

New Structures

• `VkCalibratedTimestampInfoEXT`

New Enums

• `VkTimeDomainEXT`

New Enum Constants

• `VK_EXT_CALIBRATED_TIMESTAMPS_EXTENSION_NAME`
• `VK_EXT_CALIBRATED_TIMESTAMPS_SPEC_VERSION`

Extending `VkStructureType`:

• `VK_STRUCTURE_TYPE_CALIBRATED_TIMESTAMP_INFO_EXT`

Version History

• Revision 2, 2021-03-16 (Lionel Landwerlin)
  ◦ Specify requirement on device timestamps
VK_EXT_color_write_enable

Name String
VK_EXT_color_write_enable

Extension Type
Device extension

Registered Extension Number
382

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2
or
Version 1.1

Contact
• Sharif Elcott selcott

Other Extension Metadata

Last Modified Date
2020-02-25

IP Status
No known IP claims.

Contributors
• Sharif Elcott, Google
• Tobias Hector, AMD
• Piers Daniell, NVIDIA

Description

This extension allows for selectively enabling and disabling writes to output color attachments via a pipeline dynamic state.

The intended use cases for this new state are mostly identical to those of colorWriteMask, such as
selectively disabling writes to avoid feedback loops between subpasses or bandwidth savings for unused outputs. By making the state dynamic, one additional benefit is the ability to reduce pipeline counts and pipeline switching via shaders that write a superset of the desired data of which subsets are selected dynamically. The reason for a new state, colorWriteEnable, rather than making colorWriteMask dynamic is that, on many implementations, the more flexible per-component semantics of the colorWriteMask state cannot be made dynamic in a performant manner.

**New Commands**

- `vkCmdSetColorWriteEnableEXT`

**New Structures**

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceColorWriteEnableFeaturesEXT`
- Extending `VkPipelineColorBlendStateCreateInfo`:
  - `VkPipelineColorWriteCreateInfoEXT`

**New Enum Constants**

- `VK_EXT_COLOR_WRITE_ENABLE_EXTENSION_NAME`
- `VK_EXT_COLOR_WRITE_ENABLE_SPEC_VERSION`
- Extending `VkDynamicState`:
  - `VK_DYNAMIC_STATE_COLOR_WRITE_ENABLE_EXT`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COLOR_WRITE_ENABLE_FEATURES_EXT`
  - `VK_STRUCTURE_TYPE_PIPELINE_COLOR_WRITE_CREATE_INFO_EXT`

**Version History**

- Revision 1, 2020-01-25 (Sharif Elcott)
  - Internal revisions

**VK_EXT_conditional_rendering**

**Name String**

```
VK_EXT_conditional_rendering
```

**Extension Type**

Device extension

**Registered Extension Number**

82
Description

This extension allows the execution of one or more rendering commands to be conditional on a value in buffer memory. This may help an application reduce the latency by conditionally discarding rendering commands without application intervention. The conditional rendering commands are limited to draws, compute dispatches and clearing attachments within a conditional rendering block.

New Commands

• `vkCmdBeginConditionalRenderingEXT`
• `vkCmdEndConditionalRenderingEXT`

New Structures

• `VkConditionalRenderingBeginInfoEXT`
• Extending `VkCommandBufferInheritanceInfo`:
New Enums

- VkConditionalRenderingFlagBitsEXT

New Bitmasks

- VkConditionalRenderingFlagsEXT

New Enum Constants

- VK_EXT_CONDITIONAL_RENDERING_EXTENSION_NAME
- VK_EXT_CONDITIONAL_RENDERING_SPEC_VERSION
- Extending VkAccessFlagBits:
  - VK_ACCESS_CONDITIONAL_RENDERING_READ_BIT_EXT
- Extending VkBufferUsageFlagBits:
  - VK_BUFFER_USAGE_CONDITIONAL_RENDERING_BIT_EXT
- Extending VkPipelineStageFlagBits:
  - VK_PIPELINE_STAGE_CONDITIONAL_RENDERING_BIT_EXT
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_CONDITIONAL_RENDERING_INFO_EXT
  - VK_STRUCTURE_TYPE_CONDITIONAL_RENDERING_BEGIN_INFO_EXT
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CONDITIONAL_RENDERING_FEATURES_EXT

Issues

1) Should conditional rendering affect copy and blit commands?

**RESOLVED**: Conditional rendering should not affect copies and blits.

2) Should secondary command buffers be allowed to execute while conditional rendering is active in the primary command buffer?

**RESOLVED**: The rendering commands in secondary command buffer will be affected by an active conditional rendering in primary command buffer if the `conditionalRenderingEnable` is set to VK_TRUE. Conditional rendering must not be active in the primary command buffer if `conditionalRenderingEnable` is VK_FALSE.

Examples

None.
Version History

- Revision 1, 2018-04-19 (Vikram Kushwaha)
  - First Version
- Revision 2, 2018-05-21 (Vikram Kushwaha)
  - Add new pipeline stage, access flags and limit conditional rendering to a subpass or entire render pass.

VK_EXT_conservative_rasterization

Name String
VK_EXT_conservative_rasterization

Extension Type
Device extension

Registered Extension Number
102

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2
or
Version 1.1

Contact
- Piers Daniell pdaniell-nv

Other Extension Metadata

Last Modified Date
2020-06-09

Interactions and External Dependencies

- This extension requires SPV_EXT_fragment_fully_covered if the VkPhysicalDeviceConservativeRasterizationPropertiesEXT::fullyCoveredFragmentShaderInputVariable feature is used.
- This extension requires SPV_KHR_post_depth_coverage if the VkPhysicalDeviceConservativeRasterizationPropertiesEXT::conservativeRasterizationPostDepthCoverage feature is used.
- This extension provides API support for GL_NV_conservative_raster_underestimation if the
VkPhysicalDeviceConservativeRasterizationPropertiesEXT::fullyCoveredFragmentShaderInputVariable feature is used.

Contributors
• Daniel Koch, NVIDIA
• Daniel Rakos, AMD
• Jeff Bolz, NVIDIA
• Slawomir Grajewski, Intel
• Stu Smith, Imagination Technologies

Description
This extension adds a new rasterization mode called conservative rasterization. There are two modes of conservative rasterization; overestimation and underestimation.

When overestimation is enabled, if any part of the primitive, including its edges, covers any part of the rectangular pixel area, including its sides, then a fragment is generated with all coverage samples turned on. This extension allows for some variation in implementations by accounting for differences in overestimation, where the generating primitive size is increased at each of its edges by some sub-pixel amount to further increase conservative pixel coverage. Implementations can allow the application to specify an extra overestimation beyond the base overestimation the implementation already does. It also allows implementations to either cull degenerate primitives or rasterize them.

When underestimation is enabled, fragments are only generated if the rectangular pixel area is fully covered by the generating primitive. If supported by the implementation, when a pixel rectangle is fully covered the fragment shader input variable builtin called FullyCoveredEXT is set to true. The shader variable works in either overestimation or underestimation mode.

Implementations can process degenerate triangles and lines by either discarding them or generating conservative fragments for them. Degenerate triangles are those that end up with zero area after the rasterizer quantizes them to the fixed-point pixel grid. Degenerate lines are those with zero length after quantization.

New Structures
• Extending VkPhysicalDeviceProperties2:
  ◦ VkPhysicalDeviceConservativeRasterizationPropertiesEXT
• Extending VkPipelineRasterizationStateCreateInfo:
  ◦ VkPipelineRasterizationConservativeStateCreateInfoEXT

New Enums
• VkConservativeRasterizationModeEXT
New Bitmasks

- VkPipelineRasterizationConservativeStateCreateFlagsEXT

New Enum Constants

- VK_EXT_CONSERVATIVE_RASTERIZATION_EXTENSION_NAME
- VK_EXT_CONSERVATIVE_RASTERIZATION_SPEC_VERSION

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CONSERVATIVE_RASTERIZATION_PROPERTIES_EXT
  - VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_CONSERVATIVE_STATE_CREATE_INFO_EXT

New Built-In Variables

- FullyCoveredEXT

New SPIR-V Capabilities

- FragmentFullyCoveredEXT

Version History

- Revision 1.1, 2020-09-06 (Piers Daniell)
  - Add missing SPIR-V and GLSL dependencies.
- Revision 1, 2017-08-28 (Piers Daniell)
  - Internal revisions

VK_EXT_custom_border_color

Name String

VK_EXT_custom_border_color

Extension Type

Device extension

Registered Extension Number

288

Revision

12

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2
Version 1.1

Special Uses
- OpenGL / ES support
- D3D support

Contact
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Other Extension Metadata

Last Modified Date
2020-04-16

IP Status
No known IP claims.

Contributors
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Description
This extension provides cross-vendor functionality to specify a custom border color for use when the sampler address mode `VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_BORDER` is used.

To create a sampler which uses a custom border color set `VkSamplerCreateInfo::borderColor` to one
of:

- VK_BORDER_COLOR_FLOAT_CUSTOM_EXT
- VK_BORDER_COLOR_INT_CUSTOM_EXT

When VK_BORDER_COLOR_FLOAT_CUSTOM_EXT or VK_BORDER_COLOR_INT_CUSTOM_EXT is used, applications must provide a VkSamplerCustomBorderColorCreateInfoEXT in the pNext chain for VkSamplerCreateInfo.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceCustomBorderColorFeaturesEXT
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceCustomBorderColorPropertiesEXT
- Extending VkSamplerCreateInfo:
  - VkSamplerCustomBorderColorCreateInfoEXT

New Enum Constants

- VK_EXT_CUSTOM_BORDER_COLOR_EXTENSION_NAME
- VK_EXT_CUSTOM_BORDER_COLOR_SPEC_VERSION
- Extending VkBorderColor:
  - VK_BORDER_COLOR_FLOAT_CUSTOM_EXT
  - VK_BORDER_COLOR_INT_CUSTOM_EXT
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CUSTOM_BORDER_COLOR_FEATURES_EXT
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CUSTOM_BORDER_COLOR_PROPERTIES_EXT
  - VK_STRUCTURE_TYPE_SAMPLER_CUSTOM_BORDER_COLOR_CREATE_INFO_EXT

Issues

1) Should VkClearColorValue be used for the border color value, or should we have our own struct/union? Do we need to specify the type of the input values for the components? This is more of a concern if VkClearColorValue is used here because it provides a union of float,int,uint types.

**RESOLVED:** Will reuse existing VkClearColorValue structure in order to easily take advantage of float,int,uint borderColor types.

2) For hardware which supports a limited number of border colors what happens if that number is exceeded? Should this be handled by the driver unbeknownst to the application? In Revision 1 we had solved this issue using a new Object type, however that may have lead to additional system resource consumption which would otherwise not be required.
RESOLVED: Added `VkPhysicalDeviceCustomBorderColorPropertiesEXT::maxCustomBorderColorSamplers` for tracking implementation-specific limit, and Valid Usage statement handling overflow.

3) Should this be supported for immutable samplers at all, or by a feature bit? Some implementations may not be able to support custom border colors on immutable samplers—is it worthwhile enabling this to work on them for implementations that can support it, or forbidding it entirely.

RESOLVED: Samplers created with a custom border color are forbidden from being immutable. This resolves concerns for implementations where the custom border color is an index to a LUT instead of being directly embedded into sampler state.

4) Should UINT and SINT (unsigned integer and signed integer) border color types be separated or should they be combined into one generic INT (integer) type?

RESOLVED: Separating these does not make much sense as the existing fixed border color types do not have this distinction, and there is no reason in hardware to do so. This separation would also create unnecessary work and considerations for the application.

Version History

- Revision 1, 2019-10-10 (Joshua Ashton)
  - Internal revisions.
- Revision 2, 2019-10-11 (Liam Middlebrook)
  - Remove `VkCustomBorderColor` object and associated functions
  - Add issues concerning HW limitations for custom border color count
- Revision 3, 2019-10-12 (Joshua Ashton)
  - Re-expose the limits for the maximum number of unique border colors
  - Add extra details about border color tracking
  - Fix typos
- Revision 4, 2019-10-12 (Joshua Ashton)
  - Changed `maxUniqueCustomBorderColors` to a `uint32_t` from a `VkDeviceSize`
- Revision 5, 2019-10-14 (Liam Middlebrook)
  - Added features bit
- Revision 6, 2019-10-15 (Joshua Ashton)
  - Type-ize `VK_BORDER_COLOR_CUSTOM`
  - Fix const-ness on `pNext` of `VkSamplerCustomBorderColorCreateInfoEXT`
- Revision 7, 2019-11-26 (Liam Middlebrook)
  - Renamed `maxUniqueCustomBorderColors` to `maxCustomBorderColors`
- Revision 8, 2019-11-29 (Joshua Ashton)
  - Renamed `borderColor` member of `VkSamplerCustomBorderColorCreateInfoEXT` to
customBorderColor

• Revision 9, 2020-02-19 (Joshua Ashton)
  ◦ Renamed maxCustomBorderColors to maxCustomBorderColorSamplers

• Revision 10, 2020-02-21 (Joshua Ashton)
  ◦ Added format to VkSamplerCustomBorderColorCreateInfoEXT and feature bit

• Revision 11, 2020-04-07 (Joshua Ashton)
  ◦ Dropped UINT/SINT border color differences, consolidated types

• Revision 12, 2020-04-16 (Joshua Ashton)
  ◦ Renamed VK_BORDER_COLOR_CUSTOM_FLOAT_EXT to VK_BORDER_COLOR_FLOAT_CUSTOM_EXT for consistency

VK_EXT_debug-utils

Name String

VK_EXT_debug-utils

Extension Type

Instance extension

Registered Extension Number

129

Revision

2

Ratification Status

Not ratified

Extension and Version Dependencies

Special Use

• Debugging tools

Contact

• Mark Young marky-lunarg

Other Extension Metadata

Last Modified Date

2020-04-03

Revision

2

IP Status

No known IP claims.
Dependencies

- This extension is written against version 1.0 of the Vulkan API.
- Requires \texttt{VkObjectType}

Contributors

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- Baldur Karlsson
- Ian Elliott, Google
- Courtney Goeltzenleuchter, Google
- Karl Schultz, LunarG
- Mark Lobodzinski, LunarG
- Mike Schuchardt, LunarG
- Jaakko Konttinen, AMD
- Dan Ginsburg, Valve Software
- Rolando Olivares, Epic Games
- Dan Baker, Oxide Games
- Kyle Spagnoli, NVIDIA
- Jon Ashburn, LunarG
- Piers Daniell, NVIDIA

Description

Due to the nature of the Vulkan interface, there is very little error information available to the developer and application. By using the \texttt{VK_EXT_debug_utils} extension, developers \textbf{can} obtain more information. When combined with validation layers, even more detailed feedback on the application's use of Vulkan will be provided.

This extension provides the following capabilities:

- The ability to create a debug messenger which will pass along debug messages to an application supplied callback.
- The ability to identify specific Vulkan objects using a name or tag to improve tracking.
- The ability to identify specific sections within a \texttt{VkQueue} or \texttt{VkCommandBuffer} using labels to aid organization and offline analysis in external tools.

The main difference between this extension and \texttt{VK_EXT_debug_report} and \texttt{VK_EXT_debug_marker} is that those extensions use \texttt{VkDebugReportObjectTypeEXT} to identify objects. This extension uses the core \texttt{VkObjectType} in place of \texttt{VkDebugReportObjectTypeEXT}. The primary reason for this move is that no future object type handle enumeration values will be added to \texttt{VkDebugReportObjectTypeEXT} since the creation of \texttt{VkObjectType}.

In addition, this extension combines the functionality of both \texttt{VK_EXT_debug_report} and \texttt{VK_EXT_debug_marker} by allowing object name and debug markers (now called labels) to be returned.
to the application's callback function. This should assist in clarifying the details of a debug message including: what objects are involved and potentially which location within a VkQueue or VkCommandBuffer the message occurred.

**New Object Types**

- VkDebugUtilsMessengerEXT

**New Commands**

- vkCmdBeginDebugUtilsLabelEXT
- vkCmdEndDebugUtilsLabelEXT
- vkCmdInsertDebugUtilsLabelEXT
- vkCreateDebugUtilsMessengerEXT
- vkDestroyDebugUtilsMessengerEXT
- vkQueueBeginDebugUtilsLabelEXT
- vkQueueEndDebugUtilsLabelEXT
- vkQueueInsertDebugUtilsLabelEXT
- vkSetDebugUtilsObjectNameEXT
- vkSetDebugUtilsObjectTagEXT
- vkSubmitDebugUtilsMessageEXT

**New Structures**

- VkDebugUtilsLabelEXT
- VkDebugUtilsMessengerCallbackDataEXT
- VkDebugUtilsObjectTagInfoEXT
- Extending VkInstanceCreateInfo:
  - VkDebugUtilsMessengerCreateInfoEXT
- Extending VkPipelineShaderStageCreateInfo:
  - VkDebugUtilsObjectNameInfoEXT

**New Function Pointers**

- PFN_vkDebugUtilsMessengerCallbackEXT

**New Enums**

- VkDebugUtilsMessageSeverityFlagBitsEXT
- VkDebugUtilsMessageTypeFlagBitsEXT
New Bitmasks

- VkDebugUtilsMessageSeverityFlagsEXT
- VkDebugUtilsMessageTypeFlagsEXT
- VkDebugUtilsMessengerCallbackDataFlagsEXT
- VkDebugUtilsMessengerCreateFlagsEXT

New Enum Constants

- VK_EXT_DEBUG_UTILS_EXTENSION_NAME
- VK_EXT_DEBUG_UTILS_SPEC_VERSION

Extending VkObjectType:

- VK_OBJECT_TYPE_DEBUG_UTILS_MESSENGER_EXT

Extending VkStructureType:

- VK_STRUCTURE_TYPE_DEBUG_UTILS_LABEL_EXT
- VK_STRUCTURE_TYPE_DEBUG_UTILS_MESSENGER_CALLBACK_DATA_EXT
- VK_STRUCTURE_TYPE_DEBUG_UTILS_MESSENGER_CREATE_INFO_EXT
- VK_STRUCTURE_TYPE_DEBUG_UTILS_OBJECT_NAME_INFO_EXT
- VK_STRUCTURE_TYPE_DEBUG_UTILS_OBJECT_TAG_INFO_EXT

Examples

Example 1

VK_EXT_debug_utils allows an application to register multiple callbacks with any Vulkan component wishing to report debug information. Some callbacks may log the information to a file, others may cause a debug break point or other application defined behavior. An application can register callbacks even when no validation layers are enabled, but they will only be called for loader and, if implemented, driver events.

To capture events that occur while creating or destroying an instance an application can link a VkDebugUtilsMessengerCreateInfoEXT structure to the pNext element of the VkInstanceCreateInfo structure given to vkCreateInstance.

Example uses: Create three callback objects. One will log errors and warnings to the debug console using Windows OutputDebugString. The second will cause the debugger to break at that callback when an error happens and the third will log warnings to stdout.

```c
extern VkInstance instance;
VkResult res;
VkDebugUtilsMessengerEXT cb1, cb2, cb3;

// Must call extension functions through a function pointer:
PFN_vkCreateDebugUtilsMessengerEXT pfnCreateDebugUtilsMessengerEXT =
```
PFN_vkCreateDebugUtilsMessengerEXT vkGetInstanceProcAddr(instance, "vkCreateDebugUtilsMessengerEXT");
PFN_vkDestroyDebugUtilsMessengerEXT pfnDestroyDebugUtilsMessengerEXT = (PFN_vkDestroyDebugUtilsMessengerEXT)vkGetInstanceProcAddr(instance, "vkDestroyDebugUtilsMessengerEXT");

VkDebugUtilsMessengerCreateInfoEXT callback1 = {
    .sType = VK_STRUCTURE_TYPE_DEBUG_UTILS_MESSENGER_CREATE_INFO_EXT,
    .pNext = NULL,
    .flags = 0,
    .messageSeverity = VK_DEBUG_UTILS_MESSAGE_SEVERITY_ERROR_BIT_EXT | VK_DEBUG_UTILS_MESSAGE_SEVERITY_WARNING_BIT_EXT,
    .messageType = VK_DEBUG_UTILS_MESSAGE_TYPE_GENERAL_BIT_EXT | VK_DEBUG_UTILS_MESSAGE_TYPE_VALIDATION_BIT_EXT,
    .pfnUserCallback = myOutputDebugString,
    .pUserData = NULL
};
res = pfnCreateDebugUtilsMessengerEXT(instance, &callback1, NULL, &cb1);
if (res != VK_SUCCESS) {
    // Do error handling for VK_ERROR_OUT_OF_MEMORY
}
callback1.messageSeverity = VK_DEBUG_UTILS_MESSAGE_SEVERITY_ERROR_BIT_EXT;
callback1.pfnUserCallback = myDebugBreak;
callback1.pUserData = NULL;
res = pfnCreateDebugUtilsMessengerEXT(instance, &callback1, NULL, &cb2);
if (res != VK_SUCCESS) {
    // Do error handling for VK_ERROR_OUT_OF_MEMORY
}

VkDebugUtilsMessengerCreateInfoEXT callback3 = {
    .sType = VK_STRUCTURE_TYPE_DEBUG_UTILS_MESSENGER_CREATE_INFO_EXT,
    .pNext = NULL,
    .flags = 0,
    .messageSeverity = VK_DEBUG_UTILS_MESSAGE_SEVERITY_WARNING_BIT_EXT,
    .messageType = VK_DEBUG_UTILS_MESSAGE_TYPE_GENERAL_BIT_EXT | VK_DEBUG_UTILS_MESSAGE_TYPE_VALIDATION_BIT_EXT,
    .pfnUserCallback = mystdOutLogger,
    .pUserData = NULL
};
res = pfnCreateDebugUtilsMessengerEXT(instance, &callback3, NULL, &cb3);
if (res != VK_SUCCESS) {
    // Do error handling for VK_ERROR_OUT_OF_MEMORY
}
...

// Remove callbacks when cleaning up
pfnDestroyDebugUtilsMessengerEXT(instance, cb1, NULL);
pfnDestroyDebugUtilsMessengerEXT(instance, cb2, NULL);
pfnDestroyDebugUtilsMessengerEXT(instance, cb3, NULL);

Example 2

Associate a name with an image, for easier debugging in external tools or with validation layers that can print a friendly name when referring to objects in error messages.

```c
extern VkInstance instance;
extern VkDevice device;
extern VkImage image;

// Must call extension functions through a function pointer:
PFN_vkSetDebugUtilsObjectNameEXT pfnSetDebugUtilsObjectNameEXT = (PFN_vkSetDebugUtilsObjectNameEXT)vkGetInstanceProcAddr(instance, "vkSetDebugUtilsObjectNameEXT");

// Set a name on the image
const VkDebugUtilsObjectNameInfoEXT imageNameInfo = {
    .sType = VK_STRUCTURE_TYPE_DEBUG_UTILS_OBJECT_NAME_INFO_EXT,
    .pNext = NULL,
    .objectType = VK_OBJECT_TYPE_IMAGE,
    .objectHandle = (uint64_t)image,
    .pObjectName = "Brick Diffuse Texture",
};

pfnSetDebugUtilsObjectNameEXT(device, &imageNameInfo);

// A subsequent error might print:
// Image 'Brick Diffuse Texture' (0xc0dec0dedeadbeef) is used in a command buffer with no memory bound to it.
```

Example 3

Annotating regions of a workload with naming information so that offline analysis tools can display a more usable visualization of the commands submitted.

```c
extern VkInstance instance;
extern VkCommandBuffer commandBuffer;

// Must call extension functions through a function pointer:
PFN_vkQueueBeginDebugUtilsLabelEXT pfnQueueBeginDebugUtilsLabelEXT = (PFN_vkQueueBeginDebugUtilsLabelEXT)vkGetInstanceProcAddr(instance, "vkQueueBeginDebugUtilsLabelEXT");
PFN_vkQueueEndDebugUtilsLabelEXT pfnQueueEndDebugUtilsLabelEXT = (PFN_vkQueueEndDebugUtilsLabelEXT)vkGetInstanceProcAddr(instance, "vkQueueEndDebugUtilsLabelEXT");
PFN_vkCmdBeginDebugUtilsLabelEXT pfnCmdBeginDebugUtilsLabelEXT = (PFN_vkCmdBeginDebugUtilsLabelEXT)vkGetInstanceProcAddr(instance,
"vkCmdBeginDebugUtilsLabelEXT";
PFN_vkCmdBeginDebugUtilsLabelEXT pfnCmdBeginDebugUtilsLabelEXT =
(PFN_vkCmdBeginDebugUtilsLabelEXT)vkGetInstanceProcAddr(instance,
"vkCmdBeginDebugUtilsLabelEXT");
PFN_vkCmdInsertDebugUtilsLabelEXT pfnCmdInsertDebugUtilsLabelEXT =
(PFN_vkCmdInsertDebugUtilsLabelEXT)vkGetInstanceProcAddr(instance,
"vkCmdInsertDebugUtilsLabelEXT");

// Describe the area being rendered
const VkDebugUtilsLabelEXT houseLabel =
{
    .sType = VK_STRUCTURE_TYPE_DEBUG_UTILS_LABEL_EXT,
    .pNext = NULL,
    .pLabelName = "Brick House",
    .color = { 1.0f, 0.0f, 0.0f, 1.0f },
};

// Start an annotated group of calls under the 'Brick House' name
pfnCmdBeginDebugUtilsLabelEXT(commandBuffer, &houseLabel);
{
    // A mutable structure for each part being rendered
    VkDebugUtilsLabelEXT housePartLabel =
    {
        .sType = VK_STRUCTURE_TYPE_DEBUG_UTILS_LABEL_EXT,
        .pNext = NULL,
        .pLabelName = NULL,
        .color = { 0.0f, 0.0f, 0.0f, 0.0f },
    };

    // Set the name and insert the marker
    housePartLabel.pLabelName = "Walls";
pfnCmdInsertDebugUtilsLabelEXT(commandBuffer, &housePartLabel);

    // Insert the drawcall for the walls
    vkCmdDrawIndexed(commandBuffer, 1000, 1, 0, 0, 0);

    // Insert a recursive region for two sets of windows
    housePartLabel.pLabelName = "Windows";
pfnCmdBeginDebugUtilsLabelEXT(commandBuffer, &housePartLabel);
    {
        vkCmdDrawIndexed(commandBuffer, 75, 6, 1000, 0, 0);
        vkCmdDrawIndexed(commandBuffer, 100, 2, 1450, 0, 0);
    }
pfnCmdEndDebugUtilsLabelEXT(commandBuffer);

    housePartLabel.pLabelName = "Front Door";
pfnCmdInsertDebugUtilsLabelEXT(commandBuffer, &housePartLabel);

    vkCmdDrawIndexed(commandBuffer, 350, 1, 1650, 0, 0);

    housePartLabel.pLabelName = "Roof";
pfnCmdInsertDebugUtilsLabelEXT(commandBuffer, &housePartLabel);

vkCmdDrawIndexed(commandBuffer, 500, 1, 2000, 0, 0);

// End the house annotation started above
pfnCmdEndDebugUtilsLabelEXT(commandBuffer);

// Do other work
vkEndCommandBuffer(commandBuffer);

// Describe the queue being used
const VkDebugUtilsLabelEXT queueLabel = {
    .sType = VK_STRUCTURE_TYPE_DEBUG_UTILS_LABEL_EXT,
    .pNext = NULL,
    .pLabelName = "Main Render Work",
    .color = {0.0f, 1.0f, 0.0f, 1.0f},
};

// Identify the queue label region
pfnQueueBeginDebugUtilsLabelEXT(queue, &queueLabel);

// Submit the work for the main render thread
const VkCommandBuffer cmd_bufs[] = {commandBuffer};
VkSubmitInfo submit_info = {
    .sType = VK_STRUCTURE_TYPE_SUBMIT_INFO,
    .pNext = NULL,
    .waitSemaphoreCount = 0,
    .pWaitSemaphores = NULL,
    .pWaitDstStageMask = NULL,
    .commandBufferCount = 1,
    .pCommandBuffers = cmd_bufs,
    .signalSemaphoreCount = 0,
    .pSignalSemaphores = NULL
};
vkQueueSubmit(queue, 1, &submit_info, fence);

// End the queue label region
pfnQueueEndDebugUtilsLabelEXT(queue);

Issues

1) Should we just name this extension VK_EXT_debug_report2

RESOLVED: No. There is enough additional changes to the structures to break backwards compatibility. So, a new name was decided that would not indicate any interaction with the previous extension.
2) Will validation layers immediately support all the new features.

**RESOLVED:** Not immediately. As one can imagine, there is a lot of work involved with converting the validation layer logging over to the new functionality. Basic logging, as seen in the origin `VK_EXT_debug_report` extension will be made available immediately. However, adding the labels and object names will take time. Since the priority for Khronos at this time is to continue focusing on Valid Usage statements, it may take a while before the new functionality is fully exposed.

3) If the validation layers will not expose the new functionality immediately, then what is the point of this extension?

**RESOLVED:** We needed a replacement for `VK_EXT_debug_report` because the `VkDebugReportObjectTypeEXT` enumeration will no longer be updated and any new objects will need to be debugged using the new functionality provided by this extension.

4) Should this extension be split into two separate parts (1 extension that is an instance extension providing the callback functionality, and another device extension providing the general debug marker and annotation functionality)?

**RESOLVED:** No, the functionality for this extension is too closely related. If we did split up the extension, where would the structures and enums live, and how would you define that the device behavior in the instance extension is really only valid if the device extension is enabled, and the functionality is passed in. It is cleaner to just define this all as an instance extension, plus it allows the application to enable all debug functionality provided with one enable string during `vkCreateInstance`.

**Version History**

- Revision 1, 2017-09-14 (Mark Young and all listed Contributors)
  - Initial draft, based on `VK_EXT_debug_report` and `VK_EXT_debug_marker` in addition to previous feedback supplied from various companies including Valve, Epic, and Oxide games.
- Revision 2, 2020-04-03 (Mark Young and Piers Daniell)
  - Updated to allow either `NULL` or an empty string to be passed in for `pObjectName` in `VkDebugUtilsObjectNameInfoEXT`, because the loader and various drivers support `NULL` already.

**VK_EXT_depth_bias_control**

**Name String**

`VK_EXT_depth_bias_control`

**Extension Type**

Device extension

**Registered Extension Number**

284

**Revision**

1
**Ratification Status**
Ratified

**Extension and Version Dependencies**
VK_KHR_get_physical_device_properties2

**Special Use**
- D3D support

**Contact**
- Joshua Ashton [Joshua-Ashton](#)

**Extension Proposal**
VK_EXT_depth_bias_control

**Other Extension Metadata**

**Last Modified Date**
2023-02-15

**IP Status**
No known IP claims.

**Contributors**
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- Tobias Hector, AMD
- Ricardo Garcia, IGALIA
- Jan-Harald Fredriksen, ARM
- Shahbaz Youssefi, GOOGLE
- Tom Olson, ARM

**Description**

This extension adds a new structure, VkDepthBiasRepresentationInfoEXT, that can be added to a pNext chain of VkPipelineRasterizationStateCreateInfo and allows setting the scaling and representation of depth bias for a pipeline.

This state can also be set dynamically by using the new structure mentioned above in combination with the new vkCmdSetDepthBias2EXT command.
New Commands

• vkCmdSetDepthBias2EXT

New Structures

• VkDepthBiasInfoEXT
• Extending VkDepthBiasInfoEXT, VkPipelineRasterizationStateCreateInfo:
  ◦ VkDepthBiasRepresentationInfoEXT
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceDepthBiasControlFeaturesEXT

New Enums

• VkDepthBiasRepresentationEXT

New Enum Constants

• VK_EXT_DEPTH_BIAS_CONTROL_EXTENSION_NAME
• VK_EXT_DEPTH_BIAS_CONTROL_SPEC_VERSION
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_DEPTH_BIAS_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_DEPTH_BIAS_REPRESENTATION_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_BIAS_CONTROL_FEATURES_EXT

Version History

• Revision 1, 2022-09-22 (Joshua Ashton)
  ◦ Initial draft.

VK_EXT_depth_clamp_zero_one

Name String

VK_EXT_depth_clamp_zero_one

Extension Type

Device extension

Registered Extension Number

422

Revision

1
Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2

Contact
• Graeme Leese @gnl21

Other Extension Metadata

Last Modified Date
2021-07-29

Contributors
• Graeme Leese, Broadcom

Description
This extension gives defined behavior to fragment depth values which end up outside the conventional [0, 1] range. It can be used to ensure portability in edge cases of features like depthBias. The particular behavior is chosen to match OpenGL to aid porting or emulation.

New Structures
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceDepthClampZeroOneFeaturesEXT

New Enum Constants
• VK_EXT_DEPTH_CLAMP_ZERO_ONE_EXTENSION_NAME
• VK_EXT_DEPTH_CLAMP_ZERO_ONE_SPEC_VERSION
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_CLAMP_ZERO_ONE_FEATURES_EXT

Version History
• Revision 1, 2021-07-29 (Graeme Leese)
  ◦ Internal revisions

VK_EXT_depth_clip_control

Name String
VK_EXT_depth_clip_control
**Description**

This extension allows the application to use the OpenGL depth range in NDC, i.e. with depth in range \([-1, 1]\), as opposed to Vulkan’s default of \([0, 1]\). The purpose of this extension is to allow efficient layering of OpenGL over Vulkan, by avoiding emulation in the pre-rasterization shader stages. This emulation, which effectively duplicates gl_Position but with a different depth value, costs ALU and consumes shader output components that the implementation may not have to spare to meet OpenGL minimum requirements.

**New Structures**

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceDepthClipControlFeaturesEXT`
- Extending `VkPipelineViewportStateCreateInfo`:
  - `VkPipelineViewportDepthClipControlCreateInfoEXT`
New Enum Constants

- VK_EXT_DEPTH_CLIP_CONTROL_EXTENSION_NAME
- VK_EXT_DEPTH_CLIP_CONTROL_SPEC_VERSION

Extending VkStructureType:

- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_CLIP_CONTROL_FEATURES_EXT
- VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_DEPTH_CLIP_CONTROL_CREATE_INFO_EXT

Issues

1) Should this extension include an origin control option to match GL_LOWER_LEFT found in ARB_clip_control?

**RESOLVED:** No. The fix for porting over the origin is a simple y-axis flip. The depth clip control is a much harder problem to solve than what this extension is aimed to solve. Adding an equivalent to GL_LOWER_LEFT would require more testing.

2) Should this pipeline state be dynamic?

**RESOLVED:** Yes. The purpose of this extension is to emulate the OpenGL depth range, which is expected to be globally fixed (in case of OpenGL ES) or very infrequently changed (with glClipControl in OpenGL).

3) Should the control provided in this extension be an enum that could be extended in the future?

**RESOLVED:** No. It is highly unlikely that the depth range is changed to anything other than [0, 1] in the future. Should that happen a new extension will be required to extend such an enum, and that extension might as well add a new struct to chain to VkPipelineViewportStateCreateInfo::pNext instead.

Version History

- Revision 0, 2020-10-01 (Spencer Fricke)
  - Internal revisions
- Revision 1, 2020-11-26 (Shahbaz Youssefi)
  - Language fixes

**VK_EXT_depth_clip_enable**

Name String

VK_EXT_depth_clip_enable

Extension Type

Device extension

Registered Extension Number

103
Description

This extension allows the depth clipping operation, that is normally implicitly controlled by `VkPipelineRasterizationStateCreateInfo::depthClampEnable`, to instead be controlled explicitly by `VkPipelineRasterizationDepthClipStateCreateInfoEXT::depthClipEnable`.

This is useful for translating DX content which assumes depth clamping is always enabled, but depth clip can be controlled by the DepthClipEnable rasterization state (D3D12_RASTERIZER_DESC).

New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceDepthClipEnableFeaturesEXT`
- Extending `VkPipelineRasterizationStateCreateInfo`:
  - `VkPipelineRasterizationDepthClipStateCreateInfoEXT`
New Bitmasks

• VkPipelineRasterizationDepthClipStateCreateFlagsEXT

New Enum Constants

• VK_EXT_DEPTH_CLIP_ENABLE_EXTENSION_NAME
• VK_EXT_DEPTH_CLIP_ENABLE_SPEC_VERSION
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_CLIP_ENABLE_FEATURES_EXT
  ◦ VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_DEPTH_CLIP_STATE_CREATE_INFO_EXT

Version History

• Revision 1, 2018-12-20 (Piers Daniell)
  ◦ Internal revisions

VK_EXT_depth_range_unrestricted

Name String

VK_EXT_depth_range_unrestricted

Extension Type

Device extension

Registered Extension Number

14

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

Contact

• Piers Daniell pdaniell-nv

Other Extension Metadata

Last Modified Date

2017-06-22

Contributors

• Daniel Koch, NVIDIA
• Jeff Bolz, NVIDIA
Description

This extension removes the VkViewport minDepth and maxDepth restrictions that the values must be between 0.0 and 1.0, inclusive. It also removes the same restriction on VkPipelineDepthStencilStateCreateInfo minDepthBounds and maxDepthBounds. Finally it removes the restriction on the depth value in VkClearDepthStencilValue.

New Enum Constants

- VK_EXT_DEPTH_RANGE_UNRESTRICTED_EXTENSION_NAME
- VK_EXT_DEPTH_RANGE_UNRESTRICTED_SPEC_VERSION

Issues

1) How do VkViewport minDepth and maxDepth values outside of the 0.0 to 1.0 range interact with Primitive Clipping?

RESOLVED: The behavior described in Primitive Clipping still applies. If depth clamping is disabled the depth values are still clipped to $0 \leq z_c \leq w_c$ before the viewport transform. If depth clamping is enabled the above equation is ignored and the depth values are instead clamped to the VkViewport minDepth and maxDepth values, which in the case of this extension can be outside of the 0.0 to 1.0 range.

2) What happens if a resulting depth fragment is outside of the 0.0 to 1.0 range and the depth buffer is fixed-point rather than floating-point?

RESOLVED: This situation can also arise without this extension (when fragment shaders replace depth values, for example), and this extension does not change the behaviour, which is defined in the Depth Test section of the Fragment Operations chapter.

Version History

- Revision 1, 2017-06-22 (Piers Daniell)
  - Internal revisions

VK_EXT_descriptor_buffer

Name String

- VK_EXT_descriptor_buffer

Extension Type

- Device extension

Registered Extension Number

- 317

Revision

- 1
Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2
and
VK_KHR_buffer_device_address
and
VK_KHR_synchronization2
and
VK_EXT_descriptor_indexing

Contact
• Tobias Hector @tobski

Extension Proposal
VK_EXT_descriptor_buffer

Other Extension Metadata

Last Modified Date
2021-06-07

IP Status
No known IP claims.

Contributors
• Tobias Hector, AMD
• Stu Smith, AMD
• Maciej Jesionowski, AMD
• Boris Zanin, AMD
• Hans-Kristian Arntzen, Valve
• Connor Abbott, Valve
• Baldur Karlsson, Valve
• Mike Blumenkrantz, Valve
• Graeme Leese, Broadcom
• Jan-Harald Fredriksen, Arm
• Rodrigo Locatti, NVIDIA
• Jeff Bolz, NVIDIA
• Piers Daniell, NVIDIA
• Jeff Leger, QUALCOMM
• Lionel Landwerlin, Intel
Description

This extension introduces new commands to put shader-accessible descriptors directly in memory, making the management of descriptor data more explicit.

New Commands

- `vkCmdBindDescriptorBufferEmbeddedSamplersEXT`
- `vkCmdBindDescriptorBuffersEXT`
- `vkCmdSetDescriptorBufferOffsetsEXT`
- `vkGetBufferOpaqueCaptureDescriptorDataEXT`
- `vkGetDescriptorEXT`
- `vkGetDescriptorSetLayoutBindingOffsetEXT`
- `vkGetDescriptorSetLayoutSizeEXT`
- `vkGetImageOpaqueCaptureDescriptorDataEXT`
- `vkGetImageViewOpaqueCaptureDescriptorDataEXT`
- `vkGetSamplerOpaqueCaptureDescriptorDataEXT`

If `VK_KHR_acceleration_structure` or `VK_NV_ray_tracing` is supported:

- `vkGetAccelerationStructureOpaqueCaptureDescriptorDataEXT`

New Structures

- `VkBufferCaptureDescriptorDataInfoEXT`
- `VkDescriptorAddressInfoEXT`
- `VkDescriptorBufferBindingInfoEXT`
- `VkDescriptorGetInfoEXT`
- `VkImageCaptureDescriptorDataInfoEXT`
- `VkImageViewCaptureDescriptorDataInfoEXT`
- `VkSamplerCaptureDescriptorDataInfoEXT`
- Extending `VkBufferCreateInfo`, `VkImageCreateInfo`, `VkImageViewCreateInfo`, `VkSamplerCreateInfo`, `VkAccelerationStructureCreateInfoKHR`, `VkAccelerationStructureCreateInfoNV`:
  - `VkOpaqueCaptureDescriptorDataCreateInfoEXT`
- Extending `VkDescriptorBufferBindingInfoEXT`:
  - `VkDescriptorBufferBindingPushDescriptorBufferHandleEXT`
- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
- `VkPhysicalDeviceDescriptorBufferFeaturesEXT`

- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceDescriptorBufferDensityMapPropertiesEXT`
  - `VkPhysicalDeviceDescriptorBufferPropertiesEXT`

If `VK_KHR_acceleration_structure` or `VK_NV_ray_tracing` is supported:

- `VkAccelerationStructureCaptureDescriptorDataInfoEXT`

**New Unions**

- `VkDescriptorDataEXT`

**New Enum Constants**

- `VK_EXT_DESCRIPTOR_BUFFER_EXTENSION_NAME`
- `VK_EXT_DESCRIPTOR_BUFFER_SPEC_VERSION`

Extending `VkAccelerationStructureCreateFlagBitsKHR`:

- `VK_ACCELERATION_STRUCTURE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT`

Extending `VkAccessFlagBits2`:

- `VK_ACCESS_2_DESCRIPTOR_BUFFER_READ_BIT_EXT`

Extending `VkBufferCreateFlagBits`:

- `VK_BUFFER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT`

Extending `VkBufferUsageFlagBits`:

- `VK_BUFFER_USAGE_PUSH_DESCRIPTORS_DESCRIPTOR_BUFFER_BIT_EXT`
- `VK_BUFFER_USAGERESOURCE_DESCRIPTOR_BUFFER_BIT_EXT`
- `VK_BUFFER_USAGE_SAMPLER_DESCRIPTOR_BUFFER_BIT_EXT`

Extending `VkDescriptorSetLayoutCreateFlagBits`:

- `VK_DESCRIPTOR_SET_LAYOUT_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`
- `VK_DESCRIPTOR_SET_LAYOUT_CREATE_EMBEDDED_IMMUTABLE_SAMPLERS_BIT_EXT`

Extending `VkImageCreateFlagBits`:

- `VK_IMAGE_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT`

Extending `VkImageViewCreateFlagBits`:

- `VK_IMAGE_VIEW_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT`

Extending `VkPipelineCreateFlagBits`:

- `VK_PIPELINE_CREATE_DESCRIPTOR_BUFFER_BIT_EXT`

Extending `VkSamplerCreateFlagBits`:

- `VK_SAMPLER_CREATE_DESCRIPTOR_BUFFER_CAPTURE_REPLAY_BIT_EXT`
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_BUFFER_CAPTURE_DESCRIPTOR_DATA_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_DESCRIPTOR_ADDRESS_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_DESCRIPTOR_BUFFER_BINDING_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_DESCRIPTOR_BUFFER_BINDING_PUSH_DESCRIPTOR_BUFFER_HANDLE_EXT
  ◦ VK_STRUCTURE_TYPE_DESCRIPTOR_GET_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_IMAGE_CAPTURE_DESCRIPTOR_DATA_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_IMAGE_VIEW_CAPTURE_DESCRIPTOR_DATA_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_OPAQUE_CAPTURE_DESCRIPTOR_DATA_CREATE_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_BUFFER_DENSITY_MAP_PROPERTIES_EXT
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_BUFFER_FEATURES_EXT
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_BUFFER_PROPERTIES_EXT
  ◦ VK_STRUCTURE_TYPE_SAMPLER_CAPTURE_DESCRIPTOR_DATA_INFO_EXT

If VK_KHR_acceleration_structure or VK_NV_ray_tracing is supported:

• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_CAPTURE_DESCRIPTOR_DATA_INFO_EXT

Version History

• Revision 1, 2021-06-07 (Stu Smith)
  ◦ Initial revision

VK_EXT_device_address_binding_report

Name String

  VK_EXT_device_address_binding_report

Extension Type

  Device extension

Registered Extension Number

  355

Revision

  1

Ratification Status

  Not ratified

Extension and Version Dependencies

  VK_KHR_get_physical_device_properties2
This extension enables applications to track the binding of regions of the GPU virtual address space, and to associate those regions with Vulkan objects. This extension is primarily intended to aid in crash postmortem, where applications may wish to map a faulting GPU address to a Vulkan object.

For example, a page fault triggered by accessing an address located within a region of the GPU virtual address space that was previously reported as bound and then unbound may indicate a use-after-free error. Similarly, faults generated by accessing virtual addresses outside the limits of a bound region of GPU virtual address space may indicate indexing beyond the bounds of a resource.
New Enums

- VkDeviceAddressBindingFlagBitsEXT
- VkDeviceAddressBindingTypeEXT

New Bitmasks

- VkDeviceAddressBindingFlagsEXT

New Enum Constants

- VK_EXT_DEVICE_ADDRESS_BINDING_REPORT_EXTENSION_NAME
- VK_EXT_DEVICE_ADDRESS_BINDING_REPORT_SPEC_VERSION
- Extending VkDebugUtilsMessageTypeFlagBitsEXT:
  - VK_DEBUG_UTILS_MESSAGE_TYPE_DEVICE_ADDRESS_BINDING_BIT_EXT
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_DEVICE_ADDRESS_BINDING_CALLBACK_DATA_EXT
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ADDRESS_BINDING_REPORT_FEATURES_EXT

Issues

1.) Should this extend VK_EXT_debug_utils or VK_EXT_device_memory_report?

RESOLVED: Extend VK_EXT_debug_utils. VK_EXT_device_memory_report focuses on memory allocations and would not normally trigger callbacks in all of the situations where VK_EXT_device_address_binding_report is expected to.

2.) Should this extension cover all Vulkan object types, or only resources such as buffers and images?

RESOLVED: The extension covers all Vulkan objects, and is not restricted to objects backed by VkDeviceMemory objects.

3.) Should reallocation be identified explicitly, or as a unbind/bind pair?

RESOLVED: Reallocation should be represented as an unbind/bind pair.

4.) Can multiple Vulkan objects share an overlapping virtual address range?

RESOLVED: Yes. This can be expected to occur due to resources aliasing.

5.) Can a single Vulkan object be associated with multiple virtual address ranges concurrently?

RESOLVED: Yes. These should be reported via multiple calls to the reporting callback.

6.) Should the virtual address ranges associated with internal allocations such as memory pools be reported?
**RESOLVED:** Virtual address ranges associated with internal allocations should only be reported when they become associated with a specific Vulkan object. In the case of internal pool allocations, a bind event should be reported when resources from the pool are assigned to a Vulkan object, and an unbind event should be reported when those resources are returned to the pool. Implementations should not report the binding or unbinding of virtual address ranges for which there are no related API objects visible to the application developer.

7.) Can an implementation report binding a virtual address range at VkImage or VkImageView creation, rather than in response to vkBindImageMemory?

**RESOLVED:** Yes. Virtual address range binding should be reported at the appropriate point at which it occurs within the implementation. This extension does not mandate when that should occur, and applications should anticipate receiving callback events at any point after registering callbacks.

8.) Can reporting of binding/unbinding be deferred until a resource is referenced by an executing command buffer?

**RESOLVED:** Changes to the virtual address ranges associated with a Vulkan object should be reported as close as possible to where they occur within the implementation. If virtual address binding is deferred, then the callback should also be deferred to match.

9.) Do bind/unbind callbacks have to form matched pairs? Can a large region be bound, and then subregions unbound, resulting in fragmentation?

**RESOLVED:** Splitting of virtual address regions, and unmatched bind/unbind callbacks may occur. Developers should anticipate that sparse memory may exhibit this behaviour.

10.) The specification mandates that a callback must be triggered whenever a GPU virtual address range associated with any Vulkan object is bound or unbound. Do we need queries or properties indicating which Vulkan objects will report binding modifications?

**RESOLVED:** No. This extension is not intended to mandate how and when implementations bind virtual ranges to objects. Adding queries or properties would constrain implementations, which might otherwise vary how virtual address bindings occur based on usage.

11.) Should vkAllocateMemory and vkFreeMemory trigger reporting callbacks?

**RESOLVED:** If an implementation binds a GPU virtual address range when vkAllocateMemory is called, then the callbacks must be triggered associating the virtual address range with the VkDeviceMemory object. If the device memory is subsequently bound to a buffer or image via vkBind*Memory, the callbacks should be triggered a second time, reporting the association between virtual address range and the buffer/image.

**Version History**

- Revision 1, 2020-09-23 (Ralph Potter)
  - Internal revisions
**Name String**

`VK_EXT_device_fault`

**Extension Type**

Device extension

**Registered Extension Number**

342

**Revision**

2

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

`VK_KHR_get_physical_device_properties2`

**Contact**

- Ralph Potter r_potter

**Extension Proposal**

`VK_EXT_device_fault`

**Other Extension Metadata**

**Last Modified Date**

2021-03-10

**IP Status**

No known IP claims.

**Contributors**

- Ralph Potter, Samsung
- Stuart Smith, AMD
- Jan-Harald Fredriksen, ARM
- Mark Bellamy, ARM
- Andrew Ellem, Google
- Alex Walters, IMG
- Jeff Bolz, NVIDIA
- Baldur Karlsson, Valve
Description

Device loss can be triggered by a variety of issues, including invalid API usage, implementation errors, or hardware failures.

This extension introduces a new command: `vkGetDeviceFaultInfoEXT`, which may be called subsequent to a `VK_ERROR_DEVICE_LOST` error code having been returned by the implementation. This command allows developers to query for additional information on GPU faults which may have caused device loss, and to generate binary crash dumps, which may be loaded into external tools for further diagnosis.

New Commands

- `vkGetDeviceFaultInfoEXT`

New Structures

- `VkDeviceFaultAddressInfoEXT`
- `VkDeviceFaultCountsEXT`
- `VkDeviceFaultInfoEXT`
- `VkDeviceFaultVendorBinaryHeaderVersionOneEXT`
- `VkDeviceFaultVendorInfoEXT`
- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDeviceFaultFeaturesEXT`

New Enums

- `VkDeviceFaultAddressTypeEXT`
- `VkDeviceFaultVendorBinaryHeaderVersionEXT`

New Enum Constants

- `VK_EXT_DEVICE_FAULT_EXTENSION_NAME`
- `VK_EXT_DEVICE_FAULT_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPEDEVICE_FAULT_COUNTEXT`
  - `VK_STRUCTURE_TYPEDEVICE_FAULT_INFOEXT`
  - `VK_STRUCTURE_TYPEPHYSICALDEVICE_FAULT_FEATURES_EXT`

Version History

- Revision 2, 2023-04-05 (Ralph Potter)
  - Restored two missing members to the XML definition of `VkDeviceFaultVendorBinaryHeaderVersionOneEXT`. No functional change to the
This device extension allows registration of device memory event callbacks upon device creation, so that applications or middleware can obtain detailed information about memory usage and how memory is associated with Vulkan objects. This extension exposes the actual underlying device
memory usage, including allocations that are not normally visible to the application, such as memory consumed by \texttt{vkCreateGraphicsPipelines}. It is intended primarily for use by debug tooling rather than for production applications.

**New Structures**

- \texttt{VkDeviceMemoryReportCallbackDataEXT}
- Extending \texttt{VkDeviceCreateInfo}:
  - \texttt{VkDeviceDeviceMemoryReportCreateInfoEXT}
- Extending \texttt{VkPhysicalDeviceFeatures2, VkDeviceCreateInfo}:
  - \texttt{VkPhysicalDeviceDeviceMemoryReportFeaturesEXT}

**New Function Pointers**

- \texttt{PFN_vkDeviceMemoryReportCallbackEXT}

**New Enums**

- \texttt{VkDeviceMemoryReportEventTypeEXT}

**New Bitmasks**

- \texttt{VkDeviceMemoryReportFlagsEXT}

**New Enum Constants**

- \texttt{VK_EXT_DEVICE_MEMORY_REPORT_EXTENSION_NAME}
- \texttt{VK_EXT_DEVICE_MEMORY_REPORT_SPEC_VERSION}
- Extending \texttt{VkStructureType}:
  - \texttt{VK_STRUCTURE_TYPE_DEVICE_DEVICE_MEMORY_REPORT_CREATE_INFO_EXT}
  - \texttt{VK_STRUCTURE_TYPE_DEVICE_DEVICE_MEMORY_REPORT_CALLBACK_DATA_EXT}
  - \texttt{VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEVICE_MEMORY_REPORT_FEATURES_EXT}

**Issues**

1) Should this be better expressed as an extension to \texttt{VK_EXT_debug_utils} and its general-purpose messenger construct?

**RESOLVED**: No. The intended lifecycle is quite different. We want to make this extension tied to the device's lifecycle. Each ICD just handles its own implementation of this extension, and this extension will only be directly exposed from the ICD. So we can avoid the extra implementation complexity used to accommodate the flexibility of \texttt{VK_EXT_debug_utils} extension.

2) Can we extend and use the existing internal allocation callbacks instead of adding the new callback structure in this extension?
**RESOLVED**: No. Our memory reporting layer that combines this information with other memory information it collects directly (e.g. bindings of resources to `VkDeviceMemory`) would have to intercept all entry points that take a `VkAllocationCallbacks` parameter and inject its own `PFNInternalAllocation` and `PFNInternalFree`. That may be doable for the extensions we know about, but not for ones we do not. The proposal would work fine in the face of most unknown extensions. But even for ones we know about, since apps can provide a different set of callbacks and userdata and those can be retained by the driver and used later (esp. for pool object, but not just those), we would have to dynamically allocate the interception trampoline every time. That is getting to be an unreasonably large amount of complexity and (possibly) overhead.

We are interested in both alloc/free and import/unimport. The latter is fairly important for tracking (and avoiding double-counting) of swapchain images (still true with “native swapchains” based on external memory) and media/camera interop. Though we might be able to handle this with additional `VkInternalAllocationType` values, for import/export we do want to be able to tie this to the external resource, which is one thing that the `memoryObjectId` is for.

The internal alloc/free callbacks are not extensible except via new `VkInternalAllocationType` values. The `VkDeviceMemoryReportCallbackDataEXT` in this extension is extensible. That was deliberate: there is a real possibility we will want to get extra information in the future. As one example, currently this reports only physical allocations, but we believe there are interesting cases for tracking how populated that VA region is.

The callbacks are clearly specified as only callable within the context of a call from the app into Vulkan. We believe there are some cases where drivers can allocate device memory asynchronously. This was one of the sticky issues that derailed the internal device memory allocation reporting design (which is essentially what this extension is trying to do) leading up to 1.0.

`VkAllocationCallbacks` is described in a section called “Host memory” and the intro to it is very explicitly about host memory. The other callbacks are all inherently about host memory. But this extension is very focused on device memory.

3) Should the callback be reporting which heap is used?

**RESOLVED**: Yes. It is important for non-UMA systems to have all the device memory allocations attributed to the corresponding device memory heaps. For internally-allocated device memory, `heapIndex` will always correspond to an advertised heap, rather than having a magic value indicating a non-advertised heap. Drivers can advertise heaps that do not have any corresponding memory types if they need to.

4) Should we use an array of callback for the layers to intercept instead of chaining multiple of the `VkDeviceDeviceMemoryReportCreateInfoEXT` structures in the `pNext` of `VkDeviceCreateInfo`?

**RESOLVED** No. The pointer to the `VkDeviceDeviceMemoryReportCreateInfoEXT` structure itself is const and you cannot just cast it away. Thus we cannot update the callback array inside the structure. In addition, we cannot drop this `pNext` chain either, so making a copy of this whole structure does not work either.

5) Should we track bulk allocations shared among multiple objects?
RESOLVED No. Take the shader heap as an example. Some implementations will let multiple VkPipeline objects share the same shader heap. We are not asking the implementation to report VK_OBJECT_TYPE_PIPELINE along with a VK_NULL_HANDLE for this bulk allocation. Instead, this bulk allocation is considered as a layer below what this extension is interested in. Later, when the actual VkPipeline objects are created by suballocating from the bulk allocation, we ask the implementation to report the valid handles of the VkPipeline objects along with the actual suballocated sizes and different memoryObjectId.

6) Can we require the callbacks to be always called in the same thread with the Vulkan commands?

RESOLVED No. Some implementations might choose to multiplex work from multiple application threads into a single backend thread and perform JIT allocations as a part of that flow. Since this behavior is theoretically legit, we cannot require the callbacks to be always called in the same thread with the Vulkan commands, and the note is to remind the applications to handle this case properly.

7) Should we add an additional “allocation failed” event type with things like size and heap index reported?

RESOLVED Yes. This fits in well with the callback infrastructure added in this extension, and implementation touches the same code and has the same overheads as the rest of the extension. It could help debugging things like getting an VK_ERROR_OUT_OF_HOST_MEMORY error when ending a command buffer. Right now the allocation failure could have happened anywhere during recording, and a callback would be really useful to understand where and why.

**Version History**

- Revision 1, 2020-08-26 (Yiwei Zhang)
  - Initial version
- Revision 2, 2021-01-06 (Yiwei Zhang)
  - Minor description update

**VK_EXT_direct_mode_display**

**Name String**

VK_EXT_direct_mode_display

**Extension Type**

Instance extension

**Registered Extension Number**

89

**Revision**

1

**Ratification Status**

Not ratified
Extension and Version Dependencies

**VK_KHR_display**

Contact

- James Jones [cubanismo](#)

Other Extension Metadata

**Last Modified Date**

2016-12-13

**IP Status**

No known IP claims.

Contributors

- Pierre Boudier, NVIDIA
- James Jones, NVIDIA
- Damien Leone, NVIDIA
- Pierre-Loup Griffais, Valve
- Liam Middlebrook, NVIDIA

Description

This extension, along with related platform extensions, allows applications to take exclusive control of displays associated with a native windowing system. This is especially useful for virtual reality applications that wish to hide HMDs (head mounted displays) from the native platform’s display management system, desktop, and/or other applications.

New Commands

- `vkReleaseDisplayEXT`

New Enum Constants

- `VK_EXT_DIRECT_MODE_DISPLAY_EXTENSION_NAME`
- `VK_EXT_DIRECT_MODE_DISPLAY_SPEC_VERSION`

Issues

1) Should this extension and its related platform-specific extensions leverage `VK_KHR_display`, or provide separate equivalent interfaces.

**RESOLVED:** Use `VK_KHR_display` concepts and objects. `VK_KHR_display` can be used to enumerate all displays on the system, including those attached to/in use by a window system or native platform, but `VK_KHR_display_swapchain` will fail to create a swapchain on in-use displays. This extension and its platform-specific children will allow applications to grab in-use displays away from window...
systems and/or native platforms, allowing them to be used with `VK_KHR_display_swapchain`.

2) Are separate calls needed to acquire displays and enable direct mode?

**RESOLVED**: No, these operations happen in one combined command. Acquiring a display puts it into direct mode.

**Version History**

- Revision 1, 2016-12-13 (James Jones)
  - Initial draft

**VK_EXT_directfb_surface**

**Name String**

`VK_EXT_directfb_surface`

**Extension Type**

Instance extension

**Registered Extension Number**

347

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

`VK_KHR_surface`

**Contact**

- Nicolas Caramelli 📩caramelli

**Other Extension Metadata**

**Last Modified Date**

2020-06-16

**IP Status**

No known IP claims.

**Contributors**

- Nicolas Caramelli
Description

The VK_EXT_directfb_surface extension is an instance extension. It provides a mechanism to create a VkSurfaceKHR object (defined by the VK_KHR_surface extension) that refers to a DirectFB IDirectFBSurface, as well as a query to determine support for rendering via DirectFB.

New Commands

- vkCreateDirectFBSurfaceEXT
- vkGetPhysicalDeviceDirectFBSurfacePresentationSupportEXT

New Structures

- VkDirectFBSurfaceCreateInfoEXT

New Bitmasks

- VkDirectFBSurfaceCreateFlagsEXT

New Enum Constants

- VK_EXT_DIRECTFB_SURFACE_EXTENSION_NAME
- VK_EXT_DIRECTFB_SURFACE_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_DIRECTFB_SURFACE_CREATE_INFO_EXT

Version History

- Revision 1, 2020-06-16 (Nicolas Caramelli)
  - Initial version

VK_EXT_discard_rectangles

Name String

VK_EXT_discard_rectangles

Extension Type

Device extension

Registered Extension Number

100

Revision

2

Ratification Status

Not ratified
Extension and Version Dependencies

- VK_KHR_get_physical_device_properties2
- or
- Version 1.1

Contact

- Piers Daniell @pdaniell-nv

Other Extension Metadata

Last Modified Date

2023-01-18

Interactions and External Dependencies

- Interacts with VK_KHR_device_group
- Interacts with Vulkan 1.1

Contributors

- Daniel Koch, NVIDIA
- Jeff Bolz, NVIDIA

Description

This extension provides additional orthogonally aligned “discard rectangles” specified in framebuffer-space coordinates that restrict rasterization of all points, lines and triangles.

From zero to an implementation-dependent limit (specified by maxDiscardRectangles) number of discard rectangles can be operational at once. When one or more discard rectangles are active, rasterized fragments can either survive if the fragment is within any of the operational discard rectangles (VK_DISCARD_RECTANGLE_MODE_INCLUSIVE_EXT mode) or be rejected if the fragment is within any of the operational discard rectangles (VK_DISCARD_RECTANGLE_MODE_EXCLUSIVE_EXT mode).

These discard rectangles operate orthogonally to the existing scissor test functionality. The discard rectangles can be different for each physical device in a device group by specifying the device mask and setting discard rectangle dynamic state.

Version 2 of this extension introduces new dynamic states VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT and VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT, and the corresponding functions vkCmdSetDiscardRectangleEnableEXT and vkCmdSetDiscardRectangleModeEXT. Applications that use these dynamic states must ensure the implementation advertises at least specVersion 2 of this extension.

New Commands

- vkCmdSetDiscardRectangleEXT
- vkCmdSetDiscardRectangle EnableEXT
- vkCmdSetDiscardRectangleModeEXT
New Structures

- Extending `VkGraphicsPipelineCreateInfo`:
  - `VkPipelineDiscardRectangleStateCreateInfoEXT`

- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceDiscardRectanglePropertiesEXT`

New Enums

- `VkDiscardRectangleModeEXT`

New Bitmasks

- `VkPipelineDiscardRectangleStateCreateFlagsEXT`

New Enum Constants

- `VK_EXT_DISCARD_RECTANGLES_EXTENSION_NAME`
- `VK_EXT_DISCARD_RECTANGLES_SPEC_VERSION`

- Extending `VkDynamicState`:
  - `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_ENABLE_EXT`
  - `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_EXT`
  - `VK_DYNAMIC_STATE_DISCARD_RECTANGLE_MODE_EXT`

- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DISCARD_RECTANGLE_PROPERTIES_EXT`
  - `VK_STRUCTURE_TYPE_PIPELINE_DISCARD_RECTANGLE_STATE_CREATE_INFO_EXT`

Version History

- Revision 2, 2023-01-18 (Piers Daniell)
  - Add dynamic states for discard rectangle enable/disable and mode.

- Revision 1, 2016-12-22 (Piers Daniell)
  - Internal revisions

VK_EXT_display_control

Name String

`VK_EXT_display_control`

Extension Type

Device extension
Registered Extension Number
92

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_EXT_display_surface_counter
and
VK_KHR_swapchain

Contact
• James Jones 🌀cubanismo

Other Extension Metadata

Last Modified Date
2016-12-13

IP Status
No known IP claims.

Contributors
• Pierre Boudier, NVIDIA
• James Jones, NVIDIA
• Damien Leone, NVIDIA
• Pierre-Loup Griffais, Valve
• Daniel Vetter, Intel

Description
This extension defines a set of utility functions for use with the VK_KHR_display and VK_KHR_display_swapchain extensions.

New Commands
• vkDisplayPowerControlEXT
• vkGetSwapchainCounterEXT
• vkRegisterDeviceEventEXT
• vkRegisterDisplayEventEXT
**New Structures**

- VkDeviceEventInfoEXT
- VkDisplayEventInfoEXT
- VkDisplayPowerInfoEXT
- Extending VkSwapchainCreateInfoKHR:
  - VkSwapchainCounterCreateInfoEXT

**New Enums**

- VkDeviceEventTypeEXT
- VkDisplayEventTypeEXT
- VkDisplayPowerStateEXT

**New Enum Constants**

- VK_EXT_DISPLAY_CONTROL_EXTENSION_NAME
- VK_EXT_DISPLAY_CONTROL_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_DEVICE_EVENT_INFO_EXT
  - VK_STRUCTURE_TYPE_DISPLAY_EVENT_INFO_EXT
  - VK_STRUCTURE_TYPE_DISPLAY_POWER_INFO_EXT
  - VK_STRUCTURE_TYPE_SWAPCHAIN_COUNTER_CREATE_INFO_EXT

**Issues**

1) Should this extension add an explicit “WaitForVsync” API or a fence signaled at vsync that the application can wait on?

**RESOLVED:** A fence. A separate API could later be provided that allows exporting the fence to a native object that could be inserted into standard run loops on POSIX and Windows systems.

2) Should callbacks be added for a vsync event, or in general to monitor events in Vulkan?

**RESOLVED:** No, fences should be used. Some events are generated by interrupts which are managed in the kernel. In order to use a callback provided by the application, drivers would need to have the userspace driver spawn threads that would wait on the kernel event, and hence the callbacks could be difficult for the application to synchronize with its other work given they would arrive on a foreign thread.

3) Should vblank or scanline events be exposed?

**RESOLVED:** Vblank events. Scanline events could be added by a separate extension, but the latency of processing an interrupt and waking up a userspace event is high enough that the accuracy of a scanline event would be rather low. Further, per-scanline interrupts are not supported by all
**Version History**

- Revision 1, 2016-12-13 (James Jones)
  - Initial draft

**VK_EXT_display_surface_counter**

**Name String**

`VK_EXT_display_surface_counter`

**Extension Type**

Instance extension

**Registered Extension Number**

91

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

`VK_KHR_display`

**Contact**

- James Jones `@cubanismo`

**Other Extension Metadata**

**Last Modified Date**

2016-12-13

**IP Status**

No known IP claims.

**Contributors**

- Pierre Boudier, NVIDIA
- James Jones, NVIDIA
- Damien Leone, NVIDIA
- Pierre-Loup Griffais, Valve
- Daniel Vetter, Intel
Description

This extension defines a vertical blanking period counter associated with display surfaces. It provides a mechanism to query support for such a counter from a `VkSurfaceKHR` object.

New Commands

- `vkGetPhysicalDeviceSurfaceCapabilities2EXT`

New Structures

- `VkSurfaceCapabilities2EXT`

New Enums

- `VkSurfaceCounterFlagBitsEXT`

New Bitmasks

- `VkSurfaceCounterFlagsEXT`

New Enum Constants

- `VK_EXT_DISPLAY_SURFACE_COUNTER_EXTENSION_NAME`
- `VK_EXT_DISPLAY_SURFACE_COUNTER_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_SURFACE_CAPABILITIES2_EXT`
  - `VK_STRUCTURE_TYPE_SURFACE_CAPABILITIES_2_EXT`

Version History

- Revision 1, 2016-12-13 (James Jones)
  - Initial draft

**VK_EXT_dynamic_rendering_unused_attachments**

Name String

- `VK_EXT_dynamic_rendering_unused_attachments`

Extension Type

- Device extension

Registered Extension Number

- 500

Revision

- 1
Ratification Status
Ratified

Extension and Version Dependencies

- `VK_KHR_get_physical_device_properties2` or Version 1.1
- `VK_KHR_dynamic_rendering` or Version 1.3

Contact

- Piers Daniell @pdaniell-nv

Extension Proposal

- `VK_EXT_dynamic_renderingUnusedAttachments`

Other Extension Metadata

Last Modified Date
2023-05-22

IP Status
No known IP claims.

Contributors

- Daniel Story, Nintendo
- Hans-Kristian Arntzen, Valve
- Jan-Harald Fredriksen, Arm
- James Fitzpatrick, Imagination Technologies
- Pan Gao, Huawei Technologies
- Ricardo Garcia, Igalia
- Stu Smith, AMD

Description

This extension lifts some restrictions in the `VK_KHR_dynamic_rendering` extension to allow render pass instances and bound pipelines within those render pass instances to have an unused attachment specified in one but not the other. It also allows pipelines to use different formats in a render pass as long as the attachment is NULL.

New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceDynamicRenderingUnusedAttachmentsFeaturesEXT`
New Enum Constants

- VK_EXT_DYNAMIC RENDERING UNUSED ATTACHMENTS EXTENSION NAME
- VK_EXT_DYNAMIC RENDERING UNUSED ATTACHMENTS SPEC VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DYNAMIC_RENDERING_UNUSED_ATTACHMENTS_FEATURES_EXT

Issues

None.

Version History

- Revision 1, 2023-05-22 (Piers Daniell)
  - Internal revisions

VK_EXT_extended_dynamic_state3

Name String

VK_EXT_extended_dynamic_state3

Extension Type

Device extension

Registered Extension Number

456

Revision

2

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Contact

- Piers Daniell(pdaniell-nv)

Extension Proposal

VK_EXT_extended_dynamic_state3

Other Extension Metadata

Last Modified Date

2022-09-02
IP Status
No known IP claims.

Contributors
- Daniel Story, Nintendo
- Jamie Madill, Google
- Jan-Harald Fredriksen, Arm
- Faith Ekstrand, Collabora
- Mike Blumenkrantz, Valve
- Ricardo Garcia, Igalia
- Samuel Pitoiset, Valve
- Shahbaz Youssefi, Google
- Stu Smith, AMD
- Tapani Pälli, Intel

Description
This extension adds almost all of the remaining pipeline state as dynamic state to help applications further reduce the number of monolithic pipelines they need to create and bind.

New Commands
- vkCmdSetAlphaToCoverageEnableEXT
- vkCmdSetAlphaToOneEnableEXT
- vkCmdSetColorBlendAdvancedEXT
- vkCmdSetColorBlendEnableEXT
- vkCmdSetColorBlendEquationEXT
- vkCmdSetColorWriteMaskEXT
- vkCmdSetConservativeRasterizationModeEXT
- vkCmdSetDepthClampEnableEXT
- vkCmdSetDepthClipEnableEXT
- vkCmdSetDepthClipNegativeOneToOneEXT
- vkCmdSetExtraPrimitiveOverestimationSizeEXT
- vkCmdSetLineRasterizationModeEXT
- vkCmdSetLineStippleEnableEXT
- vkCmdSetLogicOpEnableEXT
- vkCmdSetPolygonModeEXT
- vkCmdSetProvokingVertexModeEXT
• `vkCmdSetRasterizationSamplesEXT`
• `vkCmdSetRasterizationStreamEXT`
• `vkCmdSetSampleLocationsEnableEXT`
• `vkCmdSetSampleMaskEXT`
• `vkCmdSetTessellationDomainOriginEXT`

If `VK_NV_clip_space_w_scaling` is supported:
  • `vkCmdSetViewportWScalingEnableNV`

If `VK_NV_coverage_reduction_mode` is supported:
  • `vkCmdSetCoverageReductionModeNV`

If `VK_NV_fragment_coverage_to_color` is supported:
  • `vkCmdSetCoverageToColorEnableNV`
  • `vkCmdSetCoverageToColorLocationNV`

If `VK_NV_framebuffer_mixed_samples` is supported:
  • `vkCmdSetCoverageModulationModeNV`
  • `vkCmdSetCoverageModulationTableEnableNV`
  • `vkCmdSetCoverageModulationTableNV`

If `VK_NV_representative_fragment_test` is supported:
  • `vkCmdSetRepresentativeFragmentTestEnableNV`

If `VK_NV_shading_rate_image` is supported:
  • `vkCmdSetShadingRateImageEnableNV`

If `VK_NV_viewport_swizzle` is supported:
  • `vkCmdSetViewportSwizzleNV`

**New Structures**

• `VkColorBlendAdvancedEXT`
• `VkColorBlendEquationEXT`

• Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  ◦ `VkPhysicalDeviceExtendedDynamicState3FeaturesEXT`

• Extending `VkPhysicalDeviceProperties2`:
  ◦ `VkPhysicalDeviceExtendedDynamicState3PropertiesEXT`
New Enum Constants

- `VK_EXT_EXTENDED_DYNAMIC_STATE_3_EXTENSION_NAME`
- `VK_EXT_EXTENDED_DYNAMIC_STATE_3_SPEC_VERSION`
- **Extending** `VkDynamicState`:
  - `VK_DYNAMIC_STATE_ALPHA_TO_COVERAGE_ENABLE_EXT`
  - `VK_DYNAMIC_STATE_ALPHA_TO_ONE_ENABLE_EXT`
  - `VK_DYNAMIC_STATE_COLOR_BLEND_ADVANCED_EXT`
  - `VK_DYNAMIC_STATE_COLOR_BLEND_ENABLE_EXT`
  - `VK_DYNAMIC_STATE_COLOR_BLEND_EQUATION_EXT`
  - `VK_DYNAMIC_STATE_COLOR_WRITE_MASK_EXT`
  - `VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT`
  - `VK_DYNAMIC_STATE_DEPTH_CLAMP_ENABLE_EXT`
  - `VK_DYNAMIC_STATE_DEPTH_CLIP_ENABLE_EXT`
  - `VK_DYNAMIC_STATE_DEPTH_CLIP_NEGATIVE_ONE_TO_ONE_EXT`
  - `VK_DYNAMIC_STATE_EXTRA_PRIMITIVE_OVERESTIMATION_SIZE_EXT`
  - `VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT`
  - `VK_DYNAMIC_STATE_LINE_STIPPLE_ENABLE_EXT`
  - `VK_DYNAMIC_STATE_LOGIC_OP_ENABLE_EXT`
  - `VK_DYNAMIC_STATE_POLYGON_MODE_EXT`
  - `VK_DYNAMIC_STATE_PROVOKING_VERTEX_MODE_EXT`
  - `VK_DYNAMIC_STATE_RASTERIZATION_SAMPLES_EXT`
  - `VK_DYNAMIC_STATE_RASTERIZATION_STREAM_EXT`
  - `VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_ENABLE_EXT`
  - `VK_DYNAMIC_STATE_SAMPLE_MASK_EXT`
  - `VK_DYNAMIC_STATE_TESSELLATION_DOMAIN_ORIGIN_EXT`
- **Extending** `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTENDED_DYNAMIC_STATE_3_FEATURES_EXT`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTENDED_DYNAMIC_STATE_3_PROPERTIES_EXT`

If `VK_NV_clip_space_w_scaling` is supported:

- **Extending** `VkDynamicState`:
  - `VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_ENABLE_NV`

If `VK_NV_coverage_reduction_mode` is supported:

- **Extending** `VkDynamicState`:
If `VK_NV_fragment_coverage_to_color` is supported:

- Extending `VkDynamicState`:
  - `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_ENABLE_NV`
  - `VK_DYNAMIC_STATE_COVERAGE_TO_COLOR_LOCATION_NV`

If `VK_NV_framebuffer_mixed_samples` is supported:

- Extending `VkDynamicState`:
  - `VK_DYNAMIC_STATE_COVERAGE_MODULATION_MODE_NV`
  - `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_ENABLE_NV`
  - `VK_DYNAMIC_STATE_COVERAGE_MODULATION_TABLE_NV`

If `VK_NV_representative_fragment_test` is supported:

- Extending `VkDynamicState`:
  - `VK_DYNAMIC_STATE_REPRESENTATIVE_FRAGMENT_TEST_ENABLE_NV`

If `VK_NV_shading_rate_image` is supported:

- Extending `VkDynamicState`:
  - `VK_DYNAMIC_STATE_SHADING_RATE_IMAGE_ENABLE_NV`

If `VK_NV_viewport_swizzle` is supported:

- Extending `VkDynamicState`:
  - `VK_DYNAMIC_STATE_VIEWPORT_SWIZZLE_NV`

**Issues**

1) What about the `VkPipelineMultisampleStateCreateInfo` state `sampleShadingEnable` and `minSampleShading`?

**UNRESOLVED**

- `sampleShadingEnable` and `minSampleShading` are required when compiling the fragment shader, and it is not meaningful to set them dynamically since they always need to match the fragment shader state, so this hardware state may as well just come from the pipeline with the fragment shader.

**Version History**

- Revision 2, 2022-07-18 (Piers Daniell)
  - Added rasterizationSamples
- Revision 1, 2022-05-18 (Piers Daniell)
VK_EXT_external_memory_acquire_unmodified

Name String
VK_EXT_external_memory_acquire_unmodified

Extension Type
Device extension

Registered Extension Number
454

Revision
1

Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_external_memory

Contact
• Lina Versace versalinyaa

Extension Proposal
VK_EXT_external_memory_acquire_unmodified

Other Extension Metadata

Last Modified Date
2023-03-09

Contributors
• Lina Versace, Google
• Chia-I Wu, Google
• James Jones, NVIDIA
• Yiwei Zhang, Google

Description
A memory barrier may have a performance penalty when acquiring ownership of a subresource range from an external queue family. This extension provides API that may reduce the performance penalty if ownership of the subresource range was previously released to the external queue family and if the resource's memory has remained unmodified between the release and acquire operations.
New Structures

• Extending VkBufferMemoryBarrier, VkBufferMemoryBarrier2, VkImageMemoryBarrier, VkImageMemoryBarrier2:
  ◦ VkExternalMemoryAcquireUnmodifiedEXT

New Enum Constants

• VK_EXT_EXTERNAL_MEMORY_ACQUIRE_UNMODIFIED_EXTENSION_NAME
• VK_EXT_EXTERNAL_MEMORY_ACQUIRE_UNMODIFIED_SPEC_VERSION

• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_ACQUIRE_UNMODIFIED_EXT

Version History

• Revision 1, 2023-03-09 (Lina Versace)
  ◦ Initial revision

VK_EXT_external_memory_dma_buf

Name String
  VK_EXT_external_memory_dma_buf

Extension Type
  Device extension

Registered Extension Number
  126

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_external_memory_fd

Contact
  • Lina Versace versalinyaa

Other Extension Metadata

Last Modified Date
  2017-10-10
IP Status
No known IP claims.

Contributors
- Lina Versace, Google
- James Jones, NVIDIA
- Faith Ekstrand, Intel

Description
A dma_buf is a type of file descriptor, defined by the Linux kernel, that allows sharing memory across kernel device drivers and across processes. This extension enables applications to import a dma_buf as VkDeviceMemory, to export VkDeviceMemory as a dma_buf, and to create VkBuffer objects that can be bound to that memory.

New Enum Constants
- VK_EXT_EXTERNAL_MEMORY_DMA_BUF_EXTENSION_NAME
- VK_EXT_EXTERNAL_MEMORY_DMA_BUF_SPEC_VERSION
- Extending VkExternalMemoryHandleTypeFlagBits:
  - VK_EXTERNAL_MEMORY_HANDLE_TYPE_DMA_BUF_BIT_EXT

Issues
1) How does the application, when creating a VkImage that it intends to bind to dma_buf VkDeviceMemory containing an externally produced image, specify the memory layout (such as row pitch and DRM format modifier) of the VkImage? In other words, how does the application achieve behavior comparable to that provided by EGL_EXT_image_dma_buf_import and EGL_EXT_image_dma_buf_import_modifiers?

RESOLVED: Features comparable to those in EGL_EXT_image_dma_buf_import and EGL_EXT_image_dma_buf_import_modifiers will be provided by an extension layered atop this one.

2) Without the ability to specify the memory layout of external dma_buf images, how is this extension useful?

RESOLVED: This extension provides exactly one new feature: the ability to import/export between dma_buf and VkDeviceMemory. This feature, together with features provided by VK_KHR_external_memory_fd, is sufficient to bind a VkBuffer to dma_buf.

Version History
- Revision 1, 2017-10-10 (Lina Versace)
  - Squashed internal revisions
VK_EXT_external_memory_host

Name String
  VK_EXT_external_memory_host

Extension Type
  Device extension

Registered Extension Number
  179

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_external_memory
  or
  Version 1.1

Contact
  • Daniel Rakos drakos

Other Extension Metadata

Last Modified Date
  2017-11-10

IP Status
  No known IP claims.

Contributors
  • Jaakko Konttinen, AMD
  • David Mao, AMD
  • Daniel Rakos, AMD
  • Tobias Hector, Imagination Technologies
  • Faith Ekstrand, Intel
  • James Jones, NVIDIA

Description
This extension enables an application to import host allocations and host mapped foreign device memory to Vulkan memory objects.
New Commands

- vkGetMemoryHostPointerPropertiesEXT

New Structures

- VkMemoryHostPointerPropertiesEXT
- Extending VkMemoryAllocateInfo:
  - VkImportMemoryHostPointerInfoEXT
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceExternalMemoryHostPropertiesEXT

New Enum Constants

- VK_EXT_EXTERNAL_MEMORY_HOST_EXTENSION_NAME
- VK_EXT_EXTERNAL_MEMORY_HOST_SPEC_VERSION
- Extending VkExternalMemoryHandleTypeFlagBits:
  - VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_ALLOCATION_BIT_EXT
  - VK_EXTERNAL_MEMORY_HANDLE_TYPE_HOST_MAPPED_FOREIGN_MEMORY_BIT_EXT
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_IMPORT_MEMORY_HOST_POINTER_INFO_EXT
  - VK_STRUCTURE_TYPE_MEMORY_HOST_POINTER_PROPERTIES_EXT
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_MEMORY_HOST_PROPERTIES_EXT

Issues

1) What memory type has to be used to import host pointers?

**RESOLVED:** Depends on the implementation. Applications have to use the new `vkGetMemoryHostPointerPropertiesEXT` command to query the supported memory types for a particular host pointer. The reported memory types may include memory types that come from a memory heap that is otherwise not usable for regular memory object allocation and thus such a heap’s size may be zero.

2) Can the application still access the contents of the host allocation after importing?

**RESOLVED:** Yes. However, usual synchronization requirements apply.

3) Can the application free the host allocation?

**RESOLVED:** No, it violates valid usage conditions. Using the memory object imported from a host allocation that is already freed thus results in undefined behavior.

4) Is `vkMapMemory` expected to return the same host address which was specified when importing it to the memory object?
RESOLVED: No. Implementations are allowed to return the same address but it is not required. Some implementations might return a different virtual mapping of the allocation, although the same physical pages will be used.

5) Is there any limitation on the alignment of the host pointer and/or size?

RESOLVED: Yes. Both the address and the size have to be an integer multiple of minImportedHostPointerAlignment. In addition, some platforms and foreign devices may have additional restrictions.

6) Can the same host allocation be imported multiple times into a given physical device?

RESOLVED: No, at least not guaranteed by this extension. Some platforms do not allow locking the same physical pages for device access multiple times, so attempting to do it may result in undefined behavior.

7) Does this extension support exporting the new handle type?

RESOLVED: No.

8) Should we include the possibility to import host mapped foreign device memory using this API?

RESOLVED: Yes, through a separate handle type. Implementations are still allowed to support only one of the handle types introduced by this extension by not returning import support for a particular handle type as returned in VkExternalMemoryPropertiesKHR.

Version History

- Revision 1, 2017-11-10 (Daniel Rakos)
  - Internal revisions

VK_EXT_filter_cubic

Name String

VK_EXT_filter_cubic

Extension Type

Device extension

Registered Extension Number

171

Revision

3

Ratification Status

Not ratified
Description

VK_EXT_filter_cubic extends VK_IMG_filter_cubic.

It documents cubic filtering of other image view types. It adds new structures that can be added to the pNext chain of VkPhysicalDeviceImageFormatInfo2 and VkImageFormatProperties2 that can be used to determine which image types and which image view types support cubic filtering.

New Structures

- Extending VkImageFormatProperties2:
  - VkFilterCubicImageViewImageFormatPropertiesEXT
- Extending VkPhysicalDeviceImageFormatInfo2:
  - VkPhysicalDeviceImageViewImageFormatInfoEXT

New Enum Constants

- VK_EXT_FILTER_CUBIC_EXTENSION_NAME
- VK_EXT_FILTER_CUBIC_SPEC_VERSION
- Extending VkFilter:
  - VK_FILTER_CUBIC_EXT
• Extending `VkFormatFeatureFlagBits`:
  ◦ `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_EXT`

• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_FILTER_CUBIC_IMAGE_VIEW_IMAGE_FORMAT_PROPERTIES_EXT`
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_VIEW_IMAGE_FORMAT_INFO_EXT`

**Version History**

• Revision 3, 2019-12-13 (wwlk)
  ◦ Delete requirement to cubic filter the formats USCALED_PACKED32, SScaled_PACKED32, UINT_PACK32, and SINT_PACK32 (cut/paste error)

• Revision 2, 2019-06-05 (wwlk)
  ◦ Clarify 1D optional

• Revision 1, 2019-01-24 (wwlk)
  ◦ Initial version

**VK_EXT_fragment_density_map**

**Name String**

`VK_EXT_fragment_density_map`

**Extension Type**

Device extension

**Registered Extension Number**

219

**Revision**

2

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

`VK_KHR_get_physical_device_properties2`

**Contact**

• Matthew Netsch [mnetsch](mailto:mnetsch)

**Other Extension Metadata**

**Last Modified Date**

2021-09-30
Interactions and External Dependencies

- This extension requires `SPV_EXT_fragment_invocation_density`
- This extension provides API support for `GL_EXT_fragment_invocation_density`

Contributors

- Matthew Netsch, Qualcomm Technologies, Inc.
- Robert VanReenen, Qualcomm Technologies, Inc.
- Jonathan Wicks, Qualcomm Technologies, Inc.
- Tate Hornbeck, Qualcomm Technologies, Inc.
- Sam Holmes, Qualcomm Technologies, Inc.
- Jeff Leger, Qualcomm Technologies, Inc.
- Jan-Harald Fredriksen, ARM
- Jeff Bolz, NVIDIA
- Pat Brown, NVIDIA
- Daniel Rakos, AMD
- Piers Daniell, NVIDIA

Description

This extension allows an application to specify areas of the render target where the fragment shader may be invoked fewer times. These fragments are broadcasted out to multiple pixels to cover the render target.

The primary use of this extension is to reduce workloads in areas where lower quality may not be perceived such as the distorted edges of a lens or the periphery of a user’s gaze.

New Structures

- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDeviceFragmentDensityMapFeaturesEXT`
- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceFragmentDensityMapPropertiesEXT`
- Extending `VkRenderPassCreateInfo, VkRenderPassCreateInfo2`:
  - `VkRenderPassFragmentDensityMapCreateInfoEXT`

New Enum Constants

- `VK_EXT_FRAGMENT_DENSITY_MAP_EXTENSION_NAME`
- `VK_EXT_FRAGMENT_DENSITY_MAP_SPEC_VERSION`
- Extending `VkAccessFlagBits`:
  - `VK_ACCESS_FRAGMENT_DENSITY_MAP_READ_BIT_EXT`
• Extending **VkFormatFeatureFlagBits**:
  ◦ **VK_FORMAT_FEATURE_FRAGMENT_DENSITY_MAP_BIT_EXT**

• Extending **VkImageCreateFlagBits**:
  ◦ **VK_IMAGE_CREATE_SUBSAMPLED_BIT_EXT**

• Extending **VkImageLayout**:
  ◦ **VK_IMAGE_LAYOUT_FRAGMENT_DENSITY_MAP_OPTIMAL_EXT**

• Extending **VkImageUsageFlagBits**:
  ◦ **VK_IMAGE_USAGE_FRAGMENT_DENSITY_MAP_BIT_EXT**

• Extending **VkImageViewCreateFlagBits**:
  ◦ **VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DYNAMIC_BIT_EXT**

• Extending **VkPipelineStageFlagBits**:
  ◦ **VK_PIPELINE_STAGE_FRAGMENT_DENSITY_PROCESS_BIT_EXT**

• Extending **VkSamplerCreateFlagBits**:
  ◦ **VK_SAMPLER_CREATE_SUBSAMPLED_BIT_EXT**
  ◦ **VK_SAMPLER_CREATE_SUBSAMPLED_COARSE_RECONSTRUCTION_BIT_EXT**

• Extending **VkStructureType**:
  ◦ **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_FEATURES_EXT**
  ◦ **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_PROPERTIES_EXT**
  ◦ **VK_STRUCTURE_TYPE_RENDER_PASS_FRAGMENT_DENSITY_MAP_CREATE_INFO_EXT**

If **VK_KHR_format_feature_flags2** is supported:

• Extending **VkFormatFeatureFlagBits2**:
  ◦ **VK_FORMAT_FEATURE_2_FRAGMENT_DENSITY_MAP_BIT_EXT**

**New or Modified Built-In Variables**

• **FragInvocationCountEXT**

• **FragSizeEXT**

**New SPIR-V Capabilities**

• **FragmentDensityEXT**

**Version History**

• Revision 1, 2018-09-25 (Matthew Netsch)
  ◦ Initial version

• Revision 2, 2021-09-30 (Jon Leech)
  ◦ Add interaction with **VK_KHR_format_feature_flags2** to **vk.xml**
VK_EXT_fragment_density_map2

Name String
VK_EXT_fragment_density_map2

Extension Type
Device extension

Registered Extension Number
333

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_EXT_fragment_density_map

Contact
• Matthew Netsch mnetsch

Other Extension Metadata

Last Modified Date
2020-06-16

Interactions and External Dependencies
• Interacts with Vulkan 1.1

Contributors
• Matthew Netsch, Qualcomm Technologies, Inc.
• Jonathan Tinkham, Qualcomm Technologies, Inc.
• Jonathan Wicks, Qualcomm Technologies, Inc.
• Jan-Harald Fredriksen, ARM

Description
This extension adds additional features and properties to VK_EXT_fragment_density_map in order to reduce fragment density map host latency as well as improved queries for subsampled sampler implementation-dependent behavior.

New Structures
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  • VkPhysicalDeviceFragmentDensityMap2FeaturesEXT
• Extending VkPhysicalDeviceProperties2:
  ◦ VkPhysicalDeviceFragmentDensityMap2PropertiesEXT

New Enum Constants

• VK_EXT_FRAGMENT_DENSITY_MAP_2_EXTENSION_NAME
• VK_EXT_FRAGMENT_DENSITY_MAP_2_SPEC_VERSION

• Extending VkImageViewCreateFlagBits:
  ◦ VK_IMAGE_VIEW_CREATE_FRAGMENT_DENSITY_MAP_DEFERRED_BIT_EXT

• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_2_FEATURES_EXT
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_2_PROPERTIES_EXT

Version History

• Revision 1, 2020-06-16 (Matthew Netsch)
  ◦ Initial version

VK_EXT_fragment_shader_interlock

Name String
  VK_EXT_fragment_shader_interlock

Extension Type
  Device extension

Registered Extension Number
  252

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_get_physical_device_properties2
  or
  Version 1.1

Contact
  • Piers Daniell pdaniell-nv
Other Extension Metadata

Last Modified Date
2019-05-02

Interactions and External Dependencies
• This extension requires SPV_EXT_fragment_shader_interlock
• This extension provides API support for GL_ARB_fragment_shader_interlock

Contributors
• Daniel Koch, NVIDIA
• Graeme Leese, Broadcom
• Jan-Harald Fredriksen, Arm
• Faith Ekstrand, Intel
• Jeff Bolz, NVIDIA
• Ruihao Zhang, Qualcomm
• Slawomir Grajewski, Intel
• Spencer Fricke, Samsung

Description
This extension adds support for the FragmentShaderPixelInterlockEXT, FragmentShaderSampleInterlockEXT, and FragmentShaderShadingRateInterlockEXT capabilities from the SPV_EXT_fragment_shader_interlock extension to Vulkan.

Enabling these capabilities provides a critical section for fragment shaders to avoid overlapping pixels being processed at the same time, and certain guarantees about the ordering of fragment shader invocations of fragments of overlapping pixels.

This extension can be useful for algorithms that need to access per-pixel data structures via shader loads and stores. Algorithms using this extension can access per-pixel data structures in critical sections without other invocations accessing the same per-pixel data. Additionally, the ordering guarantees are useful for cases where the API ordering of fragments is meaningful. For example, applications may be able to execute programmable blending operations in the fragment shader, where the destination buffer is read via image loads and the final value is written via image stores.

New Structures
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceFragmentShaderInterlockFeaturesEXT

New Enum Constants
• VK_EXT_FRAGMENT_SHADER_INTERLOCK_EXTENSION_NAME
• VK_EXT_FRAGMENT_SHADER_INTERLOCK_SPEC_VERSION
• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADER_INTERLOCK_FEATURES_EXT`

New SPIR-V Capabilities

• `FragmentShaderInterlockEXT`
• `FragmentShaderPixelInterlockEXT`
• `FragmentShaderShadingRateInterlockEXT`

Version History

• Revision 1, 2019-05-24 (Piers Daniell)
  ◦ Internal revisions

`VK_EXT_frame_boundary`

Name String

`VK_EXT_frame_boundary`

Extension Type

Device extension

Registered Extension Number

376

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

Contact

• James Fitzpatrick @jamesfitzpatrick

Extension Proposal

`VK_EXT_frame_boundary`

Other Extension Metadata

Last Modified Date

2023-06-14

Contributors

• James Fitzpatrick, Imagination Technologies
• Hugues Evrard, Google
Description

VK_EXT_frame_boundary is a device extension that helps tools (such as debuggers) to group queue submissions per frames in non-trivial scenarios, typically when vkQueuePresentKHR is not a relevant frame boundary delimiter.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceFrameBoundaryFeaturesEXT
- Extending VkSubmitInfo, VkSubmitInfo2, VkPresentInfoKHR, VkBindSparseInfo:
  - VkFrameBoundaryEXT

New Enums

- VkFrameBoundaryFlagBitsEXT

New Bitmasks

- VkFrameBoundaryFlagsEXT

New Enum Constants

- VK_EXT_FRAME_BOUNDARY_EXTENSION_NAME
- VK_EXT_FRAME_BOUNDARY_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_FRAME_BOUNDARY_EXT
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAME_BOUNDARY_FEATURES_EXT

Version History

- Revision 0, 2022-01-14 (Hugues Evard)
  - Initial proposal
- Revision 1, 2023-06-14 (James Fitzpatrick)
  - Initial draft
VK_EXT_full_screen_exclusive

Name String
   VK_EXT_full_screen_exclusive

Extension Type
   Device extension

Registered Extension Number
   256

Revision
   4

Ratification Status
   Not ratified

Extension and Version Dependencies
   VK_KHR_get_physical_device_properties2
   and
   VK_KHR_surface
   and
   VK_KHR_get_surface_capabilities2
   and
   VK_KHR_swapchain

Contact
   • James Jones 🌼cubanismo

Other Extension Metadata

Last Modified Date
   2019-03-12

IP Status
   No known IP claims.

Interactions and External Dependencies
   • Interacts with Vulkan 1.1
   • Interacts with VK_KHR_device_group
   • Interacts with VK_KHR_win32_surface

Contributors
   • Hans-Kristian Arntzen, ARM
   • Slawomir Grajewski, Intel
   • Tobias Hector, AMD
Description

This extension allows applications to set the policy for swapchain creation and presentation mechanisms relating to full-screen access. Implementations may be able to acquire exclusive access to a particular display for an application window that covers the whole screen. This can increase performance on some systems by bypassing composition, however it can also result in disruptive or expensive transitions in the underlying windowing system when a change occurs.

Applications can choose between explicitly disallowing or allowing this behavior, letting the implementation decide, or managing this mode of operation directly using the new `vkAcquireFullScreenExclusiveModeEXT` and `vkReleaseFullScreenExclusiveModeEXT` commands.

New Commands

- `vkAcquireFullScreenExclusiveModeEXT`
- `vkGetPhysicalDeviceSurfacePresentModes2EXT`
- `vkReleaseFullScreenExclusiveModeEXT`

If `VK_KHR_device_group` is supported:

- `vkGetDeviceGroupSurfacePresentModes2EXT`

If Version 1.1 is supported:

- `vkGetDeviceGroupSurfacePresentModes2EXT`

New Structures

- Extending `VkPhysicalDeviceSurfaceInfo2KHR`, `VkSwapchainCreateInfoKHR`:
  - `VkSurfaceFullScreenExclusiveInfoEXT`
- Extending `VkSurfaceCapabilities2KHR`:
  - `VkSurfaceCapabilitiesFullScreenExclusiveEXT`

If `VK_KHR_win32_surface` is supported:

- Extending `VkPhysicalDeviceSurfaceInfo2KHR`, `VkSwapchainCreateInfoKHR`:
  - `VkSurfaceFullScreenExclusiveWin32InfoEXT`
New Enums

• VkFullScreenExclusiveEXT

New Enum Constants

• VK_EXT_FULL_SCREEN_EXCLUSIVE_EXTENSION_NAME
• VK_EXT_FULL_SCREEN_EXCLUSIVE_SPEC_VERSION

• Extending VkResult:
  ◦ VK_ERROR_FULL_SCREEN_EXCLUSIVE_MODE_LOST_EXT

• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_SURFACE_CAPABILITIES_FULL_SCREEN_EXCLUSIVE_EXT
  ◦ VK_STRUCTURE_TYPE_SURFACE_FULL_SCREEN_EXCLUSIVE_INFO_EXT

If VK_KHR_win32_surface is supported:

• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_SURFACE_FULL_SCREEN_EXCLUSIVE_WIN32_INFO_EXT

Issues

1) What should the extension & flag be called?

**RESOLVED:** VK_EXT_full-screen-exclusive.

Other options considered (prior to the app-controlled mode) were:

• VK_EXT_smooth_fullscreen_transition
• VK_EXT_fullscreen_behavior
• VK_EXT_fullscreen_preference
• VK_EXT_fullscreen_hint
• VK_EXT_fast_fullscreen_transition
• VK_EXT_avoid_fullscreen_exclusive

2) Do we need more than a boolean toggle?

**RESOLVED:** Yes.

Using an enum with default/allowed/disallowed/app-controlled enables applications to accept driver default behavior, specifically override it in either direction without implying the driver is ever required to use full-screen exclusive mechanisms, or manage this mode explicitly.

3) Should this be a KHR or EXT extension?

**RESOLVED:** EXT, in order to allow it to be shipped faster.
4) Can the fullscreen hint affect the surface capabilities, and if so, should the hint also be specified as input when querying the surface capabilities?

**RESOLVED:** Yes on both accounts.

While the hint does not guarantee a particular fullscreen mode will be used when the swapchain is created, it can sometimes imply particular modes will NOT be used. If the driver determines that it will opt-out of using a particular mode based on the policy, and knows it can only support certain capabilities if that mode is used, it would be confusing at best to the application to report those capabilities in such cases. Not allowing implementations to report this state to applications could result in situations where applications are unable to determine why swapchain creation fails when they specify certain hint values, which could result in never-terminating surface creation loops.

5) Should full-screen be one word or two?

**RESOLVED:** Two words.

"Fullscreen" is not in my dictionary, and web searches did not turn up definitive proof that it is a colloquially accepted compound word. Documentation for the corresponding Windows API mechanisms dithers. The text consistently uses a hyphen, but none-the-less, there is a SetFullScreenState method in the DXGI swapchain object. Given this inconclusive external guidance, it is best to adhere to the Vulkan style guidelines and avoid inventing new compound words.

**Version History**

- **Revision 4, 2019-03-12 (Tobias Hector)**
  - Added application-controlled mode, and related functions
  - Tidied up appendix
- **Revision 3, 2019-01-03 (James Jones)**
  - Renamed to VK_EXT_full_screen_exclusive
  - Made related adjustments to the tri-state enumerant names.
- **Revision 2, 2018-11-27 (James Jones)**
  - Renamed to VK_KHR_fullscreen_behavior
  - Switched from boolean flag to tri-state enum
- **Revision 1, 2018-11-06 (James Jones)**
  - Internal revision

**VK_EXT_graphics_pipeline_library**

**Name String**

VK_EXT_graphics_pipeline_library

**Extension Type**

Device extension
Description

This extension allows the separate compilation of four distinct parts of graphics pipelines, with the intent of allowing faster pipeline loading for applications reusing the same shaders or state in
multiple pipelines. Each part can be independently compiled into a graphics pipeline library, with a final link step required to create an executable pipeline that can be bound to a command buffer.

New Structures

- Extending `VkGraphicsPipelineCreateInfo`
  - `VkGraphicsPipelineLibraryCreateInfoEXT`
- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`
  - `VkPhysicalDeviceGraphicsPipelineLibraryFeaturesEXT`
- Extending `VkPhysicalDeviceProperties2`
  - `VkPhysicalDeviceGraphicsPipelineLibraryPropertiesEXT`

New Enums

- `VkGraphicsPipelineLibraryFlagBitsEXT`
- `VkPipelineLayoutCreateFlagBits`

New Bitmasks

- `VkGraphicsPipelineLibraryFlagsEXT`

New Enum Constants

- `VK_EXT_GRAPHICS_PIPELINE_LIBRARY_EXTENSION_NAME`
- `VK_EXT_GRAPHICS_PIPELINE_LIBRARY_SPEC_VERSION`
- Extending `VkPipelineCreateFlagBits`
  - `VK_PIPELINE_CREATE_LINK_TIME_OPTIMIZATION_BIT_EXT`
  - `VK_PIPELINE_CREATE_RETAIN_LINK_TIME_OPTIMIZATION_INFO_BIT_EXT`
- Extending `VkPipelineLayoutCreateFlagBits`
  - `VK_PIPELINE_LAYOUT_CREATE_INDEPENDENT_SETS_BIT_EXT`
- Extending `VkStructureType`
  - `VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_LIBRARY_CREATE_INFO_EXT`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GRAPHICS_PIPELINE_LIBRARY_FEATURES_EXT`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GRAPHICS_PIPELINE_LIBRARY_PROPERTIES_EXT`

Version History

- Revision 1, 2021-08-17 (Tobias Hector)
  - Initial draft.
VK_EXT_hdr_metadata

Name String

VK_EXT_hdr_metadata

Extension Type

Device extension

Registered Extension Number

106

Revision

2

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_swapchain

Contact

• Courtney Goeltzenleuchter courtney-g

Other Extension Metadata

Last Modified Date

2018-12-19

IP Status

No known IP claims.

Contributors

• Courtney Goeltzenleuchter, Google

Description

This extension defines two new structures and a function to assign SMPTE (the Society of Motion Picture and Television Engineers) 2086 metadata and CTA (Consumer Technology Association) 861.3 metadata to a swapchain. The metadata includes the color primaries, white point, and luminance range of the reference monitor, which all together define the color volume containing all the possible colors the reference monitor can produce. The reference monitor is the display where creative work is done and creative intent is established. To preserve such creative intent as much as possible and achieve consistent color reproduction on different viewing displays, it is useful for the display pipeline to know the color volume of the original reference monitor where content was created or tuned. This avoids performing unnecessary mapping of colors that are not displayable on the original reference monitor. The metadata also includes the maxContentLightLevel and maxFrameAverageLightLevel as defined by CTA 861.3.
While the intended purpose of the metadata is to assist in the transformation between different color volumes of different displays and help achieve better color reproduction, it is not in the scope of this extension to define how exactly the metadata should be used in such a process. It is up to the implementation to determine how to make use of the metadata.

**New Commands**

- `vkSetHdrMetadataEXT`

**New Structures**

- `VkHdrMetadataEXT`
- `VkXYColorEXT`

**New Enum Constants**

- `VK_EXT_HDR_METADATA_EXTENSION_NAME`
- `VK_EXT_HDR_METADATA_SPEC_VERSION`

Extending `VkStructureType`:
- `VK_STRUCTURE_TYPE_HDR_METADATA_EXT`

**Issues**

1) Do we need a query function?

**PROPOSED:** No, Vulkan does not provide queries for state that the application can track on its own.

2) Should we specify default if not specified by the application?

**PROPOSED:** No, that leaves the default up to the display.

**Version History**

- Revision 1, 2016-12-27 (Courtney Goeltzenleuchter)
  - Initial version
- Revision 2, 2018-12-19 (Courtney Goeltzenleuchter)
  - Correct implicit validity for `VkHdrMetadataEXT` structure

**VK_EXT_headless_surface**

**Name String**

- `VK_EXT_headless_surface`

**Extension Type**

- Instance extension
Description

The VK_EXT_headless_surface extension is an instance extension. It provides a mechanism to create VkSurfaceKHR objects independently of any window system or display device. The presentation operation for a swapchain created from a headless surface is by default a no-op, resulting in no externally-visible result.

Because there is no real presentation target, future extensions can layer on top of the headless surface to introduce arbitrary or customisable sets of restrictions or features. These could include features like saving to a file or restrictions to emulate a particular presentation target.

This functionality is expected to be useful for application and driver development because it allows any platform to expose an arbitrary or customisable set of restrictions and features of a presentation engine. This makes it a useful portable test target for applications targeting a wide range of presentation engines where the actual target presentation engines might be scarce, unavailable or otherwise undesirable or inconvenient to use for general Vulkan application development.

New Commands

- vkCreateHeadlessSurfaceEXT
New Structures
- VkHeadlessSurfaceCreateInfoEXT

New Bitmasks
- VkHeadlessSurfaceCreateFlagsEXT

New Enum Constants
- VK_EXT_HEADLESS_SURFACE_EXTENSION_NAME
- VK_EXT_HEADLESS_SURFACE_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_HEADLESS_SURFACE_CREATE_INFO_EXT

Version History
- Revision 1, 2019-03-21 (Ray Smith)
  - Initial draft

VK_EXT_host_image_copy

Name String
VK_EXT_host_image_copy

Extension Type
Device extension

Registered Extension Number
271

Revision
1

Ratification Status
Ratified

Extension and Version Dependencies
- VK_KHR_get_physical_device_properties2
- VK_KHR_copy_commands2
- VK_KHR_format_feature_flags2

Contact
- Shahbaz Youssefi syoussefi
Extension Proposal

VK_EXT_host_image_copy

Other Extension Metadata

Last Modified Date
2023-04-26

Contributors

• Shahbaz Youssefi, Google
• Faith Ekstrand, Collabora
• Hans-Kristian Arntzen, Valve
• Piers Daniell, NVIDIA
• Jan-Harald Fredriksen, Arm
• James Fitzpatrick, Imagination
• Daniel Story, Nintendo

Description

This extension allows applications to copy data between host memory and images on the host processor, without staging the data through a GPU-accessible buffer. This removes the need to allocate and manage the buffer and its associated memory. On some architectures it may also eliminate an extra copy operation. This extension additionally allows applications to copy data between images on the host.

To support initializing a new image in preparation for a host copy, it is now possible to transition a new image to VK_IMAGE_LAYOUT_GENERAL or other host-copyable layouts via vkTransitionImageLayoutEXT. Additionally, it is possible to perform copies that preserve the swizzling layout of the image by using the VK_HOST_IMAGE_COPY_MEMCPY_EXT flag. In that case, the memory size needed for copies to or from a buffer can be retrieved by chaining VkSubresourceHostMemcpySizeEXT to pLayout in vkGetImageSubresourceLayout2EXT.

New Commands

• vkCopyImageToImageEXT
• vkCopyImageToMemoryEXT
• vkCopyMemoryToImageEXT
• vkGetImageSubresourceLayout2EXT
• vkTransitionImageLayoutEXT

New Structures

• VkCopyImageToImageInfoEXT
• VkCopyImageToMemoryInfoEXT
• VkCopyMemoryToImageInfoEXT
• VkHostImageLayoutTransitionInfoEXT
• VkImageSubresource2EXT
• VkImageToMemoryCopyEXT
• VkMemoryToImageCopyEXT
• VkSubresourceLayout2EXT
• Extending VkImageFormatProperties2:
  ◦ VkHostImageCopyDevicePerformanceQueryEXT
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceHostImageCopyFeaturesEXT
• Extending VkPhysicalDeviceProperties2:
  ◦ VkPhysicalDeviceHostImageCopyPropertiesEXT
• Extending VkSubresourceLayout2KHR:
  ◦ VkSubresourceHostMemcpySizeEXT

New Enums
• VkHostImageCopyFlagBitsEXT

New Bitmasks
• VkHostImageCopyFlagsEXT

New Enum Constants
• VK_EXT_HOST_IMAGE_COPY_EXTENSION_NAME
• VK_EXT_HOST_IMAGE_COPY_SPEC_VERSION
• Extending VkFormatFeatureFlagBits2:
  ◦ VK_FORMAT_FEATURE_2_HOST_IMAGE_TRANSFER_BIT_EXT
• Extending VkImageUsageFlagBits:
  ◦ VK_IMAGE_USAGE_HOST_TRANSFER_BIT_EXT
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_COPY_IMAGE_TO_IMAGE_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_COPY_IMAGE_TO_MEMORY_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_COPY_MEMORY_TO_IMAGE_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_HOST_IMAGE_COPY_DEVICE_PERFORMANCE_QUERY_EXT
  ◦ VK_STRUCTURE_TYPE_HOST_IMAGE_LAYOUT_TRANSITION_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_IMAGE_TO_MEMORY_COPY_EXT
Issues

1) When uploading data to an image, the data is usually loaded from disk. Why not have the application load the data directly into a `VkDeviceMemory` bound to a buffer (instead of host memory), and use `vkCmdCopyBufferToImage`? The same could be done when downloading data from an image.

**RESOLVED:** This may not always be possible. Complicated Vulkan applications such as game engines often have decoupled subsystems for streaming data and rendering. It may be unreasonable to require the streaming subsystem to coordinate with the rendering subsystem to allocate memory on its behalf, especially as Vulkan may not be the only API supported by the engine. In emulation layers, the image data is necessarily provided by the application in host memory, so an optimization as suggested is not possible. Most importantly, the device memory may not be mappable by an application, but still accessible to the driver.

2) Are `optimalBufferCopyOffsetAlignment` and `optimalBufferCopyRowPitchAlignment` applicable to host memory as well with the functions introduced by this extension? Or should there be new limits?

**RESOLVED:** No alignment requirements for the host memory pointer.

3) Should there be granularity requirements for image offsets and extents?

**RESOLVED:** No granularity requirements, i.e. a granularity of 1 pixel (for non-compressed formats) and 1 texel block (for compressed formats) is assumed.

4) How should the application deal with layout transitions before or after copying to or from images?

**RESOLVED:** An existing issue with linear images is that when emulating other APIs, it is impossible to know when to transition them as they are written to by the host and then used bindlessly. The copy operations in this extension are affected by the same limitation. A new command is thus introduced by this extension to address this problem by allowing the host to perform an image layout transition between a handful of layouts.

Version History

- Revision 0, 2021-01-20 (Faith Ekstrand)
  - Initial idea and xml
- Revision 1, 2023-04-26 (Shahbaz Youssefi)
  - Initial revision
VK_EXT_image_2d_view_of_3d

Name String

VK_EXT_image_2d_view_of_3d

Extension Type

Device extension

Registered Extension Number

394

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_maintenance1
and
VK_KHR_get_physical_device_properties2

Special Use

- OpenGL / ES support

Contact

- Mike Blumenkrantz zmike

Other Extension Metadata

Last Modified Date

2022-02-22

IP Status

No known IP claims.

Contributors

- Mike Blumenkrantz, Valve
- Piers Daniell, NVIDIA
- Spencer Fricke, Samsung
- Ricardo Garcia, Igalia
- Graeme Leese, Broadcom
- Ralph Potter, Samsung
- Stu Smith, AMD
- Shahbaz Youssefi, Google
Description

This extension allows a single slice of a 3D image to be used as a 2D view in image descriptors, matching both the functionality of glBindImageTexture in OpenGL with the layer parameter set to true and 2D view binding provided by the extension EGL_KHR_gl_texture_3D_image. It is primarily intended to support GL emulation.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceImage2DViewOf3DFeaturesEXT

New Enum Constants

- VK_EXT_IMAGE_2D_VIEW_OF_3D_EXTENSION_NAME
- VK_EXT_IMAGE_2D_VIEW_OF_3D_SPEC_VERSION
- Extending VkImageCreateFlagBits:
  - VK_IMAGE_CREATE_2D_VIEW_COMPATIBLE_BIT_EXT
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_2D_VIEW_OF_3D_FEATURES_EXT

Version History

- Revision 1, 2022-03-25 (Mike Blumenkrantz)
  - Internal revisions

VK_EXT_image_compression_control

Name String

VK_EXT_image_compression_control

Extension Type

Device extension

Registered Extension Number

339

Revision

1

RatIFICATION STATUS

Not ratified
Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Contact

• Jan-Harald Fredriksen 📧janharaldfredriksen-arm

Extension Proposal

VK_EXT_image_compression_control

Other Extension Metadata

Last Modified Date

2022-05-02

IP Status

No known IP claims.

Contributors

• Jan-Harald Fredriksen, Arm
• Graeme Leese, Broadcom
• Andrew Garrard, Imagination
• Lisa Wu, Arm
• Peter Kohaut, Arm

Description

This extension enables fixed-rate image compression and adds the ability to control when this kind of compression can be applied. Many implementations support some form of framebuffer compression. This is typically transparent to applications as lossless compression schemes are used. With fixed-rate compression, the compression is done at a defined bitrate. Such compression algorithms generally produce results that are visually lossless, but the results are typically not bit-exact when compared to a non-compressed result. The implementation may not be able to use the requested compression rate in all cases. This extension adds a query that can be used to determine the compression scheme and rate that was applied to an image.

New Commands

• vkGetImageSubresourceLayout2EXT

New Structures

• VkImageSubresource2EXT
• VkSubresourceLayout2EXT
• Extending VkImageCreateInfo, VkSwapchainCreateInfoKHR, VkPhysicalDeviceImageFormatInfo2:
  • VkImageCompressionControlEXT
• Extending `VkImageFormatProperties2`, `VkSurfaceFormat2KHR`, `VkSubresourceLayout2KHR`:
  ◦ `VkImageCompressionPropertiesEXT`

• Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  ◦ `VkPhysicalDeviceImageCompressionControlFeaturesEXT`

**New Enums**

• `VkImageCompressionFixedRateFlagBitsEXT`

• `VkImageCompressionFlagBitsEXT`

**New Bitmasks**

• `VkImageCompressionFixedRateFlagsEXT`

• `VkImageCompressionFlagsEXT`

**New Enum Constants**

• `VK_EXT_IMAGE_COMPRESSION_CONTROL_EXTENSION_NAME`

• `VK_EXT_IMAGE_COMPRESSION_CONTROL_SPEC_VERSION`

• Extending `VkResult`:
  ◦ `VK_ERROR_COMPRESSION_EXHAUSTED_EXT`

• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_IMAGE_COMPRESSION_CONTROL_EXT`
  ◦ `VK_STRUCTURE_TYPE_IMAGE_COMPRESSION_PROPERTIES_EXT`
  ◦ `VK_STRUCTURE_TYPE_IMAGE_SUBRESOURCE_2_EXT`
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_COMPRESSION_CONTROL_FEATURES_EXT`
  ◦ `VK_STRUCTURE_TYPE_SUBRESOURCE_LAYOUT_2_EXT`

**Version History**

• Revision 1, 2022-05-02 (Jan-Harald Fredriksen)
  ◦ Initial draft

**VK_EXT_image_compression_control_swapchain**

**Name String**

`VK_EXT_image_compression_control_swapchain`

**Extension Type**

Device extension
Registered Extension Number
438

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_EXT_image_compression_control

Contact
• Jan-Harald Fredriksen janharaldfredriksen-arm

Other Extension Metadata

Last Modified Date
2022-05-02

IP Status
No known IP claims.

Contributors
• Jan-Harald Fredriksen, Arm
• Graeme Leese, Broadcom
• Andrew Garrard, Imagination
• Lisa Wu, Arm
• Peter Kohaut, Arm
• Ian Elliott, Google

Description
This extension enables fixed-rate image compression and adds the ability to control when this kind of compression can be applied to swapchain images.

New Structures
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceImageCompressionControlSwapchainFeaturesEXT

New Enum Constants
• VK_EXT_IMAGE_COMPRESSION_CONTROL_SWAPCHAIN_EXTENSION_NAME
• VK_EXT_IMAGE_COMPRESSION_CONTROL_SWAPCHAIN_SPEC_VERSION
• Extending **VkStructureType**:
  ◦ **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_COMPRESSION_CONTROL_SWAPCHAIN_FEATURES_EXT**

**Version History**

• Revision 1, 2022-05-02 (Jan-Harald Fredriksen)
  ◦ Initial draft

**VK_EXT_image_drm_format_modifier**

**Name String**

VK_EXT_image_drm_format_modifier

**Extension Type**

Device extension

**Registered Extension Number**

159

**Revision**

2

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

VK_KHR_bind_memory2
and
VK_KHR_get_physical_device_properties2
and
VK_KHR_sampler_ycbcr_conversion
or
Version 1.1
and
VK_KHR_image_format_list
or
Version 1.2

**Contact**

• Lina Versace [versalinyaa](https://twitter.com/versalinyaa)

**Other Extension Metadata**

**Last Modified Date**

2021-09-30
Description

This extension provides the ability to use DRM format modifiers with images, enabling Vulkan to better integrate with the Linux ecosystem of graphics, video, and display APIs.

Its functionality closely overlaps with EGL_EXT_image_dma_buf_import_modifiers and EGL_MESA_image_dma_buf_export. Unlike the EGL extensions, this extension does not require the use of a specific handle type (such as a dma_buf) for external memory and provides more explicit control of image creation.

Introduction to DRM Format Modifiers

A DRM format modifier is a 64-bit, vendor-prefixed, semi-opaque unsigned integer. Most modifiers represent a concrete, vendor-specific tiling format for images. Some exceptions are DRM_FORMAT_MOD_LINEAR (which is not vendor-specific); DRM_FORMAT_MOD_NONE (which is an alias of DRM_FORMAT_MOD_LINEAR due to historical accident); and DRM_FORMAT_MOD_INVALID (which does not represent a tiling format). The modifier’s vendor prefix consists of the 8 most significant bits. The canonical list of modifiers and vendor prefixes is found in drm_fourcc.h in the Linux kernel source. The other dominant source of modifiers are vendor kernel trees.

One goal of modifiers in the Linux ecosystem is to enumerate for each vendor a reasonably sized set of tiling formats that are appropriate for images shared across processes, APIs, and/or devices, where each participating component may possibly be from different vendors. A non-goal is to enumerate all tiling formats supported by all vendors. Some tiling formats used internally by vendors are inappropriate for sharing; no modifiers should be assigned to such tiling formats.

Modifier values typically do not describe memory layouts. More precisely, a modifier’s lower 56 bits usually have no structure. Instead, modifiers name memory layouts; they name a small set of vendor-preferred layouts for image sharing. As a consequence, in each vendor namespace the modifier values are often sequentially allocated starting at 1.

Each modifier is usually supported by a single vendor and its name matches the pattern {VENDOR}_FORMAT_MOD_* or DRM_FORMAT_MOD_{VENDOR}_*. Examples are I915_FORMAT_MOD_X_TILED and
An exception is `DRM_FORMAT_MOD_LINEAR`, which is supported by most vendors.

Many APIs in Linux use *modifiers* to negotiate and specify the memory layout of shared images. For example, a Wayland compositor and Wayland client may, by relaying *modifiers* over the Wayland protocol `zwp_linux_dmabuf_v1`, negotiate a vendor-specific tiling format for a shared `wl_buffer`. The client may allocate the underlying memory for the `wl_buffer` with GBM, providing the chosen *modifier* to `gbm_bo_create_with_modifiers`. The client may then import the `wl_buffer` into Vulkan for producing image content, providing the resource’s `dma_buf` to `VkImportMemoryFdInfoKHR` and its *modifier* to `VkImageDrmFormatModifierExplicitCreateInfoEXT`. The compositor may then import the `wl_buffer` into OpenGL for sampling, providing the resource’s `dma_buf` and *modifier* to `eglCreateImage`. The compositor may also bypass OpenGL and submit the `wl_buffer` directly to the kernel’s display API, providing the `dma_buf` and *modifier* through `drm_mode_fb_cmd2`.

### Format Translation

*Modifier*-capable APIs often pair *modifiers* with DRM formats, which are defined in `drm_fourcc.h`. However, `VK_EXT_image_drm_format_modifier` uses `VkFormat` instead of DRM formats. The application must convert between `VkFormat` and DRM format when it sends or receives a DRM format to or from an external API.

The mapping from `VkFormat` to DRM format is lossy. Therefore, when receiving a DRM format from an external API, often the application must use information from the external API to accurately map the DRM format to a `VkFormat`. For example, DRM formats do not distinguish between RGB and sRGB (as of 2018-03-28); external information is required to identify the image’s color space.

The mapping between `VkFormat` and DRM format is also incomplete. For some DRM formats there exist no corresponding Vulkan format, and for some Vulkan formats there exist no corresponding DRM format.

### Usage Patterns

Three primary usage patterns are intended for this extension:

- **Negotiation.** The application negotiates with *modifier*-aware, external components to determine sets of image creation parameters supported among all components.

  In the Linux ecosystem, the negotiation usually assumes the image is a 2D, single-sampled, non-mipmapmed, non-array image; this extension permits that assumption but does not require it. The result of the negotiation usually resembles a set of tuples such as `(drmFormat, drmFormatModifier)`, where each participating component supports all tuples in the set.

  Many details of this negotiation - such as the protocol used during negotiation, the set of image creation parameters expressible in the protocol, and how the protocol chooses which process and which API will create the image - are outside the scope of this specification.

  In this extension, `vkGetPhysicalDeviceFormatProperties2` with `VkDrmFormatModifierPropertiesListEXT` serves a primary role during the negotiation, and `vkGetPhysicalDeviceImageFormatProperties2` with...


**VkPhysicalDeviceImageDrmFormatModifierInfoEXT** serves a secondary role.

- **Import.** The application imports an image with a *modifier*.

  In this pattern, the application receives from an external source the image's memory and its creation parameters, which are often the result of the negotiation described above. Some image creation parameters are implicitly defined by the external source; for example, `VK_IMAGE_TYPE_2D` is often assumed. Some image creation parameters are usually explicit, such as the image's *format*, *drmFormatModifier*, and *extent*; and each plane's *offset* and *rowPitch*.

  Before creating the image, the application first verifies that the physical device supports the received creation parameters by querying `vkGetPhysicalDeviceFormatProperties2` with `VkDrmFormatModifierPropertiesListEXT` and `vkGetPhysicalDeviceImageFormatProperties2` with `VkPhysicalDeviceImageDrmFormatModifierInfoEXT`. Then the application creates the image by chaining `VkImageDrmFormatModifierExplicitCreateInfoEXT` and `VkExternalMemoryImageCreateInfo` onto `VkImageCreateInfo`.

- **Export.** The application creates an image and allocates its memory. Then the application exports to *modifier*-aware consumers the image's memory handles; its creation parameters; its *modifier*; and the *offset*, *size*, and *rowPitch* of each *memory plane*.

  In this pattern, the Vulkan device is the authority for the image; it is the allocator of the image's memory and the decider of the image's creation parameters. When choosing the image's creation parameters, the application usually chooses a tuple (*format*, *drmFormatModifier*) from the result of the negotiation described above. The negotiation's result often contains multiple tuples that share the same *format* but differ in their *modifier*. In this case, the application should defer the choice of the image's *modifier* to the Vulkan implementation by providing all such *modifiers* to `VkImageDrmFormatModifierListCreateInfoEXT::pDrmFormatModifiers`; and the implementation should choose from `pDrmFormatModifiers` the optimal *modifier* in consideration with the other image parameters.

  The application creates the image by chaining `VkImageDrmFormatModifierListCreateInfoEXT` and `VkExternalMemoryImageCreateInfo` onto `VkImageCreateInfo`. The protocol and APIs by which the application will share the image with external consumers will likely determine the value of `VkExternalMemoryImageCreateInfo::handleTypes`. The implementation chooses for the image an optimal *modifier* from `VkImageDrmFormatModifierListCreateInfoEXT::pDrmFormatModifiers`. The application then queries the implementation-chosen *modifier* with `vkGetImageDrmFormatModifierPropertiesEXT`, and queries the memory layout of each plane with `vkGetImageSubresourceLayout`.

  The application then allocates the image's memory with `VkMemoryAllocateInfo`, adding chained extending structures for external memory; binds it to the image; and exports the memory, for example, with `vkGetMemoryFdKHR`.

  Finally, the application sends the image's creation parameters, its *modifier*, its per-plane memory layout, and the exported memory handle to the external consumers. The details of how the application transmits this information to external consumers is outside the scope of this specification.
Prior Art

Extension **EGL_EXT_image_dma_buf_import**\(^1\) introduced the ability to create an **EGLImage** by importing for each plane a dma_buf, offset, and row pitch.

Later, extension **EGL_EXT_image_dma_buf_import_modifiers**\(^2\) introduced the ability to query which combination of formats and **modifiers** the implementation supports and to specify **modifiers** during creation of the **EGLImage**.

Extension **EGL_MESA_image_dma_buf_export**\(^3\) is the inverse of **EGL_EXT_image_dma_buf_import_modifiers**.

The Linux kernel modesetting API (KMS), when configuring the display's framebuffer with **struct drm_mode_fb_cmd2**\(^4\), allows one to specify the framebuffer's **modifier** as well as a per-plane memory handle, offset, and row pitch.

GBM, a graphics buffer manager for Linux, allows creation of a **gbm_bo** (that is, a graphics **buffer object**) by importing data similar to that in **EGL_EXT_image_dma_buf_import_modifiers**\(^1\); and symmetrically allows exporting the same data from the **gbm_bo**. See the references to **modifier** and **plane** in **gbm.h**\(^5\).

New Commands

- **vkGetImageDrmFormatModifierPropertiesEXT**

New Structures

- **VkDrmFormatModifierPropertiesEXT**
- **VkImageDrmFormatModifierPropertiesEXT**
- Extending **VkFormatProperties2**:
  - **VkDrmFormatModifierPropertiesListEXT**
- Extending **VkImageCreateInfo**:
  - **VkImageDrmFormatModifierExplicitCreateInfoEXT**
  - **VkImageDrmFormatModifierListCreateInfoEXT**
- Extending **VkPhysicalDeviceImageFormatInfo2**:
  - **VkPhysicalDeviceImageDrmFormatModifierInfoEXT**

If **VK_KHR_format_feature_flags2** is supported:

- **VkDrmFormatModifierProperties2EXT**
- Extending **VkFormatProperties2**:
  - **VkDrmFormatModifierPropertiesList2EXT**

New Enum Constants

- **VK_EXT_IMAGE_DRM_FORMAT_MODIFIER_EXTENSION_NAME**
• **VK_EXT_IMAGE_DRM_FORMAT_MODIFIER_SPEC_VERSION**

• **Extending VkImageAspectFlagBits:**
  ◦ VK_IMAGE_ASPECT_MEMORY_PLANE_0_BIT_EXT
  ◦ VK_IMAGE_ASPECT_MEMORY_PLANE_1_BIT_EXT
  ◦ VK_IMAGE_ASPECT_MEMORY_PLANE_2_BIT_EXT
  ◦ VK_IMAGE_ASPECT_MEMORY_PLANE_3_BIT_EXT

• **Extending VkImageTiling:**
  ◦ VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT

• **Extending VkResult:**
  ◦ VK_ERROR_INVALID_DRM_FORMAT_MODIFIER_PLANE_LAYOUT_EXT

• **Extending VkStructureType:**
  ◦ VK_STRUCTURE_TYPE_DRM_FORMAT_MODIFIER_PROPERTIES_LIST_EXT
  ◦ VK_STRUCTURE_TYPE_IMAGE_DRM_FORMAT_MODIFIER_EXPLICIT_CREATE_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_IMAGE_DRM_FORMAT_MODIFIER_LIST_CREATE_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_IMAGE_DRM_FORMAT_MODIFIER_PROPERTIES_EXT
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_DRM_FORMAT_MODIFIER_INFO_EXT

If **VK_KHR_format_feature_flags2** is supported:

• **Extending VkStructureType:**
  ◦ VK_STRUCTURE_TYPE_DRM_FORMAT_MODIFIER_PROPERTIES_LIST_2_EXT

**Issues**

1) Should this extension define a single DRM format modifier per **VkImage**? Or define one per plane?

+ **RESOLVED:** There exists a single DRM format modifier per **VkImage**.

**DISCUSSION:** Prior art, such as **EGL_EXT_image_dma_buf_import_modifiers**, **struct drm_mode_fb_cmd2**, and **struct gbm_import_fd_modifier_data**, allows defining one **modifier** per plane. However, developers of the GBM and kernel APIs concede it was a mistake. Beginning in Linux 4.10, the kernel requires that the application provide the same DRM format **modifier** for each plane. (See Linux commit bae781b259269590109e8a4a8227331362b88212). And GBM provides an entry point, **gbm_bo_get_modifier**, for querying the **modifier** of the image but does not provide one to query the **modifier** of individual planes.

2) When creating an image with **VkImageDrmFormatModifierExplicitCreateInfoEXT**, which is typically used when **importing** an image, should the application explicitly provide the size of each plane?

+
RESOLVED: No. The application must not provide the size. To enforce this, the API requires that `VkImageDrmFormatModifierExplicitCreateInfoEXT::pPlaneLayouts->size` must be 0.

DISCUSSION: Prior art, such as `EGL_EXT_image_dma_buf_import_modifiers`, `struct drm_mode_fb_cmd2`, and `struct gbm_import_fd_modifier_data`, omits from the API the size of each plane. Instead, the APIs infer each plane’s size from the import parameters, which include the image’s pixel format and a dma_buf, offset, and row pitch for each plane.

However, Vulkan differs from EGL and GBM with regards to image creation in the following ways:

**Differences in Image Creation**

- **Undedicated allocation by default.** When importing or exporting a set of dma_bufs as an `EGLImage` or `gbm_bo`, common practice mandates that each dma_buf’s memory be dedicated (in the sense of `VK_KHR_dedicated_allocation`) to the image (though not necessarily dedicated to a single plane). In particular, neither the GBM documentation nor the EGL extension specifications explicitly state this requirement, but in light of common practice this is likely due to under-specification rather than intentional omission. In contrast, `VK_EXT_image_drm_format_modifier` permits, but does not require, the implementation to require dedicated allocations for images created with `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT`.

- **Separation of image creation and memory allocation.** When importing a set of dma_bufs as an `EGLImage` or `gbm_bo`, EGL and GBM create the image resource and bind it to memory (the dma_bufs) simultaneously. This allows EGL and GBM to query each dma_buf’s size during image creation. In Vulkan, image creation and memory allocation are independent unless a dedicated allocation is used (as in `VK_KHR_dedicated_allocation`). Therefore, without requiring dedicated allocation, Vulkan cannot query the size of each dma_buf (or other external handle) when calculating the image’s memory layout. Even if dedication allocation were required, Vulkan cannot calculate the image’s memory layout until after the image is bound to its dma_ufs.

The above differences complicate the potential inference of plane size in Vulkan. Consider the following problematic cases:

**Problematic Plane Size Calculations**

- **Padding.** Some plane of the image may require implementation-dependent padding.

- **Metadata.** For some modifiers, the image may have a metadata plane which requires a non-trivial calculation to determine its size.

- **Mipmapped, array, and 3D images.** The implementation may support `VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT` for images whose `mipLevels`, `arrayLayers`, or `depth` is greater than 1. For such images with certain modifiers, the calculation of each plane’s size may be non-trivial.

However, an application-provided plane size solves none of the above problems.

For simplicity, consider an external image with a single memory plane. The implementation is obviously capable calculating the image’s size when its tiling is `VK_IMAGE_TILING_OPTIMAL`. Likewise, any reasonable implementation is capable of calculating the image’s size when its tiling uses a supported modifier.
Suppose that the external image’s size is smaller than the implementation-calculated size. If the application provided the external image’s size to \texttt{vkCreateImage}, the implementation would observe the mismatched size and recognize its inability to comprehend the external image’s layout (unless the implementation used the application-provided size to select a refinement of the tiling layout indicated by the \textit{modifier}, which is strongly discouraged). The implementation would observe the conflict, and reject image creation with \texttt{VK\_ERROR\_INVALID\_DRM\_FORMAT\_MODIFIER\_PLANE\_LAYOUT\_EXT}. On the other hand, if the application did not provide the external image’s size to \texttt{vkCreateImage}, then the application would observe after calling \texttt{vkGetImageMemoryRequirements} that the external image’s size is less than the size required by the implementation. The application would observe the conflict and refuse to bind the \texttt{VkImage} to the external memory. In both cases, the result is explicit failure.

Suppose that the external image’s size is larger than the implementation-calculated size. If the application provided the external image’s size to \texttt{vkCreateImage}, for reasons similar to above the implementation would observe the mismatched size and recognize its inability to comprehend the image data residing in the extra size. The implementation, however, must assume that image data resides in the entire size provided by the application. The implementation would observe the conflict and reject image creation with \texttt{VK\_ERROR\_INVALID\_DRM\_FORMAT\_MODIFIER\_PLANE\_LAYOUT\_EXT}. On the other hand, if the application did not provide the external image’s size to \texttt{vkCreateImage}, then the application would observe after calling \texttt{vkGetImageMemoryRequirements} that the external image’s size is larger than the implementation-usable size. The application would observe the conflict and refuse to bind the \texttt{VkImage} to the external memory. In both cases, the result is explicit failure.

Therefore, an application-provided size provides no benefit, and this extension should not require it. This decision renders \texttt{VkSubresourceLayout::size} an unused field during image creation, and thus introduces a risk that implementations may require applications to submit sideband creation parameters in the unused field. To prevent implementations from relying on sideband data, this extension \textit{requires} the application to set \texttt{size} to 0.

References

1. \texttt{EGL\_EXT\_image\_dma\_buf\_import}
2. \texttt{EGL\_EXT\_image\_dma\_buf\_import\_modifiers}
3. \texttt{EGL\_MESA\_image\_dma\_buf\_export}
4. \texttt{struct drm\_mode\_fb\_cmd2}
5. \texttt{gbm.h}

Version History

- Revision 1, 2018-08-29 (Lina Versace)
  - First stable revision
- Revision 2, 2021-09-30 (Jon Leech)
  - Add interaction with \texttt{VK\_KHR\_format\_feature\_flags2} to \texttt{vk.xml}
VK_EXT_image_sliced_view_of_3d

Name String
VK_EXT_image_sliced_view_of_3d

Extension Type
Device extension

Registered Extension Number
419

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_maintenance1
and
VK_KHR_get_physical_device_properties2

Special Use
• D3D support

Contact
• Mike Blumenkrantz zmike

Extension Proposal
VK_EXT_image_sliced_view_of_3d

Other Extension Metadata

Last Modified Date
2023-01-24

IP Status
No known IP claims.

Contributors
• Mike Blumenkrantz, Valve
• Hans-Kristian Arntzen, Valve
• Ricardo Garcia, Igalia
• Shahbaz Youssefi, Google
• Piers Daniell, NVIDIA
Description

This extension allows creating 3D views of 3D images such that the views contain a subset of the slices in the image, using a Z offset and range, for the purpose of using the views as storage image descriptors. This matches functionality in D3D12 and is primarily intended to support D3D12 emulation.

New Structures

- Extending `VkImageViewCreateInfo`:
  - `VkImageViewSlicedCreateInfoEXT`
- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceImageSlicedViewOf3DFeaturesEXT`

New Enum Constants

- `VK_EXT_IMAGE_SLICED_VIEW_OF_3D_EXTENSION_NAME`
- `VK_EXT_IMAGE_SLICED_VIEW_OF_3D_SPEC_VERSION`
- `VK_REMAINING_3D_SLICES_EXT`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_IMAGE_VIEW_SLICED_CREATE_INFO_EXT`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_SLICED_VIEW_OF_3D_FEATURES_EXT`

Version History

- Revision 1, 2022-10-21 (Mike Blumenkrantz)
  - Initial revision

`VK_EXT_image_view_min_lod`

Name String

`VK_EXT_image_view_min_lod`

Extension Type

Device extension

Registered Extension Number

392

Revision

1

Ratification Status

Not ratified
Extension and Version Dependencies
VK_KHR_get_physical_device_properties2

Contact
• Joshua Ashton [Joshua-Ashton]

Other Extension Metadata

Last Modified Date
2021-11-09

IP Status
No known IP claims.

Contributors
• Joshua Ashton, Valve
• Hans-Kristian Arntzen, Valve
• Samuel Iglesias Gonsalvez, Igalia
• Tobias Hector, AMD
• Faith Ekstrand, Intel
• Tom Olson, ARM

Description
This extension allows applications to clamp the minimum LOD value during Image Level(s) Selection, Texel Gathering and Integer Texel Coordinate Operations with a given VkImageView by VkImageViewMinLodCreateInfoEXT::minLod.

This extension may be useful to restrict a VkImageView to only mips which have been uploaded, and the use of fractional minLod can be useful for smoothly introducing new mip levels when using linear mipmap filtering.

New Structures
• Extending VkImageViewCreateInfo:
  ◦ VkImageViewMinLodCreateInfoEXT
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceImageViewMinLodFeaturesEXT

New Enum Constants
• VK_EXT_IMAGE_VIEW_MIN_LOD_EXTENSION_NAME
• VK_EXT_IMAGE_VIEW_MIN_LOD_SPEC_VERSION
• Extending VkStructureType:
Version History

- Revision 1, 2021-07-06 (Joshua Ashton)
  - Initial version

**VK_EXT_index_type_uint8**

Name String

- **VK_EXT_index_type_uint8**

Extension Type

- Device extension

Registered Extension Number

- 266

Revision

- 1

Ratification Status

- Not ratified

Extension and Version Dependencies

- **VK_KHR_get_physical_device_properties2**
- Or
- **Version 1.1**

Contact

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Other Extension Metadata

Last Modified Date

- 2019-05-02

IP Status

- No known IP claims.

Contributors

- Jeff Bolz, NVIDIA

Description

This extension allows `uint8_t` indices to be used with `vkCmdBindIndexBuffer`. 
New Structures

• Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  ◦ `VkPhysicalDeviceIndexTypeUint8FeaturesEXT`

New Enum Constants

• `VK_EXT_INDEX_TYPE_UINT8_EXTENSION_NAME`
• `VK_EXT_INDEX_TYPE_UINT8_SPEC_VERSION`
• Extending `VkIndexType`:
  ◦ `VK_INDEX_TYPE_UINT8_EXT`
• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INDEX_TYPE_UINT8_FEATURES_EXT`

Version History

• Revision 1, 2019-05-02 (Piers Daniell)
  ◦ Internal revisions

VK_EXT_legacy_dithering

Name String

`VK_EXT_legacy_dithering`

Extension Type

Device extension

Registered Extension Number

466

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

`VK_KHR_get_physical_device_properties2`

Special Use

• OpenGL / ES support

Contact

• Shahbaz Youssefi @syoussefi
Extension Proposal

VK_EXT_legacy_dithering

Other Extension Metadata

Last Modified Date
2022-03-31

Contributors

• Shahbaz Youssefi, Google
• Graeme Leese, Broadcom
• Jan-Harald Fredriksen, Arm

Description

This extension exposes a hardware feature used by some vendors to implement OpenGL's dithering. The purpose of this extension is to support layering OpenGL over Vulkan, by allowing the layer to take advantage of the same hardware feature and provide equivalent dithering to OpenGL applications.

New Structures

• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceLegacyDitheringFeaturesEXT

New Enum Constants

• VK_EXT_LEGACY_DITHERING_EXTENSION_NAME
• VK_EXT_LEGACY_DITHERING_SPEC_VERSION
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_LEGACY_DITHERING_FEATURES_EXT
• Extending VkSubpassDescriptionFlagBits:
  ◦ VK_SUBPASS_DESCRIPTION_ENABLE_LEGACY_DITHERING_BIT_EXT

If VK_KHR_dynamic_rendering is supported:

• Extending VkRenderingFlagBits:
  ◦ VK_RENDERING_ENABLE_LEGACY_DITHERING_BIT_EXT

If Version 1.3 is supported:

• Extending VkRenderingFlagBits:
  ◦ VK_RENDERING_ENABLE_LEGACY_DITHERING_BIT_EXT
Issues

1) In OpenGL, the dither state can change dynamically. Should this extension add a pipeline state for dither?

**RESOLVED:** No. Changing dither state is rarely, if ever, done during rendering. Every surveyed Android application either entirely disables dither, explicitly enables it, or uses the default state (which is enabled). Additionally, on some hardware dither can only be specified in a render pass granularity, so a change in dither state would necessarily need to cause a render pass break. This extension considers dynamic changes in OpenGL dither state a theoretical situation, and expects the layer to break the render pass in such a situation without any practical downsides.

**VK_EXT_line_rasterization**

**Name String**

`VK_EXT_line_rasterization`

**Extension Type**

Device extension

**Registered Extension Number**

260

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

- `VK_KHR_get_physical_device_properties2`
  - or
  - Version 1.1

**Special Use**

- CAD support

**Contact**

- Jeff Bolz [jeffbolznv](mailto:jeffbolznv)

**Other Extension Metadata**
Description

This extension adds some line rasterization features that are commonly used in CAD applications and supported in other APIs like OpenGL. Bresenham-style line rasterization is supported, smooth rectangular lines (coverage to alpha) are supported, and stippled lines are supported for all three line rasterization modes.

New Commands

- `vkCmdSetLineStippleEXT`

New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceLineRasterizationFeaturesEXT`
- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceLineRasterizationPropertiesEXT`
- Extending `VkPipelineRasterizationStateCreateInfo`:
  - `VkPipelineRasterizationLineStateCreateInfoEXT`

New Enums

- `VkLineRasterizationModeEXT`

New Enum Constants

- `VK_EXT_LINE_RASTERIZATION_EXTENSION_NAME`
- `VK_EXT_LINE_RASTERIZATION_SPEC_VERSION`
- Extending `VkDynamicState`:
  - `VK_DYNAMIC_STATE_LINE_STIPPLE_EXT`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_LINE_RASTERIZATION_FEATURES_EXT`
Issues

1) Do we need to support Bresenham-style and smooth lines with more than one rasterization sample? i.e. the equivalent of `glDisable(GL_MULTISAMPLE)` in OpenGL when the framebuffer has more than one sample?

RESOLVED: Yes. For simplicity, Bresenham line rasterization carries forward a few restrictions from OpenGL, such as not supporting per-sample shading, alpha to coverage, or alpha to one.

Version History

- Revision 1, 2019-05-09 (Jeff Bolz)
  - Initial draft

**VK_EXT_load_store_op_none**

Name String

VK_EXT_load_store_op_none

Extension Type

Device extension

Registered Extension Number

401

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

Contact

- Shahbaz Youssefi syoussefi

Other Extension Metadata

Last Modified Date

2021-06-06

Contributors

- Shahbaz Youssefi, Google
- Bill Licea-Kane, Qualcomm Technologies, Inc.
- Tobias Hector, AMD
Description

This extension incorporates `VK_ATTACHMENT_STORE_OP_NONE_EXT` from `VK_QCOM_render_pass_store_ops`, enabling applications to avoid unnecessary synchronization when an attachment is not written during a render pass.

Additionally, `VK_ATTACHMENT_LOAD_OP_NONE_EXT` is introduced to avoid unnecessary synchronization when an attachment is not used during a render pass at all. In combination with `VK_ATTACHMENT_STORE_OP_NONE_EXT`, this is useful as an alternative to preserve attachments in applications that cannot decide if an attachment will be used in a render pass until after the necessary pipelines have been created.

New Enum Constants

- `VK_EXT_LOAD_STORE_OP_NONE_EXTENSION_NAME`
- `VK_EXT_LOAD_STORE_OP_NONE_SPEC_VERSION`
- Extending `VkAttachmentLoadOp`:
  - `VK_ATTACHMENT_LOAD_OP_NONE_EXT`
- Extending `VkAttachmentStoreOp`:
  - `VK_ATTACHMENT_STORE_OP_NONE_EXT`

Version History

- Revision 1, 2021-06-06 (Shahbaz Youssefi)
  - Initial revision, based on `VK_QCOM_render_pass_store_ops`.
  - Added `VK_ATTACHMENT_LOAD_OP_NONE_EXT`.

**VK_EXT_memory_budget**

Name String

- `VK_EXT_memory_budget`

Extension Type

- Device extension

Registered Extension Number

- 238

Revision

- 1

Ratification Status

- Not ratified

Extension and Version Dependencies

- `VK_KHR_get_physical_device_properties2`
Description

While running a Vulkan application, other processes on the machine might also be attempting to use the same device memory, which can pose problems. This extension adds support for querying the amount of memory used and the total memory budget for a memory heap. The values returned by this query are implementation-dependent and can depend on a variety of factors including operating system and system load.

The `VkPhysicalDeviceMemoryBudgetPropertiesEXT::heapBudget` values can be used as a guideline for how much total memory from each heap the current process can use at any given time, before allocations may start failing or causing performance degradation. The values may change based on other activity in the system that is outside the scope and control of the Vulkan implementation.

The `VkPhysicalDeviceMemoryBudgetPropertiesEXT::heapUsage` will display the current process estimated heap usage.

With this information, the idea is for an application at some interval (once per frame, per few seconds, etc) to query `heapBudget` and `heapUsage`. From here the application can notice if it is over budget and decide how it wants to handle the memory situation (free it, move to host memory, changing mipmap levels, etc). This extension is designed to be used in concert with `VK_EXT_memory_priority` to help with this part of memory management.

New Structures

- Extending `VkPhysicalDeviceMemoryProperties2`:
  - `VkPhysicalDeviceMemoryBudgetPropertiesEXT`

New Enum Constants

- `VK_EXT_MEMORY_BUDGET_EXTENSION_NAME`
- `VK_EXT_MEMORY_BUDGET_SPEC_VERSION`

- Extending `VkStructureType`:
Version History

- Revision 1, 2018-10-08 (Jeff Bolz)
  - Initial revision

**VK_EXT_memory_priority**

Name String

VK_EXT_memory_priority

Extension Type

Device extension

Registered Extension Number

239

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Contact

- Jeff Bolz [jeffbolznv](mailto:jeffbolznv)

Other Extension Metadata

Last Modified Date

2018-10-08

Contributors

- Jeff Bolz, NVIDIA
- Jeff Juliano, NVIDIA

Description

This extension adds a priority value specified at memory allocation time. On some systems with both device-local and non-device-local memory heaps, the implementation may transparently move memory from one heap to another when a heap becomes full (for example, when the total memory used across all processes exceeds the size of the heap). In such a case, this priority value may be used to determine which allocations are more likely to remain in device-local memory.
New Structures

- Extending VkMemoryAllocateInfo:
  - VkMemoryPriorityAllocateInfoEXT

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceMemoryPriorityFeaturesEXT

New Enum Constants

- VK_EXT_MEMORY_PRIORITY_EXTENSION_NAME
- VK_EXT_MEMORY_PRIORITY_SPEC_VERSION

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_MEMORY_PRIORITY_ALLOCATE_INFO_EXT
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_PRIORITY_FEATURES_EXT

Version History

- Revision 1, 2018-10-08 (Jeff Bolz)
  - Initial revision

VK_EXT_mesh_shader

Name String

VK_EXT_mesh_shader

Extension Type

Device extension

Registered Extension Number

329

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_spirv_1_4

Contact

- Christoph Kubisch 🧁pixeljetstream

Extension Proposal

VK_EXT_mesh_shader
Other Extension Metadata

Last Modified Date
2022-01-20

Interactions and External Dependencies
- This extension requires `SPV_EXT_mesh_shader`
- This extension provides API support for `GLSL_EXT_mesh_shader`
- Interacts with Vulkan 1.1
- Interacts with `VK_KHR_multiview`
- Interacts with `VK_KHR_fragment_shading_rate`

Contributors
- Christoph Kubisch, NVIDIA
- Pat Brown, NVIDIA
- Jeff Bolz, NVIDIA
- Daniel Koch, NVIDIA
- Piers Daniell, NVIDIA
- Pierre Boudier, NVIDIA
- Patrick Mours, NVIDIA
- David Zhao Akeley, NVIDIA
- Kedarnath Thangudu, NVIDIA
- Timur Kristóf, Valve
- Hans-Kristian Arntzen, Valve
- Philip Rebohle, Valve
- Mike Blumenkrantz, Valve
- Slawomir Grajewski, Intel
- Michal Pietrasiuk, Intel
- Mariusz Merecki, Intel
- Tom Olson, ARM
- Jan-Harald Fredriksen, ARM
- Sandeep Kakarlapudi, ARM
- Ruihao Zhang, QUALCOMM
- Ricardo Garcia, Igalia, S.L.
- Tobias Hector, AMD
- Stu Smith, AMD
Description

This extension provides a new mechanism allowing applications to generate collections of geometric primitives via programmable mesh shading. It is an alternative to the existing programmable primitive shading pipeline, which relied on generating input primitives by a fixed function assembler as well as fixed function vertex fetch.

This extension also adds support for the following SPIR-V extension in Vulkan:

- SPV_EXT_mesh_shader

New Commands

- vkCmdDrawMeshTasksEXT
- vkCmdDrawMeshTasksIndirectCountEXT
- vkCmdDrawMeshTasksIndirectEXT

New Structures

- VkDrawMeshTasksIndirectCommandEXT
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - Extending VkPhysicalDeviceMeshShaderFeaturesEXT
- Extending VkPhysicalDeviceProperties2:
  - Extending VkPhysicalDeviceMeshShaderPropertiesEXT

New Enum Constants

- VK_EXT_MESH_SHADER_EXTENSION_NAME
- VK_EXT_MESH_SHADER_SPEC_VERSION
- Extending VkPipelineStageFlagBits:
  - VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT
  - VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT
- Extending VkQueryPipelineStatisticFlagBits:
  - VK_QUERY_PIPELINE_STATISTIC_MESH_SHADER_INVOCATIONS_BIT_EXT
  - VK_QUERY_PIPELINE_STATISTIC_TASK_SHADER_INVOCATIONS_BIT_EXT
- Extending VkQueryType:
  - VK_QUERY_TYPE_MESH_PRIMITIVES_GENERATED_EXT
- Extending VkShaderStageFlagBits:
  - VK_SHADER_STAGE_MESH_BIT_EXT
  - VK_SHADER_STAGE_TASK_BIT_EXT
- Extending VkStructureType:
If `VK_NV_device_generated_commands` is supported:

- Extending `VkIndirectCommandsTokenTypeNV`:
  - `VK_INDIRECT_COMMANDS_TOKEN_TYPE_DRAW_MESH_TASKS_NV`

### New or Modified Built-In Variables

- `CullPrimitiveEXT`
- `PrimitivePointIndicesEXT`
- `PrimitiveLineIndicesEXT`
- `PrimitiveTriangleIndicesEXT`
- (modified) `Position`
- (modified) `PointSize`
- (modified) `ClipDistance`
- (modified) `CullDistance`
- (modified) `PrimitiveId`
- (modified) `Layer`
- (modified) `ViewportIndex`
- (modified) `NumWorkgroups`
- (modified) `WorkgroupSize`
- (modified) `WorkgroupId`
- (modified) `LocalInvocationId`
- (modified) `GlobalInvocationId`
- (modified) `LocalInvocationIndex`
- (modified) `NumSubgroups`
- (modified) `SubgroupId`
- (modified) `DrawIndex`
- (modified) `PrimitiveShadingRateKHR`
- (modified) `ViewIndex`

### New SPIR-V Capability

- `MeshShadingEXT`
Version History

- Revision 1, 2022-03-08 (Christoph Kubisch, Daniel Koch, Patrick Mours)
  - Initial revision

VK_EXT_metal_objects

Name String
VK_EXT_metal_objects

Extension Type
Device extension

Registered Extension Number
312

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies

Contact
- Bill Hollings billhollings

Extension Proposal
VK_EXT_metal_objects

Other Extension Metadata

Last Modified Date
2022-05-28

IP Status
No known IP claims.

Contributors
- Bill Hollings, The Brenwill Workshop Ltd.
- Dzmitry Malyshau, Mozilla Corp.

Description

In a Vulkan implementation that is layered on top of Metal on Apple device platforms, this extension provides the ability to import and export the underlying Metal objects associated with specific Vulkan objects.

As detailed in the extension proposal document, this extension adds one new Vulkan command,
vkExportMetalObjectsEXT, to export underlying Metal objects from Vulkan objects, and supports importing the appropriate existing Metal objects when creating Vulkan objects of types `VkDeviceMemory`, `VkImage`, `VkSemaphore`, and `VkEvent`,

The intent is that this extension will be advertised and supported only on implementations that are layered on top of Metal on Apple device platforms.

**New Base Types**

- IOSurfaceRef
- MTLBuffer_id
- MTLCommandQueue_id
- MTLDevice_id
- MTLSharedEvent_id
- MTLTexture_id

**New Commands**

- `vkExportMetalObjectsEXT`

**New Structures**

- `VkExportMetalObjectsInfoEXT`
- Extending `VkExportMetalObjectsInfoEXT`:
  - `VkExportMetalBufferInfoEXT`
  - `VkExportMetalCommandQueueInfoEXT`
  - `VkExportMetalDeviceInfoEXT`
  - `VkExportMetalIOSurfaceInfoEXT`
  - `VkExportMetalSharedEventInfoEXT`
  - `VkExportMetalTextureInfoEXT`
- Extending `VkImageCreateInfo`:
  - `VkImportMetalIOSurfaceInfoEXT`
  - `VkImportMetalTextureInfoEXT`
- Extending `VkInstanceCreateInfo`, `VkMemoryAllocateInfo`, `VkImageCreateInfo`, `VkImageViewCreateInfo`, `VkBufferViewCreateInfo`, `VkSemaphoreCreateInfo`, `VkEventCreateInfo`:
  - `VkExportMetalObjectCreateInfoEXT`
- Extending `VkMemoryAllocateInfo`:
  - `VkImportMetalBufferInfoEXT`
- Extending `VkSemaphoreCreateInfo`, `VkEventCreateInfo`:
New Enums

- VkExportMetalObjectTypeFlagBitsEXT

New Bitmasks

- VkExportMetalObjectTypeFlagsEXT

New Enum Constants

- VK_EXT_METAL_OBJECTS_EXTENSION_NAME
- VK_EXT_METAL_OBJECTS_SPEC_VERSION

Extending VkStructureType:

- VK_STRUCTURE_TYPE_EXPORT_METAL_BUFFER_INFO_EXT
- VK_STRUCTURE_TYPE_EXPORT_METAL_COMMAND_QUEUE_INFO_EXT
- VK_STRUCTURE_TYPE_EXPORT_METAL_DEVICE_INFO_EXT
- VK_STRUCTURE_TYPE_EXPORT_METAL_IO_SURFACE_INFO_EXT
- VK_STRUCTURE_TYPE_EXPORT_METAL_OBJECTS_INFO_EXT
- VK_STRUCTURE_TYPE_EXPORT_METAL_OBJECT_CREATE_INFO_EXT
- VK_STRUCTURE_TYPE_EXPORT_METAL_SHARED_EVENT_INFO_EXT
- VK_STRUCTURE_TYPE_EXPORT_METAL_TEXTURE_INFO_EXT
- VK_STRUCTURE_TYPE_IMPORT_METAL_BUFFER_INFO_EXT
- VK_STRUCTURE_TYPE_IMPORT_METAL_IO_SURFACE_INFO_EXT
- VK_STRUCTURE_TYPE_IMPORT_METAL_SHARED_EVENT_INFO_EXT
- VK_STRUCTURE_TYPE_IMPORT_METAL_TEXTURE_INFO_EXT

Issues

None.

Version History

- Revision 1, 2022-05-28 (Bill Hollings)
  - Initial draft.
  - Incorporated feedback from review by the Vulkan Working Group. Renamed many structures, moved import/export of MTLBuffer to VkDeviceMemory, added export of MTLSharedEvent, added import of MTLSharedEvent for VkSemaphore and VkEvent, and changed used bit mask fields to individual bit fields to simplify Valid Usage rules.
VK_EXT_metal_surface

Name String
VK_EXT_metal_surface

Extension Type
Instance extension

Registered Extension Number
218

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_surface

Contact
• Dzmitry Malyshau kvark

Other Extension Metadata

Last Modified Date
2018-10-01

IP Status
No known IP claims.

Contributors
• Dzmitry Malyshau, Mozilla Corp.

Description
The VK_EXT_metal_surface extension is an instance extension. It provides a mechanism to create a VkSurfaceKHR object (defined by the VK_KHR_surface extension) from CAMetalLayer, which is the native rendering surface of Apple’s Metal framework.

New Base Types
• CAMetalLayer

New Commands
• vkCreateMetalSurfaceEXT
New Structures

- VkMetalSurfaceCreateInfoEXT

New Bitmasks

- VkMetalSurfaceCreateFlagsEXT

New Enum Constants

- VK_EXT_METAL_SURFACE_EXTENSION_NAME
- VK_EXT_METAL_SURFACE_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_METAL_SURFACE_CREATE_INFO_EXT

Version History

- Revision 1, 2018-10-01 (Dzmitry Malyshau)
  - Initial version

VK_EXT_multi_draw

Name String

VK_EXT_multi_draw

Extension Type

Device extension

Registered Extension Number

393

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Contact

- Mike Blumenkrantz zmike

Other Extension Metadata

Last Modified Date

2021-05-19
IP Status
No known IP claims.

Contributors
• Mike Blumenkrantz, VALVE
• Piers Daniell, NVIDIA
• Faith Ekstrand, INTEL
• Spencer Fricke, SAMSUNG
• Ricardo Garcia, IGALIA
• Jon Leech, KHRONOS
• Stu Smith, AMD

Description
Processing multiple draw commands in sequence incurs measurable overhead within drivers due to repeated state checks and updates during dispatch. This extension enables passing the entire sequence of draws directly to the driver in order to avoid any such overhead, using an array of `VkMultiDrawInfoEXT` or `VkMultiDrawIndexedInfoEXT` structs with `vkCmdDrawMultiEXT` or `vkCmdDrawMultiIndexedEXT`, respectively. These functions could be used any time multiple draw commands are being recorded without any state changes between them in order to maximize performance.

New Commands
• `vkCmdDrawMultiEXT`
• `vkCmdDrawMultiIndexedEXT`

New Structures
• `VkMultiDrawIndexedInfoEXT`
• `VkMultiDrawInfoEXT`
• Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  ◦ `VkPhysicalDeviceMultiDrawFeaturesEXT`
• Extending `VkPhysicalDeviceProperties2`:
  ◦ `VkPhysicalDeviceMultiDrawPropertiesEXT`

New Enum Constants
• `VK_EXT_MULTI_DRAW_EXTENSION_NAME`
• `VK_EXT_MULTI_DRAW_SPEC_VERSION`
• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTI_DRAW_FEATURES_EXT`
New or Modified Built-In Variables

- (modified)\texttt{DrawIndex}

Version History

- Revision 1, 2021-01-20 (Mike Blumenkrantz)
  - Initial version

\texttt{VK\_EXT\_multisampled\_render\_to\_single\_sampled}

Name String

\texttt{VK\_EXT\_multisampled\_render\_to\_single\_sampled}

Extension Type

Device extension

Registered Extension Number

377

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

\texttt{VK\_KHR\_create\_renderpass2}
and
\texttt{VK\_KHR\_depth\_stencil\_resolve}

Contact

- Shahbaz Youssefi @syoussefi

Extension Proposal

\texttt{VK\_EXT\_multisampled\_render\_to\_single\_sampled}

Other Extension Metadata

Last Modified Date

2021-04-16

IP Status

No known IP claims.
Contributors

- Shahbaz Youssefi, Google
- Jan-Harald Fredriksen, Arm
- Jörg Wagner, Arm
- Matthew Netsch, Qualcomm Technologies, Inc.
- Jarred Davies, Imagination Technologies

Description

With careful usage of resolve attachments, multisampled image memory allocated with `VK_MEMORY_PROPERTY_LAZILY_ALLOCATED_BIT`, `loadOp` not equal to `VK_ATTACHMENT_LOAD_OP_LOAD` and `storeOp` not equal to `VK_ATTACHMENT_STORE_OP_STORE`, a Vulkan application is able to efficiently perform multisampled rendering without incurring any additional memory penalty on some implementations.

Under certain circumstances however, the application may not be able to complete its multisampled rendering within a single render pass; for example if it does partial rasterization from frame to frame, blending on an image from a previous frame, or in emulation of `GL_EXT_multisampled_render_to_texture`. In such cases, the application can use an initial subpass to effectively load single-sampled data from the next subpass’s resolve attachment and fill in the multisampled attachment which otherwise uses `loadOp` equal to `VK_ATTACHMENT_LOAD_OP_DONT_CARE`. However, this is not always possible (for example for stencil in the absence of `VK_EXT_shader_stencil_export`) and has multiple drawbacks.

Some implementations are able to perform said operation efficiently in hardware, effectively loading a multisampled attachment from the contents of a single sampled one. Together with the ability to perform a resolve operation at the end of a subpass, these implementations are able to perform multisampled rendering on single-sampled attachments with no extra memory or bandwidth overhead. This extension exposes this capability by allowing a framebuffer and render pass to include single-sampled attachments while rendering is done with a specified number of samples.

New Structures

- Extending `VkFormatProperties2`:
  - `VkSubpassResolvePerformanceQueryEXT`
- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDeviceMultisampledRenderToSingleSampledFeaturesEXT`
- Extending `VkSubpassDescription2, VkRenderingInfo`:
  - `VkMultisampledRenderToSingleSampledInfoEXT`

New Enum Constants

- `VK_EXT_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_EXTENSION_NAME`
• **VK_EXT_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_SPEC_VERSION**

• Extending **VkImageCreateFlagBits:**
  ◦ **VK_IMAGE_CREATE_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_BIT_EXT**

• Extending **VkStructureType:**
  ◦ **VK_STRUCTURE_TYPE_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_INFO_EXT**
  ◦ **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTISAMPLED_RENDER_TO_SINGLE_SAMPLED_FEATURES_EXT**
  ◦ **VK_STRUCTURE_TYPE_SUBPASS_RESOLVE_PERFORMANCE_QUERY_EXT**

**Issues**

1) Could the multisampled attachment be initialized through some form of copy?

**RESOLVED:** No. Some implementations do not support copying between attachments in general, and find expressing this operation through a copy unnatural.

2) Another way to achieve this is by introducing a new **loadOp** to load the contents of the multisampled image from a single-sampled one. Why is this extension preferred?

**RESOLVED:** Using this extension simplifies the application, as it does not need to manage a secondary lazily-allocated image. Additionally, using this extension leaves less room for error; for example a single mistake in **loadOp** or **storeOp** would result in the lazily-allocated image to actually take up memory, and remain so until destruction.

3) There is no guarantee that multisampled data between two subpasses with the same number of samples will be retained as the implementation may be forced to split the render pass implicitly for various reasons. Should this extension require that every subpass that uses multisampled-render-to-single-sampled end in an implicit render pass split (which results in a resolve operation)?

**RESOLVED:** No. Not requiring this allows render passes with multiple multisampled-render-to-single-sampled subpasses to potentially execute more efficiently (though there is no guarantee).

**Version History**

• Revision 1, 2021-04-12 (Shahbaz Youssefi)

**VK_EXT_mutable_descriptor_type**

**Name String**

**VK_EXT_mutable_descriptor_type**

**Extension Type**

Device extension

**Registered Extension Number**

495
Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_maintenance3

Special Use
  • D3D support

Contact
  • Joshua Ashton ♫Joshua-Ashton
  • Hans-Kristian Arntzen ♫HansKristian-Work

Extension Proposal
  VK_EXT_mutable_descriptor_type

Other Extension Metadata

Last Modified Date
  2022-08-22

IP Status
  No known IP claims.

Contributors
  • Joshua Ashton, Valve
  • Hans-Kristian Arntzen, Valve

Description

This extension allows applications to reduce descriptor memory footprint by allowing a descriptor to be able to mutate to a given list of descriptor types depending on which descriptor types are written into, or copied into a descriptor set.

The main use case this extension intends to address is descriptor indexing with VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT where the descriptor types are completely generic, as this means applications can allocate one large descriptor set, rather than having one large descriptor set per descriptor type, which significantly bloats descriptor memory usage and causes performance issues.

This extension also adds a mechanism to declare that a descriptor pool, and therefore the descriptor sets that are allocated from it, reside only in host memory; as such these descriptors can only be updated/copied, but not bound.

These features together allow much more efficient emulation of the raw D3D12 binding model. This extension is primarily intended to be useful for API layering efforts.
New Structures

- **VkMutableDescriptorTypeListEXT**
- **Extending** `VkDescriptorSetLayoutCreateInfo`, `VkDescriptorPoolCreateInfo`:
  - `VkMutableDescriptorTypeCreateInfoEXT`
- **Extending** `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceMutableDescriptorTypeFeaturesEXT`

New Enum Constants

- **VK_EXT_MUTABLE_DESCRIPTOR_TYPE_EXTENSION_NAME**
- **VK_EXT_MUTABLE_DESCRIPTOR_TYPE_SPEC_VERSION**
- **Extending** `VkDescriptorPoolCreateFlagBits`:
  - `VK_DESCRIPTOR_POOL_CREATE_HOST_ONLY_BIT_EXT`
- **Extending** `VkDescriptorSetLayoutCreateFlagBits`:
  - `VK_DESCRIPTOR_SET_LAYOUT_CREATE_HOST_ONLY_POOL_BIT_EXT`
- **Extending** `VkDescriptorType`:
  - `VK_DESCRIPTOR_TYPE_MUTABLE_EXT`
- **Extending** `VkStructureType`:
  - `VK_STRUCTURE_TYPE_MUTABLE_DESCRIPTOR_TYPE_CREATE_INFO_EXT`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MUTABLE_DESCRIPTOR_TYPE_FEATURES_EXT`

Version History

- Revision 1, 2022-08-22 (Jon Leech)
  - Initial version, promoted from `VK_VALVE_mutable_descriptor_type`.

**VK_EXT_non_seamless_cube_map**

Name String

`VK_EXT_non_seamless_cube_map`

Extension Type

Device extension

Registered Extension Number

423

Revision

1
Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2

Special Uses
- D3D support
- OpenGL / ES support

Contact
- Georg Lehmann DadSchoorse

Extension Proposal
VK_EXT_non_seamless_cube_map

Other Extension Metadata

Last Modified Date
2021-09-04

IP Status
No known IP claims.

Contributors
- Georg Lehmann

Description
This extension provides functionality to disable cube map edge handling on a per sampler level which matches the behavior of other graphics APIs.

This extension may be useful for building translation layers for those APIs or for porting applications that rely on this cube map behavior.

New Structures
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceNonSeamlessCubeMapFeaturesEXT

New Enum Constants
- VK_EXT_NON_SEAMLESS_CUBE_MAP_EXTENSION_NAME
- VK_EXT_NON_SEAMLESS_CUBE_MAP_SPEC_VERSION
- Extending VkSamplerCreateFlagBits:
  - VK_SAMPLER_CREATE_NON_SEAMLESS_CUBE_MAP_BIT_EXT
- Extending VkStructureType:
VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_NON_SEAMLESS_CUBE_MAP_FEATURES_EXT

Version History

- Revision 1, 2021-09-04 (Georg Lehmann)
  - First Version

VK_EXT_opacity_micromap

Name String

VK_EXT_opacity_micromap

Extension Type

Device extension

Registered Extension Number

397

Revision

2

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_acceleration_structure
and
VK_KHR_synchronization2

Contact

- Christoph Kubisch pixeljetstream
- Eric Werness

Extension Proposal

VK_EXT_opacity_micromap

Other Extension Metadata

Last Modified Date

2022-08-24

Interactions and External Dependencies

- This extension requires SPV_EXT_opacity_micromap
- This extension provides API support for GLSL_EXT_opacity_micromap

Contributors

- Christoph Kubisch, NVIDIA
Description

When adding transparency to a ray traced scene, an application can choose between further tessellating the geometry or using an any hit shader to allow the ray through specific parts of the geometry. These options have the downside of either significantly increasing memory consumption or adding runtime overhead to run shader code in the middle of traversal, respectively.

This extension adds the ability to add an opacity micromap to geometry when building an acceleration structure. The opacity micromap compactly encodes opacity information which can be read by the implementation to mark parts of triangles as opaque or transparent. The format is externally visible to allow the application to compress its internal geometry and surface representations into the compressed format ahead of time. The compressed format subdivides each triangle into a set of subtriangles, each of which can be assigned either two or four opacity values. These opacity values can control if a ray hitting that subtriangle is treated as an opaque hit, complete miss, or possible hit, depending on the controls described in Ray Opacity Micromap.

This extension provides:

- a VkMicromapEXT structure to store the micromap,
- functions similar to acceleration structure build functions to build the opacity micromap array, and
- a structure to extend VkAccelerationStructureGeometryTrianglesDataKHR to attach a micromap to the geometry of the acceleration structure.

New Object Types

- VkMicromapEXT

New Commands

- vkBuildMicromapsEXT
- vkCmdBuildMicromapsEXT
- vkCmdCopyMemoryToMicromapEXT
- vkCmdCopyMicromapEXT
- vkCmdCopyMicromapToMemoryEXT
- vkCmdWriteMicromapsPropertiesEXT
- vkCopyMemoryToMicromapEXT
- vkCopyMicromapEXT
- vkCopyMicromapToMemoryEXT
- vkCreateMicromapEXT
• vkDestroyMicromapEXT
• vkGetDeviceMicromapCompatibilityEXT
• vkGetMicromapBuildSizesEXT
• vkWriteMicromapsPropertiesEXT

**New Structures**

• VkCopyMemoryToMicromapInfoEXT
• VkCopyMicromapInfoEXT
• VkCopyMicromapToMemoryInfoEXT
• VkMicromapBuildInfoEXT
• VkMicromapBuildSizesInfoEXT
• VkMicromapCreateInfoEXT
• VkMicromapTriangleEXT
• VkMicromapUsageEXT
• VkMicromapVersionInfoEXT

• Extending VkAccelerationStructureGeometryTrianglesDataKHR:
  ◦ VkAccelerationStructureTrianglesOpacityMicromapEXT

• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceOpacityMicromapFeaturesEXT

• Extending VkPhysicalDeviceProperties2:
  ◦ VkPhysicalDeviceOpacityMicromapPropertiesEXT

**New Enums**

• VkBuildMicromapFlagBitsEXT
• VkBuildMicromapModeEXT
• VkCopyMicromapModeEXT
• VkMicromapCreateFlagBitsEXT
• VkMicromapTypeEXT
• VkOpacityMicromapFormatEXT
• VkOpacityMicromapSpecialIndexEXT

**New Bitmasks**

• VkBuildMicromapFlagsEXT
• VkMicromapCreateFlagsEXT
New Enum Constants

- VK_EXT_OPACITY_MICROMAP_EXTENSION_NAME
- VK_EXT_OPACITY_MICROMAP_SPEC_VERSION
- Extending VkAccessFlagBits2:
  - VK_ACCESS_2_MICROMAP_READ_BIT_EXT
  - VK_ACCESS_2_MICROMAP_WRITE_BIT_EXT
- Extending VkBufferUsageFlagBits:
  - VK_BUFFER_USAGE_MICROMAP_BUILD_INPUT_READ_ONLY_BIT_EXT
  - VK_BUFFER_USAGE_MICROMAP_STORAGE_BIT_EXT
- Extending VkBuildAccelerationStructureFlagBitsKHR:
  - VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_DISABLE_OPACITY_MICROMAPS_EXT
  - VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_OPACITY_MICROMAP_DATA_UPDATE_EXT
  - VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_OPACITY_MICROMAP_UPDATE_EXT
- Extending VkGeometryInstanceFlagBitsKHR:
  - VK_GEOMETRY_INSTANCE_DISABLE_OPACITY_MICROMAPS_EXT
  - VK_GEOMETRY_INSTANCE_FORCE_OPACITY_MICROMAP_2_STATE_EXT
- Extending VkObjectType:
  - VK_OBJECT_TYPE_MICROMAP_EXT
- Extending VkPipelineCreateFlagBits:
  - VK_PIPELINE_CREATE_RAY_TRACING_OPACITY_MICROMAP_BIT_EXT
- Extending VkPipelineStageFlagBits2:
  - VK_PIPELINE_STAGE_2_MICROMAP_BUILD_BIT_EXT
- Extending VkQueryType:
  - VK_QUERY_TYPE_MICROMAP_COMPACTED_SIZE_EXT
  - VK_QUERY_TYPE_MICROMAP_SERIALIZATION_SIZE_EXT
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_TRIANGLES_OPACITY_MICROMAP_EXT
  - VK_STRUCTURE_TYPE_COPY_MEMORY_TO_MICROMAP_INFO_EXT
  - VK_STRUCTURE_TYPE_COPY_MICROMAP_INFO_EXT
  - VK_STRUCTURE_TYPE_COPY_MICROMAP_TO_MEMORY_INFO_EXT
  - VK_STRUCTURE_TYPE_MICROMAP_BUILD_INFO_EXT
  - VK_STRUCTURE_TYPE_MICROMAP_BUILD_SIZES_INFO_EXT
  - VK_STRUCTURE_TYPE_MICROMAP_CREATE_INFO_EXT
  - VK_STRUCTURE_TYPE_MICROMAP_VERSION_INFO_EXT
Reference Code

```c
uint32_t BarycentricsToSpaceFillingCurveIndex(float u, float v, uint32_t level)
{
    u = clamp(u, 0.0f, 1.0f);
    v = clamp(v, 0.0f, 1.0f);

    uint32_t iu, iv, iw;

    // Quantize barycentric coordinates
    float fu = u * (1u << level);
    float fv = v * (1u << level);

    iu = (uint32_t)fu;
    iv = (uint32_t)fv;

    float uf = fu - float(iu);
    float vf = fv - float(iv);

    if (iu >= (1u << level)) iu = (1u << level) - 1u;
    if (iv >= (1u << level)) iv = (1u << level) - 1u;

    uint32_t iuv = iu + iv;

    if (iuv >= (1u << level))
        iu -= iuv - (1u << level) + 1u;

    iw = ~(iu + iv);

    if (uf + vf >= 1.0f && iuv < (1u << level) - 1u) --iw;

    uint32_t b0 = ~(iu ^ iw);
    b0 &= ((1u << level) - 1u);
    uint32_t t = (iu ^ iv) & b0;

    uint32_t f = t;
    f ^= f >> 1u;
    f ^= f >> 2u;
    f ^= f >> 4u;
    f ^= f >> 8u;
    uint32_t b1 = ((f ^ iu) & ~b0) | t;

    // Interleave bits
    b0 = (b0 | (b0 << 8u)) & 0x00ff00ffu;
    b0 = (b0 | (b0 << 4u)) & 0x0f0f0f0fu;
    b0 = (b0 | (b0 << 2u)) & 0x33333333u;
    b0 = (b0 | (b0 << 1u)) & 0x55555555u;
```

b1 = (b1 | (b1 << 8u)) & 0x00ff00ffu;
b1 = (b1 | (b1 << 4u)) & 0x0f0f0f0fu;
b1 = (b1 | (b1 << 2u)) & 0x33333333u;
b1 = (b1 | (b1 << 1u)) & 0x55555555u;

return b0 | (b1 << 1u);

Issues

(1) Is the build actually similar to an acceleration structure build?

• Resolved: The build should be much lighter-weight than an acceleration structure build, but the infrastructure is similar enough that it makes sense to keep the concepts compatible.

(2) Why does VkMicromapUsageEXT not have type/pNext?

• Resolved: There can be a very large number of these structures, so doubling the size of these can be significant memory consumption. Also, an application may be loading these directly from a file which is more compatible with it being a flat structure. The including structures are extensible and are probably a more suitable place to add extensibility.

(3) Why is there a SPIR-V extension?

• Resolved: There is a ray flag. To be consistent with how the existing ray tracing extensions work that ray flag needs its own extension.

(4) Should there be indirect micromap build?

• Resolved: Not for now. There is more in-depth usage metadata required and it seems less likely that something like a GPU culling system would need to change the counts for a micromap.

(5) Should micromaps have a micromap device address?

• Resolved: There is no need right now (can just use the handle) but that is a bit different from acceleration structures, though the two are not completely parallel in their usage.

(6) Why are the alignment requirements defined as a mix of hardcoded values and caps?

• Resolved: This is most parallel with the definition of VK_KHR_acceleration_structure and maintaining commonality makes it easier for applications to share memory.

Version History

• Revision 2, 2022-06-22 (Eric Werness)
  ◦ EXTify and clean up for discussion

• Revision 1, 2022-01-01 (Eric Werness)
  ◦ Initial revision
VK_EXT_pageable_device_local_memory

Name String

   VK_EXT_pageable_device_local_memory

Extension Type

   Device extension

Registered Extension Number

   413

Revision

   1

Ratification Status

   Not ratified

Extension and Version Dependencies

   VK_EXT_memory_priority

Contact

   • Piers Daniell pdaniell-nv

Other Extension Metadata

Last Modified Date

   2021-08-24

Contributors

   • Hans-Kristian Arntzen, Valve
   • Axel Gneiting, id Software
   • Billy Khan, id Software
   • Daniel Koch, NVIDIA
   • Chris Lentini, NVIDIA
   • Joshua Schnarr, NVIDIA
   • Stu Smith, AMD

Description

Vulkan is frequently implemented on multi-user and multi-process operating systems where the device-local memory can be shared by more than one process. On such systems the size of the device-local memory available to the application may not be the full size of the memory heap at all times. In order for these operating systems to support multiple applications the device-local memory is virtualized and paging is used to move memory between device-local and host-local memory heaps, transparent to the application.
The current Vulkan specification does not expose this behavior well and may cause applications to make suboptimal memory choices when allocating memory. For example, in a system with multiple applications running, the application may think that device-local memory is full and revert to making performance-sensitive allocations from host-local memory. In reality the memory heap might not have been full, it just appeared to be at the time memory consumption was queried, and a device-local allocation would have succeeded. A well designed operating system that implements pageable device-local memory will try to have all memory allocations for the foreground application paged into device-local memory, and paged out for other applications as needed when not in use.

When this extension is exposed by the Vulkan implementation it indicates to the application that the operating system implements pageable device-local memory and the application should adjust its memory allocation strategy accordingly. The extension also exposes a new `vkSetDeviceMemoryPriorityEXT` function to allow the application to dynamically adjust the priority of existing memory allocations based on its current needs. This will help the operating system page out lower priority memory allocations before higher priority allocations when needed. It will also help the operating system decide which memory allocations to page back into device-local memory first.

To take best advantage of pageable device-local memory the application must create the Vulkan device with the `VkPhysicalDevicePageableDeviceLocalMemoryFeaturesEXT::pageableDeviceLocalMemory` feature enabled. When enabled the Vulkan implementation will allow device-local memory allocations to be paged in and out by the operating system, and may not return `VK_ERROR_OUT_OF_DEVICE_MEMORY` even if device-local memory appears to be full, but will instead page this, or other allocations, out to make room. The Vulkan implementation will also ensure that host-local memory allocations will never be promoted to device-local memory by the operating system, or consume device-local memory.

**New Commands**

- `vkSetDeviceMemoryPriorityEXT`

**New Structures**

- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDevicePageableDeviceLocalMemoryFeaturesEXT`

**New Enum Constants**

- `VK_EXT_PAGEABLE_DEVICE_LOCAL_MEMORY_EXTENSION_NAME`
- `VK_EXT_PAGEABLE_DEVICE_LOCAL_MEMORY_SPEC_VERSION`

- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PAGEABLE_DEVICE_LOCAL_MEMORY_FEATURES_EXT`

**Version History**

- Revision 1, 2021-08-24 (Piers Daniell)
VK_EXT_pci_bus_info

Name String
VK_EXT_pci_bus_info

Extension Type
Device extension

Registered Extension Number
213

Revision
2

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2
or
Version 1.1

Contact
• Matthaeus G. Chajdas anteru

Other Extension Metadata

Last Modified Date
2018-12-10

IP Status
No known IP claims.

Contributors
• Matthaeus G. Chajdas, AMD
• Daniel Rakos, AMD

Description
This extension adds a new query to obtain PCI bus information about a physical device.

Not all physical devices have PCI bus information, either due to the device not being connected to the system through a PCI interface or due to platform specific restrictions and policies. Thus this extension is only expected to be supported by physical devices which can provide the information.

As a consequence, applications should always check for the presence of the extension string for
each individual physical device for which they intend to issue the new query for and should not have any assumptions about the availability of the extension on any given platform.

**New Structures**

- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDevicePCIBusInfoPropertiesEXT`

**New Enum Constants**

- `VK_EXT_PCI_BUS_INFO_EXTENSION_NAME`
- `VK_EXT_PCI_BUS_INFO_SPEC_VERSION`

- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PCI_BUS_INFO_PROPERTIES_EXT`

**Version History**

- Revision 2, 2018-12-10 (Daniel Rakos)
  - Changed all members of the new structure to have the `uint32_t` type
- Revision 1, 2018-10-11 (Daniel Rakos)
  - Initial revision

**VK_EXT_physical_device_drm**

**Name String**

- `VK_EXT_physical_device_drm`

**Extension Type**

- Device extension

**Registered Extension Number**

- 354

**Revision**

- 1

**Ratification Status**

- Not ratified

**Extension and Version Dependencies**

- `VK_KHR_get_physical_device_properties2`

**Contact**

- Simon Ser [Emersion](https://www.emersion.com)
Other Extension Metadata

Last Modified Date
2021-06-09

IP Status
No known IP claims.

Contributors
• Simon Ser

Description
This extension provides new facilities to query DRM properties for physical devices, enabling users to match Vulkan physical devices with DRM nodes on Linux.

Its functionality closely overlaps with EGL_EXT_device_drm. Unlike the EGL extension, this extension does not expose a string containing the name of the device file and instead exposes device minor numbers.

DRM defines multiple device node types. Each physical device may have one primary node and one render node associated. Physical devices may have no primary node (e.g. if the device does not have a display subsystem), may have no render node (e.g. if it is a software rendering engine), or may have neither (e.g. if it is a software rendering engine without a display subsystem).

To query DRM properties for a physical device, chain VkPhysicalDeviceDrmPropertiesEXT to VkPhysicalDeviceProperties2.

New Structures
• Extending VkPhysicalDeviceProperties2:
  ◦ VkPhysicalDeviceDrmPropertiesEXT

New Enum Constants
• VK_EXT_PHYSICAL_DEVICE_DRM_EXTENSION_NAME
• VK_EXT_PHYSICAL_DEVICE_DRM_SPEC_VERSION
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DRM_PROPERTIES_EXT

References
1. EGL_EXT_device_drm

Version History
• Revision 1, 2021-06-09
VK_EXT_pipeline_library_group_handles

Name String
VK_EXT_pipeline_library_group_handles

Extension Type
Device extension

Registered Extension Number
499

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_ray_tracing_pipeline
and
VK_KHR_pipeline_library

Contact
- Hans-Kristian Arntzen

Extension Proposal
VK_EXT_pipeline_library_group_handles

Other Extension Metadata

Last Modified Date
2023-01-25

IP Status
No known IP claims.

Contributors
- Hans-Kristian Arntzen, Valve
- Stuart Smith, AMD
- Ricardo Garcia, Igalia
- Lionel Landwerlin, Intel
- Eric Werness, NVIDIA
- Daniel Koch, NVIDIA
Description

When using pipeline libraries in ray tracing pipelines, a library might get linked into different pipelines in an incremental way. An application can have a strategy where a ray tracing pipeline is comprised of N pipeline libraries and is later augmented by creating a new pipeline with N + 1 libraries. Without this extension, all group handles must be re-queried as the group handle is tied to the pipeline, not the library. This is problematic for applications which aim to decouple construction of record buffers and the linkage of ray tracing pipelines.

To aid in this, this extension enables support for querying group handles directly from pipeline libraries. Group handles obtained from a library must remain bitwise identical in any VkPipeline that links to the library.

With this feature, the extension also improves compatibility with DXR 1.1 AddToStateObject(), which guarantees that group handles returned remain bitwise identical between parent and child pipelines. In addition, querying group handles from COLLECTION objects is also supported with that API.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDevicePipelineLibraryGroupHandlesFeaturesEXT

New Enum Constants

- VK_EXT_PIPELINE_LIBRARY_GROUP_HANDLES_EXTENSION_NAME
- VK_EXT_PIPELINE_LIBRARY_GROUP_HANDLES_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_LIBRARY_GROUP_HANDLES_FEATURES_EXT

Version History

- Revision 1, 2023-01-25 (Hans-Kristian Arntzen)
  - Initial draft

VK_EXT_pipeline_properties

Name String

VK_EXT_pipeline_properties

Extension Type

Device extension

Registered Extension Number

373
Description

Vulkan SC requires offline compilation of pipelines. In order to support this, the pipeline state is represented in a JSON schema that is read by an offline tool for compilation.

One method of developing a Vulkan SC application is to author a Vulkan application and use a layer to record and serialize the pipeline state and shaders for offline compilation. Each pipeline is represented by a separate JSON file, and can be identified with a pipelineIdentifier.

Once the pipelines have been compiled by the offline pipeline cache compiler, the Vulkan SC application can then use this pipelineIdentifier for identifying the pipeline via Vulkan SC's VkPipelineIdentifierInfo structure.

This extension allows the Vulkan application to query the pipelineIdentifier associated with each pipeline so that the application can store this with its pipeline metadata and the Vulkan SC application will then use to map the same state to an entry in the Vulkan SC pipeline cache.

It is expected that this extension will initially be implemented in the json generation layer, although we can envision that there might be future uses for it in native Vulkan drivers as well.

New Commands

- vkGetPipelinePropertiesEXT
New Structures

- VkPipelineInfoEXT
- VkPipelinePropertiesIdentifierEXT
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDevicePipelinePropertiesFeaturesEXT

New Enum Constants

- VK_EXT_PIPELINE_PROPERTIES_EXTENSION_NAME
- VK_EXT_PIPELINE_PROPERTIES_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_PROPERTIES_FEATURES_EXT
  - VK_STRUCTURE_TYPE_PIPELINE_INFO_EXT
  - VK_STRUCTURE_TYPE_PIPELINE_PROPERTIES_IDENTIFIER_EXT

Issues

(1) This extension does not make sense on a strict Vulkan SC implementation. It may however be of potential use in a non-strict Vulkan SC implementation. Should this extension be enabled as part of Vulkan SC as well?

**RESOLVED:** No. This extension will not be enabled for Vulkan SC.

(2) This is intended to be a general pipeline properties query, but is currently only retrieving the pipeline identifier. Should the pipeline identifier query be mandatory for this extension and for all queries using this entry point?

**RESOLVED:** Use VkBaseOutStructure for the return parameter. Currently this is required to actually be a VkPipelinePropertiesIdentifierEXT structure, but that could be relaxed in the future to allow other structure types or to allow other structures to be chained in along with this one.

(3) Should there be a feature structure? Should it be required?

**RESOLVED:** Add a feature structure, and a feature for querying pipeline identifier, but allow it to be optional so that this extension can be used as the basis for other pipeline property queries without requiring the pipeline identifier to be supported.

Version History

- Revision 1, 2022-04-19 (Mukund Keshava, Daniel Koch)
  - Initial draft

**VK_EXT_pipeline_protected_access**
Name String

VK_EXT_pipeline_protected_access

Extension Type

Device extension

Registered Extension Number

467

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Contact

• Shahbaz Youssefi syoussefi

Extension Proposal

VK_EXT_pipeline_protected_access

Other Extension Metadata

Last Modified Date

2022-07-28

Contributors

• Shahbaz Youssefi, Google
• Jörg Wagner, Arm
• Ralph Potter, Samsung
• Daniel Koch, NVIDIA

Description

This extension allows protected memory access to be specified per pipeline as opposed to per device. Through the usage of this extension, any performance penalty paid due to access to protected memory will be limited to the specific pipelines that make such accesses.

New Structures

• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  • VkPhysicalDevicePipelineProtectedAccessFeaturesEXT
New Enum Constants

- VK_EXT_PIPELINE_PROTECTED_ACCESS_EXTENSION_NAME
- VK_EXT_PIPELINE_PROTECTED_ACCESS_SPEC_VERSION

Extending VkPipelineCreateFlagBits:
- VK_PIPELINE_CREATE_NO_PROTECTED_ACCESS_BIT_EXT
- VK_PIPELINE_CREATE_PROTECTED_ACCESS_ONLY_BIT_EXT

Extending VkStructureType:
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_PROTECTED_ACCESS_FEATURES_EXT

Version History

- Revision 1, 2022-07-28 (Shahbaz Youssefi)
  - Internal revisions

VK_EXT_pipeline_robustness

Name String
  VK_EXT_pipeline_robustness

Extension Type
  Device extension

Registered Extension Number
  69

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_get_physical_device_properties2

Contact
  - Jarred Davies

Other Extension Metadata

Last Modified Date
  2022-07-12

Interactions and External Dependencies
  - Interacts with VK_EXT_robustness2
• Interacts with VK_EXT_image_robustness
• Interacts with VK_KHR_ray_tracing_pipeline

Contributors
• Jarred Davies, Imagination Technologies
• Alex Walters, Imagination Technologies
• Piers Daniell, NVIDIA
• Graeme Leese, Broadcom Corporation
• Jeff Leger, Qualcomm Technologies, Inc.
• Faith Ekstrand, Intel
• Lionel Landwerlin, Intel
• Shahbaz Youssefi, Google, Inc.

Description
This extension allows users to request robustness on a per-pipeline stage basis.

As robustBufferAccess and other robustness features may have an adverse effect on performance, this extension is designed to allow users to request robust behavior only where it may be needed.

New Structures
• Extending VkGraphicsPipelineCreateInfo, VkComputePipelineCreateInfo, VkPipelineShaderStageCreateInfo, VkRayTracingPipelineCreateInfoKHR:
  ◦ VkPipelineRobustnessCreateInfoEXT
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDevicePipelineRobustnessFeaturesEXT
• Extending VkPhysicalDeviceProperties2:
  ◦ VkPhysicalDevicePipelineRobustnessPropertiesEXT

New Enums
• VkPipelineRobustnessBufferBehaviorEXT
• VkPipelineRobustnessImageBehaviorEXT

New Enum Constants
• VK_EXT_PIPELINE_ROBUSTNESS_EXTENSION_NAME
• VK_EXT_PIPELINE_ROBUSTNESS_SPEC_VERSION
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_ROBUSTNESS_FEATURES_EXT
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_ROBUSTNESS_PROPERTIES_EXT
VK_STRUCTURE_TYPE_PIPELINE_ROBUSTNESS_CREATE_INFO_EXT

Version History
• Revision 1, 2022-07-12 (Jarred Davies)
  ◦ Initial version

VK_EXT_post_depth_coverage

Name String
VK_EXT_post_depth_coverage

Extension Type
Device extension

Registered Extension Number
156

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
Contact
• Daniel Koch (dgkoch)

Other Extension Metadata

Last Modified Date
2017-07-17

Interactions and External Dependencies
• This extension requires SPV_KHR_post_depth_coverage
• This extension provides API support for GL_ARB_post_depth_coverage and GL_EXT_post_depth_coverage

Contributors
• Jeff Bolz, NVIDIA

Description
This extension adds support for the following SPIR-V extension in Vulkan:
• SPV_KHR_post_depth_coverage

which allows the fragment shader to control whether values in the SampleMask built-in input
variable reflect the coverage after early \textit{depth} and \textit{stencil} tests are applied.

This extension adds a new \texttt{PostDepthCoverage} execution mode under the \texttt{SampleMaskPostDepthCoverage} capability. When this mode is specified along with \texttt{EarlyFragmentTests}, the value of an input variable decorated with the \texttt{SampleMask} built-in reflects the coverage after the early fragment tests are applied. Otherwise, it reflects the coverage before the depth and stencil tests.

When using GLSL source-based shading languages, the \texttt{post_depth_coverage} layout qualifier from \texttt{GL_ARB_post_depth_coverage} or \texttt{GL_EXT_post_depth_coverage} maps to the \texttt{PostDepthCoverage} execution mode.

\textbf{New Enum Constants}

- \texttt{VK_EXT_POST_DEPTH_COVERAGE_EXTENSION_NAME}
- \texttt{VK_EXT_POST_DEPTH_COVERAGE_SPEC_VERSION}

\textbf{New SPIR-V Capabilities}

- \texttt{SampleMaskPostDepthCoverage}

\textbf{Version History}

- Revision 1, 2017-07-17 (Daniel Koch)
  - Internal revisions

\textbf{VK_EXT_primitive_topology_list_restart}

\textbf{Name String}

\texttt{VK_EXT_primitive_topology_list_restart}

\textbf{Extension Type}

- Device extension

\textbf{Registered Extension Number}

- 357

\textbf{Revision}

- 1

\textbf{Ratification Status}

- Not ratified

\textbf{Extension and Version Dependencies}

- \texttt{VK_KHR_get_physical_device_properties2}

\textbf{Special Use}

- \texttt{OpenGL / ES support}
Description

This extension allows list primitives to use the primitive restart index value. This provides a more efficient implementation when layering OpenGL functionality on Vulkan by avoiding emulation which incurs data copies.

New Structures

- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDevicePrimitiveTopologyListRestartFeaturesEXT`

New Enum Constants

- `VK_EXT_PRIMITIVE_TOPOLOGY_LIST_RESTART_EXTENSION_NAME`
- `VK_EXT_PRIMITIVE_TOPOLOGY_LIST_RESTART_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRIMITIVE_TOPOLOGY_LIST_RESTART_FEATURES_EXT`

Version History

- Revision 0, 2020-09-14 (Courtney Goeltzenleuchter)
  - Internal revisions
- Revision 1, 2021-01-11 (Shahbaz Youssefi)
  - Add the `primitiveTopologyPatchListRestart` feature
  - Internal revisions

`VK_EXT_primitives_generated_query`
Name String
VK_EXT_primitives_generated_query

Extension Type
Device extension

Registered Extension Number
383

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_EXT_transform_feedback

Special Use
• OpenGL / ES support

Contact
• Shahbaz Youssefi syousefi

Extension Proposal
VK_EXT_primitives_generated_query

Other Extension Metadata

Last Modified Date
2022-01-24

Contributors
• Shahbaz Youssefi, Google
• Piers Daniell, NVIDIA
• Faith Ekstrand, Collabora
• Jan-Harald Fredriksen, Arm

Description
This extension adds support for a new query type to match OpenGL's GL_PRIMITIVES_GENERATED to support layering.

New Structures
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  • VkPhysicalDevicePrimitivesGeneratedQueryFeaturesEXT
New Enum Constants

- `VK_EXT_PRIMITIVES_GENERATED_QUERY_EXTENSION_NAME`
- `VK_EXT_PRIMITIVES_GENERATED_QUERY_SPEC_VERSION`
- Extending `VkQueryType`:
  - `VK_QUERY_TYPE_PRIMITIVES_GENERATED_EXT`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRIMITIVES_GENERATED_QUERY_FEATURES_EXT`

Issues

1) Can the query from `VK_EXT_transform_feedback` be used instead?

**RESOLVED:** No. While the query from `VK_EXT_transform_feedback` can produce the same results as in this extension, it is only available while transform feedback is active. The OpenGL `GL_PRIMITIVES_GENERATED` query is independent from transform feedback. Emulation through artificial transform feedback is unnecessarily inefficient.

2) Can `VK_QUERY_PIPELINE_STATISTIC_CLIPPING_INVOCATIONS_BIT` be used instead?

**RESOLVED:** It could, but we prefer the extension for simplicity. Vulkan requires that only one query be active at a time. If both the `GL_PRIMITIVES_GENERATED` and the `GL_CLIPPING_INPUT_PRIMITIVES_ARB` queries need to be simultaneously enabled, emulation of both through `VK_QUERY_PIPELINE_STATISTIC_CLIPPING_INVOCATIONS_BIT` is inconvenient.

3) On some hardware, this query cannot be implemented if `VkPipelineRasterizationStateCreateInfo::rasterizerDiscardEnable` is enabled. How will this be handled?

**RESOLVED:** A feature flag is exposed by this extension for this. On said hardware, the GL implementation disables rasterizer-discard and achieves the same effect through other means. It will not be able to do the same in Vulkan due to lack of state information. A feature flag is exposed by this extension so the OpenGL implementation on top of Vulkan would be able to implement a similar workaround.

4) On some hardware, this query cannot be implemented for non-zero query indices. How will this be handled?

**RESOLVED:** A feature flag is exposed by this extension for this. If this feature is not present, the query from `VK_EXT_transform_feedback` can be used to the same effect.

5) How is the interaction of this extension with `transformFeedbackRasterizationStreamSelect` handled?

**RESOLVED:** Disallowed for non-zero streams. In OpenGL, the rasterization stream is always stream zero.
Version History

• Revision 1, 2021-06-23 (Shahbaz Youssefi)
  ◦ Internal revisions

VK_EXT_provoking_vertex

Name String

VK_EXT_provoking_vertex

Extension Type

Device extension

Registered Extension Number

255

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Special Use

• OpenGL / ES support

Contact

• Jesse Hall jessehall

Other Extension Metadata

Last Modified Date

2021-02-22

IP Status

No known IP claims.

Contributors

• Alexis Hétu, Google
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• Daniel Koch, Nvidia
• Jamie Madill, Google
• Jan-Harald Fredriksen, Arm
• Faith Ekstrand, Intel
This extension allows changing the provoking vertex convention between Vulkan’s default convention (first vertex) and OpenGL’s convention (last vertex).

This extension is intended for use by API-translation layers that implement APIs like OpenGL on top of Vulkan, and need to match the source API’s provoking vertex convention. Applications using Vulkan directly should use Vulkan’s default convention.

New Structures

- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDeviceProvokingVertexFeaturesEXT`
- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceProvokingVertexPropertiesEXT`
- Extending `VkPipelineRasterizationStateCreateInfo`:
  - `VkPipelineRasterizationProvokingVertexStateCreateInfoEXT`

New Enums

- `VkProvokingVertexModeEXT`

New Enum Constants

- `VK_EXT_PROVOKING_VERTEX_EXTENSION_NAME`
- `VK_EXT_PROVOKING_VERTEX_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PROVOKING_VERTEX_FEATURES_EXT`
  - `VK_STRUCTURE_TYPE_PHYSICAL DEVICE_PROVOKING_VERTEX_PROPERTIES_EXT`
  - `VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_PROVOKING_VERTEX_STATE_CREATE_INFO_EXT`
Issues

1) At what granularity should this state be set?

**RESOLVED:** At pipeline bind, with an optional per-render pass restriction.

The most natural place to put this state is in the graphics pipeline object. Some implementations require it to be known when creating the pipeline, and pipeline state is convenient for implementing OpenGL 3.2’s `glProvokingVertex`, which can change the state between draw calls. However, some implementations can only change it approximately render pass granularity. To accommodate both, provoking vertex will be pipeline state, but implementations can require that only one mode is used within a render pass instance; the render pass’s mode is chosen implicitly when the first pipeline is bound.

2) Does the provoking vertex mode affect the order that vertices are written to transform feedback buffers?

**RESOLVED:** Yes, to enable layered implementations of OpenGL and D3D.

All of OpenGL, OpenGL ES, and Direct3D 11 require that vertices are written to transform feedback buffers such that flat-shaded attributes have the same value when drawing the contents of the transform feedback buffer as they did in the original drawing when the transform feedback buffer was written (assuming the provoking vertex mode has not changed, in APIs that support more than one mode).

Version History

- Revision 1, (1c) 2021-02-22 (Jesse Hall)
  - Added `VkPhysicalDeviceProvokingVertexPropertiesEXT::transformFeedbackPreservesTriangleFanProvokingVertex` to accommodate implementations that cannot change the transform feedback vertex order for triangle fans.

- Revision 1, (1b) 2020-06-14 (Jesse Hall)
  - Added `VkPhysicalDeviceProvokingVertexFeaturesEXT::transformFeedbackPreservesProvokingVertex` and required that transform feedback write vertices so as to preserve the provoking vertex of each primitive.

- Revision 1, (1a) 2019-10-23 (Jesse Hall)
  - Initial draft, based on a proposal by Alexis Hétu

**VK_EXT_queue_family_foreign**

**Name String**

`VK_EXT_queue_family_foreign`

**Extension Type**

Device extension
This extension defines a special queue family, `VK_QUEUE_FAMILY_FOREIGN_EXT`, which can be used to transfer ownership of resources backed by external memory to foreign, external queues. This is similar to `VK_QUEUE_FAMILY_EXTERNAL_KHR`, defined in `VK_KHR_external_memory`. The key differences between the two are:

- The queues represented by `VK_QUEUE_FAMILY_EXTERNAL_KHR` must share the same physical device and the same driver version as the current `VkInstance`. `VK_QUEUE_FAMILY_FOREIGN_EXT` has no such restrictions. It can represent devices and drivers from other vendors, and can even represent non-Vulkan-capable devices.
- All resources backed by external memory support `VK_QUEUE_FAMILY_EXTERNAL_KHR`. Support for `VK_QUEUE_FAMILY_FOREIGN_EXT` is more restrictive.
Applications should expect transitions to/from `VK_QUEUE_FAMILY_FOREIGN_EXT` to be more expensive than transitions to/from `VK_QUEUE_FAMILY_EXTERNAL_KHR`.

**New Enum Constants**

- `VK_EXT_QUEUE_FAMILY_FOREIGN_EXTENSION_NAME`
- `VK_EXT_QUEUE_FAMILY_FOREIGN_SPEC_VERSION`
- `VK_QUEUE_FAMILY_FOREIGN_EXT`

**Version History**

- Revision 1, 2017-11-01 (Lina Versace)
  - Squashed internal revisions

**VK_EXT_rasterization_order_attachment_access**

**Name String**

`VK_EXT_rasterization_order_attachment_access`

**Extension Type**

Device extension

**Registered Extension Number**

464

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

- `VK_KHR_get_physical_device_properties2`

**Contact**

- Jan-Harald Fredriksen @janharaldfredriksen-arm

**Extension Proposal**

- `VK_EXT_rasterization_order_attachment_access`

**Other Extension Metadata**

**Last Modified Date**

2022-07-04

**IP Status**

No known IP claims.
Contributors

- Tobias Hector, AMD
- Jan-Harald Fredriksen, Arm

Description

This extension extends the mechanism of input attachments to allow access to framebuffer attachments that are used both as input and as color or depth/stencil attachments from one fragment to the next, in rasterization order, without explicit synchronization.

New Structures

- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  ```
  VkPhysicalDeviceRasterizationOrderAttachmentAccessFeaturesEXT
  ```

New Enums

- `VkPipelineColorBlendStateCreateFlagBits`
- `VkPipelineDepthStencilStateCreateFlagBits`

New Enum Constants

- `VK_EXT_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_EXTENSION_NAME`
- `VK_EXT_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_SPEC_VERSION`

- Extending `VkPipelineColorBlendStateCreateFlagBits`:
  ```
  VK_PIPELINE_COLOR_BLEND_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_BIT_EXT
  ```

- Extending `VkPipelineDepthStencilStateCreateFlagBits`:
  ```
  VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT
  ```
  ```
  VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT
  ```

- Extending `VkStructureType`:
  ```
  VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_FEATURES_EXT
  ```

- Extending `VkSubpassDescriptionFlagBits`:
  ```
  VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_COLOR_ACCESS_BIT_EXT
  ```
  ```
  VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_EXT
  ```
  ```
  VK_SUBPASS_DESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_EXT
  ```

Examples

None.
**Version History**

- Revision 1, 2022-07-04 (Jan-Harald Fredriksen)
  - Initial draft

**VK_EXT_rgba10x6_formats**

**Name String**

VK_EXT_rgba10x6_formats

**Extension Type**

Device extension

**Registered Extension Number**

345

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

VK_KHR_sampler_ycbcr_conversion

**Contact**

- Jan-Harald Fredriksen 📧janharaldfredriksen-arm

**Other Extension Metadata**

**Last Modified Date**

2021-09-29

**IP Status**

No known IP claims.

**Contributors**

- Jan-Harald Fredriksen, Arm
- Graeme Leese, Broadcom
- Spencer Fricke, Samsung

**Description**

This extension enables the **VK_FORMAT_R10X6G10X6B10X6A10X6_UNORM_4PACK16** format to be used without a sampler Y’C6C8 conversion enabled.
New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceRGBA10X6FormatsFeaturesEXT

New Enum Constants

- VK_EXT_RGBA10X6_FORMATS_EXTENSION_NAME
- VK_EXT_RGBA10X6_FORMATS_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RGBA10X6_FORMATS_FEATURES_EXT

Issues

1) Should we reuse the existing format enumeration or introduce a new one?

**RESOLVED:** We reuse an existing format enumeration, `VK_FORMAT_R10X6G10X6B10X6A10X6_UNORM_4PACK16`, that was previously exclusively used for YCbCr and therefore had a set of limitations related to that usage. The alternative was to introduce a new format token with exactly the same bit representation as the existing token, but without the limitations.

2) Should we only introduce `VK_FORMAT_R10X6G10X6B10X6A10X6_UNORM_4PACK16` or also 1-3 component variations?

**RESOLVED:** Only the 4-component format is introduced because the 1- and 2- component variations are already not exclusive to YCbCr, and the 3-component variation is not a good match for hardware capabilities.

Version History

- Revision 1, 2021-09-29 (Jan-Harald Fredriksen)
  - Initial EXT version

**VK_EXT_robustness2**

Name String

- `VK_EXT_robustness2`

Extension Type

- Device extension

Registered Extension Number

- 287

Revision

- 1
Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2
or
Version 1.1

Contact
• Liam Middlebrook @liam-middlebrook

Other Extension Metadata

Last Modified Date
2020-01-29

IP Status
No known IP claims.

Contributors
• Liam Middlebrook, NVIDIA
• Jeff Bolz, NVIDIA

Description
This extension adds stricter requirements for how out of bounds reads and writes are handled. Most accesses must be tightly bounds-checked, out of bounds writes must be discarded, out of bound reads must return zero. Rather than allowing multiple possible (0,0,0,x) vectors, the out of bounds values are treated as zero, and then missing components are inserted based on the format as described in Conversion to RGBA and vertex input attribute extraction.

These additional requirements may be expensive on some implementations, and should only be enabled when truly necessary.

This extension also adds support for “null descriptors”, where VK_NULL_HANDLE can be used instead of a valid handle. Accesses to null descriptors have well-defined behavior, and do not rely on robustness.

New Structures
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceRobustness2FeaturesEXT
• Extending VkPhysicalDeviceProperties2:
  ◦ VkPhysicalDeviceRobustness2PropertiesEXT

4363
New Enum Constants

- VK_EXT_ROBUSTNESS_2_EXTENSION_NAME
- VK_EXT_ROBUSTNESS_2_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ROBUSTNESS_2_FEATURES_EXT
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ROBUSTNESS_2_PROPERTIES_EXT

Issues


RESOLVED: Some implementations cannot efficiently tightly bounds-check all buffer accesses. Rather, the size of the bound range is padded to some power of two multiple, up to 256 bytes for uniform buffers and up to 4 bytes for storage buffers, and that padded size is bounds-checked. This is sufficient to implement D3D-like behavior, because D3D only allows binding whole uniform buffers or ranges that are a multiple of 256 bytes, and D3D raw and structured buffers only support 32-bit accesses.

Examples

None.

Version History

- Revision 1, 2019-11-01 (Jeff Bolz, Liam Middlebrook)
  - Initial draft

VK_EXT_sample_locations

Name String

VK_EXT_sample_locations

Extension Type

Device extension

Registered Extension Number

144

Revision

1

Ratification Status

Not ratified
Extension and Version Dependencies

VK_KHR_get_physical_device_properties2
or
Version 1.1

Contact
• Daniel Rakos drakos-amd

Other Extension Metadata

Last Modified Date
2017-08-02

Contributors
• Mais Alnasser, AMD
• Matthaeus G. Chajdas, AMD
• Maciej Jesionowski, AMD
• Daniel Rakos, AMD
• Slawomir Grajewski, Intel
• Jeff Bolz, NVIDIA
• Bill Licea-Kane, Qualcomm

Description

This extension allows an application to modify the locations of samples within a pixel used in rasterization. Additionally, it allows applications to specify different sample locations for each pixel in a group of adjacent pixels, which can increase antialiasing quality (particularly if a custom resolve shader is used that takes advantage of these different locations).

It is common for implementations to optimize the storage of depth values by storing values that can be used to reconstruct depth at each sample location, rather than storing separate depth values for each sample. For example, the depth values from a single triangle may be represented using plane equations. When the depth value for a sample is needed, it is automatically evaluated at the sample location. Modifying the sample locations causes the reconstruction to no longer evaluate the same depth values as when the samples were originally generated, thus the depth aspect of a depth/stencil attachment must be cleared before rendering to it using different sample locations.

Some implementations may need to evaluate depth image values while performing image layout transitions. To accommodate this, instances of the VkSampleLocationsInfoEXT structure can be specified for each situation where an explicit or automatic layout transition has to take place. VkSampleLocationsInfoEXT can be chained from VkImageMemoryBarrier structures to provide sample locations for layout transitions performed by vkCmdWaitEvents and vkCmdPipelineBarrier calls, and VkRenderPassSampleLocationsBeginInfoEXT can be chained from VkRenderPassBeginInfo to provide sample locations for layout transitions performed implicitly by a render pass instance.
New Commands

- vkCmdSetSampleLocationsEXT
- vkGetPhysicalDeviceMultisamplePropertiesEXT

New Structures

- VkAttachmentSampleLocationsEXT
- VkMultisamplePropertiesEXT
- VkSampleLocationEXT
- VkSubpassSampleLocationsEXT
- Extending VkImageMemoryBarrier, VkImageMemoryBarrier2:
  - VkSampleLocationsInfoEXT
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceSampleLocationsPropertiesEXT
- Extending VkPipelineMultisampleStateCreateInfo:
  - VkPipelineSampleLocationsStateCreateInfoEXT
- Extending VkRenderPassBeginInfo:
  - VkRenderPassSampleLocationsBeginInfoEXT

New Enum Constants

- VK_EXT_SAMPLE_LOCATIONS_EXTENSION_NAME
- VK_EXT_SAMPLE_LOCATIONS_SPEC_VERSION
- Extending VkDynamicState:
  - VK_DYNAMIC_STATE_SAMPLE_LOCATIONS_EXT
- Extending VkImageCreateFlagBits:
  - VK_IMAGE_CREATE_SAMPLE_LOCATIONS_COMPATIBLE_DEPTH_BIT_EXT
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_MULTISAMPLE_PROPERTIES_EXT
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SAMPLE_LOCATIONS_PROPERTIES_EXT
  - VK_STRUCTURE_TYPE_PIPELINE_SAMPLE_LOCATIONS_STATE_CREATE_INFO_EXT
  - VK_STRUCTURE_TYPE_RENDER_PASS_SAMPLE_LOCATIONS_BEGIN_INFO_EXT
  - VK_STRUCTURE_TYPE_SAMPLE_LOCATIONS_INFO_EXT

Version History

- Revision 1, 2017-08-02 (Daniel Rakos)
  - Internal revisions
VK_EXT_shader_atomic_float

Name String
    VK_EXT_shader_atomic_float

Extension Type
    Device extension

Registered Extension Number
    261

Revision
    1

Ratification Status
    Not ratified

Extension and Version Dependencies
    VK_KHR_get_physical_device_properties2
    or
    Version 1.1

Contact
    • Vikram Kushwaha vkushwaha-nv

Other Extension Metadata

Last Modified Date
    2020-07-15

IP Status
    No known IP claims.

Interactions and External Dependencies
    • This extension requires SPV_EXT_shader_atomic_float_add
    • This extension provides API support for GL_EXT_shader_atomic_float

Contributors
    • Vikram Kushwaha, NVIDIA
    • Jeff Bolz, NVIDIA

Description
This extension allows a shader to contain floating-point atomic operations on buffer, workgroup, and image memory. It also advertises the SPIR-V AtomicFloat32AddEXT and AtomicFloat64AddEXT capabilities that allows atomic addition on floating-points numbers. The supported operations include OpAtomicFAddEXT, OpAtomicExchange, OpAtomicLoad and OpAtomicStore.
New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceShaderAtomicFloatFeaturesEXT`

New Enum Constants

- `VK_EXT_SHADER_ATOMIC_FLOAT_EXTENSION_NAME`
- `VK_EXT_SHADER_ATOMIC_FLOAT_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ATOMIC_FLOAT_FEATURES_EXT`

New SPIR-V Capabilities

- `AtomicFloat32AddEXT`
- `AtomicFloat64AddEXT`

Version History

- Revision 1, 2020-07-15 (Vikram Kushwaha)
  - Internal revisions

**VK_EXT_shader_atomic_float2**

**Name String**

- `VK_EXT_shader_atomic_float2`

**Extension Type**

- Device extension

**Registered Extension Number**

- 274

**Revision**

- 1

**Ratification Status**

- Not ratified

**Extension and Version Dependencies**

- `VK_EXT_shader_atomic_float`

**Contact**

- Faith Ekstrand [gfxstrand](https://gfxstrand.com)
Other Extension Metadata

Last Modified Date
2020-08-14

IP Status
No known IP claims.

Interactions and External Dependencies
- This extension requires the VK_EXT_shader_atomic_float extension.
- This extension requires SPV_EXT_shader_atomic_float_min_max and SPV_EXT_shader_atomic_float16_add
- This extension provides API support for GLSL_EXT_shader_atomic_float2

Contributors
- Faith Ekstrand, Intel

Description
This extension allows a shader to perform 16-bit floating-point atomic operations on buffer and workgroup memory as well as floating-point atomic minimum and maximum operations on buffer, workgroup, and image memory. It advertises the SPIR-V AtomicFloat16AddEXT capability which allows atomic add operations on 16-bit floating-point numbers and the SPIR-V AtomicFloat16MinMaxEXT, AtomicFloat32MinMaxEXT and AtomicFloat64MinMaxEXT capabilities which allow atomic minimum and maximum operations on floating-point numbers. The supported operations include OpAtomicFAddEXT, OpAtomicFMinEXT and OpAtomicFMaxEXT.

New Structures
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceShaderAtomicFloat2FeaturesEXT

New Enum Constants
- VK_EXT_SHADER_ATOMIC_FLOAT_2_EXTENSION_NAME
- VK_EXT_SHADER_ATOMIC_FLOAT_2_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ATOMIC_FLOAT_2_FEATURES_EXT

Issues
1) Should this extension add support for 16-bit image atomics?

**RESOLVED:** No. While Vulkan supports creating storage images with VK_FORMAT_R16_SFLOAT and doing load and store on them, the data in the shader has a 32-bit representation. Vulkan currently has no facility for even basic reading or writing such images using 16-bit float values in the shader. Adding such functionality would be required before 16-bit image atomics would make sense and is
New SPIR-V Capabilities

- AtomicFloat32MinMaxEXT
- AtomicFloat32MinMaxEXT
- AtomicFloat32MinMaxEXT
- AtomicFloat64MinMaxEXT

Version History

- Revision 1, 2020-08-14 (Faith Ekstrand)
  - Internal revisions

VK_EXT_shader_image_atomic_int64

Name String

VK_EXT_shader_image_atomic_int64

Extension Type

Device extension

Registered Extension Number

235

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2
or
Version 1.1

Contact

- Tobias Hector tobuki

Other Extension Metadata

Last Modified Date

2020-07-14

IP Status

No known IP claims.
Interactions and External Dependencies

- This extension requires `SPV_EXT_shader_image_int64`
- This extension provides API support for `GLSL_EXT_shader_image_int64`

Contributors

- Matthaeus Chajdas, AMD
- Graham Wihlidal, Epic Games
- Tobias Hector, AMD
- Jeff Bolz, Nvidia
- Faith Ekstrand, Intel

Description

This extension extends existing 64-bit integer atomic support to enable these operations on images as well.

When working with large 2- or 3-dimensional data sets (e.g. rasterization or screen-space effects), image accesses are generally more efficient than equivalent buffer accesses. This extension allows applications relying on 64-bit integer atomics in this manner to quickly improve performance with only relatively minor code changes.

64-bit integer atomic support is guaranteed for optimally tiled images with the `VK_FORMAT_R64_UINT` and `VK_FORMAT_R64_SINT` formats.

New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceShaderImageAtomicInt64FeaturesEXT`

New Enum Constants

- `VK_EXT_SHADER_IMAGE_ATOMIC_INT64_EXTENSION_NAME`
- `VK_EXT_SHADER_IMAGE_ATOMIC_INT64_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_IMAGE_ATOMIC_INT64_FEATURES_EXT`

Version History

- Revision 1, 2020-07-14 (Tobias Hector)
  - Initial draft

VK_EXT_shader_module_identifier

Name String

- `VK_EXT_shader_module_identifier`
Extension Type
  Device extension

Registered Extension Number
  463

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_get_physical_device_properties2
  and
  VK_EXT_pipeline_creation_cache_control

Contact
  • Hans-Kristian Arntzen ♦HansKristian-Work

Extension Proposal
  VK_EXT_shader_module_identifier

Other Extension Metadata

Last Modified Date
  2022-05-16

IP Status
  No known IP claims.

Contributors
  • Hans-Kristian Arntzen, Valve
  • Ricardo Garcia, Igalia
  • Piers Daniell, NVIDIA
  • Jan-Harald Fredriksen, Arm
  • Tom Olson, Arm
  • Faith Ekstrand, Collabora

Description

Some applications generate SPIR-V code at runtime. When pipeline caches are primed, either
explicitly through e.g. VkPipelineCache mechanisms, or implicitly through driver managed caches,
having to re-generate SPIR-V modules is redundant. SPIR-V modules could be cached on disk by an
application, but the extra disk size requirement might be prohibitive in some use cases.

This extension adds the ability for an application to query a small identifier associated with a
VkShaderModule. On subsequent runs of the application, the same identifier can be provided in lieu of a VkShaderModule object. A pipeline creation call with such a module may succeed if a pipeline could be created without invoking compilation, and information inside the SPIR-V module is not required by the implementation.

VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT must be used if only the identifier is provided, and this use case is intended to work like a non-blocking, speculative compile. Applications can fallback as necessary.

The main motivation for identifying the module itself and not the entire pipeline is that pipeline identifiers change when a driver is updated, but module identifiers are expected to be stable for any particular driver implementation. This approach is helpful for shader pre-compilation systems which can prime pipeline caches ahead of time. When on-disk pipeline caches are updated, the same shader identifiers could lead to a pipeline cache hit.

New Commands

- vkGetShaderModuleCreateInfoIdentifierEXT
- vkGetShaderModuleIdentifierEXT

New Structures

- VkShaderModuleIdentifierEXT
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceShaderModuleIdentifierFeaturesEXT
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceShaderModuleIdentifierPropertiesEXT
- Extending VkPipelineShaderStageCreateInfo:
  - VkPipelineShaderStageModuleIdentifierCreateInfoEXT

New Enum Constants

- VK_EXT_SHADER_MODULE_IDENTIFIER_EXTENSION_NAME
- VK_EXT_SHADER_MODULE_IDENTIFIER_SPEC_VERSION
- VK_MAX_SHADER_MODULE_IDENTIFIER_SIZE_EXT
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_MODULE_IDENTIFIER_FEATURES_EXT
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_MODULE_IDENTIFIER_PROPERTIES_EXT
  - VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_MODULE_IDENTIFIER_CREATE_INFO_EXT
  - VK_STRUCTURE_TYPE_SHADER_MODULE_IDENTIFIER_EXT
**Version History**

- Revision 1, 2022-03-16 (Hans-Kristian Arntzen)
  - Initial draft

**VK_EXT_shader_object**

**Name String**

VK_EXT_shader_object

**Extension Type**

Device extension

**Registered Extension Number**

483

**Revision**

1

**Ratification Status**

Ratified

**Extension and Version Dependencies**

- VK_KHR_get_physical_device_properties2
  - or
  - Version 1.1
  - and
  - VK_KHR_dynamic_rendering
  - or
  - Version 1.3

**Contact**

- Daniel Story daniel-story

**Extension Proposal**

VK_EXT_shader_object

**Other Extension Metadata**

**Last Modified Date**

2023-03-30

**Interactions and External Dependencies**

- Interacts with VK_EXT_extended_dynamic_state
- Interacts with VK_EXT_extended_dynamic_state2
- Interacts with VK_EXT_extended_dynamic_state3
- Interacts with VK_EXT_vertex_input_dynamic_state
**IP Status**
No known IP claims.

**Contributors**
- Piers Daniell, NVIDIA
- Sandy Jamieson, Nintendo
- Žiga Markuš, LunarG
- Tobias Hector, AMD
- Alex Walters, Imagination
- Shahbaz Youssefi, Google
- Ralph Potter, Samsung
- Jan-Harald Fredriksen, ARM
- Connor Abott, Valve
- Arseny Kapoulkine, Roblox
- Patrick Doane, Activision
- Jeff Leger, Qualcomm
- Stu Smith, AMD
- Chris Glover, Google
- Ricardo Garcia, Igalia
- Faith Ekstrand, Collabora
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- Daniel Koch, NVIDIA
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- Mike Blumenkrantz, Valve
- Samuel Pitoiset, Valve
- Qun Lin, AMD
- Spencer Fricke, LunarG
- Soroush Faghihi Kashani, Imagination

**Description**
This extension introduces a new **VkShaderEXT** object type which represents a single compiled shader stage. Shader objects provide a more flexible alternative to **VkPipeline** objects, which may be helpful in certain use cases.
New Object Types

- VkShaderEXT

New Commands

- vkCmdBindShadersEXT
- vkCmdBindVertexBuffers2EXT
- vkCmdSetAlphaToCoverageEnableEXT
- vkCmdSetAlphaToOneEnableEXT
- vkCmdSetColorBlendAdvancedEXT
- vkCmdSetColorBlendEnableEXT
- vkCmdSetColorBlendEquationEXT
- vkCmdSetColorWriteMaskEXT
- vkCmdSetConservativeRasterizationModeEXT
- vkCmdSetCullModeEXT
- vkCmdSetDepthBiasEnableEXT
- vkCmdSetDepthBoundsTestEnableEXT
- vkCmdSetDepthClipEnableEXT
- vkCmdSetDepthClipNegativeOneToOneEXT
- vkCmdSetDepthCompareOpEXT
- vkCmdSetDepthTestEnableEXT
- vkCmdSetDepthWriteEnableEXT
- vkCmdSetExtraPrimitiveOverestimationSizeEXT
- vkCmdSetFrontFaceEXT
- vkCmdSetLineRasterizationModeEXT
- vkCmdSetLineStippleEnableEXT
- vkCmdSetLogicOpEXT
- vkCmdSetLogicOpEnableEXT
- vkCmdSetPatchControlPointsEXT
- vkCmdSetPolygonModeEXT
- vkCmdSetPrimitiveRestartEnableEXT
- vkCmdSetPrimitiveTopologyEXT
- vkCmdSetProvokingVertexModeEXT
- vkCmdSetRasterizationSamplesEXT
• `vkCmdSetRasterizationStreamEXT`
• `vkCmdSetRasterizerDiscardEnableEXT`
• `vkCmdSetSampleLocationsEnableEXT`
• `vkCmdSetSampleMaskEXT`
• `vkCmdSetScissorWithCountEXT`
• `vkCmdSetStencilOpEXT`
• `vkCmdSetStencilTestEnableEXT`
• `vkCmdSetTessellationDomainOriginEXT`
• `vkCmdSetVertexInputEXT`
• `vkCmdSetViewportWithCountEXT`
• `vkCreateShadersEXT`
• `vkDestroyShaderEXT`
• `vkGetShaderBinaryDataEXT`

If `VK_NV_clip_space_w_scaling` is supported:
  • `vkCmdSetViewportWScalingEnableNV`

If `VK_NV_coverage_reduction_mode` is supported:
  • `vkCmdSetCoverageReductionModeNV`

If `VK_NV_fragment_coverage_to_color` is supported:
  • `vkCmdSetCoverageToColorEnableNV`
  • `vkCmdSetCoverageToColorLocationNV`

If `VK_NV_framebuffer_mixed_samples` is supported:
  • `vkCmdSetCoverageModulationModeNV`
  • `vkCmdSetCoverageModulationTableEnableNV`
  • `vkCmdSetCoverageModulationTableNV`

If `VK_NV_representative_fragment_test` is supported:
  • `vkCmdSetRepresentativeFragmentTestEnableNV`

If `VK_NV_shading_rate_image` is supported:
  • `vkCmdSetShadingRateImageEnableNV`

If `VK_NV_viewport_swizzle` is supported:
  • `vkCmdSetViewportSwizzleNV`
New Structures

- VkColorBlendAdvancedEXT
- VkColorBlendEquationEXT
- VkShaderCreateInfoEXT
- VkVertexInputAttributeDescription2EXT
- VkVertexInputBindingDescription2EXT
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - Extending VkPhysicalDeviceShaderObjectFeaturesEXT
- Extending VkPhysicalDeviceProperties2:
  - Extending VkPhysicalDeviceShaderObjectPropertiesEXT
- Extending VkPipelineShaderStageCreateInfo, VkShaderCreateInfoEXT:
  - Extending VkShaderRequiredSubgroupSizeCreateInfoEXT

New Enums

- VkShaderCodeTypeEXT
- VkShaderCreateFlagBitsEXT

New Bitmasks

- VkShaderCreateFlagsEXT

New Enum Constants

- VK_EXT_SHADER_OBJECT_EXTENSION_NAME
- VK_EXT_SHADER_OBJECT_SPEC_VERSION
- Extending VkObjectType:
  - VK_OBJECT_TYPE_SHADER_EXT
- Extending VkResult:
  - VK_ERROR_INCOMPATIBLE_SHADER_BINARY_EXT
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_OBJECT_FEATURES_EXT
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_OBJECT_PROPERTIES_EXT
  - VK_STRUCTURE_TYPE_SHADER_CREATE_INFO_EXT
  - VK_STRUCTURE_TYPE_SHADER_REQUIRED_SUBGROUP_SIZE_CREATE_INFO_EXT
  - VK_STRUCTURE_TYPE_VERTEX_INPUT_ATTRIBUTE_DESCRIPTION_2_EXT
  - VK_STRUCTURE_TYPE_VERTEX_INPUT_BINDING_DESCRIPTION_2_EXT

If VK_EXT_fragment_density_map is supported:
• Extending `VkShaderCreateFlagBitsEXT`:
  ◦ `VK_SHADER_CREATE_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT`

If `VK_EXT_mesh_shader` or `VK_NV_mesh_shader` is supported:

• Extending `VkShaderCreateFlagBitsEXT`:
  ◦ `VK_SHADER_CREATE_NO_TASK_SHADER_BIT_EXT`

If `VK_EXT_subgroup_size_control` or Version 1.3 is supported:

• Extending `VkShaderCreateFlagBitsEXT`:
  ◦ `VK_SHADER_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT_EXT`
  ◦ `VK_SHADER_CREATE_REQUIRE_FULL_SUBGROUPS_BIT_EXT`

If `VK_KHR_device_group` or Version 1.1 is supported:

• Extending `VkShaderCreateFlagBitsEXT`:
  ◦ `VK_SHADER_CREATE_DISPATCH_BASE_BIT_EXT`

If `VK_KHR_fragment_shading_rate` is supported:

• Extending `VkShaderCreateFlagBitsEXT`:
  ◦ `VK_SHADER_CREATE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_EXT`

Examples

Example 1

Create linked pair of vertex and fragment shaders.

```c
// Logical device created with the shaderObject feature enabled
VkDevice device;

// SPIR-V shader code for a vertex shader, along with its size in bytes
void* pVertexSpirv;
size_t vertexSpirvSize;

// SPIR-V shader code for a fragment shader, along with its size in bytes
void* pFragmentSpirv;
size_t fragmentSpirvSize;

// Descriptor set layout compatible with the shaders
VkDescriptorSetLayout descriptorSetLayout;

VkShaderCreateInfoEXT shaderCreateInfos[2] = {
  
  { .sType = VK_STRUCTURE_TYPE_SHADER_CREATE_INFO_EXT,
    
```
.pNext = NULL,
.flags = VK_SHADER_CREATE_LINK_STAGE_BIT_EXT,
.stage = VK_SHADER_STAGE_VERTEX_BIT,
.nextStage = VK_SHADER_STAGE_FRAGMENT_BIT,
.codeType = VK_SHADER_CODE_TYPE_SPIRV_EXT,
.codeSize = vertexSpirvSize,
.pCode = pVertexSpirv,
.pName = "main",
setLayoutCount = 1,
pSetLayouts = &descriptorSetLayout;
.pushConstantRangeCount = 0,
pPushConstantRanges = NULL,
pSpecializationInfo = NULL
},
{
.sType = VK_STRUCTURE_TYPE_SHADER_CREATE_INFO_EXT,
.pNext = NULL,
.flags = VK_SHADER_CREATE_LINK_STAGE_BIT_EXT,
.stage = VK_SHADER_STAGE_FRAGMENT_BIT,
.nextStage = 0,
.codeType = VK_SHADER_CODE_TYPE_SPIRV_EXT,
.codeSize = fragmentSpirvSize,
.pCode = pFragmentSpirv,
.pName = "main",
setLayoutCount = 1,
pSetLayouts = &descriptorSetLayout;
.pushConstantRangeCount = 0,
pPushConstantRanges = NULL,
pSpecializationInfo = NULL
}
};

VkResult result;
VkShaderEXT shaders[2];

result = vkCreateShadersEXT(device, 2, shaderCreateInfos, NULL, shaders);
if (result != VK_SUCCESS)
{
    // Handle error
}

Later, during command buffer recording, bind the linked shaders and draw.

// Command buffer in the recording state
VkCommandBuffer commandBuffer;

// Vertex and fragment shader objects created above
VkShaderEXT shaders[2];

// Assume vertex buffers, descriptor sets, etc. have been bound, and existing
// state setting commands have been called to set all required state

const VkShaderStageFlagBits stages[2] =
{
    VK_SHADER_STAGE_VERTEX_BIT,
    VK_SHADER_STAGE_FRAGMENT_BIT
};

// Bind linked shaders
vkCmdBindShadersEXT(commandBuffer, 2, stages, shaders);

// Equivalent to the previous line. Linked shaders can be bound one at a time,
// in any order:
// vkCmdBindShadersEXT(commandBuffer, 1, &stages[1], &shaders[1]);
// vkCmdBindShadersEXT(commandBuffer, 1, &stages[0], &shaders[0]);

// The above is sufficient to draw if the device was created with the
tessellationShader and geometryShader features disabled. Otherwise, since
// those stages should not execute, vkCmdBindShadersEXT() must be called at
// least once with each of their stages in pStages before drawing:

const VkShaderStageFlagBits unusedStages[3] =
{
    VK_SHADER_STAGE_TESSELLATION_CONTROL_BIT,
    VK_SHADER_STAGE_TESSELLATION_EVALUATION_BIT,
    VK_SHADER_STAGE_GEOMETRY_BIT
};

// NULL pShaders is equivalent to an array of stageCount VK_NULL_HANDLE values,
// meaning no shaders are bound to those stages, and that any previously bound
// shaders are unbound
vkCmdBindShadersEXT(commandBuffer, 3, unusedStages, NULL);

// Graphics shader objects may only be used to draw inside dynamic render pass
// instances begun with vkCmdBeginRendering(), assume one has already been begun

// Draw a triangle
vkCmdDraw(commandBuffer, 3, 1, 0, 0);

Example 2
Create unlinked vertex, geometry, and fragment shaders.

// Logical device created with the shaderObject feature enabled
VkDevice device;

// SPIR-V shader code for vertex shaders, along with their sizes in bytes
void* pVertexSpirv[2];
size_t vertexSpirvSize[2];
// SPIR-V shader code for a geometry shader, along with its size in bytes
void pGeometrySpirv;
size_t geometrySpirvSize;

// SPIR-V shader code for fragment shaders, along with their sizes in bytes
void* pFragmentSpirv[2];
size_t fragmentSpirvSize[2];

// Descriptor set layout compatible with the shaders
VkDescriptorSetLayout descriptorSetLayout;

VkShaderCreateInfoEXT shaderCreateInfos[5] =
{
    // Stage order does not matter
    {
        .sType = VK_STRUCTURE_TYPE_SHADER_CREATE_INFO_EXT,
        .pNext = NULL,
        .flags = 0,
        .stage = VK_SHADER_STAGE_GEOMETRY_BIT,
        .nextStage = VK_SHADER_STAGE_FRAGMENT_BIT,
        .codeType = VK_SHADER_CODE_TYPE_SPIRV_EXT,
        .codeSize = pGeometrySpirv,
        .pCode = geometrySpirvSize,
        .pName = "main",
        .setLayoutCount = 1,
        .pSetLayouts = &descriptorSetLayout;
        .pushConstantRangeCount = 0,
        .pPushConstantRanges = NULL,
        .pSpecializationInfo = NULL
    },
    {
        .sType = VK_STRUCTURE_TYPE_SHADER_CREATE_INFO_EXT,
        .pNext = NULL,
        .flags = 0,
        .stage = VK_SHADER_STAGE_VERTEX_BIT,
        .nextStage = VK_SHADER_STAGE_GEOMETRY_BIT,
        .codeType = VK_SHADER_CODE_TYPE_SPIRV_EXT,
        .codeSize = vertexSpirvSize[0],
        .pCode = pVertexSpirv[0],
        .pName = "main",
        .setLayoutCount = 1,
        .pSetLayouts = &descriptorSetLayout;
        .pushConstantRangeCount = 0,
        .pPushConstantRanges = NULL,
        .pSpecializationInfo = NULL
    },
    {
        .sType = VK_STRUCTURE_TYPE_SHADER_CREATE_INFO_EXT,
        .pNext = NULL,
        .flags = 0,
        .stage = VK_SHADER_STAGE_FRAGMENT_BIT,

.nextStage = 0,
.codeType = VK_SHADER_CODE_TYPE_SPIRV_EXT,
.codeSize = fragmentSpirvSize[0],
pCode = pFragmentSpirv[0],
pName = "main",
.setLayoutCount = 1,
pSetLayouts = &descriptorSetLayout;
pushConstantRangeCount = 0,
pPushConstantRanges = NULL,
pSpecializationInfo = NULL
},
{
.sType = VK_STRUCTURE_TYPE_SHADER_CREATE_INFO_EXT,
pNext = NULL,
.flags = 0,
.stage = VK_SHADER_STAGE_FRAGMENT_BIT,
.nextStage = 0,
.codeType = VK_SHADER_CODE_TYPE_SPIRV_EXT,
.codeSize = fragmentSpirvSize[1],
pCode = pFragmentSpirv[1],
pName = "main",
.setLayoutCount = 1,
pSetLayouts = &descriptorSetLayout;
pushConstantRangeCount = 0,
pPushConstantRanges = NULL,
pSpecializationInfo = NULL
}.sType = VK_STRUCTURE_TYPE_SHADER_CREATE_INFO_EXT,
pNext = NULL,
.flags = 0,
.stage = VK_SHADER_STAGE_VERTEX_BIT,
// Suppose we want this vertex shader to be able to be followed by
// either a geometry shader or fragment shader:
.nextStage = VK_SHADER_STAGE_GEOMETRY_BIT | VK_SHADER_STAGE_FRAGMENT_BIT,
.codeType = VK_SHADER_CODE_TYPE_SPIRV_EXT,
.codeSize = vertexSpirvSize[1],
pCode = pVertexSpirv[1],
pName = "main",
.setLayoutCount = 1,
pSetLayouts = &descriptorSetLayout;
pushConstantRangeCount = 0,
pPushConstantRanges = NULL,
pSpecializationInfo = NULL
}

VkResult result;
VkShaderEXT shaders[5];
result = vkCreateShadersEXT(device, 5, shaderCreateInfos, NULL, shaders);
Later, during command buffer recording, bind the linked shaders in different combinations and
draw.

```cpp
if (result != VK_SUCCESS)
{
    // Handle error
}
```

// Command buffer in the recording state
VkCommandBuffer commandBuffer;

// Vertex, geometry, and fragment shader objects created above
VkShaderEXT shaders[5];

// Assume vertex buffers, descriptor sets, etc. have been bound, and existing
// state setting commands have been called to set all required state

const VkShaderStageFlagBits stages[3] =
{
    // Any order is allowed
    VK_SHADER_STAGE_FRAGMENT_BIT,
    VK_SHADER_STAGE_VERTEX_BIT,
    VK_SHADER_STAGE_GEOMETRY_BIT,
};

VkShaderEXT bindShaders[3] =
{
    shaders[2], // FS
    shaders[1], // VS
    shaders[0] // GS
};

// Bind unlinked shaders
vkCmdBindShadersEXT(commandBuffer, 3, stages, bindShaders);

// Assume the tessellationShader feature is disabled, so vkCmdBindShadersEXT()
// need not have been called with either tessellation stage

// Graphics shader objects may only be used to draw inside dynamic render pass
// instances begun with vkCmdBeginRendering(), assume one has already been begun

// Draw a triangle
vkCmdDraw(commandBuffer, 3, 1, 0, 0);

// Bind a different unlinked fragment shader
const VkShaderStageFlagBits fragmentStage = VK_SHADER_STAGE_FRAGMENT_BIT;
vkCmdBindShadersEXT(commandBuffer, 1, &fragmentStage, &shaders[3]);

// Draw another triangle
vkCmdDraw(commandBuffer, 3, 1, 0, 0);
// Bind a different unlinked vertex shader
const VkShaderStageFlagBits vertexStage = VK_SHADER_STAGE_VERTEX_BIT;
vkCmdBindShadersEXT(commandBuffer, 1, &vertexStage, shaders[4]);

// Draw another triangle
vkCmdDraw(commandBuffer, 3, 1, 0, 0);

Version History

• Revision 1, 2023-03-30 (Daniel Story)
  ◦ Initial draft

VK_EXT_shader_stencil_export

Name String
  VK_EXT_shader_stencil_export

Extension Type
  Device extension

Registered Extension Number
  141

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies

Contact
  • Dominik Witczak @dominikwitczakamd

Other Extension Metadata

Last Modified Date
  2017-07-19

IP Status
  No known IP claims.

Interactions and External Dependencies
  • This extension requires SPV_EXT_shader_stencil_export
  • This extension provides API support for GL_ARB_shader_stencil_export
Contributors

• Dominik Witczak, AMD
• Daniel Rakos, AMD
• Rex Xu, AMD

Description

This extension adds support for the SPIR-V extension `SPV_EXT_shader_stencil_export`, providing a mechanism whereby a shader may generate the stencil reference value per invocation. When stencil testing is enabled, this allows the test to be performed against the value generated in the shader.

New Enum Constants

• `VK_EXT_SHADER_STENCIL_EXPORT_EXTENSION_NAME`
• `VK_EXT_SHADER_STENCIL_EXPORT_SPEC_VERSION`

Version History

• Revision 1, 2017-07-19 (Dominik Witczak)
  ◦ Initial draft

**VK_EXT_shader_tile_image**

Name String

`VK_EXT_shader_tile_image`

Extension Type

Device extension

Registered Extension Number

396

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

Version 1.3

Contact

• Jan-Harald Fredriksen janharaldfredriksen-arm

Extension Proposal

`VK_EXT_shader_tile_image`
Other Extension Metadata

Last Modified Date
2023-03-23

IP Status
No known IP claims.

Interactions and External Dependencies
- This extension requires \textit{SPV\_EXT\_shader\_tile\_image}
- This extension provides API support for \textit{GL\_EXT\_shader\_tile\_image}

Contributors
- Sandeep Kakarlapudi, Arm
- Jan-Harald Fredriksen, Arm
- James Fitzpatrick, Imagination
- Andrew Garrard, Imagination
- Jeff Leger, Qualcomm
- Huilong Wang, Huawei
- Graeme Leese, Broadcom
- Hans-Kristian Arntzen, Valve
- Tobias Hector, AMD
- Jeff Bolz, NVIDIA
- Shahbaz Youssefi, Google

Description
This extension allows fragment shader invocations to read color, depth and stencil values at their pixel location in rasterization order. The functionality is only available when using dynamic render passes introduced by \textit{VK\_KHR\_dynamic\_rendering}. Example use cases are programmable blending and deferred shading.

See \textit{fragment shader tile image reads} for more information.

New Structures
- Extending \textit{VkPhysicalDeviceFeatures2, VkDeviceCreateInfo}:
  - \textit{VkPhysicalDeviceShaderTileImageFeaturesEXT}
- Extending \textit{VkPhysicalDeviceProperties2}:
  - \textit{VkPhysicalDeviceShaderTileImagePropertiesEXT}
New Enum Constants

- VK_EXT_SHADER_TILE_IMAGE_EXTENSION_NAME
- VK_EXT_SHADER_TILE_IMAGE_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_TILE_IMAGE_FEATURES_EXT
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_TILE_IMAGE_PROPERTIES_EXT

Issues

None.

Examples

Color read example.

```glsl
layout( location = 0 /* aliased to color attachment 0 */ ) tileImageEXT highp attachmentEXT color0;
layout( location = 1 /* aliased to color attachment 1 */ ) tileImageEXT highp attachmentEXT color1;

layout( location = 0 ) out vec4 fragColor;

void main()
{
    vec4 value = colorAttachmentReadEXT(color0) + colorAttachmentReadEXT(color1);
    fragColor = value;
}
```

Depth & Stencil read example.

```glsl
void main()
{
    // read sample 0: works for non-MSAA or MSAA targets
    highp float last_depth = depthAttachmentReadEXT();
    lowp uint lastStencil = stencilAttachmentReadEXT();

    //..
}
```

Version History

- Revision 1, 2023-03-23 (Sandeep Kakarlapudi)
  - Initial version
**VK_EXT_subpass_merge_feedback**

**Name String**

VK_EXT_subpass_merge_feedback

**Extension Type**

Device extension

**Registered Extension Number**

459

**Revision**

2

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

VK_KHR_get_physical_device_properties2

**Contact**

- Ting Wei catweiting

**Extension Proposal**

VK_EXT_subpass_merge_feedback

**Other Extension Metadata**

**Last Modified Date**

2022-05-24

**IP Status**

No known IP claims.

**Contributors**

- Jan-Harald Fredriksen, Arm
- Jorg Wagner, Arm
- Ting Wei, Arm

**Description**

This extension adds a mechanism to provide feedback to an application about whether the subpasses specified on render pass creation are merged by the implementation. Additionally, it provides a control to enable or disable subpass merging in the render pass.

**New Structures**

- VkRenderPassCreationFeedbackInfoEXT
• **VkRenderPassSubpassFeedbackInfoEXT**

  • Extending **VkPhysicalDeviceFeatures2, VkDeviceCreateInfo**:
    ◦ **VkPhysicalDeviceSubpassMergeFeedbackFeaturesEXT**

  • Extending **VkPhysicalDeviceFeatures2**:
    ◦ **VkRenderPassCreationFeedbackCreateInfoEXT**

  • Extending **VkRenderPassCreateInfo2**:
    ◦ **VkRenderPassSubpassFeedbackCreateInfoEXT**

  • Extending **VkSubpassDescription2**:
    ◦ **VkRenderPassCreationControlEXT**

**New Enums**

• **VkSubpassMergeStatusEXT**

**New Enum Constants**

• **VK_EXT_SUBPASS_MERGE_FEEDBACK_EXTENSION_NAME**

• **VK_EXT_SUBPASS_MERGE_FEEDBACK_SPEC_VERSION**

• Extending **VkStructureType**:
  ◦ **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBPASS_MERGE_FEEDBACK_FEATURES_EXT**
  ◦ **VK_STRUCTURE_TYPE_RENDER_PASS_CREATION_CONTROL_EXT**
  ◦ **VK_STRUCTURE_TYPE_RENDER_PASS_CREATION_FEEDBACK_CREATE_INFO_EXT**
  ◦ **VK_STRUCTURE_TYPE_RENDER_PASS_SUBPASS_FEEDBACK_CREATE_INFO_EXT**

**Version History**

• Revision 1, 2022-03-10
  ◦ Initial draft.

• Revision 2, 2022-05-24
  ◦ Fix structextends and constness issues.

**VK_EXT_surface_maintenance1**

**Name String**

  **VK_EXT_surface_maintenance1**

**Extension Type**

  Instance extension

**Registered Extension Number**

  275
Description

VK_EXT_surface_maintenance1 adds a collection of window system integration features that were intentionally left out or overlooked in the original VK_KHR_surface extension.

The new features are as follows:

- Allow querying number of min/max images from a surface for a particular presentation mode.
- Allow querying a surface's scaled presentation capabilities.
- Allow querying a surface for the set of presentation modes which can be easily switched between without requiring swapchain recreation.
New Structures

- Extending `VkPhysicalDeviceSurfaceInfo2KHR`:
  - `VkSurfacePresentModeEXT`
- Extending `VkSurfaceCapabilities2KHR`:
  - `VkSurfacePresentModeCompatibilityEXT`
  - `VkSurfacePresentScalingCapabilitiesEXT`

New Enums

- `VkPresentGravityFlagBitsEXT`
- `VkPresentScalingFlagBitsEXT`

New Bitmasks

- `VkPresentGravityFlagsEXT`
- `VkPresentScalingFlagsEXT`

New Enum Constants

- `VK_EXT_SURFACE_MAINTENANCE_1_EXTENSION_NAME`
- `VK_EXT_SURFACE_MAINTENANCE_1_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_SURFACE_PRESENT_MODE_COMPATIBILITY_EXT`
  - `VK_STRUCTURE_TYPE_SURFACE_PRESENT_MODE_EXT`
  - `VK_STRUCTURE_TYPE_SURFACE_PRESENT_SCALING_CAPABILITIES_EXT`

Version History

- Revision 0, 2019-02-27 (Lionel Landwerlin)
  - Internal revisions
- Revision 1, 2022-11-09 (Shahbaz Youssefi)
  - Add functionality and complete spec

**VK_EXT_swapchain_colorspace**

Name String

`VK_EXT_swapchain_colorspace`

Extension Type

Instance extension
Registered Extension Number
105

Revision
4

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_surface

Contact
• Courtney Goeltzenleuchter courtney-g

Other Extension Metadata
Last Modified Date
2019-04-26

IP Status
No known IP claims.

Contributors
• Courtney Goeltzenleuchter, Google

Description
This extension expands VkColorSpaceKHR to add support for most standard color spaces beyond VK_COLOR_SPACE_SRGB_NONLINEAR_KHR. This extension also adds support for VK_COLOR_SPACE_PASS_THROUGH_EXT which allows applications to use color spaces not explicitly enumerated in VkColorSpaceKHR.

New Enum Constants
• VK_EXT_SWAPCHAIN_COLOR_SPACE_EXTENSION_NAME
• VK_EXT_SWAPCHAIN_COLOR_SPACE_SPEC_VERSION
• Extending VkColorSpaceKHR:
  ◦ VK_COLOR_SPACE_ADOBERGB_LINEAR_EXT
  ◦ VK_COLOR_SPACE_ADOBERGB_NONLINEAR_EXT
  ◦ VK_COLOR_SPACE_BT2020_LINEAR_EXT
  ◦ VK_COLOR_SPACE_BT709_LINEAR_EXT
  ◦ VK_COLOR_SPACE_BT709_NONLINEAR_EXT
  ◦ VK_COLOR_SPACE_DCI_P3_LINEAR_EXT
Issues

1) Does the spec need to specify which kinds of image formats support the color spaces?

**RESOLVED:** Pixel format is independent of color space (though some color spaces really want / need floating point color components to be useful). Therefore, do not plan on documenting what formats support which color spaces. An application can call `vkGetPhysicalDeviceSurfaceFormatsKHR` to query what a particular implementation supports.

2) How does application determine if HW supports appropriate transfer function for a color space?

**RESOLVED:** Extension indicates that implementation must not do the OETF encoding if it is not sRGB. That responsibility falls to the application shaders. Any other native OETF / EOTF functions supported by an implementation can be described by separate extension.

Version History

- Revision 1, 2016-12-27 (Courtney Goeltzenleuchter)
  - Initial version
- Revision 2, 2017-01-19 (Courtney Goeltzenleuchter)
  - Add pass through and multiple options for BT2020.
  - Clean up some issues with equations not displaying properly.
- Revision 3, 2017-06-23 (Courtney Goeltzenleuchter)
  - Add extended sRGB non-linear enum.
- Revision 4, 2019-04-26 (Graeme Leese)
  - Clarify color space transfer function usage.
  - Refer to normative definitions in the Data Format Specification.
  - Clarify DCI-P3 and Display P3 usage.

**VK_EXT_swapchain_maintenance1**
Name String

VK_EXT_swapchain_maintenance1

Extension Type

Device extension

Registered Extension Number

276

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_swapchain
and
VK_EXT_surface_maintenance1
and
VK_KHR_get_physical_device_properties2

Contact

• Shahbaz Youssefi syoussefi

Extension Proposal

VK_EXT_swapchain_maintenance1

Other Extension Metadata

Last Modified Date

2022-10-28

Contributors

• Jeff Juliano, NVIDIA
• Shahbaz Youssefi, Google
• Chris Forbes, Google
• Ian Elliott, Google
• Yiwei Zhang, Google
• Charlie Lao, Google
• Lina Versace, Google
• Ralph Potter, Samsung
• Igor Nazarov, Samsung
• Hyunchang Kim, Samsung
Description

VK_EXT_swapchain_maintenance1 adds a collection of window system integration features that were intentionally left out or overlooked in the original VK_KHR_swapchain extension.

The new features are as follows:

- Specify a fence that will be signaled when the resources associated with a present operation can be safely destroyed.
- Allow changing the present mode a swapchain is using at per-present granularity.
- Allow applications to define the behavior when presenting a swapchain image to a surface with different dimensions than the image. Using this feature may allow implementations to avoid returning VK_ERROR_OUT_OF_DATE_KHR in this situation.
- Allow applications to defer swapchain memory allocation for improved startup time and memory footprint.
- Allow applications to release previously acquired images without presenting them.

New Commands

- VkReleaseSwapchainImagesEXT

New Structures

- VkReleaseSwapchainImagesInfoEXT
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceSwapchainMaintenance1FeaturesEXT
- Extending VkPresentInfoKHR:
  - VkSwapchainPresentFenceInfoEXT
  - VkSwapchainPresentModeInfoEXT
- Extending VkSwapchainCreateInfoKHR:
  - VkSwapchainPresentModesCreateInfoEXT
  - VkSwapchainPresentScalingCreateInfoEXT
New Enum Constants

• VK_EXT_SWAPCHAIN_MAINTENANCE_1_EXTENSION_NAME

• VK_EXT_SWAPCHAIN_MAINTENANCE_1_SPEC_VERSION

• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SWAPCHAIN_MAINTENANCE_1_FEATURES_EXT
  ◦ VK_STRUCTURE_TYPE_RELEASE_SWAPCHAIN_IMAGES_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_FENCE_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_MODES_CREATE_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_MODE_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_SCALING_CREATE_INFO_EXT

• Extending VkSwapchainCreateFlagBitsKHR:
  ◦ VK_SWAPCHAIN_CREATE_DEFERRED_MEMORY_ALLOCATION_BIT_EXT

Version History

• Revision 0, 2019-05-28
  ◦ Initial revisions

• Revision 1, 2022-08-21 (Shahbaz Youssefi)
  ◦ Add functionality and complete spec

VK_EXT_transform_feedback

Name String

VK_EXT_transform_feedback

Extension Type

Device extension

Registered Extension Number

29

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Special Uses

• OpenGL / ES support
This extension adds transform feedback to the Vulkan API by exposing the SPIR-V TransformFeedback and GeometryStreams capabilities to capture vertex, tessellation or geometry shader outputs to one or more buffers. It adds API functionality to bind transform feedback buffers to capture the primitives emitted by the graphics pipeline from SPIR-V outputs decorated for transform feedback. The transform feedback capture can be paused and resumed by way of storing and retrieving a byte counter. The captured data can be drawn again where the vertex count is derived from the byte counter without CPU intervention. If the implementation is capable, a vertex stream other than zero can be rasterized.

All these features are designed to match the full capabilities of OpenGL core transform feedback functionality and beyond. Many of the features are optional to allow base OpenGL ES GPUs to also
implement this extension.

The primary purpose of the functionality exposed by this extension is to support translation layers from other 3D APIs. This functionality is not considered forward looking, and is not expected to be promoted to a KHR extension or to core Vulkan. Unless this is needed for translation, it is recommended that developers use alternative techniques of using the GPU to process and capture vertex data.

**New Commands**

- `vkCmdBeginQueryIndexedEXT`
- `vkCmdBeginTransformFeedbackEXT`
- `vkCmdBindTransformFeedbackBuffersEXT`
- `vkCmdDrawIndirectByteCountEXT`
- `vkCmdEndQueryIndexedEXT`
- `vkCmdEndTransformFeedbackEXT`

**New Structures**

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceTransformFeedbackFeaturesEXT`
- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceTransformFeedbackPropertiesEXT`
- Extending `VkPipelineRasterizationStateCreateInfo`:
  - `VkPipelineRasterizationStateStreamCreateInfoEXT`

**New Bitmasks**

- `VkPipelineRasterizationStateStreamCreateFlagsEXT`

**New Enum Constants**

- `VK_EXT_TRANSFORM_FEEDBACK_EXTENSION_NAME`
- `VK_EXT_TRANSFORM_FEEDBACK_SPEC_VERSION`
- Extending `VkAccessFlagBits`:
  - `VK_ACCESS_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT`
  - `VK_ACCESS_TRANSFORM_FEEDBACK_COUNTER_WRITE_BIT_EXT`
  - `VK_ACCESS_TRANSFORM_FEEDBACK_WRITE_BIT_EXT`
- Extending `VkBufferUsageFlagBits`:
  - `VK_BUFFER_USAGE_TRANSFORM_FEEDBACK_BUFFER_BIT_EXT`
  - `VK_BUFFER_USAGE_TRANSFORM_FEEDBACK_COUNTER_BUFFER_BIT_EXT`
• Extending VkPipelineStageFlagBits:
  ◦ VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT

• Extending VkQueryType:
  ◦ VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT

• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TRANSFORM_FEEDBACK_FEATURES_EXT
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TRANSFORM_FEEDBACK_PROPERTIES_EXT
  ◦ VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_STATE_STREAM_CREATE_INFO_EXT

Issues

1) Should we include pause/resume functionality?

**RESOLVED:** Yes, this is needed to ease layering other APIs which have this functionality. To pause use `vkCmdEndTransformFeedbackEXT` and provide valid buffer handles in the `pCounterBuffers` array and offsets in the `pCounterBufferOffsets` array for the implementation to save the resume points. Then to resume use `vkCmdBeginTransformFeedbackEXT` with the previous `pCounterBuffers` and `pCounterBufferOffsets` values. Between the pause and resume there needs to be a memory barrier for the counter buffers with a source access of `VK_ACCESS_TRANSFORM_FEEDBACK_COUNTER_WRITE_BIT_EXT` at pipeline stage `VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT` to a destination access of `VK_ACCESS_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT` at pipeline stage `VK_PIPELINE_STAGE_TRANSFORM_FEEDBACK_BIT_EXT`.

2) How does this interact with multiview?

**RESOLVED:** Transform feedback cannot be made active in a render pass with multiview enabled.

3) How should queries be done?

**RESOLVED:** There is a new query type `VK_QUERY_TYPE_TRANSFORM_FEEDBACK_STREAM_EXT`. A query pool created with this type will capture 2 integers - `numPrimitivesWritten` and `numPrimitivesNeeded` - for the specified vertex stream output from the last pre-rasterization shader stage. The vertex stream output queried is zero by default, but can be specified with the new `vkCmdBeginQueryIndexedEXT` and `vkCmdEndQueryIndexedEXT` commands.

Version History

• Revision 1, 2018-10-09 (Piers Daniell)
  ◦ Internal revisions

**VK_EXT_validation_cache**

Name String

  VK_EXT_validation_cache
This extension provides a mechanism for caching the results of potentially expensive internal validation operations across multiple runs of a Vulkan application. At the core is the `VkValidationCacheEXT` object type, which is managed similarly to the existing `VkPipelineCache`.

The new struct `VkShaderModuleValidationCacheCreateInfoEXT` can be included in the `pNext` chain at `vkCreateShaderModule` time. It contains a `VkValidationCacheEXT` to use when validating the `VkShaderModule`.

**New Object Types**

- `VkValidationCacheEXT`

**New Commands**

- `vkCreateValidationCacheEXT`
- `vkDestroyValidationCacheEXT`
- `vkGetValidationCacheDataEXT`
• vkMergeValidationCachesEXT

New Structures

• VkValidationCacheCreateInfoEXT

Extending VkShaderModuleCreateInfo, VkPipelineShaderStageCreateInfo:
  ◦ VkShaderModuleValidationCacheCreateInfoEXT

New Enums

• VkValidationCacheHeaderVersionEXT

New Bitmasks

• VkValidationCacheCreateFlagsEXT

New Enum Constants

• VK_EXT_VALIDATION_CACHE_EXTENSION_NAME
• VK_EXT_VALIDATION_CACHE_SPEC_VERSION

Extending VkObjectType:
  ◦ VK_OBJECT_TYPE_VALIDATION_CACHE_EXT

Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_SHADER_MODULE_VALIDATION_CACHE_CREATE_INFO_EXT
  ◦ VK_STRUCTURE_TYPE_VALIDATION_CACHE_CREATE_INFO_EXT

Version History

• Revision 1, 2017-08-29 (Cort Stratton)
  ◦ Initial draft

VK_EXT_validation_features

Name String
  VK_EXT_validation_features

Extension Type
  Instance extension

Registered Extension Number
  248

Revision
  5
Ratification Status
Not ratified

Extension and Version Dependencies

Special Use
• Debugging tools

Contact
• Karl Schultz @karl-lunarg

Other Extension Metadata

Last Modified Date
2018-11-14

IP Status
No known IP claims.

Contributors
• Karl Schultz, LunarG
• Dave Houlton, LunarG
• Mark Lobodzinski, LunarG
• Camden Stocker, LunarG
• Tony Barbour, LunarG
• John Zulauf, LunarG

Description
This extension provides the VkValidationFeaturesEXT struct that can be included in the pNext chain of the VkInstanceCreateInfo structure passed as the pCreateInfo parameter of vkCreateInstance. The structure contains an array of VkValidationFeatureEnableEXT enum values that enable specific validation features that are disabled by default. The structure also contains an array of VkValidationFeatureDisableEXT enum values that disable specific validation layer features that are enabled by default.

Note
The VK_EXT_validation_features extension subsumes all the functionality provided in the VK_EXT_validation_flags extension.

New Structures
• Extending VkInstanceCreateInfo:
  ◦ VkValidationFeaturesEXT
New Enums

- VkValidationFeatureDisableEXT
- VkValidationFeatureEnableEXT

New Enum Constants

- VK_EXT_VALIDATION_FEATURES_EXTENSION_NAME
- VK_EXT_VALIDATION_FEATURES_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_VALIDATION_FEATURES_EXT

Version History

- Revision 1, 2018-11-14 (Karl Schultz)
  - Initial revision
- Revision 2, 2019-08-06 (Mark Lobodzinski)
  - Add Best Practices enable
- Revision 3, 2020-03-04 (Tony Barbour)
  - Add Debug Printf enable
- Revision 4, 2020-07-29 (John Zulauf)
  - Add Synchronization Validation enable
- Revision 5, 2021-05-18 (Tony Barbour)
  - Add Shader Validation Cache disable

VK_EXT_vertex_attribute_divisor

Name String

VK_EXT_vertex_attribute_divisor

Extension Type

Device extension

Registered Extension Number

191

Revision

3

Ratification Status

Not ratified
Extension and Version Dependencies

VK_KHR_get_physical_device_properties2
or
Version 1.1

Contact

- Vikram Kushwaha @vkushwaha

Other Extension Metadata

Last Modified Date
2018-08-03

IP Status
No known IP claims.

Contributors

- Vikram Kushwaha, NVIDIA
- Faith Ekstrand, Intel

Description

This extension allows instance-rate vertex attributes to be repeated for certain number of instances instead of advancing for every instance when instanced rendering is enabled.

New Structures

- VkVertexInputBindingDivisorDescriptionEXT
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceVertexAttributeDivisorFeaturesEXT
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceVertexAttributeDivisorPropertiesEXT
- Extending VkPipelineVertexInputStateCreateInfo:
  - VkPipelineVertexInputDivisorStateCreateInfoEXT

New Enum Constants

- VK_EXT_VERTEX_ATTRIBUTE_DIVISOR_EXTENSION_NAME
- VK_EXT_VERTEX_ATTRIBUTE_DIVISOR_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VERTEX_ATTRIBUTE_DIVISOR_FEATURES_EXT
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VERTEX_ATTRIBUTE_DIVISOR_PROPERTIES_EXT
  - VK_STRUCTURE_TYPE_PIPELINE_VERTEX_INPUT_DIVISOR_STATE_CREATE_INFO_EXT
Issues

1) What is the effect of a non-zero value for `firstInstance`?

**RESOLVED:** The Vulkan API should follow the OpenGL convention and offset attribute fetching by `firstInstance` while computing vertex attribute offsets.

2) Should zero be an allowed divisor?

**RESOLVED:** Yes. A zero divisor means the vertex attribute is repeated for all instances.

Examples

To create a vertex binding such that the first binding uses instanced rendering and the same attribute is used for every 4 draw instances, an application could use the following set of structures:

```c
const VkVertexInputBindingDivisorDescriptionEXT divisorDesc =
{
    .binding = 0,
    .divisor = 4
};

const VkPipelineVertexInputDivisorStateCreateInfoEXT divisorInfo =
{
    .sType = VK_STRUCTURE_TYPE_PIPELINE_VERTEX_INPUT_DIVISOR_STATE_CREATE_INFO_EXT,
    .pNext = NULL,
    .vertexBindingDivisorCount = 1,
    .pVertexBindingDivisors = &divisorDesc
};

const VkVertexInputBindingDescription binding =
{
    .binding = 0,
    .stride = sizeof(Vertex),
    .inputRate = VK_VERTEX_INPUT_RATE_INSTANCE
};

const VkPipelineVertexInputStateCreateInfo viInfo =
{
    .sType = VK_STRUCTURE_TYPE_PIPELINE_VERTEX_INPUT_CREATE_INFO,
    .pNext = &divisorInfo,
    ...  
};

//...
```

Version History

- Revision 1, 2017-12-04 (Vikram Kushwaha)
First Version

- Revision 2, 2018-07-16 (Faith Ekstrand)
  - Adjust the interaction between divisor and firstInstance to match the OpenGL convention.
  - Disallow divisors of zero.

- Revision 3, 2018-08-03 (Vikram Kushwaha)
  - Allow a zero divisor.
  - Add a physical device features structure to query/enable this feature.

**VK_EXT_vertex_input_dynamic_state**

**Name String**

VK_EXT_vertex_input_dynamic_state

**Extension Type**

Device extension

**Registered Extension Number**

353

**Revision**

2

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

VK_KHR_get_physical_device_properties2

or

Version 1.1

**Contact**

- Piers Daniell pdaniell-nv

**Other Extension Metadata**

**Last Modified Date**

2020-08-21

**IP Status**

No known IP claims.

**Contributors**

- Jeff Bolz, NVIDIA
- Spencer Fricke, Samsung
- Stu Smith, AMD
Description

One of the states that contributes to the combinatorial explosion of pipeline state objects that need to be created, is the vertex input binding and attribute descriptions. By allowing them to be dynamic applications may reduce the number of pipeline objects they need to create.

This extension adds dynamic state support for what is normally static state in VkPipelineVertexInputStateCreateInfo.

New Commands

• vkCmdSetVertexInputEXT

New Structures

• VkVertexInputAttributeDescription2EXT
• VkVertexInputBindingDescription2EXT

Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceVertexInputDynamicStateFeaturesEXT

New Enum Constants

• VK_EXT_VERTEX_INPUT_DYNAMIC_STATE_EXTENSION_NAME
• VK_EXT_VERTEX_INPUT_DYNAMIC_STATE_SPEC_VERSION

Extending VkDynamicState:
  ◦ VK_DYNAMIC_STATE_VERTEX_INPUT_EXT

Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VERTEX_INPUT_DYNAMIC_STATE_FEATURES_EXT
  ◦ VK_STRUCTURE_TYPE_VERTEX_INPUT_ATTRIBUTE_DESCRIPTION_2_EXT
  ◦ VK_STRUCTURE_TYPE_VERTEX_INPUT_BINDING_DESCRIPTION_2_EXT

Version History

• Revision 2, 2020-11-05 (Piers Daniell)
  ◦ Make VkVertexInputBindingDescription2EXT extensible
  ◦ Add new VkVertexInputAttributeDescription2EXT struct for the pVertexAttributeDescriptions parameter to vkCmdSetVertexInputEXT so it is also extensible

• Revision 1, 2020-08-21 (Piers Daniell)
  ◦ Internal revisions

VK_EXT_ycbcr_image_arrays
Name String
   VK_EXT_ycbcr_image_arrays

Extension Type
   Device extension

Registered Extension Number
   253

Revision
   1

Ratification Status
   Not ratified

Extension and Version Dependencies
   VK_KHR_sampler_ycbcr_conversion
   or
   Version 1.1

Contact
   • Piers Daniell pdaniell-nv

Other Extension Metadata

Last Modified Date
   2019-01-15

Contributors
   • Piers Daniell, NVIDIA

Description
This extension allows images of a format that requires $Y'C_B'C_R$ conversion to be created with multiple array layers, which is otherwise restricted.

New Structures

   • Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
     ◦ VkPhysicalDeviceYcbcrImageArraysFeaturesEXT

New Enum Constants

   • VK_EXT_YCBCR_IMAGEARRAYS_EXTENSION_NAME
   • VK_EXT_YCBCR_IMAGEARRAYS_SPEC_VERSION
   • Extending VkStructureType:
     ◦ VK_STRUCTURE_TYPE_PHYSICALDEVICEYCBCRIMAGEARRAYSFEATURESEXT
**Version History**

- Revision 1, 2019-01-15 (Piers Daniell)
  - Initial revision

**VK_AMD_buffer_marker**

**Name String**

VK_AMD_buffer_marker

**Extension Type**

Device extension

**Registered Extension Number**

180

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

**Special Use**

- Developer tools

**Contact**

- Daniel Rakos drakos-amd

**Other Extension Metadata**

**Last Modified Date**

2018-01-26

**IP Status**

No known IP claims.

**Contributors**

- Matthaeus G. Chajdas, AMD
- Jaakko Konttinen, AMD
- Daniel Rakos, AMD

**Description**

This extension adds a new operation to execute pipelined writes of small marker values into a VkBuffer object.
The primary purpose of these markers is to facilitate the development of debugging tools for tracking which pipelined command contributed to device loss.

**New Commands**

- `vkCmdWriteBufferMarkerAMD`

**New Enum Constants**

- `VK_AMD_BUFFER_MARKER_EXTENSION_NAME`
- `VK_AMD_BUFFER_MARKER_SPEC_VERSION`

**Examples**

None.

**Version History**

- Revision 1, 2018-01-26 (Jaakko Konttinen)
  - Initial revision

**VK_AMD_device_coherent_memory**

**Name String**

- `VK_AMD_device_coherent_memory`

**Extension Type**

- Device extension

**Registered Extension Number**

- 230

**Revision**

- 1

**Ratification Status**

- Not ratified

**Extension and Version Dependencies**

- `VK_KHR_get_physical_device_properties2`

**Contact**

- Tobias Hector [tobski](mailto:tobski)

**Other Extension Metadata**
Description

This extension adds the device coherent and device uncached memory types. Any device accesses to device coherent memory are automatically made visible to any other device access. Device uncached memory indicates to applications that caches are disabled for a particular memory type, which guarantees device coherence.

Device coherent and uncached memory are expected to have lower performance for general access than non-device coherent memory, but can be useful in certain scenarios; particularly so for debugging.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceCoherentMemoryFeaturesAMD

New Enum Constants

- VK_AMD_DEVICE_COHERENT_MEMORY_EXTENSION_NAME
- VK_AMD_DEVICE_COHERENT_MEMORY_SPEC_VERSION

- Extending VkMemoryPropertyFlagBits:
  - VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD
  - VK_MEMORY_PROPERTY_DEVICE_UNCACHED_BIT_AMD

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICALDEVICECOHERENTMEMORYFEATURESAMD

Version History

- Revision 1, 2019-02-04 (Tobias Hector)
  - Initial revision

VK_AMD_display_native_hdr

Name String

VK_AMD_display_native_hdr
This extension introduces the following display native HDR features to Vulkan:

- A new VkColorSpaceKHR enum for setting the native display color space. For example, this color space would be set by the swapchain to use the native color space in Freesync2 displays.
- Local dimming control
New Commands

- vkSetLocalDimmingAMD

New Structures

- Extending VkSurfaceCapabilities2KHR:
  - VkDisplayNativeHdrSurfaceCapabilitiesAMD
- Extending VkSwapchainCreateInfoKHR:
  - VkSwapchainDisplayNativeHdrCreateInfoAMD

New Enum Constants

- VK_AMD_DISPLAY_NATIVE_HDR_EXTENSION_NAME
- VK_AMD_DISPLAY_NATIVE_HDR_SPEC_VERSION
- Extending VkColorSpaceKHR:
  - VK_COLOR_SPACE_DISPLAY_NATIVE_AMD
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_DISPLAY_NATIVE_HDR_SURFACE_CAPABILITIES_AMD
  - VK_STRUCTURE_TYPE_SWAPCHAIN_DISPLAY_NATIVE_HDR_CREATE_INFO_AMD

Issues

None.

Examples

None.

Version History

- Revision 1, 2018-12-18 (Daniel Rakos)
  - Initial revision

VK_AMD_gcn_shader

Name String

VK_AMD_gcn_shader

Extension Type

Device extension

Registered Extension Number

26
Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies

Contact
- Dominik Witczak dominikwitczakamd

Other Extension Metadata

Last Modified Date
2016-05-30

IP Status
No known IP claims.

Interactions and External Dependencies
- This extension requires SPV_AMD_gcn_shader
- This extension provides API support for GL_AMD_gcn_shader

Contributors
- Dominik Witczak, AMD
- Daniel Rakos, AMD
- Rex Xu, AMD
- Graham Sellers, AMD

Description
This extension adds support for the following SPIR-V extension in Vulkan:
- SPV_AMD_gcn_shader

New Enum Constants
- VK_AMD_GCN_SHADER_EXTENSION_NAME
- VK_AMD_GCN_SHADER_SPEC_VERSION

Version History
- Revision 1, 2016-05-30 (Dominik Witczak)
  - Initial draft

4415
VK_AMD_memory_overallocation_behavior

Name String
VK_AMD_memory_overallocation_behavior

Extension Type
Device extension

Registered Extension Number
190

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies

Contact
• Martin Dinkov @mdinkov

Other Extension Metadata

Last Modified Date
2018-09-19

IP Status
No known IP claims.

Contributors
• Martin Dinkov, AMD
• Matthaeus Chajdas, AMD
• Daniel Rakos, AMD
• Jon Campbell, AMD

Description
This extension allows controlling whether explicit overallocation beyond the device memory heap sizes (reported by `VkPhysicalDeviceMemoryProperties`) is allowed or not. Overallocation may lead to performance loss and is not supported for all platforms.

New Structures
• Extending `VkDeviceCreateInfo`:
  ◦ `VkDeviceMemoryOverallocationCreateInfoAMD`
New Enums

- VkMemoryOverallocationBehaviorAMD

New Enum Constants

- VK_AMD_MEMORY_OVERALLOCATION_BEHAVIOR_EXTENSION_NAME
- VK_AMD_MEMORY_OVERALLOCATION_BEHAVIOR_SPEC_VERSION

Extending VkStructureType:
  - VK_STRUCTURE_TYPE_DEVICE_MEMORY_OVERALLOCATION_CREATE_INFO_AMD

Version History

- Revision 1, 2018-09-19 (Martin Dinkov)
  - Initial draft.

VK_AMD_mixed_attachment_samples

Name String

VK_AMD_mixed_attachment_samples

Extension Type

Device extension

Registered Extension Number

137

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

Contact

- Matthaeus G. Chajdas @anteru

Other Extension Metadata

Last Modified Date

2017-07-24

Contributors

- Mais Alnasser, AMD
- Matthaeus G. Chajdas, AMD
- Maciej Jesionowski, AMD
Description

This extension enables applications to use multisampled rendering with a depth/stencil sample count that is larger than the color sample count. Having a depth/stencil sample count larger than the color sample count allows maintaining geometry and coverage information at a higher sample rate than color information. All samples are depth/stencil tested, but only the first color sample count number of samples get a corresponding color output.

New Enum Constants

- VK_AMD_MIXED_ATTACHMENT_SAMPLES_EXTENSION_NAME
- VK_AMD_MIXED_ATTACHMENT_SAMPLES_SPEC_VERSION

Issues

None.

Version History

- Revision 1, 2017-07-24 (Daniel Rakos)
  - Internal revisions

VK_AMD_pipeline_compiler_control

Name String

  VK_AMD_pipeline_compiler_control

Extension Type

  Device extension

Registered Extension Number

  184

Revision

  1

Ratification Status

  Not ratified

Extension and Version Dependencies

Contact

  • Matthaeus G. Chajdas anteru
Other Extension Metadata

Last Modified Date
2019-07-26

IP Status
No known IP claims.

Contributors
- Matthaeus G. Chajdas, AMD
- Daniel Rakos, AMD
- Maciej Jesionowski, AMD
- Tobias Hector, AMD

Description
This extension introduces `VkPipelineCompilerControlCreateInfoAMD` structure that can be chained to a pipeline’s creation information to specify additional flags that affect pipeline compilation.

New Structures
- Extending `VkGraphicsPipelineCreateInfo`, `VkComputePipelineCreateInfo`, `VkExecutionGraphPipelineCreateInfoAMDX`:
  - `VkPipelineCompilerControlCreateInfoAMD`

New Enums
- `VkPipelineCompilerControlFlagBitsAMD`

New Bitmasks
- `VkPipelineCompilerControlFlagsAMD`

New Enum Constants
- `VK_AMD_PIPELINE_COMPILER_CONTROL_EXTENSION_NAME`
- `VK_AMD_PIPELINE_COMPILER_CONTROL_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PIPELINE_COMPILER_CONTROL_CREATE_INFO_AMD`

Issues
None.
Examples
None.

Version History
- Revision 1, 2019-07-26 (Tobias Hector)
  - Initial revision.

VK_AMD_rasterization_order

Name String
VK_AMD_rasterization_order

Extension Type
Device extension

Registered Extension Number
19

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies

Contact
- Daniel Rakos drakos-amd

Other Extension Metadata

Last Modified Date
2016-04-25

IP Status
No known IP claims.

Contributors
- Matthaeus G. Chajdas, AMD
- Jaakko Konttinen, AMD
- Daniel Rakos, AMD
- Graham Sellers, AMD
- Dominik Witczak, AMD
Description

This extension introduces the possibility for the application to control the order of primitive rasterization. In unextended Vulkan, the following stages are guaranteed to execute in API order:

- depth bounds test
- stencil test, stencil op, and stencil write
- depth test and depth write
- occlusion queries
- blending, logic op, and color write

This extension enables applications to opt into a relaxed, implementation defined primitive rasterization order that may allow better parallel processing of primitives and thus enabling higher primitive throughput. It is applicable in cases where the primitive rasterization order is known to not affect the output of the rendering or any differences caused by a different rasterization order are not a concern from the point of view of the application’s purpose.

A few examples of cases when using the relaxed primitive rasterization order would not have an effect on the final rendering:

- If the primitives rendered are known to not overlap in framebuffer space.
- If depth testing is used with a comparison operator of `VK_COMPARE_OP_LESS`, `VK_COMPARE_OP_LESS_OR_EQUAL`, `VK_COMPARE_OP_GREATER`, or `VK_COMPARE_OP_GREATER_OR_EQUAL`, and the primitives rendered are known to not overlap in clip space.
- If depth testing is not used and blending is enabled for all attachments with a commutative blend operator.

New Structures

- Extending `VkPipelineRasterizationStateCreateInfo`:
  - `VkPipelineRasterizationStateRasterizationOrderAMD`

New Enums

- `VkRasterizationOrderAMD`

New Enum Constants

- `VK_AMD_RASTERIZATION_ORDER_EXTENSION_NAME`
- `VK_AMD_RASTERIZATION_ORDER_SPEC_VERSION`

Extending `VkStructureType`:

- `VK_STRUCTURE_TYPE_PIPELINE_RASTERIZATION_STATE_RASTERIZATION_ORDER_AMD`
Issues

1) How is this extension useful to application developers?

RESOLVED: Allows them to increase primitive throughput for cases when strict API order rasterization is not important due to the nature of the content, the configuration used, or the requirements towards the output of the rendering.

2) How does this extension interact with content optimizations aiming to reduce overdraw by appropriately ordering the input primitives?

RESOLVED: While the relaxed rasterization order might somewhat limit the effectiveness of such content optimizations, most of the benefits of it are expected to be retained even when the relaxed rasterization order is used, so applications should still apply these optimizations even if they intend to use the extension.

3) Are there any guarantees about the primitive rasterization order when using the new relaxed mode?

RESOLVED: No. In this case the rasterization order is completely implementation-dependent, but in practice it is expected to partially still follow the order of incoming primitives.

4) Does the new relaxed rasterization order have any adverse effect on repeatability and other invariance rules of the API?

RESOLVED: Yes, in the sense that it extends the list of exceptions when the repeatability requirement does not apply.

Examples

None

Issues

None

Version History

- Revision 1, 2016-04-25 (Daniel Rakos)
  - Initial draft.

VK_AMD_shader_ballot

Name String

VK_AMD_shader_ballot

Extension Type

Device extension
Registered Extension Number
38

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies

Contact
• Dominik Witczak dominikwitczakamd

Other Extension Metadata

Last Modified Date
2016-09-19

IP Status
No known IP claims.

Interactions and External Dependencies
• This extension requires SPV_AMD_shader_ballot
• This extension provides API support for GL_AMD_shader_ballot

Contributors
• Qun Lin, AMD
• Graham Sellers, AMD
• Daniel Rakos, AMD
• Rex Xu, AMD
• Dominik Witczak, AMD
• Matthäus G. Chajdas, AMD

Description
This extension adds support for the following SPIR-V extension in Vulkan:
• SPV_AMD_shader_ballot

New Enum Constants
• VK_AMD_SHADER_BALLOT_EXTENSION_NAME
• VK_AMD_SHADER_BALLOT_SPEC_VERSION
**Version History**

- Revision 1, 2016-09-19 (Dominik Witczak)
  - Initial draft

**VK_AMD_shader_core_properties**

**Name String**

VK_AMD_shader_core_properties

**Extension Type**

Device extension

**Registered Extension Number**

186

**Revision**

2

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

VK_KHR_get_physical_device_properties2

**Contact**

- Martin Dinkov [mdinkov](mailto:mdinkov)

**Other Extension Metadata**

**Last Modified Date**

2019-06-25

**IP Status**

No known IP claims.

**Contributors**

- Martin Dinkov, AMD
  - Matthaeus G. Chajdas, AMD

**Description**

This extension exposes shader core properties for a target physical device through the VK_KHR_get_physical_device_properties2 extension. Please refer to the example below for proper usage.
New Structures

- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceShaderCorePropertiesAMD`

New Enum Constants

- `VK_AMD_SHADER_CORE_PROPERTIES_EXTENSION_NAME`
- `VK_AMD_SHADER_CORE_PROPERTIES_SPEC_VERSION`

- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CORE_PROPERTIES_AMD`

Examples

This example retrieves the shader core properties for a physical device.

```c
extern VkInstance instance;

PFN_vkGetPhysicalDeviceProperties2 pfnVkGetPhysicalDeviceProperties2 =
  reinterpret_cast<PFN_vkGetPhysicalDeviceProperties2>(
vkGetInstanceProcAddr(instance, "vkGetPhysicalDeviceProperties2"));

VkPhysicalDeviceProperties2 general_props;
VkPhysicalDeviceShaderCorePropertiesAMD shader_core_properties;

shader_core_properties.pNext = nullptr;
shader_core_properties.sType = VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CORE_PROPERTIES_AMD;

general_props.pNext = &shader_core_properties;
general_props.sType = VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PROPERTIES_2;

// After this call, shader_core_properties has been populated
pfnVkGetPhysicalDeviceProperties2(device, &general_props);

printf("Number of shader engines: %d\n",
  m_shader_core_properties.shader_engine_count =
  shader_core_properties.shaderEngineCount;
printf("Number of shader arrays: %d\n",
  m_shader_core_properties.shader_arrays_per_engine_count =
  shader_core_properties.shaderArraysPerEngineCount;
printf("Number of CUs per shader array: %d\n",
  m_shader_core_properties.compute_units_per_shader_array =
  shader_core_properties.computeUnitsPerShaderArray;
printf("Number of SIMDs per compute unit: %d\n",
  m_shader_core_properties.simd_per_compute_unit =
  shader_core_properties.simdPerComputeUnit;
printf("Number of wavefront slots in each SIMD: %d\n",
```
m_shader_core_properties.wavefronts_per_simd = 
shader_core_properties.wavefrontsPerSimd;

printf("Number of threads per wavefront: %d\n", 
m_shader_core_properties.wavefront_size = 
shader_core_properties.wavefrontSize;

printf("Number of physical SGPRs per SIMD: %d\n", 
m_shader_core_properties.sgprs_per_simd = 
shader_core_properties.sgprsPerSimd;

printf("Minimum number of SGPRs that can be allocated by a wave: %d\n", 
m_shader_core_properties.min_sgpr_allocation = 
shader_core_properties.minSgprAllocation;

printf("Number of available SGPRs: %d\n", 
m_shader_core_properties.max_sgpr_allocation = 
shader_core_properties.maxSgprAllocation;

printf("SGPRs are allocated in groups of this size: %d\n", 
m_shader_core_properties.sgpr_allocation_granularity = 
shader_core_properties.sgprAllocationGranularity;

printf("Number of physical VGPRs per SIMD: %d\n", 
m_shader_core_properties.vgprs_per_simd = 
shader_core_properties.vgprsPerSimd;

printf("Minimum number of VGPRs that can be allocated by a wave: %d\n", 
m_shader_core_properties.min_vgpr_allocation = 
shader_core_properties.minVgprAllocation;

printf("Number of available VGPRs: %d\n", 
m_shader_core_properties.max_vgpr_allocation = 
shader_core_properties.maxVgprAllocation;

printf("VGPRs are allocated in groups of this size: %d\n", 
m_shader_core_properties.vgpr_allocation_granularity = 
shader_core_properties.vgprAllocationGranularity;

Version History

- Revision 2, 2019-06-25 (Matthaeus G. Chajdas)
  - Clarified the meaning of a few fields.
- Revision 1, 2018-02-15 (Martin Dinkov)
  - Initial draft.

VK_AMD_shader_core_properties2

Name String

VK_AMD_shader_core_properties2

Extension Type

Device extension

Registered Extension Number

228
Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_AMD_shader_core_properties

Contact
• Matthaeus G. Chajdas anteru

Other Extension Metadata

Last Modified Date
2019-07-26

IP Status
No known IP claims.

Contributors
• Matthaeus G. Chajdas, AMD
• Tobias Hector, AMD

Description
This extension exposes additional shader core properties for a target physical device through the VK_KHR_get_physical_device_properties2 extension.

New Structures
• Extending VkPhysicalDeviceProperties2:
  • VkPhysicalDeviceShaderCoreProperties2AMD

New Enums
• VkShaderCorePropertiesFlagBitsAMD

New Bitmasks
• VkShaderCorePropertiesFlagsAMD

New Enum Constants
• VK_AMD_SHADER_CORE_PROPERTIES_2_EXTENSION_NAME
• VK_AMD_SHADER_CORE_PROPERTIES_2_SPEC_VERSION
• Extending VkStructureType:
Examples
None.

Version History

• Revision 1, 2019-07-26 (Matthaeus G. Chajdas)
  ◦ Initial draft.

VK_AMD_shader_early_and_late_fragment_tests

Name String
VK_AMD_shader_early_and_late_fragment_tests

Extension Type
Device extension

Registered Extension Number
322

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2

Contact
• Tobias Hector tobshi

Extension Proposal
VK_AMD_shader_early_and_late_fragment_tests

Other Extension Metadata

Last Modified Date
2021-09-14

Interactions and External Dependencies
• This extension requires SPV_AMD_shader_early_and_late Fragment_tests
• This extension interacts with VK_EXT_shader_stencil_export

Contributors
• Tobias Hector, AMD
Description

This extension adds support for the `SPV_AMD_shader_early_and_late_fragment_tests` extension, allowing shaders to explicitly opt in to allowing both early and late fragment tests with the `EarlyAndLateFragmentTestsAMD` execution mode.

If `VK_EXT_shader_stencil_export` is supported, additional execution modes allowing early depth tests similar to `DepthUnchanged`, `DepthLess`, and `DepthGreater` are provided.

New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceShaderEarlyAndLateFragmentTestsFeaturesAMD`

New Enum Constants

- `VK_AMD_SHADER_EARLY_AND_LATE_FRAGMENT_TESTS_EXTENSION_NAME`
- `VK_AMD_SHADER_EARLY_AND_LATE_FRAGMENT_TESTS_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_EARLY_AND_LATE_FRAGMENT_TESTS_FEATURES_AMD`

Version History

- Revision 1, 2021-09-14 (Tobias Hector)
  - Initial draft

**VK_AMD_shader_explicit_vertex_parameter**

Name String

- `VK_AMD_shader_explicit_vertex_parameter`

Extension Type

- Device extension

Registered Extension Number

- 22

Revision

- 1

Ratification Status

- Not ratified

Extension and Version Dependencies

Contact

- Qun Lin (`linqun`)
Other Extension Metadata

Last Modified Date
2016-05-10

IP Status
No known IP claims.

Interactions and External Dependencies

- This extension requires SPV_AMD_shader_explicit_vertex_parameter
- This extension provides API support for GL_AMD_shader_explicit_vertex_parameter

Contributors

- Matthaeus G. Chajdas, AMD
- Qun Lin, AMD
- Daniel Rakos, AMD
- Graham Sellers, AMD
- Rex Xu, AMD

Description

This extension adds support for the following SPIR-V extension in Vulkan:

- SPV_AMD_shader_explicit_vertex_parameter

New Enum Constants

- VK_AMD_SHADER_EXPLICIT_VERTEX_PARAMETER_EXTENSION_NAME
- VK_AMD_SHADER_EXPLICIT_VERTEX_PARAMETER_SPEC_VERSION

Version History

- Revision 1, 2016-05-10 (Daniel Rakos)
  - Initial draft

VK_AMD_shader_fragment_mask

Name String

VK_AMD_shader_fragment_mask

Extension Type

Device extension

Registered Extension Number

138
Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
Contact
• Aaron Hagan @AaronHaganAMD

Other Extension Metadata
Last Modified Date
2017-08-16

IP Status
No known IP claims.

Interactions and External Dependencies
• This extension requires SPV_AMD_shader_fragment_mask
• This extension provides API support for GL_AMD_shader_fragment_mask

Contributors
• Aaron Hagan, AMD
• Daniel Rakos, AMD
• Timothy Lottes, AMD

Description
This extension provides efficient read access to the fragment mask in compressed multisampled color surfaces. The fragment mask is a lookup table that associates color samples with color fragment values.

From a shader, the fragment mask can be fetched with a call to fragmentMaskFetchAMD, which returns a single uint where each subsequent four bits specify the color fragment index corresponding to the color sample, starting from the least significant bit. For example, when eight color samples are used, the color fragment index for color sample 0 will be in bits 0-3 of the fragment mask, for color sample 7 the index will be in bits 28-31.

The color fragment for a particular color sample may then be fetched with the corresponding fragment mask value using the fragmentFetchAMD shader function.

New Enum Constants
• VK_AMD_SHADER_FRAGMENT_MASK_EXTENSION_NAME
• VK_AMD_SHADER_FRAGMENT_MASK_SPEC_VERSION
New SPIR-V Capabilities

- FragmentMaskAMD

Examples

This example shows a shader that queries the fragment mask from a multisampled compressed surface and uses it to query fragment values.

```glsl
#version 450 core

#extension GL_AMD_shader_fragment_mask: enable

layout(binding = 0) uniform sampler2DMS s2DMS;
layout(binding = 1) uniform isampler2DMSArray is2DMSArray;
layout(binding = 2, input_attachment_index = 0) uniform usubpassInputMS usubpassMS;
layout(location = 0) out vec4 fragColor;

void main()
{
    vec4 fragOne = vec4(0.0);

    uint fragMask = fragmentMaskFetchAMD(s2DMS, ivec2(2, 3));
    uint fragIndex = (fragMask & 0x0F0) >> 4;
    fragOne += fragmentFetchAMD(s2DMS, ivec2(2, 3), 1);

    fragMask = fragmentMaskFetchAMD(is2DMSArray, ivec3(2, 3, 1));
    fragIndex = (fragMask & 0xF0) >> 4;
    fragOne += fragmentFetchAMD(is2DMSArray, ivec3(2, 3, 1), fragIndex);

    fragMask = fragmentMaskFetchAMD(usubpassMS);
    fragIndex = (fragMask & 0xF0) >> 4;
    fragOne += fragmentFetchAMD(usubpassMS, fragIndex);

    fragColor = fragOne;
}
```

Version History

- Revision 1, 2017-08-16 (Aaron Hagan)
  - Initial draft

VK_AMD_shader_image_load_store_lod

Name String

VK_AMD_shader_image_load_store_lod
Extension Type
  Device extension

Registered Extension Number
  47

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies

Contact
  • Dominik Witczak dominikwitczakamd

Other Extension Metadata

Last Modified Date
  2017-08-21

Interactions and External Dependencies
  • This extension requires SPV_AMD_shader_image_load_store_lod
  • This extension provides API support for GL_AMD_shader_image_load_store_lod

IP Status
  No known IP claims.

Contributors
  • Dominik Witczak, AMD
  • Qun Lin, AMD
  • Rex Xu, AMD

Description
This extension adds support for the following SPIR-V extension in Vulkan:
  • SPV_AMD_shader_image_load_store_lod

New Enum Constants
  • VK_AMD_SHADER_IMAGE_LOAD_STORE_LOD_EXTENSION_NAME
  • VK_AMD_SHADER_IMAGE_LOAD_STORE_LOD_SPEC_VERSION

Version History
  • Revision 1, 2017-08-21 (Dominik Witczak)
VK_AMD_shader_info

Name String
VK_AMD_shader_info

Extension Type
Device extension

Registered Extension Number
43

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies

Special Use
- Developer tools

Contact
- Jaakko Konttinen jaakkoamd

Other Extension Metadata

Last Modified Date
2017-10-09

IP Status
No known IP claims.

Contributors
- Jaakko Konttinen, AMD

Description
This extension adds a way to query certain information about a compiled shader which is part of a pipeline. This information may include shader disassembly, shader binary and various statistics about a shader’s resource usage.

While this extension provides a mechanism for extracting this information, the details regarding the contents or format of this information are not specified by this extension and may be provided by the vendor externally.

Furthermore, all information types are optionally supported, and users should not assume every implementation supports querying every type of information.
New Commands

• `vkGetShaderInfoAMD`

New Structures

• `VkShaderResourceUsageAMD`
• `VkShaderStatisticsInfoAMD`

New Enums

• `VkShaderInfoTypeAMD`

New Enum Constants

• `VK_AMD_SHADER_INFO_EXTENSION_NAME`
• `VK_AMD_SHADER_INFO_SPEC_VERSION`

Examples

This example extracts the register usage of a fragment shader within a particular graphics pipeline:

```c
extern VkDevice device;
extern VkPipeline gfxPipeline;

PFN_vkGetShaderInfoAMD pfnGetShaderInfoAMD = (PFN_vkGetShaderInfoAMD)
vkGetDeviceProcAddr(
    device, "vkGetShaderInfoAMD”);

VkShaderStatisticsInfoAMD statistics = {};

size_t dataSize = sizeof(statistics);

if (pfnGetShaderInfoAMD(device,
    gfxPipeline,
    VK_SHADER_STAGE_FRAGMENT_BIT,
    VK_SHADER_INFO_TYPE_STATISTICS_AMD,
    &dataSize,
    &statistics) == VK_SUCCESS)
{
    printf("VGPR usage: %d\n", statistics.resourceUsage.numUsedVgprs);
    printf("SGPR usage: %d\n", statistics.resourceUsage.numUsedSgprs);
}
```

The following example continues the previous example by subsequently attempting to query and print shader disassembly about the fragment shader:

```c
// Query disassembly size (if available)
```
if (PFNGetShaderInfoAMD(device, 
    gfxPipeline, 
    VK_SHADER_STAGE_FRAGMENT_BIT, 
    VK_SHADER_INFO_TYPE_DISASSEMBLY_AMD, 
    &dataSize, 
    nullptr) == VK_SUCCESS) 
{
    printf("Fragment shader disassembly:\n");

    void* disassembly = malloc(dataSize);

    // Query disassembly and print
    if (PFNGetShaderInfoAMD(device, 
        gfxPipeline, 
        VK_SHADER_STAGE_FRAGMENT_BIT, 
        VK_SHADER_INFO_TYPE_DISASSEMBLY_AMD, 
        &dataSize, 
        disassembly) == VK_SUCCESS)
    {
        printf((char*)disassembly);
    }

    free(disassembly);
}

Version History

- Revision 1, 2017-10-09 (Jaakko Konttinen)
  - Initial revision

VK_AMD_shader_trinary_minmax

Name String
   VK_AMD_shader_trinary_minmax

Extension Type
   Device extension

Registered Extension Number
   21

Revision
   1

Ratification Status
   Not ratified
Extension and Version Dependencies

Contact

• Qun Lin linqun

Other Extension Metadata

Last Modified Date

2016-05-10

IP Status

No known IP claims.

Interactions and External Dependencies

• This extension requires SPV_AMD_shader_trinary_minmax
• This extension provides API support for GL_AMD_shader_trinary_minmax

Contributors

• Matthaeus G. Chajdas, AMD
• Qun Lin, AMD
• Daniel Rakos, AMD
• Graham Sellers, AMD
• Rex Xu, AMD

Description

This extension adds support for the following SPIR-V extension in Vulkan:

• SPV_AMD_shader_trinary_minmax

New Enum Constants

• VK_AMD_SHADER_TRINARY_MINMAX_EXTENSION_NAME
• VK_AMD_SHADER_TRINARY_MINMAX_SPEC_VERSION

Version History

• Revision 1, 2016-05-10 (Daniel Rakos)
  ◦ Initial draft

VK_AMD_texture_gather_bias_lod

Name String

VK_AMD_texture_gather_bias_lod

Extension Type

Device extension
Description

This extension adds two related features.

Firstly, support for the following SPIR-V extension in Vulkan is added:

- \texttt{SPV_AMD_texture_gather_bias_lod}

Secondly, the extension allows the application to query which formats can be used together with the new function prototypes introduced by the SPIR-V extension.
New Structures

- Extending VkImageFormatProperties2:
  - VkTextureLODGatherFormatPropertiesAMD

New Enum Constants

- VK_AMD_TEXTURE_GATHER_BIAS_LOD_EXTENSION_NAME
- VK_AMD_TEXTURE_GATHER_BIAS_LOD_SPEC_VERSION

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_TEXTURE_LOD_GATHER_FORMAT_PROPERTIES_AMD

New SPIR-V Capabilities

- ImageGatherBiasLodAMD

Examples

```c
struct VkTextureLODGatherFormatPropertiesAMD
{
    VkStructureType sType;
    const void* pNext;
    VkBool32 supportsTextureGatherLODBiasAMD;
};

// How to detect if an image format can be used with the new function prototypes.
VkPhysicalDeviceImageFormatInfo2 formatInfo;
VkImageFormatProperties2 formatProps;
VkTextureLODGatherFormatPropertiesAMD textureLODGatherSupport;

textureLODGatherSupport.sType = VK_STRUCTURE_TYPE_TEXTURE_LOD_GATHER_FORMAT_PROPERTIES_AMD;
textureLODGatherSupport.pNext = nullptr;

formatInfo.sType = VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_FORMAT_INFO_2;
formatInfo.pNext = nullptr;
formatInfo.format = ...;
formatInfo.type = ...;
formatInfo.tiling = ...;
formatInfo.usage = ...;
formatInfo.flags = ...;

formatProps.sType = VK_STRUCTURE_TYPE_IMAGE_FORMAT_PROPERTIES_2;
formatProps.pNext = &textureLODGatherSupport;
```
vkGetPhysicalDeviceImageFormatProperties2(physical_device, &formatInfo, &formatProps);

if (textureLODGatherSupport.supportsTextureGatherLODBiasAMD == VK_TRUE)
{
    // physical device supports SPV_AMD_texture_gather_bias_lod for the specified
    // format configuration.
}
else
{
    // physical device does not support SPV_AMD_texture_gather_bias_lod for the
    // specified format configuration.
}

Version History

• Revision 1, 2017-03-21 (Dominik Witczak)
  ◦ Initial draft

VK_ANDROID_external_memory_android_hardware_buffer

Name String
VK_ANDROID_external_memory_android_hardware_buffer

Extension Type
Device extension

Registered Extension Number
130

Revision
5

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_sampler_ycbcr_conversion
and
VK_KHR_external_memory
and
VK_EXT_queue_family_foreign
and
VK_KHR_dedicated_allocation

Contact
• Jesse Hall

4440
Other Extension Metadata

Last Modified Date
2021-09-30

IP Status
No known IP claims.

Contributors
- Ray Smith, ARM
- Lina Versace, Google
- Jesse Hall, Google
- Tobias Hector, Imagination
- James Jones, NVIDIA
- Tony Zlatinski, NVIDIA
- Matthew Netsch, Qualcomm
- Andrew Garrard, Samsung

Description
This extension enables an application to import Android AHardwareBuffer objects created outside of the Vulkan device into Vulkan memory objects, where they can be bound to images and buffers. It also allows exporting an AHardwareBuffer from a Vulkan memory object for symmetry with other operating systems. But since not all AHardwareBuffer usages and formats have Vulkan equivalents, exporting from Vulkan provides strictly less functionality than creating the AHardwareBuffer externally and importing it.

Some AHardwareBuffer images have implementation-defined external formats that may not correspond to Vulkan formats. Sampler Y’CbCr conversion can be used to sample from these images and convert them to a known color space.

New Base Types
- AHardwareBuffer

New Commands
- vkGetAndroidHardwareBufferPropertiesANDROID
- vkGetMemoryAndroidHardwareBufferANDROID

New Structures
- VkAndroidHardwareBufferPropertiesANDROID
- VkMemoryGetAndroidHardwareBufferInfoANDROID
- Extending VkAndroidHardwareBufferPropertiesANDROID:
- Extending `VkImageCreateInfo`, `VkSamplerYcbcrConversionCreateInfo`:
  - `VkExternalFormatANDROID`

- Extending `VkImageFormatProperties2`:
  - `VkAndroidHardwareBufferUsageANDROID`

- Extending `VkMemoryAllocateInfo`:
  - `VkImportAndroidHardwareBufferInfoANDROID`

If `VK_KHR_format_feature_flags2` is supported:

- Extending `VkAndroidHardwareBufferPropertiesANDROID`:
  - `VkAndroidHardwareBufferFormatProperties2ANDROID`

### New Enum Constants

- `VK_ANDROID_EXTERNAL_MEMORY_ANDROID_HARDWARE_BUFFER_EXTENSION_NAME`
- `VK_ANDROID_EXTERNAL_MEMORY_ANDROID_HARDWARE_BUFFER_SPEC_VERSION`

Extending `VkExternalMemoryHandleTypeFlagBits`:

- `VK_EXTERNAL_MEMORY_HANDLE_TYPE_ANDROID_HARDWARE_BUFFER_BIT_ANDROID`

Extending `VkStructureType`:

- `VK_STRUCTURE_TYPE_ANDROID_HARDWARE_BUFFER_FORMAT_PROPERTIES_ANDROID`
- `VK_STRUCTURE_TYPE_ANDROID_HARDWARE_BUFFER_PROPERTIES_ANDROID`
- `VK_STRUCTURE_TYPE_ANDROID_HARDWARE_BUFFER_USAGE_ANDROID`
- `VK_STRUCTURE_TYPE_EXTERNAL_FORMAT_ANDROID`
- `VK_STRUCTURE_TYPE_IMPORT_ANDROID_HARDWARE_BUFFER_INFO_ANDROID`
- `VK_STRUCTURE_TYPE_EXTERNAL_FORMAT_ANDROID`

If `VK_KHR_format_feature_flags2` is supported:

- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_ANDROID_HARDWARE_BUFFER_FORMAT_PROPERTIES_2_ANDROID`

### Issues

1) Other external memory objects are represented as weakly-typed handles (e.g. Win32 `HANDLE` or POSIX file descriptor), and require a handle type parameter along with handles. `AHardwareBuffer` is strongly typed, so naming the handle type is redundant. Does symmetry justify adding handle type parameters/fields anyway?

**RESOLVED:** No. The handle type is already provided in places that treat external memory objects generically. In the places we would add it, the application code that would have to provide the handle type value is already dealing with `AHardwareBuffer`-specific commands/structures; the
extra symmetry would not be enough to make that code generic.

2) The internal layout and therefore size of a AHardwareBuffer image may depend on native usage flags that do not have corresponding Vulkan counterparts. Do we provide this information to vkCreateImage somehow, or allow the allocation size reported by vkGetImageMemoryRequirements to be approximate?

**RESOLVED**: Allow the allocation size to be unspecified when allocating the memory. It has to work this way for exported image memory anyway, since AHardwareBuffer allocation happens in vkAllocateMemory, and internally is performed by a separate HAL, not the Vulkan implementation itself. There is a similar issue with vkGetImageSubresourceLayout: the layout is determined by the allocator HAL, so it is not known until the image is bound to memory.

3) Should the result of sampling an external-format image with the suggested Y'CBCR conversion parameters yield the same results as using a samplerExternalOES in OpenGL ES?

**RESOLVED**: This would be desirable, so that apps converting from OpenGL ES to Vulkan could get the same output given the same input. But since sampling and conversion from Y'CBCR images is so loosely defined in OpenGL ES, multiple implementations do it in a way that does not conform to Vulkan's requirements. Modifying the OpenGL ES implementation would be difficult, and would change the output of existing unmodified applications. Changing the output only for applications that are being modified gives developers the chance to notice and mitigate any problems. Implementations are encouraged to minimize differences as much as possible without causing compatibility problems for existing OpenGL ES applications or violating Vulkan requirements.

4) Should an AHardwareBuffer with AHWARDEBUFFER_USAGE_CPU_* usage be mappable in Vulkan? Should it be possible to export an AHardwareBuffers with such usage?

**RESOLVED**: Optional, and mapping in Vulkan is not the same as AHardwareBuffer_lock. The semantics of these are different: mapping in memory is persistent, just gives a raw view of the memory contents, and does not involve ownership. AHardwareBuffer_lock gives the host exclusive access to the buffer, is temporary, and allows for reformattting copy-in/copy-out. Implementations are not required to support host-visible memory types for imported Android hardware buffers or resources backed by them. If a host-visible memory type is supported and used, the memory can be mapped in Vulkan, but doing so follows Vulkan semantics: it is just a raw view of the data and does not imply ownership (this means implementations must not internally call AHardwareBuffer_lock to implement vkMapMemory, or assume the application has done so). Implementations are not required to support linear-tiled images backed by Android hardware buffers, even if the AHardwareBuffer has CPU usage. There is no reliable way to allocate memory in Vulkan that can be exported to a AHardwareBuffer with CPU usage.

5) Android may add new AHardwareBuffer formats and usage flags over time. Can reference to them be added to this extension, or do they need a new extension?

**RESOLVED**: This extension can document the interaction between the new AHB formats/usages and existing Vulkan features. No new Vulkan features or implementation requirements can be added. The extension version number will be incremented when this additional documentation is added, but the version number does not indicate that an implementation supports Vulkan memory or resources that map to the new AHardwareBuffer features: support for that must be queried with
vkGetPhysicalDeviceImageFormatProperties2 or is implied by successfully allocating a AHardwareBuffer outside of Vulkan that uses the new feature and has a GPU usage flag.

In essence, these are new features added to a new Android API level, rather than new Vulkan features. The extension will only document how existing Vulkan features map to that new Android feature.

Version History

- Revision 5, 2022-02-04 (Chris Forbes)
  - Describe mapping of flags for storage image support
- Revision 4, 2021-09-30 (Jon Leech)
  - Add interaction with VK_KHR_format_feature_flags2 to vk.xml
- Revision 3, 2019-08-27 (Jon Leech)
  - Update revision history to correspond to XML version number
- Revision 2, 2018-04-09 (Petr Kraus)
  - Markup fixes and remove incorrect Draft status
- Revision 1, 2018-03-04 (Jesse Hall)
  - Initial version

VK_ARM_shader_core_builtins

Name String

```
VK_ARM_shader_core_builtins
```

Extension Type

Device extension

Registered Extension Number

498

Revision

2

Ratification Status

Not ratified

Extension and Version Dependencies

```
VK_KHR_get_physical_device_properties2
```

Contact

- Kevin Petit kp

4444
Other Extension Metadata

Last Modified Date
2022-10-05

Interactions and External Dependencies

• This extension requires SPV_ARM_core_builtins.
• This extension provides API support for GL_ARM_shader_core_builtins

Contributors

• Kevin Petit, Arm Ltd.
• Jan-Harald Fredriksen, Arm Ltd.

Description

This extension provides the ability to determine device-specific properties on Arm GPUs. It exposes properties for the number of shader cores, the maximum number of warps that can run on a shader core, and shader builtins to enable invocations to identify which core and warp a shader invocation is executing on.

This extension enables support for the SPIR-V CoreBuiltinARM capability.

These properties and built-ins can be used for debugging or performance optimisation purposes. A typical optimisation example would be to use CoreIDARM to select a per-shader-core instance of a data structure in algorithms that use atomics so as to reduce contention.

New Structures

• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceShaderCoreBuiltinsFeaturesARM
• Extending VkPhysicalDeviceProperties2:
  ◦ VkPhysicalDeviceShaderCoreBuiltinsPropertiesARM

New Enum Constants

• VK_ARM_SHADER_CORE_BUILTINS_EXTENSION_NAME
• VK_ARM_SHADER_CORE_BUILTINS_SPEC_VERSION
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CORE_BUILTINS_FEATURES_ARM
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CORE_BUILTINS_PROPERTIES_ARM

New or Modified Built-In Variables

• CoreCountARM
• CoreMaxIDARM
• CoreIDARM
• WarpsMaxIDARM
• WarpIDARM

New SPIR-V Capabilities

• CoreBuiltinsARM

Issues

None.

Version History

• Revision 1, 2022-10-05 (Kevin Petit)
  ◦ Initial revision
• Revision 2, 2022-10-26 (Kevin Petit)
  ◦ Add shaderCoreMask property

VK_ARM_shader_core_properties

Name String
  VK_ARM_shader_core_properties

Extension Type
  Device extension

Registered Extension Number
  416

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  Version 1.1

Contact
  • Jan-Harald Fredriksen janharaldfredriksen-arm

Other Extension Metadata

Last Modified Date
  2023-02-07
IP Status
No known IP claims.

Contributors
• Jan-Harald Fredriksen, Arm Ltd.

Description
This extension provides the ability to determine device-specific performance properties of Arm GPUs.

It exposes properties for the number of texel, pixel, and fused multiply-add operations per clock per shader core. This can be used in combination with the `VK_ARM_shader_core_builtins` extension that provides the ability to query the number of shader cores on the physical device.

New Structures
• Extending `VkPhysicalDeviceProperties2`:
  ◦ `VkPhysicalDeviceShaderCorePropertiesARM`

New Enum Constants
• `VK_ARM_SHADER_CORE_PROPERTIES_EXTENSION_NAME`
• `VK_ARM_SHADER_CORE_PROPERTIES_SPEC_VERSION`
• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_CORE_PROPERTIES_ARM`

Version History
• Revision 1, 2023-02-07 (Jan-Harald Fredriksen)
  ◦ Initial draft.

**VK_FUCHSIA_buffer_collection**

Name String
`VK_FUCHSIA_buffer_collection`

Extension Type
Device extension

Registered Extension Number
367

Revision
2
**Ratification Status**
Not ratified

**Extension and Version Dependencies**
- VK_FUCHSIA_external_memory
- VK_KHR_sampler_ycbcr_conversion

**Contact**
- John Rosasco @rosasco

**Other Extension Metadata**

**Last Modified Date**
2021-09-23

**IP Status**
No known IP claims.

**Contributors**
- Craig Stout, Google
- John Bauman, Google
- John Rosasco, Google

**Description**
A buffer collection is a collection of one or more buffers which were allocated together as a group and which all have the same properties. These properties describe the buffers' internal representation such as its dimensions and memory layout. This ensures that all of the buffers can be used interchangeably by tasks that require swapping among multiple buffers, such as double-buffered graphics rendering.

By sharing such a collection of buffers between components, communication about buffer lifecycle can be made much simpler and more efficient. For example, when a content producer finishes writing to a buffer, it can message the consumer of the buffer with the buffer index, rather than passing a handle to the shared memory.

On Fuchsia, the Sysmem service uses buffer collections as a core construct in its design. VK_FUCHSIA_buffer_collection is the Vulkan extension that allows Vulkan applications to interoperate with the Sysmem service on Fuchsia.

**New Object Types**
- VkBufferCollectionFUCHSIA
New Commands

- vkCreateBufferCollectionFUCHSIA
- vkDestroyBufferCollectionFUCHSIA
- vkGetBufferCollectionPropertiesFUCHSIA
- vkSetBufferCollectionBufferConstraintsFUCHSIA
- vkSetBufferCollectionImageConstraintsFUCHSIA

New Structures

- VkBufferCollectionConstraintsInfoFUCHSIA
- VkBufferCollectionCreateInfoFUCHSIA
- VkBufferCollectionPropertiesFUCHSIA
- VkBufferConstraintsInfoFUCHSIA
- VkImageConstraintsInfoFUCHSIA
- VkImageFormatConstraintsInfoFUCHSIA
- VkSystemColorSpaceFUCHSIA
- Extending VkBufferCreateInfo:
  - VkBufferCollectionBufferCreateInfoFUCHSIA
- Extending VkImageCreateInfo:
  - VkBufferCollectionImageCreateInfoFUCHSIA
- Extending VkMemoryAllocateInfo:
  - VkImportMemoryBufferCollectionFUCHSIA

New Enums

- VkImageConstraintsInfoFlagBitsFUCHSIA

New Bitmasks

- VkImageConstraintsInfoFlagsFUCHSIA
- VkImageFormatConstraintsFlagsFUCHSIA

New Enum Constants

- VK_FUCHSIA_BufferCollection_Extension_Name
- VK_FUCHSIA_BufferCollection_Spec_Version
- Extending VkObjectType:
  - VK_OBJECT_TYPE_BUFFER_COLLECTION_FUCHSIA
- Extending VkStructureType:
If VK_EXT_debug_report is supported:

- Extending VkDebugReportObjectTypeEXT:
  - VK_DEBUG_REPORT_OBJECT_TYPE_BUFFER_COLLECTION_FUCHSIA_EXT

Issues

1) When configuring a VkImageConstraintsInfoFUCHSIA structure for constraint setting, should a NULL pFormatConstraints parameter be allowed?

**RESOLVED**: No. Specifying a NULL pFormatConstraints results in logical complexity of interpreting the relationship between the VkImageCreateInfo::usage settings of the elements of the pImageCreateInfos array and the implied or desired VkFormatFeatureFlags.

The explicit requirement for pFormatConstraints to be non-NULL simplifies the implied logic of the implementation and expectations for the Vulkan application.

Version History

- Revision 2, 2021-09-23 (John Rosasco)
  - Review passes
- Revision 1, 2021-03-09 (John Rosasco)
  - Initial revision

**VK_FUCHSIA_external_memory**

Name String

VK_FUCHSIA_external_memory

Extension Type

Device extension
Vulkan apps may wish to export or import device memory handles to or from other logical devices, instances or APIs.

This memory sharing can eliminate copies of memory buffers when different subsystems need to interoperate on them. Sharing memory buffers may also facilitate a better distribution of processing workload for more complex memory manipulation pipelines.
• VkMemoryZirconHandlePropertiesFUCHSIA
• Extending VkMemoryAllocateInfo:
  ◦ VkImportMemoryZirconHandleInfoFUCHSIA

New Enum Constants

• VK_FUCHSIA_EXTERNAL_MEMORY_EXTENSION_NAME
• VK_FUCHSIA_EXTERNAL_MEMORY_SPEC_VERSION
• Extending VkExternalMemoryHandleTypeFlagBits:
  ◦ VK_EXTERNAL_MEMORY_HANDLE_TYPE_ZIRCON_VMO_BIT_FUCHSIA
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_IMPORT_MEMORY_ZIRCON_HANDLE_INFO_FUCHSIA
  ◦ VK_STRUCTURE_TYPE_MEMORY_GET_ZIRCON_HANDLE_INFO_FUCHSIA
  ◦ VK_STRUCTURE_TYPE_MEMORY_ZIRCON_HANDLE_PROPERTIES_FUCHSIA

Issues

See VK_KHR_external_memory issues list for further information.

Version History

• Revision 1, 2021-03-01 (John Rosasco)
  ◦ Initial draft

VK_FUCHSIA_external_semaphore

Name String
  VK_FUCHSIA_external_semaphore

Extension Type
  Device extension

Registered Extension Number
  366

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_external_semaphore_capabilities
and
VK_KHR_external_semaphore

Contact
- John Rosasco @rosasco

Other Extension Metadata

Last Modified Date
2021-03-08

IP Status
No known IP claims.

Contributors
- Craig Stout, Google
- John Bauman, Google
- John Rosasco, Google

Description
An application using external memory may wish to synchronize access to that memory using semaphores. This extension enables an application to export semaphore payload to and import semaphore payload from Zircon event handles.

New Commands
- vkGetSemaphoreZirconHandleFUCHSIA
- vkImportSemaphoreZirconHandleFUCHSIA

New Structures
- VkImportSemaphoreZirconHandleInfoFUCHSIA
- VkSemaphoreGetZirconHandleInfoFUCHSIA

New Enum Constants
- VK_FUCHSIA_EXTERNAL_SEMAPHORE_EXTENSION_NAME
- VK_FUCHSIA_EXTERNAL_SEMAPHORE_SPEC_VERSION
- Extending VkExternalSemaphoreHandleTypeFlagBits:
  - VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_ZIRCON_EVENT_BIT_FUCHSIA
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_IMPORT_SEMAPHORE_ZIRCON_HANDLE_INFO_FUCHSIA
  - VK_STRUCTURE_TYPE_SEMAPHORE_GET_ZIRCON_HANDLE_INFO_FUCHSIA
Issues

1) Does the application need to close the Zircon event handle returned by vkGetSemaphoreZirconHandleFUCHSIA?

**RESOLVED:** Yes, unless it is passed back in to a driver instance to import the semaphore. A successful get call transfers ownership of the Zircon event handle to the application, and a successful import transfers it back to the driver. Destroying the original semaphore object will not close the Zircon event handle nor remove its reference to the underlying semaphore resource associated with it.

Version History

- Revision 1, 2021-03-08 (John Rosasco)
  - Initial revision

**VK_FUCHSIA_imagepipe_surface**

**Name String**

`VK_FUCHSIA_imagepipe_surface`

**Extension Type**

Instance extension

**Registered Extension Number**

215

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

`VK_KHR_surface`

**Contact**

- Craig Stout [cdotstout](mailto:cdotstout)

**Other Extension Metadata**

**Last Modified Date**

2018-07-27

**IP Status**

No known IP claims.
Contributors
  • Craig Stout, Google
  • Ian Elliott, Google
  • Jesse Hall, Google

Description
The `VK_FUCHSIA_imagepipe_surface` extension is an instance extension. It provides a mechanism to create a `VkSurfaceKHR` object (defined by the `VK_KHR_surface` extension) that refers to a Fuchsia `imagePipeHandle`.

New Commands
  • `vkCreateImagePipeSurfaceFUCHSIA`

New Structures
  • `VkImagePipeSurfaceCreateInfoFUCHSIA`

New Bitmasks
  • `VkImagePipeSurfaceCreateFlagsFUCHSIA`

New Enum Constants
  • `VK_FUCHSIA_IMAGEPIPE_SURFACE_EXTENSION_NAME`
  • `VK_FUCHSIA_IMAGEPIPE_SURFACE_SPEC_VERSION`
  • Extending `VkStructureType`:
    ◦ `VK_STRUCTURE_TYPE_IMAGEPIPE_SURFACE_CREATE_INFO_FUCHSIA`

Version History
  • Revision 1, 2018-07-27 (Craig Stout)
    ◦ Initial draft.

`VK_GGP_frame_token`

Name String
  `VK_GGP_frame_token`

Extension Type
  Device extension

Registered Extension Number
  192
Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_swapchain
  and
  VK_GGP_stream_descriptor_surface

Contact
  • Jean-Francois Roy @jfroy

Other Extension Metadata

Last Modified Date
  2019-01-28

IP Status
  No known IP claims.

Contributors
  • Jean-Francois Roy, Google
  • Richard O’Grady, Google

Description

This extension allows an application that uses the VK_KHR_swapchain extension in combination with a Google Games Platform surface provided by the VK_GGP_stream_descriptor_surface extension to associate a Google Games Platform frame token with a present operation.

New Structures

  • Extending VkPresentInfoKHR:
    ◦ VkPresentFrameTokenGGP

New Enum Constants

  • VK_GGP_FRAME_TOKEN_EXTENSION_NAME
  • VK_GGP_FRAME_TOKEN_SPEC_VERSION
  • Extending VkStructureType:
    ◦ VK_STRUCTURE_TYPE_PRESENT_FRAME_TOKEN_GGP
Version History

- Revision 1, 2018-11-26 (Jean-Francois Roy)
  - Initial revision.

VK_GGP_stream_descriptor_surface

Name String

VK_GGP_stream_descriptor_surface

Extension Type

Instance extension

Registered Extension Number

50

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_surface

Contact

- Jean-Francois Roy @jfroy

Other Extension Metadata

Last Modified Date

2019-01-28

IP Status

No known IP claims.

Contributors

- Jean-Francois Roy, Google
- Brad Grantham, Google
- Connor Smith, Google
- Cort Stratton, Google
- Hai Nguyen, Google
- Ian Elliott, Google
- Jesse Hall, Google
- Jim Ray, Google
Description

The VK_GGP_stream_descriptor_surface extension is an instance extension. It provides a mechanism to create a VkSurfaceKHR object (defined by the VK_KHR_surface extension) that refers to a Google Games Platform GgpStreamDescriptor.

New Commands

- vkCreateStreamDescriptorSurfaceGGP

New Structures

- VkStreamDescriptorSurfaceCreateInfoGGP

New Bitmasks

- VkStreamDescriptorSurfaceCreateFlagsGGP

New Enum Constants

- VK_GGP_STREAM_DESCRIPTOR_SURFACE_EXTENSION_NAME
- VK_GGP_STREAM_DESCRIPTOR_SURFACE_SPEC_VERSION

Extending VkStructureType:

- VK_STRUCTURE_TYPE_STREAM_DESCRIPTOR_SURFACE_CREATE_INFO_GGP

Version History

- Revision 1, 2018-11-26 (Jean-Francois Roy)
  - Initial revision.

VK_GOOGLE_decorate_string

Name String

VK_GOOGLE_decorate_string
Extension Type
Device extension

Registered Extension Number
225

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies

Contact
• Hai Nguyen chaoticbob

Other Extension Metadata

Last Modified Date
2018-07-09

IP Status
No known IP claims.

Interactions and External Dependencies
• This extension requires SPV_GOOGLE_decorate_string

Contributors
• Hai Nguyen, Google
• Neil Henning, AMD

Description
The VK_GOOGLE_decorate_string extension allows use of the SPV_GOOGLE_decorate_string extension in SPIR-V shader modules.

New Enum Constants
• VK_GOOGLE_DECORATE_STRING_EXTENSION_NAME
• VK_GOOGLE_DECORATE_STRING_SPEC_VERSION

Version History
• Revision 1, 2018-07-09 (Neil Henning)
  ◦ Initial draft
VK_GOOGLE_display_timing

Name String
VK_GOOGLE_display_timing

Extension Type
Device extension

Registered Extension Number
93

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_swapchain

Contact
• Ian Elliott @ianelliottus

Other Extension Metadata

Last Modified Date
2017-02-14

IP Status
No known IP claims.

Contributors
• Ian Elliott, Google
• Jesse Hall, Google

Description

This device extension allows an application that uses the VK_KHR_swapchain extension to obtain information about the presentation engine's display, to obtain timing information about each present, and to schedule a present to happen no earlier than a desired time. An application can use this to minimize various visual anomalies (e.g. stuttering).

Traditional game and real-time animation applications need to correctly position their geometry for when the presentable image will be presented to the user. To accomplish this, applications need various timing information about the presentation engine's display. They need to know when presentable images were actually presented, and when they could have been presented. Applications also need to tell the presentation engine to display an image no sooner than a given time. This allows the application to avoid stuttering, so the animation looks smooth to the user.
This extension treats variable-refresh-rate (VRR) displays as if they are fixed-refresh-rate (FRR) displays.

**New Commands**

- vkGetPastPresentationTimingGOOGLE
- vkGetRefreshCycleDurationGOOGLE

**New Structures**

- VkPastPresentationTimingGOOGLE
- VkPresentTimeGOOGLE
- VkRefreshCycleDurationGOOGLE
- Extending VkPresentInfoKHR:
  - VkPresentTimesInfoGOOGLE

**New Enum Constants**

- VK_GOOGLE_DISPLAY_TIMING_EXTENSION_NAME
- VK_GOOGLE_DISPLAY_TIMING_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PRESENT_TIMES_INFO_GOOGLE

**Examples**

*Note*

The example code for the this extension (like the VK_KHR_surface and VK_GOOGLE_display_timing extensions) is contained in the cube demo that is shipped with the official Khronos SDK, and is being kept up-to-date in that location (see: https://github.com/KhronosGroup/Vulkan-Tools/blob/master/cube/cube.c).

**Version History**

- Revision 1, 2017-02-14 (Ian Elliott)
  - Internal revisions

**VK_GOOGLE_hlsl_functionality1**

**Name String**

VK_GOOGLE_hlsl_functionality1

**Extension Type**

Device extension
The **VK_GOOGLE_hlsl_functionality1** extension allows use of the **SPV_GOOGLE_hlsl_functionality1** extension in SPIR-V shader modules.

### New Enum Constants

- **VK_GOOGLE_HLSL_FUNCTIONALITY1_EXTENSION_NAME**
- **VK_GOOGLE_HLSL_FUNCTIONALITY1_SPEC_VERSION**
- **VK_GOOGLE_HLSL_FUNCTIONALITY_1_EXTENSION_NAME**
- **VK_GOOGLE_HLSL_FUNCTIONALITY_1_SPEC_VERSION**

### Version History

- Revision 1, 2018-07-09 (Neil Henning)
  - Initial draft
**VK_GOOGLE_surfaceless_query**

**Name String**
- `VK_GOOGLE_surfaceless_query`

**Extension Type**
- Instance extension

**Registered Extension Number**
- 434

**Revision**
- 2

**Ratification Status**
- Not ratified

**Extension and Version Dependencies**
- `VK_KHR_surface`

**Special Use**
- **OpenGL / ES support**

**Contact**
- Shahbaz Youssefi [syoussefi](mailto:syoussefi)

**Extension Proposal**
- `VK_GOOGLE_surfaceless_query`

**Other Extension Metadata**

**Last Modified Date**
- 2022-08-03

**IP Status**
- No known IP claims.

**Contributors**
- Ian Elliott, Google
- Shahbaz Youssefi, Google
- James Jones, NVIDIA

**Description**

This extension allows the `vkGetPhysicalDeviceSurfaceFormatsKHR` and `vkGetPhysicalDeviceSurfacePresentModesKHR` functions to accept `VK_NULL_HANDLE` as their `surface` parameter, allowing potential surface formats, color spaces and present modes to be queried without providing a surface. Identically, `vkGetPhysicalDeviceSurfaceFormats2KHR`, `vkGetPhysicalDeviceSurfacePresentModes2KHR`, and `vkGetPhysicalDeviceSurfacePresentModes2EXT` also accept `VK_NULL_HANDLE`. This makes it easier for applications to query surface-related information without having to establish a specific `surface` handle first.
vkGetPhysicalDeviceSurfacePresentModes2EXT, and vkGetPhysicalDeviceSurfaceCapabilities2KHR would accept VK_NULL_HANDLE in VkPhysicalDeviceSurfaceInfo2KHR::surface. This can only be supported on platforms where the results of these queries are surface-agnostic and a single presentation engine is the implicit target of all present operations.

New Enum Constants

- VK_GOOGLE_SURFACELESS_QUERY_EXTENSION_NAME
- VK_GOOGLE_SURFACELESS_QUERY_SPEC_VERSION

Version History

- Revision 1, 2021-12-14 (Shahbaz Youssefi)
  - Internal revisions
- Revision 2, 2022-08-03 (Shahbaz Youssefi)
  - Precisions to which parts of the query responses are defined when surfaceless

**VK_GOOGLE_user_type**

Name String

VK_GOOGLE_user_type

Extension Type

Device extension

Registered Extension Number

290

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

Contact

- Kaye Mason [chaleur](mailto:chaleur)

Other Extension Metadata

Last Modified Date

2019-07-09

IP Status

No known IP claims.
Interactions and External Dependencies

- This extension requires SPV_GOOGLE_user_type

Contributors

- Kaye Mason, Google
- Hai Nguyen, Google

Description

The VK_GOOGLE_user_type extension allows use of the SPV_GOOGLE_user_type extension in SPIR-V shader modules.

New Enum Constants

- VK_GOOGLE_USER_TYPE_EXTENSION_NAME
- VK_GOOGLE_USER_TYPE_SPEC_VERSION

Version History

- Revision 1, 2019-09-07 (Kaye Mason)
  - Initial draft

VK_HUAWEI_cluster_culling_shader

Name String

VK_HUAWEI_cluster_culling_shader

Extension Type

Device extension

Registered Extension Number

405

Revision

2

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Contact

- Yuchang Wang richard_Wang2

Extension Proposal

VK_HUAWEI_cluster_culling_shader
Description

Cluster Culling Shaders (CCS) are similar to the existing compute shaders. Their main purpose is to provide an execution environment in order to perform coarse-level geometry culling and LOD selection more efficiently on the GPU.

The traditional 2-pass GPU culling solution using a compute shader sometimes needs a pipeline barrier between compute and graphics pipeline to optimize performance. An additional compaction process may also be required. This extension addresses these shortcomings, allowing compute shaders to directly emit visible clusters to the following graphics pipeline.

A set of new built-in output variables are used to express a visible cluster. In addition, a new built-in function is used to emit these variables from CCS to the IA stage. The IA stage can use these variables to fetches vertices of a visible cluster and drive vertex shaders to shading these vertices.

Note that CCS do not work with geometry or tessellation shaders, but both IA and vertex shaders are preserved. Vertex shaders are still used for vertex position shading, instead of directly outputting transformed vertices from the compute shader. This makes CCS more suitable for mobile GPUs.

New Commands

- `vkCmdDrawClusterHUAWEI`
- `vkCmdDrawClusterIndirectHUAWEI`
New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceClusterCullingShaderFeaturesHUAWEI`

- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceClusterCullingShaderPropertiesHUAWEI`

New Enum Constants

- `VK_HUAWEI_CLUSTER_CULLING_SHADER_EXTENSION_NAME`
- `VK_HUAWEI_CLUSTER_CULLING_SHADER_SPEC_VERSION`

- Extending `VkPipelineStageFlagBits2`:
  - `VK_PIPELINE_STAGE_2_CLUSTER_CULLING_SHADER_BIT_HUAWEI`

- Extending `VkQueryPipelineStatisticFlagBits`:
  - `VK_QUERY_PIPELINE_STATISTIC_CLUSTER_CULLING_SHADER_INVOCATIONS_BIT_HUAWEI`

- Extending `VkShaderStageFlagBits`:
  - `VK_SHADER_STAGE_CLUSTER_CULLING_BIT_HUAWEI`

- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CLUSTER_CULLING_SHADER_FEATURES_HUAWEI`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CLUSTER_CULLING_SHADER_PROPERTIES_HUAWEI`

New Built-In Variables

- `IndexCountHUAWEI`
- `VertexCountHUAWEI`
- `InstanceCountHUAWEI`
- `FirstIndexHUAWEI`
- `FirstVertexHUAWEI`
- `VertexOffsetHUAWEI`
- `FirstInstanceHUAWEI`
- `ClusterIDHUAWEI`

New SPIR-V Capability

- `ClusterCullingShadingHUAWEI`

Sample code

Example of cluster culling in a GLSL shader
#extension GL_HUAWEI_cluster_culling_shader: enable

#define GPU_WARP_SIZE 32
#define GPU_GROUP_SIZE GPU_WARP_SIZE
#define GPU_CLUSTER_PER_INVOCATION 1
#define GPU_CLUSTER_PER_WORKGROUP (GPU_GROUP_SIZE * GPU_CLUSTER_PER_INVOCATION)

// Number of threads per workgroup
// - 1D only
// - warpsize = 32
layout(local_size_x=GPU_GROUP_SIZE, local_size_y=1, local_size_z=1) in;

#define GPU_CLUSTER_DESCRIPTOR_BINDING 0
#define GPU_DRAW_BUFFER_BINDING 1
#define GPU_INSTANCE_DESCRIPTOR_BINDING 2

const float pi_half = 1.570795;
uint instance_id;

struct BoundingSphere
{
  vec3 center;
  float radius;
};

struct BoundingCone
{
  vec3 normal;
  float angle;
};

struct ClusterDescriptor
{
  BoundingSphere sphere;
  BoundingCone cone;
  uint instance_idx;
};

struct InstanceData
{
  mat4 mvp_matrix;  // mvp matrix.
  vec4 frustum_planes[6];  // six frustum planes
  mat4 model_matrix_transpose_inverse;  // inverse transpose of model matrix.
  vec3 view_origin;  // view original
};

struct InstanceDescriptor
{
uint begin;
uint end;
uint cluster_count;
uint debug;
BoundingSphere sphere;
InstanceData instance_data;
}

struct DrawElementsCommand{
    uint indexcount;
    uint instanceCount;
    uint firstIndex;
    int vertexoffset;
    uint firstInstance;
    uint cluster_id;
};

// indexed mode
out gl_PerClusterHUAWEI{
    uint gl_IndexCountHUAWEI;
    uint gl_InstanceCountHUAWEI;
    uint gl_FirstIndexHUAWEI;
    int gl_VertexOffsetHUAWEI;
    uint gl_FirstInstanceHUAWEI;
    uint gl_ClusterIDHUAWEI;
};

layout(binding = GPU_CLUSTER_DESCRIPTOR_BINDING, std430) readonly buffer
cluster_descriptor_ssbo
{
    ClusterDescriptor cluster_descriptors[];
};

layout(binding = GPU_DRAW_BUFFER_BINDING, std430) buffer draw_indirect_ssbo
{
    DrawElementsCommand draw_commands[];
};

layout(binding = GPU_INSTANCE_DESCRIPTOR_BINDING, std430) buffer
instance_descriptor_ssbo
{
    InstanceDescriptor instance_descriptors[];
};

bool isFrontFaceVisible( vec3 sphere_center, float sphere_radius, vec3 cone_normal,
float cone_angle )
{
    vec3 sphere_center_dir = normalize(sphere_center -
float sin_cone_angle = \sin(\min(\cone_angle, \pi_half));
return dot(\cone_normal, \sphere_center_dir) < \sin_cone_angle;
}
Example of graphics pipeline creation with cluster culling shader

```cpp
// create a cluster culling shader stage info structure.
VkPipelineShaderStageCreateInfo ccsStageInfo{};
ccsStageInfo.sType = VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_CREATE_INFO;
ccsStageInfo.stage = VK_SHADER_STAGE_CLUSTER_CULLING_BIT_HUAWEI;
ccsStageInfo.module = clustercullingshaderModule;
ccsStageInfo.pName = "main";

// pipeline shader stage creation
VkPipelineShaderStageCreateInfo shaderStages[] = { ccsStageInfo, vertexShaderStageInfo, fragmentShaderStageInfo };

// create graphics pipeline
VkGraphicsPipelineCreateInfo pipelineInfo{};
pipelineInfo.sType = VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_CREATE_INFO;
pipelineInfo.stageCount = 3;
pipelineInfo.pStage = shaderStages;
pipelineInfo.pVertexInputState = &vertexInputInfo;
// ...
VkPipeline graphicsPipeline;
VkCreateGraphicsPipelines(device, VK_NULL_HANDLE, 1, &pipelineInfo, nullptr, &graphicsPipeline);
```

Example of launching the execution of cluster culling shader

```cpp
vkCmdBindPipeline(commandBuffer, VK_PIPELINE_BIND_POINT_GRAPHICS, graphicsPipeline);
vkCmdDrawClusterHUAWEI(commandBuffer, groupCountX, 1, 1);
vkCmdEndRenderPass(commandBuffer);
```

Version History

- Revision 1, 2022-11-18 (YuChang Wang)
  - Internal revisions
- Revision 2, 2023-04-02 (Jon Leech)
VK_HUAWEI_invocation_mask

Name String
VK_HUAWEI_invocation_mask

Extension Type
Device extension

Registered Extension Number
371

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_ray_tracing_pipeline
and
VK_KHR_synchronization2

Contact
• Pan Gao PanGao-h

Extension Proposal
VK_HUAWEI_invocation_mask

Other Extension Metadata

Last Modified Date
2021-05-27

Interactions and External Dependencies
• This extension requires VK_KHR_ray_tracing_pipeline, which allow to bind an invocation mask image before the ray tracing command
• This extension requires VK_KHR_synchronization2, which allows new pipeline stage for the invocation mask image

Contributors
• Yunpeng Zhu
• Juntao Li, Huawei
• Liang Chen, Huawei
• Shaozhuang Shi, Huawei
• Hailong Chu, Huawei
The rays to trace may be sparse in some use cases. For example, the scene only have a few regions to reflect. Providing an invocation mask image to the ray tracing commands could potentially give the hardware the hint to do certain optimization without invoking an additional pass to compact the ray buffer.

New Commands

- `vkCmdBindInvocationMaskHUAWEI`

New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceInvocationMaskFeaturesHUAWEI`

New Enum Constants

- `VK_HUAWEI_INVOCATION_MASK_EXTENSION_NAME`
- `VK_HUAWEI_INVOCATION_MASK_SPEC_VERSION`
- Extending `VkAccessFlagBits2`:
  - `VK_ACCESS_2_INVOCATION_MASK_READ_BIT_HUAWEI`
- Extending `VkImageUsageFlagBits`:
  - `VK_IMAGE_USAGE_INVOCATION_MASK_BIT_HUAWEI`
- Extending `VkPipelineStageFlagBits2`:
  - `VK_PIPELINE_STAGE_2_INVOCATION_MASK_BIT_HUAWEI`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INVOCATION_MASK_FEATURES_HUAWEI`

Examples

RT mask is updated before each traceRay.

Step 1. Generate InvocationMask.

```cpp
//the rt mask image bind as color attachment in the fragment shader
Layout(location = 2) out vec4 outRTmask
vec4 mask = vec4(x,x,x,x);
outRTmask = mask;
```

Step 2. traceRay with InvocationMask

```cpp
vkCmdBindPipeline(
    commandBuffers[imageIndex],
```
VK_PIPELINE_BIND_POINTRAY_TRACING_KHR, m_rtPipeline);
vkCmdBindDescriptorSets(commandBuffers[imageIndex],
VK_PIPELINE_BIND_POINTRAY_TRACING_NV,
&m_rtPipelineLayout, 0, 1, &m_rtDescriptorSet,
0, nullptr);

vkCmdBindInvocationMaskHUAWEI(
commandBuffers[imageIndex],
InvocationMaskimageView,
InvocationMaskimageLayout);
vkCmdTraceRaysKHR(commandBuffers[imageIndex],
pRaygenShaderBindingTable,
pMissShaderBindingTable,
swapChainExtent.width,
swapChainExtent.height, 1);

Version History

- Revision 1, 2021-05-27 (Yunpeng Zhu)
  - Initial draft.

VK_HUAWEI_subpass_shading

Name String

VK_HUAWEI_subpass_shading

Extension Type

Device extension

Registered Extension Number

370

Revision

3

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_create_renderpass2
and
VK_KHR_synchronization2

Contact

- Pan Gao PanGao-h
Other Extension Metadata

Last Modified Date
2021-06-01

Interactions and External Dependencies

• This extension requires SPV_HUAWEI_subpass_shading.
• This extension provides API support for GL_HUAWEI_subpass_shading.

Contributors

• Hueilong Wang
• Juntao Li, Huawei
• Renmiao Lu, Huawei
• Pan Gao, Huawei

Description

This extension allows applications to execute a subpass shading pipeline in a subpass of a render pass in order to save memory bandwidth for algorithms like tile-based deferred rendering and forward plus. A subpass shading pipeline is a pipeline with the compute pipeline ability, allowed to read values from input attachments, and only allowed to be dispatched inside a stand-alone subpass. Its work dimension is defined by the render pass's render area size. Its workgroup size (width, height) shall be a power-of-two number in width or height, with minimum value from 8, and maximum value shall be decided from the render pass attachments and sample counts but depends on implementation.

The GlobalInvocationId.xy of a subpass shading pipeline is equal to the FragCoord.xy of a graphic pipeline in the same render pass subtracted the offset of the VkRenderPassBeginInfo::renderArea. GlobalInvocationId.z is mapped to the Layer if VK_EXT_shader_viewport_index_layer is supported. The GlobalInvocationId.xy is equal to the index of the local workgroup multiplied by the size of the local workgroup plus the LocalInvocationId and the offset of the VkRenderPassBeginInfo ::renderArea.

This extension allows a subpass’s pipeline bind point to be VK_PIPELINE_BIND_POINT_SUBPASS_SHADING_HUAWEI.

New Commands

• vkCmdSubpassShadingHUAWEI
• vkGetDeviceSubpassShadingMaxWorkgroupSizeHUAWEI

New Structures

• Extending VkComputePipelineCreateInfo:
  ◦ VkSubpassShadingPipelineCreateInfoHUAWEI
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
• VkPhysicalDeviceSubpassShadingFeaturesHUAWEI
• Extending VkPhysicalDeviceProperties2:
  • VkPhysicalDeviceSubpassShadingPropertiesHUAWEI

New Enum Constants

• VK_HUAWEI_SUBPASS_SHADING_EXTENSION_NAME
• VK_HUAWEI_SUBPASS_SHADING_SPEC_VERSION
• Extending VkPipelineBindPoint:
  • VK_PIPELINE_BIND_POINT_SUBPASS_SHADING_HUAWEI
• Extending VkPipelineStageFlagBits2:
  • VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI
  • VK_PIPELINE_STAGE_2_SUBPASS_SHADING_BIT_HUAWEI
• Extending VkShaderStageFlagBits:
  • VK_SHADER_STAGE_SUBPASS_SHADING_BIT_HUAWEI
• Extending VkStructureType:
  • VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBPASS_SHADING_FEATURES_HUAWEI
  • VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SUBPASS_SHADING_PROPERTIES_HUAWEI
  • VK_STRUCTURE_TYPE_SUBPASS_SHADING_PIPELINE_CREATE_INFO_HUAWEI

Sample Code

Example of subpass shading in a GLSL shader

```glsl
#extension GL_HUAWEI_subpass_shading: enable
#extension GL_KHR_shader_subgroup_arithmetic: enable

layout(constant_id = 0) const uint tileWidth = 8;
layout(constant_id = 1) const uint tileHeight = 8;
layout(local_size_x_id = 0, local_size_y_id = 1, local_size_z = 1) in;
layout(set=0, binding=0, input_attachment_index=0) uniform subpassInput depth;

void main()
{
  float d = subpassLoad(depth).x;
  float minD = subgroupMin(d);
  float maxD = subgroupMax(d);
}
```

Example of subpass shading dispatching in a subpass

```glsl
vkCmdNextSubpass(commandBuffer, VK_SUBPASS CONTENTS_INLINE);
```
vkCmdBindPipeline(commandBuffer, VK_PIPELINE_BIND_POINT_SUBPASS_SHADING_HUAWEI, subpassShadingPipeline);
vkCmdBindDescriptorSets(commandBuffer, VK_PIPELINE_BIND_POINT_SUBPASS_SHADING_HUAWEI, subpassShadingPipelineLayout,
    firstSet, descriptorSetCount, pDescriptorSets, dynamicOffsetCount, pDynamicOffsets);
vkCmdSubpassShadingHUAWEI(commandBuffer)
vkCmdEndRenderPass(commandBuffer);

Example of subpass shading render pass creation

```cpp
VkAttachmentDescription2 attachments[] = {
    {
        VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_2, NULL,
        0, VK_FORMAT_R8G8B8A8_UNORM, VK_SAMPLE_COUNT_1_BIT,
        VK_ATTACHMENT_LOAD_OP_CLEAR, VK_ATTACHMENT_STORE_OP_DONT_CARE,
        VK_ATTACHMENT_LOAD_OP_DONT_CARE, VK_ATTACHMENT_LOAD_OP_DONT_CARE,
        VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL
    },
    {
        VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_2, NULL,
        0, VK_FORMAT_R8G8B8A8_UNORM, VK_SAMPLE_COUNT_1_BIT,
        VK_ATTACHMENT_LOAD_OP_CLEAR, VK_ATTACHMENT_STORE_OP_DONT_CARE,
        VK_ATTACHMENT_LOAD_OP_DONT_CARE, VK_ATTACHMENT_LOAD_OP_DONT_CARE,
        VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL
    },
    {
        VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_2, NULL,
        0, VK_FORMAT_R8G8B8A8_UNORM, VK_SAMPLE_COUNT_1_BIT,
        VK_ATTACHMENT_LOAD_OP_CLEAR, VK_ATTACHMENT_STORE_OP_DONT_CARE,
        VK_ATTACHMENT_LOAD_OP_DONT_CARE, VK_ATTACHMENT_LOAD_OP_DONT_CARE,
        VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL
    },
    {
        VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_2, NULL,
        0, VK_FORMAT_D24_UNORM_S8_UINT, VK_SAMPLE_COUNT_1_BIT,
        VK_ATTACHMENT_LOAD_OP_CLEAR, VK_ATTACHMENT_STORE_OP_DONT_CARE,
        VK_ATTACHMENT_LOAD_OP_DONT_CARE, VK_ATTACHMENT_LOAD_OP_DONT_CARE,
        VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL
    },
    {
        VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_2, NULL,
        0, VK_FORMAT_R8G8B8A8_UNORM, VK_SAMPLE_COUNT_1_BIT,
        VK_ATTACHMENT_LOAD_OP_CLEAR, VK_ATTACHMENT_STORE_OP_STORE,
        VK_ATTACHMENT_LOAD_OP_DONT_CARE, VK_ATTACHMENT_LOAD_OP_DONT_CARE,
        VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL, VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL
    }
};
VkAttachmentReference2 gBufferAttachmentReferences[] = {
```
VkAttachmentReference2 gBufferDepthStencilAttachmentReferences =
   { VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_2, NULL, 3,
   VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL, VK_IMAGE_ASPECT_DEPTH_BIT |
   VK_IMAGE_ASPECT_STENCIL_BIT },
VkAttachmentReference2 depthInputAttachmentReferences[] = {
   { VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_2, NULL, 3,
   VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL, VK_IMAGE_ASPECT_DEPTH_BIT |
   VK_IMAGE_ASPECT_STENCIL_BIT },};
VkAttachmentReference2 preserveAttachmentReferences[] = {
   { VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_2, NULL, 0,
   VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL, VK_IMAGE_ASPECT_COLOR_BIT },
   { VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_2, NULL, 1,
   VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL, VK_IMAGE_ASPECT_COLOR_BIT },
   { VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_2, NULL, 2,
   VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL, VK_IMAGE_ASPECT_COLOR_BIT },
   { VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_2, NULL, 3,
   VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL, VK_IMAGE_ASPECT_DEPTH_BIT |
   VK_IMAGE_ASPECT_STENCIL_BIT },
}; // G buffer including depth/stencil
VkAttachmentReference2 colorAttachmentReferences[] = {
   { VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_2, NULL, 4,
   VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL, VK_IMAGE_ASPECT_COLOR_BIT },
};
VkAttachmentReference2 resolveAttachmentReference =
   { VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_2, NULL, 4,
   VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL, VK_IMAGE_ASPECT_COLOR_BIT },

VkSubpassDescription2 subpasses[] = {
   {
   VK_STRUCTURE_TYPE_SUBPASS_DESCRIPTION_2, NULL, 0, VK_PIPELINE_BIND_POINT_GRAPHICS, 0,
   0, NULL, // input
   sizeof(gBufferAttachmentReferences)/sizeof(gBufferAttachmentReferences[0]),
   gBufferAttachmentReferences, // color
   NULL, 0, gBufferDepthStencilAttachmentReferences, // resolve & DS
   0, NULL
   },
   {
   VK_STRUCTURE_TYPE_SUBPASS_DESCRIPTION_2, NULL, 0,
   VK_PIPELINE_BIND_POINT_SUBPASS_SHADING_HUAWEI , 0,
   sizeof(depthInputAttachmentReferences)/sizeof(depthInputAttachmentReferences[0]),
   depthInputAttachmentReferences, // input
   0, NULL, // color

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NULL, NULL, // resolve & DS
sizeof(preserveAttachmentReferences)/sizeof(preserveAttachmentReferences[0]),
preserveAttachmentReferences,
},
{
    VK_STRUCTURE_TYPE_SUBPASS_DESCRIPTION_2, NULL, 0, VK_PIPELINE_BIND_POINT_GRAPHICS, 0,
sizeof(gBufferAttachmentReferences)/sizeof(gBufferAttachmentReferences[0]),
gBufferAttachmentReferences, // input
sizeof(colorAttachmentReferences)/sizeof(colorAttachmentReferences[0]),
colorAttachmentReferences, // color
&resolveAttachmentReference, &gBufferDepthStencilAttachmentReferences, // resolve & DS
0, NULL
},
);

VkMemoryBarrier2KHR fragmentToSubpassShading = {
    VK_STRUCTURE_TYPE_MEMORY_BARRIER_2_KHR, NULL,
    VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT_KHR, VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT |
    VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT,
    VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI, VK_ACCESS_INPUT_ATTACHMENT_READ_BIT
};

VkMemoryBarrier2KHR subpassShadingToFragment = {
    VK_STRUCTURE_TYPE_MEMORY_BARRIER_2_KHR, NULL,
    VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI, VK_ACCESS_SHADER_WRITE_BIT,
    VK_PIPELINE_STAGE_2_FRAGMENT_SHADER_BIT_KHR, VK_ACCESS_SHADER_READ_BIT
};

VkSubpassDependency2 dependencies[] = {
    {
        VK_STRUCTURE_TYPE_SUBPASS_DEPENDENCY_2, &fragmentToSubpassShading,
        0, 1,
        0, 0, 0, 0,
        0, 0
    },
    {
        VK_STRUCTURE_TYPE_SUBPASS_DEPENDENCY_2, &subpassShadingToFragment,
        1, 2,
        0, 0, 0, 0,
        0, 0
    },
};

VkRenderPassCreateInfo2 renderPassCreateInfo = {
    VK_STRUCTURE_TYPE_RENDER_PASS_CREATE_INFO_2, NULL, 0,
    sizeof(attachments)/sizeof(attachments[0]), attachments,
    sizeof(subpasses)/sizeof(subpasses[0]), subpasses,
    sizeof(dependencies)/sizeof(dependencies[0]), dependencies,
    0, NULL
};
Example of subpass shading pipeline creation

```c
VkExtent2D maxWorkgroupSize;

VkSpecializationMapEntry subpassShadingConstantMapEntries[] = {
    { 0, 0 * sizeof(uint32_t), sizeof(uint32_t) },
    { 1, 1 * sizeof(uint32_t), sizeof(uint32_t) }
};

VkSpecializationInfo subpassShadingConstants = {
    2,
    subpassShadingConstantMapEntries,
    sizeof(VkExtent2D), maxWorkgroupSize
};

VkSubpassShadingPipelineCreateInfoHUAWEI subpassShadingPipelineCreateInfo {
    VK_STRUCTURE_TYPE_SUBPASS_SHADING_PIPELINE_CREATE_INFO_HUAWEI,
    renderPass, 1
};

VkPipelineShaderStageCreateInfo subpassShadingPipelineStageCreateInfo {
    VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_CREATE_INFO,
    NULL,
    0,
    VK_SHADER_STAGE_SUBPASS_SHADING_BIT_HUAWEI,
    shaderModule, "main",
    subpassShadingConstants
};

VkComputePipelineCreateInfo subpassShadingComputePipelineCreateInfo = {
    VK_STRUCTURE_TYPE_COMPUTE_PIPELINE_CREATE_INFO, subpassShadingPipelineCreateInfo,
    0,
    subpassShadingPipelineStageCreateInfo,
    pipelineLayout, basePipelineHandle, basePipelineIndex
};

VKPipeline pipeline;

vkGetDeviceSubpassShadingMaxWorkgroupSizeHUAWEI(device, renderPass, &
maxWorkgroupSize);

vkCreateComputePipelines(device, pipelineCache, 1,
subpassShadingComputePipelineCreateInfo, NULL, &pipeline);
```

Version History

- Revision 3, 2023-06-19 (Pan Gao)
  - Rename `VK_PIPELINE_STAGE_2_SUBPASS_SHADING_BIT_HUAWEI` to `VK_PIPELINE_STAGE_2_SUBPASS_SHADER_BIT_HUAWEI` to better aligned with naming of other
pipeline stages

• Revision 2, 2021-06-28 (Hueilong Wang)
  ◦ Change `vkGetSubpassShadingMaxWorkgroupSizeHUAWEI` to `vkGetDeviceSubpassShadingMaxWorkgroupSizeHUAWEI` to resolve issue `pub1564`

• Revision 1, 2020-12-15 (Hueilong Wang)
  ◦ Initial draft.

**VK_IMG_filter_cubic**

**Name String**

`VK_IMG_filter_cubic`

**Extension Type**

Device extension

**Registered Extension Number**

16

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

**Contact**

• Tobias Hector @tobski

**Other Extension Metadata**

**Last Modified Date**

2016-02-23

**Contributors**

• Tobias Hector, Imagination Technologies

**Description**

`VK_IMG_filter_cubic` adds an additional, high quality cubic filtering mode to Vulkan, using a Catmull-Rom bicubic filter. Performing this kind of filtering can be done in a shader by using 16 samples and a number of instructions, but this can be inefficient. The cubic filter mode exposes an optimized high quality texture sampling using fixed texture sampling functionality.

**New Enum Constants**

• `VK_IMG_FILTER_CUBIC_EXTENSION_NAME`
• **VK_IMG_FILTER_CUBIC_SPEC_VERSION**

• Extending **VkFilter**:
  ◦ **VK_FILTER_CUBIC_IMG**

• Extending **VkFormatFeatureFlagBits**:
  ◦ **VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_CUBIC_BIT_IMG**

### Example

Creating a sampler with the new filter for both magnification and minification

```c
VkSamplerCreateInfo createInfo = {
    .sType = VK_STRUCTURE_TYPE_SAMPLER_CREATE_INFO,
    // Other members set to application-desired values
};

createInfo.magFilter = VK_FILTER_CUBIC_IMG;
createInfo.minFilter = VK_FILTER_CUBIC_IMG;

VkSampler sampler;
VkResult result = vkCreateSampler(
    device,
    &createInfo,
    &sampler);
```

### Version History

• Revision 1, 2016-02-23 (Tobias Hector)
  ◦ Initial version

### VK_INTEL_performance_query

**Name String**

*VK_INTEL_performance_query*

**Extension Type**

Device extension

**Registered Extension Number**

211

**Revision**

2

**Ratification Status**

Not ratified
Extension and Version Dependencies

Special Use

• Developer tools

Contact

• Lionel Landwerlin @lplus1

Other Extension Metadata

Last Modified Date

2018-05-16

IP Status

No known IP claims.

Contributors

• Lionel Landwerlin, Intel
• Piotr Maciejewski, Intel

Description

This extension allows an application to capture performance data to be interpreted by an external application or library.

Such a library is available at: https://github.com/intel/metrics-discovery

Performance analysis tools such as Graphics Performance Analyzers make use of this extension and the metrics-discovery library to present the data in a human readable way.

New Object Types

• VkPerformanceConfigurationINTEL

New Commands

• vkAcquirePerformanceConfigurationINTEL
• vkCmdSetPerformanceMarkerINTEL
• vkCmdSetPerformanceOverrideINTEL
• vkCmdSetPerformanceStreamMarkerINTEL
• vkGetPerformanceParameterINTEL
• vkInitializePerformanceApiINTEL
• vkQueueSetPerformanceConfigurationINTEL
• vkReleasePerformanceConfigurationINTEL
• vkUninitializePerformanceApiINTEL
New Structures

- VkInitializePerformanceApiInfoINTEL
- VkPerformanceConfigurationAcquireInfoINTEL
- VkPerformanceMarkerInfoINTEL
- VkPerformanceOverrideInfoINTEL
- VkPerformanceStreamMarkerInfoINTEL
- VkPerformanceValueINTEL

Extending VkQueryPoolCreateInfo:

- VkQueryPoolCreateInfoINTEL
- VkQueryPoolPerformanceQueryCreateInfoINTEL

New Unions

- VkPerformanceValueDataINTEL

New Enums

- VkPerformanceConfigurationTypeINTEL
- VkPerformanceOverrideTypeINTEL
- VkPerformanceParameterTypeINTEL
- VkPerformanceValueTypeINTEL
- VkQueryPoolSamplingModeINTEL

New Enum Constants

- VK_INTEL_PERFORMANCE_QUERY_EXTENSION_NAME
- VK_INTEL_PERFORMANCE_QUERY_SPEC_VERSION

Extending VkObjectType:

- VK_OBJECT_TYPE_PERFORMANCE_CONFIGURATION_INTEL

Extending VkQueryType:

- VK_QUERY_TYPE_PERFORMANCE_QUERY_INTEL

Extending VkStructureType:

- VK_STRUCTURE_TYPE_INITIALIZE_PERFORMANCE_API_INFO_INTEL
- VK_STRUCTURE_TYPE_PERFORMANCE_CONFIGURATION_ACQUIRE_INFO_INTEL
- VK_STRUCTURE_TYPE_PERFORMANCE_MARKER_INFO_INTEL
- VK_STRUCTURE_TYPE_PERFORMANCE_OVERRIDE_INFO_INTEL
- VK_STRUCTURE_TYPE_PERFORMANCE_STREAM_MARKER_INFO_INTEL
- VK_STRUCTURE_TYPE_QUERY_POOL_CREATE_INFO_INTEL
Example Code

```c
// A previously created device
VkDevice device;

// A queue derived from the device
VkQueue queue;

VkInitializePerformanceApiInfoINTEL performanceApiInfoIntel = {
    VK_STRUCTURE_TYPE_INITIALIZE_PERFORMANCE_API_INFO_INTEL, /* type */
    NULL, /* pNext */
    NULL /* pNext */
};

vkInitializePerformanceApiINTEL(
    device,
    &performanceApiInfoIntel);

VkQueryPoolPerformanceQueryCreateInfoINTEL queryPoolIntel = {
    VK_STRUCTURE_TYPE_QUERY_POOL_CREATE_INFO_INTEL, /* type */
    NULL, /* pNext */
    VK_QUERY_POOL_SAMPLING_MODE_MANUAL_INTEL, /* sampler */
};

VkQueryPoolCreateInfo queryPoolCreateInfo = {
    VK_STRUCTURE_TYPE_QUERY_POOL_CREATE_INFO, /* type */
    &queryPoolIntel, /* pCreateInfo */
    0, /* queueFamilyIndex */
    VK_QUERY_TYPE_PERFORMANCE_QUERY_INTEL, /* queryType */
    1, /* queryCount */
    0 /* installCount */
};

VkQueryPool queryPool;

VkResult result = vkCreateQueryPool(
    device,
    &queryPoolCreateInfo,
    NULL, /* pAllocator */
    &queryPool);

assert(VK_SUCCESS == result);

// A command buffer we want to record counters on
VkCommandBuffer commandBuffer;

VkCommandBufferBeginInfo commandBufferBeginInfo = {
    VK_STRUCTURE_TYPE_COMMAND_BUFFER_BEGIN_INFO, /* type */
    0 /* flags */
};
```
result = vkBeginCommandBuffer(commandBuffer, &commandBufferBeginInfo);
assert(VK_SUCCESS == result);

vkCmdResetQueryPool(
    commandBuffer, 
    queryPool, 
    0, 
    1);

vkCmdBeginQuery(
    commandBuffer, 
    queryPool, 
    0, 
    0);

// Perform the commands you want to get performance information on
// ...

// Perform a barrier to ensure all previous commands were complete before
// ending the query
vkCmdPipelineBarrier(commandBuffer, 
    VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT, 
    VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT, 
    0, 
    0, 
    NULL, 
    0, 
    NULL, 
    0, 
    NULL);

vkCmdEndQuery(
    commandBuffer, 
    queryPool, 
    0);

result = vkEndCommandBuffer(commandBuffer);
assert(VK_SUCCESS == result);

VkPerformanceConfigurationAcquireInfoINTEL performanceConfigurationAcquireInfo = {
    VK_STRUCTURE_TYPE_PERFORMANCE_CONFIGURATION_ACQUIRE_INFO_INTEL, 
    NULL, 
    VK_PERFORMANCE_CONFIGURATION_TYPE_COMMAND_QUEUE_METRICS_DISCOVERY_ACTIVATED_INTEL
};
VkPerformanceConfigurationINTEL performanceConfigurationIntel;

result = vkAcquirePerformanceConfigurationINTEL(
    device,
    &performanceConfigurationAcquireInfo,
    &performanceConfigurationIntel);

vkQueueSetPerformanceConfigurationINTEL(queue, performanceConfigurationIntel);

assert(VK_SUCCESS == result);

// Submit the command buffer and wait for its completion
// ...

result = vkReleasePerformanceConfigurationINTEL(
    device,
    performanceConfigurationIntel);

assert(VK_SUCCESS == result);

// Get the report size from metrics-discovery's QueryReportSize

result = vkGetQueryPoolResults(
    device,
    queryPool,
    0, 1, QueryReportSize,
    data, QueryReportSize, 0);

assert(VK_SUCCESS == result);

// The data can then be passed back to metrics-discovery from which
// human readable values can be queried.

Version History

- Revision 2, 2020-03-06 (Lionel Landwerlin)
  - Rename VkQueryPoolCreateInfoINTEL in VkQueryPoolPerformanceQueryCreateInfoINTEL
- Revision 1, 2018-05-16 (Lionel Landwerlin)
  - Initial revision

VK_INTEL_shader_integer_functions2

Name String

  VK_INTEL_shader_integer_functions2

Extension Type

  Device extension
Registered Extension Number
210

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2

Contact
• Ian Romanick @ianromanick

Other Extension Metadata

Last Modified Date
2019-04-30

IP Status
No known IP claims.

Interactions and External Dependencies
• This extension requires SPV_INTEL_shader_integer_functions2.
• This extension provides API support for GL_INTEL_shader_integer_functions2.

Contributors
• Ian Romanick, Intel
• Ben Ashbaugh, Intel

Description
This extension adds support for several new integer instructions in SPIR-V for use in graphics shaders. Many of these instructions have pre-existing counterparts in the Kernel environment.

The added integer functions are defined by the SPV_INTEL_shader_integer_functions2 SPIR-V extension and can be used with the GL_INTEL_shader_integer_functions2 GLSL extension.

New Structures
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceShaderIntegerFunctions2FeaturesINTEL

New Enum Constants
• VK_INTEL_SHADER_INTEGER_FUNCTIONS_2_EXTENSION_NAME
• VK_INTEL_SHADER_INTEGER_FUNCTIONS_2_SPEC_VERSION

Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_INTEGER_FUNCTIONS_2_FEATURES_INTEL

New SPIR-V Capabilities
  • IntegerFunctions2INTEL

Version History
  • Revision 1, 2019-04-30 (Ian Romanick)
    ◦ Initial draft

VK_LUNARG_direct_driver_loading

Name String
  VK_LUNARG_direct_driver_loading

Extension Type
  Instance extension

Registered Extension Number
  460

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies

Contact
  • Charles Giessen charles-lunarg

Extension Proposal
  VK_LUNARG_direct_driver_loading

Other Extension Metadata

Last Modified Date
  2022-11-29

Contributors
  • Charles Giessen, LunarG
Description

This extension provides a mechanism for applications to add drivers to the implementation. This allows drivers to be included with an application without requiring installation and is capable of being used in any execution environment, such as a process running with elevated privileges.

New Structures

- VkDirectDriverLoadingInfoLUNARG
- Extending VkInstanceCreateInfo:
  - VkDirectDriverLoadingListLUNARG

New Function Pointers

- PFN_vkGetInstanceProcAddrLUNARG

New Enums

- VkDirectDriverLoadingModeLUNARG

New Bitmasks

- VkDirectDriverLoadingFlagsLUNARG

New Enum Constants

- VK_LUNARG_DIRECT_DRIVER_LOADING_EXTENSION_NAME
- VK_LUNARG_DIRECT_DRIVER_LOADING_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_DIRECT_DRIVER_LOADING_INFO_LUNARG
  - VK_STRUCTURE_TYPE_DIRECT_DRIVER_LOADING_LIST_LUNARG

Version History

- Revision 1, 2022-11-29 (Charles Giessen)
  - Initial version

VK_MSFT_layered_driver

Name String

VK_MSFT_layered_driver

Extension Type

Device extension
Registered Extension Number
531

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2

Contact
• Jesse Natalie @jenatali

Extension Proposal
VK_MSFT_layered_driver

Other Extension Metadata

Last Modified Date
2023-06-21

IP Status
No known IP claims.

Contributors
• Jesse Natalie, Microsoft

Description
This extension adds new physical device properties to allow applications and the Vulkan ICD loader to understand when a physical device is implemented as a layered driver on top of another underlying API.

New Structures
• Extending VkPhysicalDeviceProperties2:
  ◦ VkPhysicalDeviceLayeredDriverPropertiesMSFT

New Enums
• VkLayeredDriverUnderlyingApiMSFT

New Enum Constants
• VK_MSFT_LAYERED_DRIVER_EXTENSION_NAME
• VK_MSFT_LAYERED_DRIVER_SPEC_VERSION
Extending VkStructureType:
  • VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_LAYERED_DRIVER_PROPERTIES_MSFT

Examples
None.

Version History
• Revision 1, 2023-06-21 (Jesse Natalie)
  ◦ Initial revision

VK_NN_vi_surface

Name String
  VK_NN_vi_surface

Extension Type
  Instance extension

Registered Extension Number
  63

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_surface

Contact
  • Mathias Heyer mheyer

Other Extension Metadata

Last Modified Date
  2016-12-02

IP Status
  No known IP claims.

Contributors
  • Mathias Heyer, NVIDIA
  • Michael Chock, NVIDIA
  • Yasuhiro Yoshioka, Nintendo
Description

The `VK_NN_vi_surface` extension is an instance extension. It provides a mechanism to create a `VkSurfaceKHR` object (defined by the `VK_KHR_surface` extension) associated with an `nn::vi::Layer`.

New Commands

- `vkCreateViSurfaceNN`

New Structures

- `VkViSurfaceCreateInfoNN`

New Bitmasks

- `VkViSurfaceCreateFlagsNN`

New Enum Constants

- `VK_NN_VI_SURFACE_EXTENSION_NAME`
- `VK_NN_VI_SURFACE_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_VI_SURFACE_CREATE_INFO_NN`

Issues

1) Does VI need a way to query for compatibility between a particular physical device (and queue family?) and a specific VI display?

**RESOLVED:** No. It is currently always assumed that the device and display will always be compatible.

2) `VkViSurfaceCreateInfoNN::pWindow` is intended to store an `nn::vi::NativeWindowHandle`, but its declared type is a bare `void*` to store the window handle. Why the discrepancy?

**RESOLVED:** It is for C compatibility. The definition for the VI native window handle type is defined inside the `nn::vi` C++ namespace. This prevents its use in C source files. `nn::vi::NativeWindowHandle` is always defined to be `void*`, so this extension uses `void*` to match.

Version History

- Revision 1, 2016-12-2 (Michael Chock)
  - Initial draft.
**VK_NV_acquire_winrt_display**

**Name String**

VK_NV_acquire_winrt_display

**Extension Type**

Device extension

**Registered Extension Number**

346

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

VK_EXT_direct_mode_display

**Contact**

• Jeff Juliano jjuliano

**Other Extension Metadata**

**Last Modified Date**

2020-09-29

**IP Status**

No known IP claims.

**Contributors**

• Jeff Juliano, NVIDIA

**Description**

This extension allows an application to take exclusive control of a display on Windows 10 provided that the display is not already controlled by a compositor. Examples of compositors include the Windows desktop compositor, other applications using this Vulkan extension, and applications that “Acquire” a “DisplayTarget” using a “WinRT” command such as “winrt::Windows::Devices::Display::Core::DisplayManager.TryAcquireTarget()”.

When control is acquired the application has exclusive access to the display until control is released or the application terminates. An application’s attempt to acquire is denied if a different application has already acquired the display.
New Commands

- `vkAcquireWinrtDisplayNV`
- `vkGetWinrtDisplayNV`

New Enum Constants

- `VK_NV_ACQUIRE_WINRT_DISPLAY_EXTENSION_NAME`
- `VK_NV_ACQUIRE_WINRT_DISPLAY_SPEC_VERSION`

Issues

1) What should the platform substring be for this extension:

**RESOLVED:** The platform substring is “Winrt”.

The substring “Winrt” matches the fact that the OS API exposing the acquire and release functionality is called “WinRT”.

The substring “Win32” is wrong because the related “WinRT” API is explicitly **not** a “Win32” API. “WinRT” is a competing API family to the “Win32” API family.

The substring “Windows” is suboptimal because there could be more than one relevant API on the Windows platform. There is preference to use the more-specific substring “Winrt”.

2) Should `vkAcquireWinrtDisplayNV` take a winRT DisplayTarget, or a Vulkan display handle as input?

**RESOLVED:** A Vulkan display handle. This matches the design of `vkAcquireXlibDisplayEXT`.

3) Should the acquire command be platform-independent named “vkAcquireDisplayNV”, or platform-specific named “vkAcquireWinrtDisplayNV”?

**RESOLVED:** Add a platform-specific command.

The inputs to the Acquire command are all Vulkan types. None are WinRT types. This opens the possibility of the winrt extension defining a platform-independent acquire command.

The X11 acquire command does need to accept a platform-specific parameter. This could be handled by adding to a platform-independent acquire command a params struct to which platform-dependent types can be chained by `pNext` pointer.

The prevailing opinion is that it would be odd to create a second platform-independent function that is used on the Windows 10 platform, but that is not used for the X11 platform. Since a Windows 10 platform-specific command is needed anyway for converting between `vkDisplayKHR` and platform-native handles, opinion was to create a platform-specific acquire function.

4) Should the `vkGetWinrtDisplayNV` parameter identifying a display be named “deviceRelativeId” or “adapterRelativeId”? 


**RESOLVED:** The WinRT name is “AdapterRelativeId”. The name “adapter” is the Windows analog to a Vulkan “physical device”. Vulkan already has precedent to use the name `deviceLUID` for the concept that Windows APIs call “AdapterLuid”. Keeping form with this precedent, the name “deviceRelativeId” is chosen.

5) Does `vkAcquireWinrtDisplayNV` cause the Windows desktop compositor to release a display?

**RESOLVED:** No. `vkAcquireWinrtDisplayNV` does not itself cause the Windows desktop compositor to release a display. This action must be performed outside of Vulkan.

Beginning with Windows 10 version 2004 it is possible to cause the Windows desktop compositor to release a display by using the “Advanced display settings” sub-page of the “Display settings” control panel. See [https://docs.microsoft.com/en-us/windows-hardware/drivers/display/specialized-monitors](https://docs.microsoft.com/en-us/windows-hardware/drivers/display/specialized-monitors)

6) Where can one find additional information about custom compositors for Windows 10?

**RESOLVED:** Relevant references are as follows.

According to Microsoft’s documentation on "building a custom compositor", the ability to write a custom compositor is not a replacement for a fullscreen desktop window. The feature is for writing compositor apps that drive specialized hardware.

Only certain editions of Windows 10 support custom compositors, "documented here”. The product type can be queried from Windows 10. See [https://docs.microsoft.com/en-us/windows/win32/api/sysinfoapi/nf-sysinfoapi-getproductinfo](https://docs.microsoft.com/en-us/windows/win32/api/sysinfoapi/nf-sysinfoapi-getproductinfo)

**Version History**

- Revision 1, 2020-09-29 (Jeff Juliano)
  - Initial draft

**VK_NV_clip_space_w_scaling**

**Name String**

`VK_NV_clip_space_w_scaling`

**Extension Type**

Device extension

**Registered Extension Number**

88

**Revision**

1

**Ratification Status**

Not ratified
Virtual Reality (VR) applications often involve a post-processing step to apply a “barrel” distortion to the rendered image to correct the “pincushion” distortion introduced by the optics in a VR device. The barrel distorted image has lower resolution along the edges compared to the center. Since the original image is rendered at high resolution, which is uniform across the complete image, a lot of pixels towards the edges do not make it to the final post-processed image.

This extension provides a mechanism to render VR scenes at a non-uniform resolution, in particular a resolution that falls linearly from the center towards the edges. This is achieved by scaling the w coordinate of the vertices in the clip space before perspective divide. The clip space w coordinate of the vertices can be offset as a function of x and y coordinates as follows:

\[ w' = w + Ax + By \]

In the intended use case for viewport position scaling, an application should use a set of four viewports, one for each of the four quadrants of a Cartesian coordinate system. Each viewport is set to the dimension of the image, but is scissored to the quadrant it represents. The application should specify A and B coefficients of the w-scaling equation above, that have the same value, but different signs, for each of the viewports. The signs of A and B should match the signs of x and y for the quadrant that they represent such that the value of \( w' \) will always be greater than or equal to the original \( w \) value for the entire image. Since the offset to \( w \), \( (Ax + By) \), is always positive, and increases with the absolute values of x and y, the effective resolution will fall off linearly from the center of the image to its edges.

**New Commands**

- `vkCmdSetViewportWScalingNV`

**New Structures**

- `VkViewportWScalingNV`
- Extending `VkPipelineViewportStateCreateInfo`:
  - `VkPipelineViewportWScalingStateCreateInfoNV`
New Enum Constants

- VK_NV_CLIP_SPACE_W_SCALING_EXTENSION_NAME
- VK_NV_CLIP_SPACE_W_SCALING_SPEC_VERSION

Extending VkDynamicState:
- VK_DYNAMIC_STATE_VIEWPORT_W_SCALING_NV

Extending VkStructureType:
- VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_W_SCALING_STATE_CREATE_INFO_NV

Issues

1) Is the pipeline struct name too long?

RESOLVED: It fits with the naming convention.

2) Separate W scaling section or fold into coordinate transformations?

RESOLVED: Leaving it as its own section for now.

Examples

```cpp
VkViewport viewports[4];
VkRect2D scissors[4];
VkViewportWScalingNV scalings[4];

for (int i = 0; i < 4; i++) {
    int x = (i & 2) ? currentWindowWidth / 2 : 0;
    int y = (i & 1) ? currentWindowHeight / 2 : 0;

    viewports[i].x = 0;
    viewports[i].y = 0;
    viewports[i].width = currentWindowWidth;
    viewports[i].height = currentWindowHeight;
    viewports[i].minDepth = 0.0f;
    viewports[i].maxDepth = 1.0f;

    scissors[i].offset.x = x;
    scissors[i].offset.y = y;
    scissors[i].extent.width = currentWindowWidth/2;
    scissors[i].extent.height = currentWindowHeight/2;

    const float factor = 0.15;
    scalings[i].xcoeff = ((i & 2) ? -1.0 : 1.0) * factor;
    scalings[i].ycoeff = ((i & 1) ? -1.0 : 1.0) * factor;
}

VkPipelineViewportWScalingStateCreateInfoNV vpWScalingStateInfo = {
    VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_W_SCALING_STATE_CREATE_INFO_NV
};
```
vpWScalingStateInfo.viewportWScalingEnable = VK_TRUE;
vpWScalingStateInfo.viewportCount = 4;
vpWScalingStateInfo.pViewportWScalings = &scalings[0];

VkPipelineViewportStateCreateInfo vpStateInfo = {
    VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_STATE_CREATE_INFO
};
vpStateInfo.viewportCount = 4;
vpStateInfo.pViewports = &viewports[0];
vpStateInfo.scissorCount = 4;
vpStateInfo.pScissors = &scissors[0];
vpStateInfo.pNext = &vpWScalingStateInfo;

Example shader to read from a w-scaled texture:

// Vertex Shader
// Draw a triangle that covers the whole screen
const vec4 positions[3] = vec4[3](vec4(-1, -1, 0, 1),
                                 vec4( 3, -1, 0, 1),
                                 vec4(-1,  3, 0, 1));

out vec2 uv;
void main()
{
    vec4 pos = positions[gl_VertexID];
    gl_Position = pos;
    uv = pos.xy;
}

// Fragment Shader
uniform sampler2D tex;
uniform float xcoeff;
uniform float ycoeff;
out vec4 Color;
in vec2 uv;

void main()
{
    // Handle uv as if upper right quadrant
    vec2 uvabs = abs(uv);

    // unscale: transform w-scaled image into an unscaled image
    // scale: transform unscaled image int a w-scaled image
    float unscale = 1.0 / (1 + xcoeff * uvabs.x + xcoeff * uvabs.y);
    //float scale = 1.0 / (1 - xcoeff * uvabs.x - xcoeff * uvabs.y);
    vec2 P = vec2(unscale * uvabs.x, unscale * uvabs.y);

    // Go back to the right quadrant
    P *= sign(uv);
}
Color = texture(tex, P * 0.5 + 0.5);
}

Version History

• Revision 1, 2017-02-15 (Eric Werness)
  ◦ Internal revisions

VK_NV_compute_shader_derivatives

Name String

VK_NV_compute_shader_derivatives

Extension Type

Device extension

Registered Extension Number

202

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Contact

• Pat Brown @nvpbrown

Other Extension Metadata

Last Modified Date

2018-07-19

IP Status

No known IP claims.

Interactions and External Dependencies

• This extension requires SPV_NV_compute_shader_derivatives
• This extension provides API support for GL_NV_compute_shader_derivatives

Contributors

• Pat Brown, NVIDIA
Description

This extension adds Vulkan support for the SPV_NV_compute_shader_derivatives SPIR-V extension.

The SPIR-V extension provides two new execution modes, both of which allow compute shaders to use built-ins that evaluate compute derivatives explicitly or implicitly. Derivatives will be computed via differencing over a 2x2 group of shader invocations. The DerivativeGroupQuadsNV execution mode assembles shader invocations into 2x2 groups, where each group has x and y coordinates of the local invocation ID of the form (2m+{0,1}, 2n+{0,1}). The DerivativeGroupLinearNV execution mode assembles shader invocations into 2x2 groups, where each group has local invocation index values of the form 4m+{0,1,2,3}.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceComputeShaderDerivativesFeaturesNV

New Enum Constants

- VK_NV_COMPUTE_SHADER_DERIVATIVES_EXTENSION_NAME
- VK_NV_COMPUTE_SHADER_DERIVATIVES_SPEC_VERSION

Extending VkStructureType:

- VK_STRUCTURE_TYPE_PHYSICALDEVICECOMPUTESHADERDERIVATIVESFEATURESNV

New SPIR-V Capability

- ComputeDerivativeGroupQuadsNV
- ComputeDerivativeGroupLinearNV

Issues

(1) Should we specify that the groups of four shader invocations used for derivatives in a compute shader are the same groups of four invocations that form a “quad” in shader subgroups?

RESOLVED: Yes.

Examples

None.

Version History

- Revision 1, 2018-07-19 (Pat Brown)
  - Initial draft
VK_NV_cooperative_matrix

Name String
VK_NV_cooperative_matrix

Extension Type
Device extension

Registered Extension Number
250

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2

Contact
• Jeff Bolz jeffbolznv

Other Extension Metadata

Last Modified Date
2019-02-05

Interactions and External Dependencies
• This extension requires SPV_NV_cooperative_matrix
• This extension provides API support for GL_NV_cooperative_matrix

Contributors
• Jeff Bolz, NVIDIA
• Markus Tavenrath, NVIDIA
• Daniel Koch, NVIDIA

Description
This extension adds support for using cooperative matrix types in SPIR-V. Cooperative matrix types are medium-sized matrices that are primarily supported in compute shaders, where the storage for the matrix is spread across all invocations in some scope (usually a subgroup) and those invocations cooperate to efficiently perform matrix multiplies.

Cooperative matrix types are defined by the SPV_NV_cooperative_matrix SPIR-V extension and can be used with the GL_NV_cooperative_matrix GLSL extension.

This extension includes support for enumerating the matrix types and dimensions that are
supported by the implementation.

**New Commands**

- `vkGetPhysicalDeviceCooperativeMatrixPropertiesNV`

**New Structures**

- `VkCooperativeMatrixPropertiesNV`
- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceCooperativeMatrixFeaturesNV`
- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceCooperativeMatrixPropertiesNV`

**New Enums**

- `VkComponentTypeNV`
- `VkScopeNV`

**New Enum Constants**

- `VK_NV_COOPERATIVE_MATRIX_EXTENSION_NAME`
- `VK_NV_COOPERATIVE_MATRIX_SPEC_VERSION`
- Extending `VkComponentTypeKHR`:
  - `VK_COMPONENT_TYPE_FLOAT16_NV`
  - `VK_COMPONENT_TYPE_FLOAT32_NV`
  - `VK_COMPONENT_TYPE_FLOAT64_NV`
  - `VK_COMPONENT_TYPE_SINT16_NV`
  - `VK_COMPONENT_TYPE_SINT32_NV`
  - `VK_COMPONENT_TYPE_SINT64_NV`
  - `VK_COMPONENT_TYPE_SINT8_NV`
  - `VK_COMPONENT_TYPE_UINT16_NV`
  - `VK_COMPONENT_TYPE_UINT32_NV`
  - `VK_COMPONENT_TYPE_UINT64_NV`
  - `VK_COMPONENT_TYPE_UINT8_NV`
- Extending `VkScopeKHR`:
  - `VK_SCOPE_DEVICE_NV`
  - `VK_SCOPE_QUEUE_FAMILY_NV`
  - `VK_SCOPE_SUBGROUP_NV`
Extending `VkStructureType`:

- `VK_STRUCTURE_TYPE_COOPERATIVE_MATRIX_PROPERTIES_NV`
- `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COOPERATIVE_MATRIX_FEATURES_NV`
- `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COOPERATIVE_MATRIX_PROPERTIES_NV`

**New SPIR-V Capabilities**

- `CooperativeMatrixNV`

**Issues**

1. What matrix properties will be supported in practice?

**RESOLVED**: In NVIDIA's initial implementation, we will support:

- `AType = BType = fp16 CType = DType = fp16 MxNxK = 16x8x16 scope = Subgroup`
- `AType = BType = fp16 CType = DType = fp16 MxNxK = 16x8x8 scope = Subgroup`
- `AType = BType = fp16 CType = DType = fp32 MxNxK = 16x8x16 scope = Subgroup`
- `AType = BType = fp16 CType = DType = fp32 MxNxK = 16x8x8 scope = Subgroup`

**Version History**

- Revision 1, 2019-02-05 (Jeff Bolz)
  - Internal revisions

**VK_NV_copy_memory_indirect**

**Name String**

`VK_NV_copy_memory_indirect`

**Extension Type**

Device extension

**Registered Extension Number**

427

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

- `VK_KHR_get_physical_device_properties2`
Description

This extension adds support for performing copies between memory and image regions using indirect parameters that are read by the device from a buffer during execution. This functionality may be useful for performing copies where the copy parameters are not known during the command buffer creation time.

New Commands

- vkCmdCopyMemoryIndirectNV
- vkCmdCopyMemoryToImageIndirectNV

New Structures

- VkCopyMemoryIndirectCommandNV
- VkCopyMemoryToImageIndirectCommandNV
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceCopyMemoryIndirectFeaturesNV
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceCopyMemoryIndirectPropertiesNV

New Enum Constants

- VK_NV_COPY_MEMORY_INDIRECT_EXTENSION_NAME
- VK_NV_COPY_MEMORY_INDIRECT_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COPY_MEMORY_INDIRECT_FEATURES_NV
Version History

- Revision 1, 2022-10-14 (Vikram Kushwaha)
  - Initial draft

**VK_NV_corner_sampled_image**

**Name String**

VK_NV_corner_sampled_image

**Extension Type**

Device extension

**Registered Extension Number**

51

**Revision**

2

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

VK_KHR_get_physical_device_properties2

**Contact**

- Daniel Koch @dgkoch

**Other Extension Metadata**

**Last Modified Date**

2018-08-13

**Contributors**

- Jeff Bolz, NVIDIA
- Pat Brown, NVIDIA
- Chris Lentini, NVIDIA

**Description**

This extension adds support for a new image organization, which this extension refers to as “corner-sampled” images. A corner-sampled image differs from a conventional image in the following ways:

- Texels are centered on integer coordinates. See Unnormalized Texel Coordinate Operations
• Normalized coordinates are scaled using \( \text{coord} \times (\text{dim} - 1) \) rather than \( \text{coord} \times \text{dim} \), where \( \text{dim} \) is the size of one dimension of the image. See normalized texel coordinate transform.

• Partial derivatives are scaled using \( \text{coord} \times (\text{dim} - 1) \) rather than \( \text{coord} \times \text{dim} \). See Scale Factor Operation.

• Calculation of the next higher LOD size goes according to \( \lceil \frac{\text{dim}}{2} \rceil \) rather than \( \lfloor \frac{\text{dim}}{2} \rfloor \). See Image Mip Level Sizing.

• The minimum level size is 2x2 for 2D images and 2x2x2 for 3D images. See Image Mip Level Sizing.

This image organization is designed to facilitate a system like Ptex with separate textures for each face of a subdivision or polygon mesh. Placing sample locations at pixel corners allows applications to maintain continuity between adjacent patches by duplicating values along shared edges. Additionally, using the modified mipmapping logic along with texture dimensions of the form \( 2^n+1 \) allows continuity across shared edges even if the adjacent patches use different LOD values.

New Structures

• Extending \( \text{VkPhysicalDeviceFeatures2, VkDeviceCreateInfo} \):
  ◦ \( \text{VkPhysicalDeviceCornerSampledImageFeaturesNV} \)

New Enum Constants

• \( \text{VK_NV_CORNER_SAMPLED_IMAGE_EXTENSION_NAME} \)
• \( \text{VK_NV_CORNER_SAMPLED_IMAGE_SPEC_VERSION} \)

Extending \( \text{VkImageCreateFlagBits} \):
  ◦ \( \text{VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV} \)

Extending \( \text{VkStructureType} \):
  ◦ \( \text{VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CORNER_SAMPLED_IMAGE_FEATURES_NV} \)

Issues

1. What should this extension be named?

   DISCUSSION: While naming this extension, we chose the most distinctive aspect of the image organization and referred to such images as “corner-sampled images”. As a result, we decided to name the extension \( \text{NV_corner_sampled_image} \).

2. Do we need a format feature flag so formats can advertise if they support corner-sampling?

   DISCUSSION: Currently NVIDIA supports this for all 2D and 3D formats, but not for cube maps or depth-stencil formats. A format feature might be useful if other vendors would only support this on some formats.

3. Do integer texel coordinates have a different range for corner-sampled images?

   RESOLVED: No, these are unchanged.
4. Do unnormalized sampler coordinates work with corner-sampled images? Are there any functional differences?

**RESOLVED:** Yes. Unnormalized coordinates are treated as already scaled for corner-sample usage.

5. Should we have a diagram in the “Image Operations” chapter demonstrating different texel sampling locations?

**UNRESOLVED:** Probably, but later.

### Version History

- **Revision 1, 2018-08-14** (Daniel Koch)
  - Internal revisions
- **Revision 2, 2018-08-14** (Daniel Koch)
  - ???

### VK_NV_coverage_reduction_mode

**Name String**

`VK_NV_coverage_reduction_mode`

**Extension Type**

Device extension

**Registered Extension Number**

251

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

- `VK_NV_framebuffer_mixed_samples`
- `VK_KHR_get_physical_device_properties2`

**Contact**

- Kedarnath Thangudu [kthangudu](https://twitter.com/kthangudu)

**Other Extension Metadata**

**Last Modified Date**

2019-01-29
Contributors

- Kedarnath Thangudu, NVIDIA
- Jeff Bolz, NVIDIA

Description

When using a framebuffer with mixed samples, a per-fragment coverage reduction operation is performed which generates color sample coverage from the pixel coverage. This extension defines the following modes to control how this reduction is performed.

- **Merge**: When there are more samples in the pixel coverage than color samples, there is an implementation-dependent association of each pixel coverage sample to a color sample. In the merge mode, the color sample coverage is computed such that only if any associated sample in the pixel coverage is covered, the color sample is covered. This is the default mode.

- **Truncate**: When there are more raster samples (N) than color samples (M), there is one to one association of the first M raster samples to the M color samples; other raster samples are ignored.

When the number of raster samples is equal to the color samples, there is a one to one mapping between them in either of the above modes.

The new command `vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV` can be used to query the various raster, color, depth/stencil sample count and reduction mode combinations that are supported by the implementation. This extension would allow an implementation to support the behavior of both `VK_NV_framebuffer_mixed_samples` and `VK_AMD_mixed_attachment_samples` extensions simultaneously.

New Commands

- `vkGetPhysicalDeviceSupportedFramebufferMixedSamplesCombinationsNV`

New Structures

- `VkFramebufferMixedSamplesCombinationNV`
- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceCoverageReductionModeFeaturesNV`
- Extending `VkPipelineMultisampleStateCreateInfo`:
  - `VkPipelineCoverageReductionStateCreateInfoNV`

New Enums

- `VkCoverageReductionModeNV`

New Bitmasks

- `VkPipelineCoverageReductionStateCreateFlagsNV`
New Enum Constants

- VK_NV_COVERAGE_REDUCTION_MODE_EXTENSION_NAME
- VK_NV_COVERAGE_REDUCTION_MODE_SPEC_VERSION

Extending VkStructureType:
  - VK_STRUCTURE_TYPE_FRAMEBUFFER_MIXED_SAMPLES_COMBINATION_NV
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_COVERAGE_REDUCTION_MODE_FEATURES_NV
  - VK_STRUCTURE_TYPE_PIPELINE_COVERAGE_REDUCTION_STATE_CREATE_INFO_NV

Version History

- Revision 1, 2019-01-29 (Kedarnath Thangudu)
  - Internal revisions

VK_NV_dedicated_allocation_image_aliasing

Name String
  VK_NV_dedicated_allocation_image_aliasing

Extension Type
  Device extension

Registered Extension Number
  241

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_dedicated_allocation
  and
  VK_KHR_get_physical_device_properties2

Contact
  • Nuno Subtil @nsubtil

Other Extension Metadata

Last Modified Date
  2019-01-04

Contributors
  • Nuno Subtil, NVIDIA
Description

This extension allows applications to alias images on dedicated allocations, subject to specific restrictions: the extent and the number of layers in the image being aliased must be smaller than or equal to those of the original image for which the allocation was created, and every other image parameter must match.

New Structures

- Extending *VkPhysicalDeviceFeatures2, VkDeviceCreateInfo*:
  - *VkPhysicalDeviceDedicatedAllocationImageAliasingFeaturesNV*

New Enum Constants

- *VK_NV_DEDICATED_ALLOCATION_IMAGE_ALIASING_EXTENSION_NAME*
- *VK_NV_DEDICATED_ALLOCATION_IMAGE_ALIASING_SPEC_VERSION*
- Extending *VkStructureType*:
  - *VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEDICATED_ALLOCATION_IMAGE_ALIASING_FEATURES_NV*

Version History

- Revision 1, 2019-01-04 (Nuno Subtil)
  - Internal revisions

**VK_NV_descriptor_pool_overallocation**

Name String

*VK_NV_descriptor_pool_overallocation*

Extension Type

Device extension

Registered Extension Number

547

Revision

1

Ratification Status

Not ratified
Extension and Version Dependencies

Version 1.1

Contact

- Piers Daniell pdaniell-nv

Other Extension Metadata

Last Modified Date

2023-08-30

Contributors

- Jeff Bolz, NVIDIA

Description

There are scenarios where the application does not know ahead of time how many descriptor sets it may need to allocate from a descriptor pool, or how many descriptors of any of the descriptor types it may need to allocate from the descriptor pool.

This extension gives applications the ability to request the implementation allow more sets or descriptors to be allocated than initially specified at descriptor pool creation time, subject to available resources.

The `VK_DESCRIPTOR_POOL_CREATE_ALLOW_OVERALLOCATION_SETS_BIT_NV` flag lets the application allocate more than `VkDescriptorPoolCreateInfo::maxSets` descriptor sets, and the `VK_DESCRIPTOR_POOL_CREATE_ALLOW_OVERALLOCATION_POOLS_BIT_NV` lets the application allocate more descriptors than initially specified by `VkDescriptorPoolSize::descriptorCount` for any descriptor types.

New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceDescriptorPoolOverallocationFeaturesNV`

New Enum Constants

- `VK_NV_DESCRIPTOR_POOL_OVERALLOCATION_EXTENSION_NAME`
- `VK_NV_DESCRIPTOR_POOL_OVERALLOCATION_SPEC_VERSION`

- Extending `VkDescriptorPoolCreateFlagBits`:
  - `VK_DESCRIPTOR_POOL_CREATE_ALLOW_OVERALLOCATION_POOLS_BIT_NV`
  - `VK_DESCRIPTOR_POOL_CREATE_ALLOW_OVERALLOCATION_SETS_BIT_NV`

- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_POOL_OVERALLOCATION_FEATURES_NV`
Version History

- Revision 1, 2023-08-30 (Piers Daniell)
  - Internal revisions

VK_NV_device_diagnostic_checkpoints

Name String
  VK_NV_device_diagnostic_checkpoints

Extension Type
  Device extension

Registered Extension Number
  207

Revision
  2

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_get_physical_device_properties2

Contact
  - Nuno Subtil @nsubtil

Other Extension Metadata

Last Modified Date
  2018-07-16

Contributors
  - Oleg Kuznetsov, NVIDIA
  - Alex Dunn, NVIDIA
  - Jeff Bolz, NVIDIA
  - Eric Werness, NVIDIA
  - Daniel Koch, NVIDIA

Description

This extension allows applications to insert markers in the command stream and associate them with custom data.

If a device lost error occurs, the application may then query the implementation for the last
markers to cross specific implementation-defined pipeline stages, in order to narrow down which commands were executing at the time and might have caused the failure.

**New Commands**

- `vkCmdSetCheckpointNV`
- `vkGetQueueCheckpointDataNV`

**New Structures**

- `VkCheckpointDataNV`
- Extending `VkQueueFamilyProperties2`:
  - `VkQueueFamilyCheckpointPropertiesNV`

**New Enum Constants**

- `VK_NV_DEVICE_DIAGNOSTIC_CHECKPOINTS_EXTENSION_NAME`
- `VK_NV_DEVICE_DIAGNOSTIC_CHECKPOINTS_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_CHECKPOINT_DATA_NV`
  - `VK_STRUCTURE_TYPE_QUEUE_FAMILY_CHECKPOINT_PROPERTIES_NV`

**Version History**

- Revision 1, 2018-07-16 (Nuno Subtil)
  - Internal revisions
- Revision 2, 2018-07-16 (Nuno Subtil)
  - ???

**VK_NV_device_diagnostics_config**

**Name String**

- `VK_NV_device_diagnostics_config`

**Extension Type**

- Device extension

**Registered Extension Number**

- 301

**Revision**

- 2
Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2

Contact
• Kedarnath Thangudu @kthangudu

Other Extension Metadata

Last Modified Date
2022-04-06

Contributors
• Kedarnath Thangudu, NVIDIA
• Thomas Klein, NVIDIA

Description
Applications using Nvidia Nsight™ Aftermath SDK for Vulkan to integrate device crash dumps into their error reporting mechanisms, may use this extension to configure options related to device crash dump creation.

Version 2 of this extension adds VK_DEVICE_DIAGNOSTICS_CONFIG_ENABLE_SHADER_ERROR_REPORTING_BIT_NV which when set enables enhanced reporting of shader execution errors.

New Structures
• Extending VkDeviceCreateInfo:
  ◦ VkDeviceDiagnosticsConfigCreateInfoNV
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceDiagnosticsConfigFeaturesNV

New Enums
• VkDeviceDiagnosticsConfigFlagBitsNV

New Bitmasks
• VkDeviceDiagnosticsConfigFlagsNV

New Enum Constants
• VK_NV_DEVICE_DIAGNOSTICS_CONFIG_EXTENSION_NAME
• **VK_NV_DEVICE_DIAGNOSTICS_CONFIG_SPEC_VERSION**

• Extending **VkStructureType**:
  ◦ **VK_STRUCTURE_TYPE_DEVICE_DIAGNOSTICS_CONFIG_CREATE_INFO_NV**
  ◦ **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DIAGNOSTICS_CONFIG_FEATURES_NV**

**Version History**

• Revision 1, 2019-11-21 (Kedarnath Thangudu)
  ◦ Internal revisions

• Revision 2, 2022-04-06 (Kedarnath Thangudu)
  ◦ Added a config bit **VK_DEVICE_DIAGNOSTICS_CONFIG_ENABLE_SHADER_ERROR_REPORTING_BIT_NV**

**VK_NV_device_generated_commands**

**Name String**

VK_NV_device_generated_commands

**Extension Type**

Device extension

**Registered Extension Number**

278

**Revision**

3

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

Version 1.1

and

VK_KHR_buffer_device_address

**Contact**

• Christoph Kubisch [pixeljetstream](https://pixeljetstream)

**Other Extension Metadata**

**Last Modified Date**

2020-02-20

**Interactions and External Dependencies**

• This extension requires Vulkan 1.1

• This extension requires **VK_EXT_buffer_device_address** or **VK_KHR_buffer_device_address** or
Vulkan 1.2 for the ability to bind vertex and index buffers on the device.

- This extension interacts with VK_NV_mesh_shader. If the latter extension is not supported, remove the command token to initiate mesh tasks drawing in this extension.

**Contributors**
- Christoph Kubisch, NVIDIA
- Pierre Boudier, NVIDIA
- Jeff Bolz, NVIDIA
- Eric Wernen, NVIDIA
- Yuriy O'Donnell, Epic Games
- Baldur Karlsson, Valve
- Mathias Schott, NVIDIA
- Tyson Smith, NVIDIA
- Ingo Esser, NVIDIA

**Description**

This extension allows the device to generate a number of critical graphics commands for command buffers.

When rendering a large number of objects, the device can be leveraged to implement a number of critical functions, like updating matrices, or implementing occlusion culling, frustum culling, front to back sorting, etc. Implementing those on the device does not require any special extension, since an application is free to define its own data structures, and just process them using shaders.

However, if the application desires to quickly kick off the rendering of the final stream of objects, then unextended Vulkan forces the application to read back the processed stream and issue graphics command from the host. For very large scenes, the synchronization overhead and cost to generate the command buffer can become the bottleneck. This extension allows an application to generate a device side stream of state changes and commands, and convert it efficiently into a command buffer without having to read it back to the host.

Furthermore, it allows incremental changes to such command buffers by manipulating only partial sections of a command stream — for example pipeline bindings. Unextended Vulkan requires recreation of entire command buffers in such a scenario, or updates synchronized on the host.

The intended usage for this extension is for the application to:

- create `VkBuffer` objects and retrieve physical addresses from them via `vkGetBufferDeviceAddressEXT`
- create a graphics pipeline using `VkGraphicsPipelineShaderGroupsCreateInfoNV` for the ability to change shaders on the device.
- create a `VkIndirectCommandsLayoutNV`, which lists the `VkIndirectCommandsTokenTypeNV` it wants to dynamically execute as an atomic command sequence. This step likely involves some internal device code compilation, since the intent is for the GPU to generate the command
buffer in the pipeline.

- fill the input stream buffers with the data for each of the inputs it needs. Each input is an array that will be filled with token-dependent data.
- set up a preprocess `VkBuffer` that uses memory according to the information retrieved via `vkGetGeneratedCommandsMemoryRequirementsNV`.
- optionally preprocess the generated content using `vkCmdPreprocessGeneratedCommandsNV`, for example on an asynchronous compute queue, or for the purpose of re-using the data in multiple executions.
- call `vkCmdExecuteGeneratedCommandsNV` to create and execute the actual device commands for all sequences based on the inputs provided.

For each draw in a sequence, the following can be specified:

- a different shader group
- a number of vertex buffer bindings
- a different index buffer, with an optional dynamic offset and index type
- a number of different push constants
- a flag that encodes the primitive winding

While the GPU can be faster than a CPU to generate the commands, it will not happen asynchronously to the device, therefore the primary use case is generating “less” total work (occlusion culling, classification to use specialized shaders, etc.).

**New Object Types**

- `VkIndirectCommandsLayoutNV`

**New Commands**

- `vkCmdBindPipelineShaderGroupNV`
- `vkCmdExecuteGeneratedCommandsNV`
- `vkCmdPreprocessGeneratedCommandsNV`
- `vkCreateIndirectCommandsLayoutNV`
- `vkDestroyIndirectCommandsLayoutNV`
- `vkGetGeneratedCommandsMemoryRequirementsNV`

**New Structures**

- `VkBindIndexBufferIndirectCommandNV`
- `VkBindShaderGroupIndirectCommandNV`
- `VkBindVertexBufferIndirectCommandNV`
- `VkGeneratedCommandsInfoNV`
- VkGeneratedCommandsMemoryRequirementsInfoNV
- VkGraphicsShaderGroupCreateInfoNV
- VkIndirectCommandsLayoutCreateInfoNV
- VkIndirectCommandsLayoutTokenNV
- VkIndirectCommandsStreamNV
- VkSetStateFlagsIndirectCommandNV

**Extending VkGraphicsPipelineCreateInfo:**
- VkGraphicsPipelineShaderGroupsCreateInfoNV

**Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:**
- VkPhysicalDeviceDeviceGeneratedCommandsFeaturesNV

**Extending VkPhysicalDeviceProperties2:**
- VkPhysicalDeviceDeviceGeneratedCommandsPropertiesNV

### New Enums
- VkIndirectCommandsLayoutUsageFlagBitsNV
- VkIndirectCommandsTokenTypeNV
- VkIndirectStateFlagBitsNV

### New Bitmasks
- VkIndirectCommandsLayoutUsageFlagsNV
- VkIndirectStateFlagsNV

### New Enum Constants
- VK_NVDEVICE_GENERATED_COMMANDS_EXTENSION_NAME
- VK_NVDEVICE_GENERATED_COMMANDS_SPEC_VERSION

**Extending VkAccessFlagBits:**
- VK_ACCESS_COMMAND_PREPROCESS_READ_BIT_NV
- VK_ACCESS_COMMAND_PREPROCESS_WRITE_BIT_NV

**Extending VkObjectType:**
- VK_OBJECT_TYPE_INDIRECT_COMMANDS_LAYOUT_NV

**Extending VkPipelineCreateFlagBits:**
- VK_PIPELINE_CREATE_INDIRECT_BINDABLE_BIT_NV

**Extending VkPipelineStageFlagBits:**
- VK_PIPELINE_STAGE_COMMAND_PREPROCESS_BIT_NV

**Extending VkStructureType:**
Issues

1) How to name this extension?

VK_NV_device_generated_commands

As usual, one of the hardest issues ;)

Alternatives: VK_gpu_commands, VK_execute_commands, VK_device_commands, VK_device_execute_commands, VK_device_execute, VK_device_created_commands, VK_device_recorded_commands, VK_device_generated_commands VK_indirect_generated_commands

2) Should we use a serial stateful token stream or stateless sequence descriptions?

Similarly to VkPipeline, fixed layouts have the most likelihood to be cross-vendor adoptable. They also benefit from being processable in parallel. This is a different design choice compared to the serial command stream generated through GL_NV_command_list.

3) How to name a sequence description?

VkIndirectCommandsLayout as in the NVX extension predecessor.

Alternative: VkGeneratedCommandsLayout

4) Do we want to provide indirectCommands inputs with layout or at indirectCommands time?

Separate layout from data as Vulkan does. Provide full flexibility for indirectCommands.

5) Should the input be provided as SoA or AoS?

Both ways are desirable. AoS can provide portability to other APIs and easier to setup, while SoA allows to update individual inputs in a cache-efficient manner, when others remain static.

6) How do we make developers aware of the memory requirements of implementation-dependent data used for the generated commands?

Make the API explicit and introduce a preprocess VkBuffer. Developers have to allocate it using vkGetGeneratedCommandsMemoryRequirementsNV.

In the NVX version the requirements were hidden implicitly as part of the command buffer
reservation process, however as the memory requirements can be substantial, we want to give developers the ability to budget the memory themselves. By lowering the maxSequencesCount the memory consumption can be reduced. Furthermore reuse of the memory is possible, for example for doing explicit preprocessing and execution in a ping-pong fashion.

The actual buffer size is implementation-dependent and may be zero, i.e. not always required.

When making use of Graphics Shader Groups, the programs should behave similar with regards to vertex inputs, clipping and culling outputs of the geometry stage, as well as sample shading behavior in fragment shaders, to reduce the amount of the worst-case memory approximation.

7) Should we allow additional per-sequence dynamic state changes?

Yes

Introduced a lightweight indirect state flag VkIndirectStateFlagBitsNV. So far only switching front face winding state is exposed. Especially in CAD/DCC mirrored transforms that require such changes are common, and similar flexibility is given in the ray tracing instance description.

The flag could be extended further, for example to switch between primitive-lists or -strips, or make other state modifications.

Furthermore, as new tokens can be added easily, future extension could add the ability to change any VkDynamicState.

8) How do we allow re-using already “generated” indirectCommands?

Expose a preprocessBuffer to reuse implementation-dependencyFlags data. Set the isPreprocessed to true in vkCmdExecuteGeneratedCommandsNV.

9) Under which conditions is vkCmdExecuteGeneratedCommandsNV legal?

It behaves like a regular draw call command.

10) Is vkCmdPreprocessGeneratedCommandsNV copying the input data or referencing it?

There are multiple implementations possible:

• one could have some emulation code that parses the inputs, and generates an output command buffer, therefore copying the inputs.
• one could just reference the inputs, and have the processing done in pipe at execution time.

If the data is mandated to be copied, then it puts a penalty on implementation that could process the inputs directly in pipe. If the data is “referenced”, then it allows both types of implementation.

The inputs are “referenced”, and must not be modified after the call to vkCmdExecuteGeneratedCommandsNV has completed.

11) Which buffer usage flags are required for the buffers referenced by VkGeneratedCommandsInfoNV?

Reuse existing VK_BUFFER_USAGE_INDIRECT_BUFFER_BIT
12) In which pipeline stage does the device generated command expansion happen?

`vkCmdPreprocessGeneratedCommandsNV` is treated as if it occurs in a separate logical pipeline from either graphics or compute, and that pipeline only includes `VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT`, a new stage `VK_PIPELINE_STAGE_COMMAND_PREPROCESS_BIT_NV`, and `VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT`. This new stage has two corresponding new access types, `VK_ACCESS_COMMAND_PREPROCESS_READ_BIT_NV` and `VK_ACCESS_COMMAND_PREPROCESS_WRITE_BIT_NV`, used to synchronize reading the buffer inputs and writing the preprocess memory output.

The generated output written in the preprocess buffer memory by `vkCmdExecuteGeneratedCommandsNV` is considered to be consumed by the `VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT` pipeline stage.

Thus, to synchronize from writing the input buffers to preprocessing via `vkCmdPreprocessGeneratedCommandsNV`, use:

- `dstStageMask = VK_PIPELINE_STAGE_COMMAND_PREPROCESS_BIT_NV`
- `dstAccessMask = VK_ACCESS_COMMAND_PREPROCESS_READ_BIT_NV`

To synchronize from `vkCmdPreprocessGeneratedCommandsNV` to executing the generated commands by `vkCmdExecuteGeneratedCommandsNV`, use:

- `srcStageMask = VK_PIPELINE_STAGE_COMMAND_PREPROCESS_BIT_NV`
- `srcAccessMask = VK_ACCESS_COMMAND_PREPROCESS_WRITE_BIT_NV`
- `dstStageMask = VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT`
- `dstAccessMask = VK_ACCESS_INDIRECT_COMMAND_READ_BIT`

When `vkCmdExecuteGeneratedCommandsNV` is used with a `isPreprocessed` of `VK_FALSE`, the generated commands are implicitly preprocessed, therefore one only needs to synchronize the inputs via:

- `dstStageMask = VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT`
- `dstAccessMask = VK_ACCESS_INDIRECT_COMMAND_READ_BIT`

13) What if most token data is “static”, but we frequently want to render a subsection?

Added “sequencesIndexBuffer”. This allows to easier sort and filter what should actually be executed.

14) What are the changes compared to the previous NVX extension?

- Compute dispatch support was removed (was never implemented in drivers). There are different approaches how dispatching from the device should work, hence we defer this to a
future extension.

- The `ObjectTableNVX` was replaced by using physical buffer addresses and introducing Shader Groups for the graphics pipeline.
- Less state changes are possible overall, but the important operations are still there (reduces complexity of implementation).
- The API was redesigned so all inputs must be passed at both preprocessing and execution time (this was implicit in NVX, now it is explicit)
- The reservation of intermediate command space is now mandatory and explicit through a preprocess buffer.
- The `VkIndirectStateFlagBitsNV` were introduced

15) When porting from other APIs, their indirect buffers may use different enums, for example for index buffer types. How to solve this?

Added “pIndexTypeValues” to map custom `uint32_t` values to corresponding `VkIndexType`.

16) Do we need more shader group state overrides?

The NVX version allowed all PSO states to be different, however as the goal is not to replace all state setup, but focus on highly-frequent state changes for drawing lots of objects, we reduced the amount of state overrides. Especially `VkPipelineLayout` as well as `VkRenderPass` configuration should be left static, the rest is still open for discussion.

The current focus is just to allow `VertexInput` changes as well as shaders, while all shader groups use the same shader stages.

Too much flexibility will increase the test coverage requirement as well. However, further extensions could allow more dynamic state as well.

17) Do we need more detailed physical device feature queries/enables?

An EXT version would need detailed implementor feedback to come up with a good set of features. Please contact us if you are interested, we are happy to make more features optional, or add further restrictions to reduce the minimum feature set of an EXT.

18) Is there an interaction with VK_KHR_pipeline_library planned?

Yes, a future version of this extension will detail the interaction, once VK_KHR_pipeline_library is no longer provisional.

**Example Code**

Open-Source samples illustrating the usage of the extension can be found at the following location (may not yet exist at time of writing):

https://github.com/nvpro-samples/vk_device_generated_cmds
Version History

- Revision 1, 2020-02-20 (Christoph Kubisch)
  - Initial version
- Revision 2, 2020-03-09 (Christoph Kubisch)
  - Remove VK_EXT_debug_report interactions
- Revision 3, 2020-03-09 (Christoph Kubisch)
  - Fix naming VkPhysicalDeviceGenerated to VkPhysicalDeviceDeviceGenerated

VK_NV_device_generated_commands_compute

Name String

VK_NV_device_generated_commands_compute

Extension Type

Device extension

Registered Extension Number

429

Revision

2

Ratification Status

Not ratified

Extension and Version Dependencies

VK_NV_device_generated_commands

Contact

- Vikram Kushwaha vkushwaha-nv

Other Extension Metadata

Last Modified Date

2023-07-21

Contributors

- Vikram Kushwaha, NVIDIA
- Jeff Bolz, NVIDIA
- Christoph Kubisch, NVIDIA
- Piers Daniell, NVIDIA
- Daniel Koch, NVIDIA
- Hans-Kristian Arntzen, Valve
Description

This extension allows the device to generate commands for binding compute pipelines, setting push constants and launching compute dispatches.

New Commands

- `vkCmdUpdatePipelineIndirectBufferNV`
- `vkGetPipelineIndirectDeviceAddressNV`
- `vkGetPipelineIndirectMemoryRequirementsNV`

New Structures

- `VkBindPipelineIndirectCommandNV`
- `VkComputePipelineIndirectBufferInfoNV`
- `VkPipelineIndirectDeviceAddressInfoNV`
- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDeviceDeviceGeneratedCommandsComputeFeaturesNV`

New Enum Constants

- `VK_NV_DEVICE_GENERATED_COMMANDS_COMPUTE_EXTENSION_NAME`
- `VK_NV_DEVICE_GENERATED_COMMANDS_COMPUTE_SPEC_VERSION`
- Extending `VkDescriptorSetLayoutCreateFlagBits`:
  - `VK_DESCRIPTOR_SET_LAYOUT_CREATE_INDIRECT_BINDABLE_BIT_NV`
- Extending `VkIndirectCommandsTokenTypeNV`:
  - `VK_INDIRECT_COMMANDS_TOKEN_TYPE_DISPATCH_NV`
  - `VK_INDIRECT_COMMANDS_TOKEN_TYPE_PIPELINE_NV`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_COMPUTE_PIPELINE_INDIRECT_BUFFER_INFO_NV`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEVICE_GENERATED_COMMANDS_COMPUTE_FEATURES_NV`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEVICE_GENERATED_COMMANDS_COMPUTE_FEATURES_NV`

Version History

- Revision 2, 2023-07-21 (Vikram Kushwaha)
  - Rename `vkCmdUpdatePipelineIndirectBuffer` to `vkCmdUpdatePipelineIndirectBufferNV`
- Revision 1, 2023-06-09 (Vikram Kushwaha)
  - First Revision
VK_NV_external_memory_rdma

Name String
VK_NV_external_memory_rdma

Extension Type
Device extension

Registered Extension Number
372

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_external_memory

Contact
• Carsten Rohde @crohde

Other Extension Metadata

Last Modified Date
2021-04-19

IP Status
No known IP claims.

Contributors
• Carsten Rohde, NVIDIA

Description
This extension adds support for allocating memory which can be used for remote direct memory access (RDMA) from other devices.

New Base Types
• VkRemoteAddressNV

New Commands
• vkGetMemoryRemoteAddressNV
New Structures

- VkMemoryGetRemoteAddressInfoNV
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceExternalMemoryRDMAFeaturesNV

New Enum Constants

- VK_NV_EXTERNAL_MEMORY_RDMA_EXTENSION_NAME
- VK_NV_EXTERNAL_MEMORY_RDMA_SPEC_VERSION
- Extending VkExternalMemoryHandleTypeFlagBits:
  - VK_EXTERNAL_MEMORY_HANDLE_TYPE_RDMA_ADDRESS_BIT_NV
- Extending VkMemoryPropertyFlagBits:
  - VK_MEMORY_PROPERTY_RDMA_CAPABLE_BIT_NV
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_MEMORY_GET_REMOTE_ADDRESS_INFO_NV
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_MEMORY_RDMA_FEATURES_NV

Issues

Examples

```c
VkPhysicalDeviceMemoryBudgetPropertiesEXT memoryBudgetProperties = {
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_BUDGET_PROPERTIES_EXT };
VkPhysicalDeviceMemoryProperties2 memoryProperties2 = {
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_PROPERTIES_2, &memoryBudgetProperties };
vkGetPhysicalDeviceMemoryProperties2(physicalDevice, &memoryProperties2);
uint32_t heapIndex = (uint32_t)-1;
for (uint32_t memoryType = 0; memoryType < memoryProperties2.memoryProperties.
    memoryTypeCount; memoryType++) {
    if (memoryProperties2.memoryProperties.memoryTypes[memoryType].propertyFlags &
        VK_MEMORY_PROPERTY_RDMA_CAPABLE_BIT_NV) {
        heapIndex = memoryProperties2.memoryProperties.memoryTypes[memoryType]
            .heapIndex;
        break;
    }
}
if ((heapIndex == (uint32_t)-1) ||
    (memoryBudgetProperties.heapBudget[heapIndex] < size)) {
    return;
}

VkPhysicalDeviceExternalBufferInfo externalBufferInfo = {
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_BUFFER_INFO };
externalBufferInfo.usage = VK_BUFFER_USAGE_TRANSFER_SRC_BIT |
```
VK_BUFFER_USAGE_TRANSFER_DST_BIT;
externalBufferInfo.handleType = VK_EXTERNAL_MEMORY_HANDLE_TYPE_RDMA_ADDRESS_BIT_NV;

VkExternalBufferProperties externalBufferProperties = {
  VK_STRUCTURE_TYPE_EXTERNAL_BUFFER_PROPERTIES
};
vkGetPhysicalDeviceExternalBufferProperties(physicalDevice, &externalBufferInfo, &externalBufferProperties);

if (!(externalBufferProperties.externalMemoryProperties.externalMemoryFeatures & VK_EXTERNAL_MEMORY_FEATURE_EXPORTABLE_BIT)) {
  return;
}

VkExternalMemoryBufferCreateInfo externalMemoryBufferCreateInfo = {
  VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_BUFFER_CREATE_INFO
};
externalMemoryBufferCreateInfo.handleTypes = VK_EXTERNAL_MEMORY_HANDLE_TYPE_RDMA_ADDRESS_BIT_NV;

VkBufferCreateInfo bufferCreateInfo = {
  VK_STRUCTURE_TYPE_BUFFER_CREATE_INFO,
  &externalMemoryBufferCreateInfo
};
bufferCreateInfo.size = size;
bufferCreateInfo.usage = VK_BUFFER_USAGE_TRANSFER_SRC_BIT | VK_BUFFER_USAGE_TRANSFER_DST_BIT;

VkMemoryRequirements mem_reqs;
vkCreateBuffer(device, &bufferCreateInfo, NULL, &buffer);
vkGetBufferMemoryRequirements(device, buffer, &mem_reqs);

VkExportMemoryAllocateInfo exportMemoryAllocateInfo = {
  VK_STRUCTURE_TYPE_EXPORT_MEMORY_ALLOCATE_INFO
};
exportMemoryAllocateInfo.handleTypes = VK_EXTERNAL_MEMORY_HANDLE_TYPE_RDMA_ADDRESS_BIT_NV;

// Find memory type index
uint32_t i = 0;
for (; i < VK_MAX_MEMORY_TYPES; i++) {
  if ((mem_reqs.memoryTypeBits & (1 << i)) &&
      (memoryProperties.memoryTypes[i].propertyFlags & VK_MEMORY_PROPERTY_RDMA_CAPABLE_BIT_NV)) {
    break;
  }
}

VkMemoryAllocateInfo memAllocInfo = {
  VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO,
  &exportMemoryAllocateInfo
};
memAllocInfo.allocationSize = mem_reqs.size;
memAllocInfo.memoryTypeIndex = i;

vkAllocateMemory(device, &memAllocInfo, NULL, &mem);
vkBindBufferMemory(device, buffer, mem, 0);
VkMemoryGetRemoteAddressInfoNV getMemoryRemoteAddressInfo = {
    VK_STRUCTURE_TYPE_MEMORY_GET_REMOTE_ADDRESS_INFO_NV
};
getMemoryRemoteAddressInfo.memory = mem;
getMemoryRemoteAddressInfo.handleType = VK_EXTERNAL_MEMORY_HANDLE_TYPE_RDMA_ADDRESS_BIT_NV;

VkRemoteAddressNV rdmaAddress;
vkGetMemoryRemoteAddressNV(device, &getMemoryRemoteAddressInfo, &rdmaAddress);
// address returned in 'rdmaAddress' can be used by external devices to initiate RDMA transfers

Version History

- Revision 1, 2020-12-15 (Carsten Rohde)
  - Internal revisions

VK_NV_fill_rectangle

Name String

VK_NV_fill_rectangle

Extension Type

Device extension

Registered Extension Number

154

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

Contact

- Jeff Bolz @jeffbolznv

Other Extension Metadata

Last Modified Date

2017-05-22

Contributors

- Jeff Bolz, NVIDIA
**Description**

This extension adds a new VkPolygonMode enum where a triangle is rasterized by computing and filling its axis-aligned screen-space bounding box, disregarding the actual triangle edges. This can be useful for drawing a rectangle without being split into two triangles with an internal edge. It is also useful to minimize the number of primitives that need to be drawn, particularly for a user interface.

**New Enum Constants**

- VK_NV_FILL_RECTANGLE_EXTENSION_NAME
- VK_NV_FILL_RECTANGLE_SPEC_VERSION
- Extending VkPolygonMode:
  - VK_POLYGON_MODE_FILL_RECTANGLE_NV

**Version History**

- Revision 1, 2017-05-22 (Jeff Bolz)
  - Internal revisions

**VK_NV_fragment_coverage_to_color**

**Name String**

VK_NV_fragment_coverage_to_color

**Extension Type**

Device extension

**Registered Extension Number**

150

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

**Contact**

- Jeff Bolz [jeffbolznv](mailto:jeffbolznv)

**Other Extension Metadata**

**Last Modified Date**

2017-05-21
Contributors

- Jeff Bolz, NVIDIA

Description

This extension allows the fragment coverage value, represented as an integer bitmask, to be substituted for a color output being written to a single-component color attachment with integer components (e.g. \texttt{VK_FORMAT_R8_UINT}). The functionality provided by this extension is different from simply writing the \texttt{SampleMask} fragment shader output, in that the coverage value written to the framebuffer is taken after stencil test and depth test, as well as after fragment operations such as alpha-to-coverage.

This functionality may be useful for deferred rendering algorithms, where the second pass needs to know which samples belong to which original fragments.

New Structures

- Extending \texttt{VkPipelineMultisampleStateCreateInfo}:
  - \texttt{VkPipelineCoverageToColorStateCreateInfoNV}

New Bitmasks

- \texttt{VkPipelineCoverageToColorStateCreateFlagsNV}

New Enum Constants

- \texttt{VK_NV_FRAGMENT_COVERAGE_TO_COLOR_EXTENSION_NAME}
- \texttt{VK_NV_FRAGMENT_COVERAGE_TO_COLOR_SPEC_VERSION}
- Extending \texttt{VkStructureType}:
  - \texttt{VK_STRUCTURE_TYPE_PIPELINE_COVERAGE_TO_COLOR_STATE_CREATE_INFO_NV}

Version History

- Revision 1, 2017-05-21 (Jeff Bolz)
  - Internal revisions

VK\_NV\_fragment\_shading\_rate\_enums

Name String

\texttt{VK_NV_fragment_shading_rate Enums}

Extension Type

Device extension

Registered Extension Number

327
Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_fragment_shading_rate

Contact
  • Pat Brown nvpbrown

Other Extension Metadata

Last Modified Date
  2020-09-02

Contributors
  • Pat Brown, NVIDIA
  • Jeff Bolz, NVIDIA

Description
This extension builds on the fragment shading rate functionality provided by the
VK_KHR_fragment_shading_rate extension, adding support for “supersample” fragment shading
rates that trigger multiple fragment shader invocations per pixel as well as a “no invocations”
shading rate that discards any portions of a primitive that would use that shading rate.

New Commands
  • vkCmdSetFragmentShadingRateEnumNV

New Structures
  • Extending VkGraphicsPipelineCreateInfo:
    ◦ VkPipelineFragmentShadingRateEnumStateCreateInfoNV
  • Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
    ◦ VkPhysicalDeviceFragmentShadingRateEnumsFeaturesNV
  • Extending VkPhysicalDeviceProperties2:
    ◦ VkPhysicalDeviceFragmentShadingRateEnumsPropertiesNV

New Enums
  • VkFragmentShadingRateNV
  • VkFragmentShadingRateTypeNV
New Enum Constants

- VK_NV_FRAGMENT_SHADING_RATE_ENUMS_EXTENSION_NAME
- VK_NV_FRAGMENT_SHADING_RATE_ENUMS_SPEC_VERSION

Extending VkStructureType:
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADING_RATE_ENUMS_FEATURES_NV
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADING_RATE_ENUMS_PROPERTIES_NV
- VK_STRUCTURE_TYPE_PIPELINE_FRAGMENT_SHADING_RATE_ENUM_STATE_CREATE_INFO_NV

Issues

1. Why was this extension created? How should it be named?

**RESOLVED:** The primary goal of this extension was to expose support for supersample and “no
invocations” shading rates, which are supported by the VK_NV_shading_rate_image extension
but not by VK_KHR_fragment_shading_rate. Because VK_KHR_fragment_shading_rate specifies
the primitive shading rate using a fragment size in pixels, it lacks a good way to specify
supersample rates. To deal with this, we defined enums covering shading rates supported by the
KHR extension as well as the new shading rates and added structures and APIs accepting
shading rate enums instead of fragment sizes.

Since this extension adds two different types of shading rates, both expressed using enums, we
chose the extension name VK_NV_fragment_shading_rate_enums.

2. Is this a standalone extension?

**RESOLVED:** No, this extension requires VK_KHR_fragment_shading_rate. In order to use the
features of this extension, applications must enable the relevant features of KHR extension.

3. How are the shading rate enums used, and how were the enum values assigned?

**RESOLVED:** The shading rates supported by the enums in this extension are accepted as
pipeline, primitive, and attachment shading rates and behave identically. For the shading rates
also supported by the KHR extension, the values assigned to the corresponding enums are
identical to the values already used for the primitive and attachment shading rates in the KHR
extension. For those enums, bits 0 and 1 specify the base two logarithm of the fragment height
and bits 2 and 3 specify the base two logarithm of the fragment width. For the new shading
rates added by this extension, we chose to use 11 through 14 (10 plus the base two logarithm of
the invocation count) for the supersample rates and 15 for the “no invocations” rate. None of
those values are supported as primitive or attachment shading rates by the KHR extension.

4. Between this extension, VK_KHR_fragment_shading_rate, and VK_NV_shading_rate_image, there
are three different ways to specify shading rate state in a pipeline. How should we handle this?

**RESOLVED:** We do not allow the concurrent use of VK_NV_shading_rate_image and
VK_KHR_fragment_shading_rate; it is an error to enable shading rate features from both
extensions. But we do allow applications to enable this extension together with
VK_KHR_fragment_shading_rate together. While we expect that applications will never attach
pipeline CreateInfo structures for both this extension and the KHR extension concurrently, Vulkan does not have any precedent forbidding such behavior and instead typically treats a pipeline created without an extension-specific CreateInfo structure as equivalent to one containing default values specified by the extension. Rather than adding such a rule considering the presence or absence of our new CreateInfo structure, we instead included a shadingRateType member to VkPipelineFragmentShadingRateEnumStateCreateInfoNV that selects between using state specified by that structure and state specified by VkPipelineFragmentShadingRateStateCreateInfoKHR.

Version History

- Revision 1, 2020-09-02 (pbrown)
  - Internal revisions

VK_NV_framebuffer_mixed_samples

Name String

VK_NV_framebuffer_mixed_samples

Extension Type

Device extension

Registered Extension Number

153

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

Contact

- Jeff Bolz [jeffbolznv]

Other Extension Metadata

Last Modified Date

2017-06-04

Contributors

- Jeff Bolz, NVIDIA

Description

This extension allows multisample rendering with a raster and depth/stencil sample count that is larger than the color sample count. Rasterization and the results of the depth and stencil tests
together determine the portion of a pixel that is “covered”. It can be useful to evaluate coverage at a higher frequency than color samples are stored. This coverage is then “reduced” to a collection of covered color samples, each having an opacity value corresponding to the fraction of the color sample covered. The opacity can optionally be blended into individual color samples.

Rendering with fewer color samples than depth/stencil samples greatly reduces the amount of memory and bandwidth consumed by the color buffer. However, converting the coverage values into opacity introduces artifacts where triangles share edges and may not be suitable for normal triangle mesh rendering.

One expected use case for this functionality is Stencil-then-Cover path rendering (similar to the OpenGL GL_NV_path_rendering extension). The stencil step determines the coverage (in the stencil buffer) for an entire path at the higher sample frequency, and then the cover step draws the path into the lower frequency color buffer using the coverage information to antialias path edges. With this two-step process, internal edges are fully covered when antialiasing is applied and there is no corruption on these edges.

The key features of this extension are:

- It allows render pass and framebuffer objects to be created where the number of samples in the depth/stencil attachment in a subpass is a multiple of the number of samples in the color attachments in the subpass.

- A coverage reduction step is added to Fragment Operations which converts a set of covered raster/depth/stencil samples to a set of color samples that perform blending and color writes. The coverage reduction step also includes an optional coverage modulation step, multiplying color values by a fractional opacity corresponding to the number of associated raster/depth/stencil samples covered.

**New Structures**

- Extending `VkPipelineMultisampleStateCreateInfo`:
  - `VkPipelineCoverageModulationStateCreateInfoNV`

**New Enums**

- `VkCoverageModulationModeNV`

**New Bitmasks**

- `VkPipelineCoverageModulationStateCreateFlagsNV`

**New Enum Constants**

- `VK_NV_FRAMEBUFFER_MIXED_SAMPLES_EXTENSION_NAME`
- `VK_NV_FRAMEBUFFER_MIXED_SAMPLES_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PIPELINE_COVERAGE_MODULATION_STATE_CREATE_INFO_NV`
Version History

• Revision 1, 2017-06-04 (Jeff Bolz)
  ◦ Internal revisions

VK_NV_geometry_shader_passthrough

Name String
VK_NV_geometry_shader_passthrough

Extension Type
Device extension

Registered Extension Number
96

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies

Contact
• Daniel Koch dgkoch

Other Extension Metadata

Last Modified Date
2017-02-15

Interactions and External Dependencies
• This extension requires SPV_NV_geometry_shader_passthrough
• This extension provides API support for GL_NV_geometry_shader_passthrough
• This extension requires the geometryShader feature.

Contributors
• Piers Daniell, NVIDIA
• Jeff Bolz, NVIDIA

Description

This extension adds support for the following SPIR-V extension in Vulkan:

• SPV_NV_geometry_shader_passthrough

Geometry shaders provide the ability for applications to process each primitive sent through the
graphics pipeline using a programmable shader. However, one common use case treats them largely as a “passthrough”. In this use case, the bulk of the geometry shader code simply copies inputs from each vertex of the input primitive to corresponding outputs in the vertices of the output primitive. Such shaders might also compute values for additional built-in or user-defined per-primitive attributes (e.g., `Layer`) to be assigned to all the vertices of the output primitive.

This extension provides access to the `PassthroughNV` decoration under the `GeometryShaderPassthroughNV` capability. Adding this to a geometry shader input variable specifies that the values of this input are copied to the corresponding vertex of the output primitive.

When using GLSL source-based shading languages, the `passthrough` layout qualifier from `GL_NV_geometry_shader_passthrough` maps to the `PassthroughNV` decoration. To use the `passthrough` layout, in GLSL the `GL_NV_geometry_shader_passthrough` extension must be enabled. Behaviour is described in the `GL_NV_geometry_shader_passthrough` extension specification.

### New Enum Constants

- `VK_NV_GEOMETRY_SHADER_PASSTHROUGH_EXTENSION_NAME`
- `VK_NV_GEOMETRY_SHADER_PASSTHROUGH_SPEC_VERSION`

### New Variable Decoration

- `PassthroughNV` in `Geometry Shader Passthrough`

### New SPIR-V Capabilities

- `GeometryShaderPassthroughNV`

### Issues

1) Should we require or allow a passthrough geometry shader to specify the output layout qualifiers for the output primitive type and maximum vertex count in the SPIR-V?

**RESOLVED:** Yes they should be required in the SPIR-V. Per `GL_NV_geometry_shader_passthrough` they are not permitted in the GLSL source shader, but SPIR-V is lower-level. It is straightforward for the GLSL compiler to infer them from the input primitive type and to explicitly emit them in the SPIR-V according to the following table.

<table>
<thead>
<tr>
<th>Input Layout</th>
<th>Implied Output Layout</th>
</tr>
</thead>
<tbody>
<tr>
<td>points</td>
<td><code>layout(points, max_vertices=1)</code></td>
</tr>
<tr>
<td>lines</td>
<td><code>layout(line_strip, max_vertices=2)</code></td>
</tr>
<tr>
<td>triangles</td>
<td><code>layout(triangle_strip, max_vertices=3)</code></td>
</tr>
</tbody>
</table>

2) How does interface matching work with passthrough geometry shaders?

**RESOLVED:** This is described in `Passthrough Interface Matching`. In GL when using passthrough geometry shaders in separable mode, all inputs must also be explicitly assigned location layout qualifiers. In Vulkan all SPIR-V shader inputs (except built-ins) must also have location decorations.
specified. Redefinitions of built-in variables that add the passthrough layout qualifier are exempted from the rule requiring location assignment because built-in variables do not have locations and are matched by BuiltIn decoration.

**Sample Code**

Consider the following simple geometry shader in unextended GLSL:

```glsl
layout(triangles) in;
layout(triangle_strip) out;
layout(max_vertices=3) out;

in Inputs {
    vec2 texcoord;
    vec4 baseColor;
} v_in[];
out Outputs {
    vec2 texcoord;
    vec4 baseColor;
};

void main()
{
    int layer = compute_layer();
    for (int i = 0; i < 3; i++) {
        gl_Position = gl_in[i].gl_Position;
        texcoord = v_in[i].texcoord;
        baseColor = v_in[i].baseColor;
        gl_Layer = layer;
        EmitVertex();
    }
}
```

In this shader, the inputs `gl_Position`, `Inputs.texcoord`, and `Inputs.baseColor` are simply copied from the input vertex to the corresponding output vertex. The only “interesting” work done by the geometry shader is computing and emitting a `gl_Layer` value for the primitive.

The following geometry shader, using this extension, is equivalent:

```glsl
#extension GL_NV_geometry_shader_passthrough : require

layout(triangles) in;
// No output primitive layout qualifiers required.

// Redeclare gl_PerVertex to pass through "gl_Position".
layout(passthrough) in gl_PerVertex {
    vec4 gl_Position;
} gl_in[];
```
// Declare "Inputs" with "passthrough" to automatically copy members.
layout(passthrough) in Inputs {
    vec2 texcoord;
    vec4 baseColor;
} v_in[];

// No output block declaration required.

void main()
{
    // The shader simply computes and writes gl_Layer. We do not
    // loop over three vertices or call EmitVertex().
    gl_Layer = compute_layer();
}

Version History

- Revision 1, 2017-02-15 (Daniel Koch)
  - Internal revisions

VK_NV_inherited_viewport_scissor

Name String
VK_NV_inherited_viewport_scissor

Extension Type
Device extension

Registered Extension Number
279

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2

Contact
- David Zhao Akeley akeley98

Other Extension Metadata

Last Modified Date
2021-02-04
Contributors

- David Zhao Akeley, NVIDIA
- Jeff Bolz, NVIDIA
- Piers Daniell, NVIDIA
- Christoph Kubisch, NVIDIA

Description

This extension adds the ability for a secondary command buffer to inherit the dynamic viewport and scissor state from a primary command buffer, or a previous secondary command buffer executed within the same `vkCmdExecuteCommands` call. It addresses a frequent scenario in applications that deal with window resizing and want to improve utilization of re-usable secondary command buffers. The functionality is provided through `VkCommandBufferInheritanceViewportScissorInfoNV`. Viewport inheritance is effectively limited to the 2D rectangle; secondary command buffers must re-specify the inherited depth range values.

New Structures

- Extending `VkCommandBufferInheritanceInfo`:
  - `VkCommandBufferInheritanceViewportScissorInfoNV`
- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceInheritedViewportScissorFeaturesNV`

New Enum Constants

- `VK_NV_INHERITED_VIEWPORT_SCISSOR_EXTENSION_NAME`
- `VK_NV_INHERITED_VIEWPORT_SCISSOR_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_VIEWPORT_SCISSOR_INFO_NV`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INHERITED_VIEWPORT_SCISSOR_FEATURES_NV`

Issues

(1) Why are viewport depth values configured in the `VkCommandBufferInheritanceViewportScissorInfoNV` struct, rather than by a `vkCmd…` function?

**DISCUSSION:**

We considered both adding a new `vkCmdSetViewportDepthNV` function, and modifying `vkCmdSetViewport` to ignore the `x`, `y`, `width`, and `height` values when called with a secondary command buffer that activates this extension.

The primary design considerations for this extension are debuggability and easy integration into existing applications. The main issue with adding a new `vkCmdSetViewportDepthNV` function is reducing ease-of-integration. A new function pointer will have to be loaded, but more importantly,
a new function would require changes to be supported in graphics debuggers; this would delay widespread adoption of the extension.

The proposal to modify `vkCmdSetViewport` would avoid these issues. However, we expect that the intent of applications using this extension is to have the viewport values used for drawing exactly match the inherited values; thus, it would be better for debuggability if no function for modifying the viewport depth alone is provided. By specifying viewport depth values when starting secondary command buffer recording, and requiring the specified depth values to match the inherited depth values, we allow for validation layers that flag depth changes as errors.

This design also better matches the hardware model. In fact, there is no need to re-execute a depth-setting command. The graphics device retains the viewport depth state; it is the CPU-side state of `VkCommandBuffer` that must be re-initialized.

(2) Why are viewport depth values specified as a partial `VkViewport` struct, rather than a leaner depth-only struct?

**DISCUSSION:**

We considered adding a new `VkViewportDepthNV` struct containing only `minDepth` and `maxDepth`. However, as application developers would need to maintain both a `VK_NV_inherited_viewport_scissor` code path and a fallback code path (at least in the short term), we ultimately chose to continue using the existing `VkViewport` structure. Doing so would allow application developers to reuse the same `VkViewport` array for both code paths, rather than constructing separate `VkViewportDepthNV` and `VkViewport` arrays for each code path.

**Version History**

- Revision 1, 2020-02-04 (David Zhao Akeley)
  - Internal revisions

**VK_NV_linear_color_attachment**

**Name String**

`VK_NV_linear_color_attachment`

**Extension Type**

- Device extension

**Registered Extension Number**

431

**Revision**

1

**Ratification Status**

- Not ratified
**Extension and Version Dependencies**

VK_KHR_get_physical_device_properties2

**Contact**

- sourav parmar @souravpNV

**Other Extension Metadata**

**Last Modified Date**

2021-12-02

**Interactions and External Dependencies**

- This extension requires VK_KHR_format_feature_flags2

**Contributors**

- Pat Brown, NVIDIA
- Piers Daniell, NVIDIA
- Sourav Parmar, NVIDIA

**Description**

This extension expands support for using `VK_IMAGE_TILING_LINEAR` images as color attachments when all the color attachments in the render pass instance have `VK_IMAGE_TILING_LINEAR` tiling. This extension adds a new flag bit `VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV` that extends the existing `VkFormatFeatureFlagBits2KHR` bits. This flag can be set for renderable color formats in the `VkFormatProperties3KHR::linearTilingFeatures` format properties structure member. Formats with the `VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV` flag may be used as color attachments as long as all the color attachments in the render pass instance have `VK_IMAGE_TILING_LINEAR` tiling, and the formats their images views are created with have `VkFormatProperties3KHR::linearTilingFeatures` which include `VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV`. This extension supports both dynamic rendering and traditional render passes.

**New Structures**

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceLinearColorAttachmentFeaturesNV`

**New Enum Constants**

- `VK_NV_LINEAR_COLOR_ATTACHMENT_EXTENSION_NAME`
- `VK_NV_LINEAR_COLOR_ATTACHMENT_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_LINEAR_COLOR_ATTACHMENT_FEATURES_NV`

If `VK_KHR_format_feature_flags2` is supported:
• Extending VkFormatFeatureFlagBits2:
  ◦ VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV

Version History

• Revision 1, 2021-11-29 (sourav parmar)
  ◦ Initial draft

VK_NV_low_latency

Name String
  VK_NV_low_latency

Extension Type
  Device extension

Registered Extension Number
  311

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies

Contact
  • Charles Hansen cshansen

Other Extension Metadata

Last Modified Date
  2023-02-10

Contributors
  • Charles Hansen, NVIDIA

Description

This extension adds the VkQueryLowLatencySupportNV structure, a structure used to query support for NVIDIA Reflex.

New Structures

• Extending VkSemaphoreCreateInfo:
  ◦ VkQueryLowLatencySupportNV
New Enum Constants

- VK_NV_LOW_LATENCY_EXTENSION_NAME
- VK_NV_LOW_LATENCY_SPEC_VERSION

Extending VkStructureType:
  - VK_STRUCTURE_TYPE_QUERY_LOW_LATENCY_SUPPORT_NV

Issues

1) Why does VkQueryLowLatencySupportNV have output parameters in an input chain?

RESOLVED: We are stuck with this for legacy reasons - we are aware this is bad behavior and this should not be used as a precedent for future extensions.

Version History

- Revision 1, 2023-02-10 (Charles Hansen)
  - Internal revisions

VK_NV_memory_decompression

Name String
  - VK_NV_memory_decompression

Extension Type
  - Device extension

Registered Extension Number
  - 428

Revision
  - 1

Ratification Status
  - Not ratified

Extension and Version Dependencies
  - VK_KHR_get_physical_device_properties2
  - VK_KHR_buffer_device_address

Contact
  - Vikram Kushwaha vkushwaha-nv

Other Extension Metadata
Description

This extension adds support for performing memory to memory decompression.

New Commands

- `vkCmdDecompressMemoryIndirectCountNV`
- `vkCmdDecompressMemoryNV`

New Structures

- `VkDecompressMemoryRegionNV`
- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceMemoryDecompressionFeaturesNV`
- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceMemoryDecompressionPropertiesNV`

New Enums

- `VkMemoryDecompressionMethodFlagBitsNV`

New Bitmasks

- `VkMemoryDecompressionMethodFlagsNV`

New Enum Constants

- `VK_NV_MEMORY_DECOMPRESSION_EXTENSION_NAME`
- `VK_NV_MEMORY_DECOMPRESSION_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_DECOMPRESSION_FEATURES_NV`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_DECOMPRESSION_PROPERTIES_NV`
Version History

- Revision 1, 2022-01-31 (Vikram Kushwaha)
  - Initial draft

**VK_NV_mesh_shader**

Name String

VK_NV_mesh_shader

Extension Type

Device extension

Registered Extension Number

203

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Contact

- Christoph Kubisch [pixeljetstream](https://www.pixeljetstream.com)

Other Extension Metadata

Last Modified Date

2018-07-19

Interactions and External Dependencies

- This extension requires SPV_NV_mesh_shader
- This extension provides API support for GLSL_NV_mesh_shader

Contributors

- Pat Brown, NVIDIA
- Jeff Bolz, NVIDIA
- Daniel Koch, NVIDIA
- Piers Daniell, NVIDIA
- Pierre Boudier, NVIDIA
Description

This extension provides a new mechanism allowing applications to generate collections of geometric primitives via programmable mesh shading. It is an alternative to the existing programmable primitive shading pipeline, which relied on generating input primitives by a fixed function assembler as well as fixed function vertex fetch.

There are new programmable shader types—the task and mesh shader—to generate these collections to be processed by fixed-function primitive assembly and rasterization logic. When task and mesh shaders are dispatched, they replace the core pre-rasterization stages, including vertex array attribute fetching, vertex shader processing, tessellation, and geometry shader processing.

This extension also adds support for the following SPIR-V extension in Vulkan:

- SPV_NV_mesh_shader

New Commands

- vkCmdDrawMeshTasksIndirectCountNV
- vkCmdDrawMeshTasksIndirectNV
- vkCmdDrawMeshTasksNV

New Structures

- VkDrawMeshTasksIndirectCommandNV
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceMeshShaderFeaturesNV
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceMeshShaderPropertiesNV

New Enum Constants

- VK_NV_MESH_SHADER_EXTENSION_NAME
- VK_NV_MESH_SHADER_SPEC_VERSION
- Extending VkPipelineStageFlagBits:
  - VK_PIPELINE_STAGE_MESH_SHADER_BIT_NV
  - VK_PIPELINE_STAGE_TASK_SHADER_BIT_NV
- Extending VkShaderStageFlagBits:
  - VK_SHADER_STAGE_MESH_BIT_NV
  - VK_SHADER_STAGE_TASK_BIT_NV
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MESH_SHADER_FEATURES_NV
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MESH_SHADER_PROPERTIES_NV
New or Modified Built-In Variables

- TaskCountNV
- PrimitiveCountNV
- PrimitiveIndicesNV
- ClipDistancePerViewNV
- CullDistancePerViewNV
- LayerPerViewNV
- MeshViewCountNV
- MeshViewIndicesNV
- (modified) Position
- (modified) PointSize
- (modified) ClipDistance
- (modified) CullDistance
- (modified) PrimitiveId
- (modified) Layer
- (modified) ViewportIndex
- (modified) WorkgroupSize
- (modified) WorkgroupId
- (modified) LocalInvocationId
- (modified) GlobalInvocationId
- (modified) LocalInvocationIndex
- (modified) DrawIndex
- (modified) ViewportMaskNV
- (modified) PositionPerViewNV
- (modified) ViewportMaskPerViewNV

New SPIR-V Capability

- MeshShadingNV

Issues

1. How to name this extension?

   **RESOLVED**: VK_NV_mesh_shader

   Other options considered:

   - VK_NV_mesh_shading
2. Do we need a new VkPrimitiveTopology?

**RESOLVED:** No. We skip the InputAssembler stage.

3. Should we allow Instancing?

**RESOLVED:** No. There is no fixed function input, other than the IDs. However, allow offsetting with a “first” value.

4. Should we use existing vkCmdDraw or introduce new functions?

**RESOLVED:** Introduce new functions.

New functions make it easier to separate from “programmable primitive shading” chapter, less “dual use” language about existing functions having alternative behavior. The text around the existing “draws” is heavily based around emitting vertices.

5. If new functions, how to name?

**RESOLVED:** CmdDrawMeshTasks*

Other options considered:

- CmdDrawMeshed
- CmdDrawTasked
- CmdDrawGrouped

6. Should VK_SHADER_STAGE_ALL_GRAPHICS be updated to include the new stages?

**RESOLVED:** No. If an application were to be recompiled with headers that include additional shader stage bits in VK_SHADER_STAGE_ALL_GRAPHICS, then the previously valid application would no longer be valid on implementations that do not support mesh or task shaders. This means the change would not be backwards compatible. It is too bad VkShaderStageFlagBits does not have a dedicated “all supported graphics stages” bit like VK_PIPELINE_STAGE_ALL_GRAPHICS_BIT, which would have avoided this problem.

**Version History**

- Revision 1, 2018-07-19 (Christoph Kubisch, Daniel Koch)
  - Internal revisions

**VK_NV_optical_flow**

**Name String**

- **VK_NV_optical_flow**
Optical flow are fundamental algorithms in computer vision (CV) area. This extension allows applications to estimate 2D displacement of pixels between two frames.

**Note**
This extension is designed to be used with upcoming NVIDIA Optical Flow SDK Version 5 which will be available on NVIDIA Developer webpage.

**New Object Types**
- VkOpticalFlowSessionNV
New Commands

- vkBindOpticalFlowSessionImageNV
- vkCmdOpticalFlowExecuteNV
- vkCreateOpticalFlowSessionNV
- vkDestroyOpticalFlowSessionNV
- vkGetPhysicalDeviceOpticalFlowImageFormatsNV

New Structures

- VkOpticalFlowExecuteInfoNV
- VkOpticalFlowImageFormatPropertiesNV
- VkOpticalFlowSessionCreateInfoNV

Extending VkOpticalFlowSessionCreateInfoNV:

- VkOpticalFlowSessionCreatePrivateDataInfoNV

Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:

- VkPhysicalDeviceOpticalFlowFeaturesNV

Extending VkPhysicalDeviceImageFormatInfo2, VkImageCreateInfo:

- VkOpticalFlowImageFormatInfoNV

Extending VkPhysicalDeviceProperties2:

- VkPhysicalDeviceOpticalFlowPropertiesNV

New Enums

- VkOpticalFlowExecuteFlagBitsNV
- VkOpticalFlowGridSizeFlagBitsNV
- VkOpticalFlowPerformanceLevelNV
- VkOpticalFlowSessionBindingPointNV
- VkOpticalFlowSessionCreateFlagBitsNV
- VkOpticalFlowUsageFlagBitsNV

New Bitmasks

- VkOpticalFlowExecuteFlagsNV
- VkOpticalFlowGridSizeFlagsNV
- VkOpticalFlowSessionCreateFlagsNV
- VkOpticalFlowUsageFlagsNV
New Enum Constants

- VK_NV_OPTICAL_FLOW_EXTENSION_NAME
- VK_NV_OPTICAL_FLOW_SPEC_VERSION

Extending VkAccessFlagBits2:
- VK_ACCESS_2_OPTICAL_FLOW_READ_BIT_NV
- VK_ACCESS_2_OPTICAL_FLOW_WRITE_BIT_NV

Extending VkFormat:
- VK_FORMAT_R16G16_S10_5_NV

Extending VkFormatFeatureFlagBits2:
- VK_FORMAT_FEATURE_2_OPTICALFLOW_COST_BIT_NV
- VK_FORMAT_FEATURE_2_OPTICALFLOW_IMAGE_BIT_NV
- VK_FORMAT_FEATURE_2_OPTICALFLOW_VECTOR_BIT_NV

Extending VkObjectType:
- VK_OBJECT_TYPE_OPTICALFLOW_SESSION_NV

Extending VkPipelineStageFlagBits2:
- VK_PIPELINE_STAGE_2_OPTICALFLOW_BIT_NV

Extending VkQueueFlagBits:
- VK_QUEUE_OPTICALFLOW_BIT_NV

Extending VkStructureType:
- VK_STRUCTURE_TYPE_OPTICALFLOW_EXECUTEINFO_NV
- VK_STRUCTURE_TYPE_OPTICALFLOW_IMAGEFORMATINFO_NV
- VK_STRUCTURE_TYPE_OPTICALFLOW_IMAGEFORMATPROPERTIES_NV
- VK_STRUCTURE_TYPE_OPTICALFLOWSESSION_CREATEINFO_NV
- VK_STRUCTURE_TYPE_OPTICALFLOWSESSION_CREATEPRIVATEDATAINFO_NV
- VK_STRUCTURE_TYPE_PHYSICALDEVICEOPTICALFLOWFEATURES_NV
- VK_STRUCTURE_TYPE_PHYSICALDEVICEOPTICALFLOWFEATURES_NV

Examples

```cpp
// Example querying available input formats
VkOpticalFlowImageFormatInfoNV ofFormatInfo = {
    VK_STRUCTURE_TYPE_OPTICALFLOW_IMAGEFORMATINFO_NV};
ofFormatInfo.usage = VK_OPTICALFLOW_USAGE_INPUT_BIT_NV;

uint32_t count = 0;
vkGetPhysicalDeviceOpticalFlowImageFormatsNV(physicalDevice, &ofFormatInfo, &count, NULL);
VkOpticalFlowImageFormatPropertiesNV* fmt = new VkOpticalFlowImageFormatPropertiesNV
```
count;
memset(fmt, 0, count * sizeof(VkOpticalFlowImageFormatPropertiesNV));
for (uint32_t i = 0; i < count; i++) {
    fmt[i].sType = VK_STRUCTURE_TYPE_OPTICAL_FLOW_IMAGE_FORMAT_PROPERTIES_NV;
}
vkGetPhysicalDeviceOpticalFlowImageFormatsNV(physicalDevice, &ofFormatInfo, &count, fmt);

// Pick one of the available formats
VkFormat inputFormat = fmt[0].format;

// Check feature support for optimal tiling
VkFormatProperties3 formatProperties3 = { VK_STRUCTURE_TYPE_FORMAT_PROPERTIES_3 };;
VkFormatProperties2 formatProperties2 = { VK_STRUCTURE_TYPE_FORMAT_PROPERTIES_2, &formatProperties3 };;
vkGetPhysicalDeviceOpticalFlowImageFormats2(physicalDevice, inputFormat, &formatProperties2);
if (!(formatProperties3.optimalTilingFeatures & VK_FORMAT_FEATURE_2_OPTICAL_FLOW_IMAGE_BIT_NV)) {
    return false;
}

// Check support for image creation parameters
VkPhysicalDeviceImageFormatInfo2 imageFormatInfo2 = {
    VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_FORMAT_INFO_2, &ofFormatInfo };
imageFormatInfo2.format = inputFormat;
imageFormatInfo2.type = VK_IMAGE_TYPE_2D;
imageFormatInfo2.tiling = VK_IMAGE_TILING_OPTIMAL;
imageFormatInfo2.usage = VK_IMAGE_USAGE_SAMPLED_BIT | VK_IMAGE_USAGE_TRANSFER_DST_BIT;

VkImageFormatProperties2 imageFormatProperties2 = {
    VK_STRUCTURE_TYPE_IMAGE_FORMAT_PROPERTIES_2 };
if (vkGetPhysicalDeviceImageFormatProperties2(physicalDevice, inputFormat, &imageFormatProperties2) != VK_SUCCESS) {
    return false;
}

VkImageCreateInfo imageCreateInfo = {
    VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO, &ofFormatInfo };
imageCreateInfo.imageType = VK_IMAGE_TYPE_2D;
imageCreateInfo.format = inputFormat;
imageCreateInfo.extent = { width, height, (uint32_t)1};
imageCreateInfo.mipLevels = 1;
imageCreateInfo.arrayLayers = 1;
imageCreateInfo.samples = VK_SAMPLE_COUNT_1_BIT;
imageCreateInfo.usage = VK_IMAGE_USAGE_SAMPLED_BIT | VK_IMAGE_USAGE_TRANSFER_DST_BIT;
imageCreateInfo.tiling = VK_IMAGE_TILING_OPTIMAL;

vkCreateImage(device, &imageCreateInfo, NULL, &input);
"allocate memory, bind image, create view"

"do the same for reference and output"
// Create optical flow session
VkOpticalFlowSessionCreateInfoNV sessionCreateInfo = {
    VK_STRUCTURE_TYPE_OPTICAL_FLOW_SESSION_CREATE_INFO_NV
};
sessionCreateInfo.width = width;
sessionCreateInfo.height = height;
sessionCreateInfo.imageFormat = inputFormat;
sessionCreateInfo.flowVectorFormat = outputFormat;
sessionCreateInfo.outputGridSize = VK_OPTICAL_FLOW_GRID_SIZE_4X4_BIT_NV;
sessionCreateInfo.performanceLevel = VK_OPTICAL_FLOW_PERFORMANCE_LEVEL_SLOW_NV;
VkOpticalFlowSessionNV session;
vkCreateOpticalFlowSessionNV(device, &sessionCreateInfo, NULL, &session);

"allocate command buffer"

"transfer images to VK_PIPELINE_STAGE_2_OPTICAL_FLOW_BIT_NV"
"transfer input images to VK_ACCESS_2_OPTICAL_FLOW_READ_BIT_NV and output image to
VK_ACCESS_2_OPTICAL_FLOW_WRITE_BIT_NV"

vkBindOpticalFlowSessionImageNV(device, session,
    VK_OPTICAL_FLOW_SESSION_BINDING_POINT_INPUT_NV, inputView, VK_IMAGE_LAYOUT_GENERAL);
vkBindOpticalFlowSessionImageNV(device, session,
    VK_OPTICAL_FLOW_SESSION_BINDING_POINT_REFERENCE_NV, refView, VK_IMAGE_LAYOUT_GENERAL);
vkBindOpticalFlowSessionImageNV(device, session,
    VK_OPTICAL_FLOW_SESSION_BINDING_POINT_FLOW_VECTOR_NV, outputView,
    VK_IMAGE_LAYOUT_GENERAL);

VkOpticalFlowExecuteInfoNV opticalFlowExecuteInfo = {
    VK_STRUCTURE_TYPE_OPTICAL_FLOW_EXECUTE_INFO_NV
};
vkCmdOpticalFlowExecuteNV(cmd, session, &opticalFlowExecuteInfo);

"submit command buffer"

Version History

- Revision 1, 2022-09-26 (Carsten Rohde)
  - Internal revisions

VK_NV_present_barrier

Name String
  VK_NV_present_barrier

Extension Type
  Device extension

Registered Extension Number
  293
Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2
and
VK_KHR_surface
and
VK_KHR_get_surface_capabilities2
and
VK_KHR_swapchain

Contact
• Liya Li

Other Extension Metadata

Last Modified Date
2022-05-16

Contributors
• Liya Li, Nvidia
• Martin Schwarzer, Nvidia
• Andy Wolf, Nvidia
• Ian Williams, Nvidia
• Ben Morris, Nvidia
• James Jones, Nvidia
• Jeff Juliano, Nvidia

Description
This extension adds support for synchronizing corresponding presentation requests across multiple swapchains using the present barrier.

New Structures
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDevicePresentBarrierFeaturesNV
• Extending VkSurfaceCapabilities2KHR:
  ◦ VkSurfaceCapabilitiesPresentBarrierNV
• Extending VkSwapchainCreateInfoKHR:
New Enum Constants

- VK_NV_PRESENT_BARRIER_EXTENSION_NAME
- VK_NV_PRESENT_BARRIER_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRESENT_BARRIER_FEATURES_NV
  - VK_STRUCTURE_TYPE_SURFACE_CAPABILITIES_PRESENT_BARRIER_NV
  - VK_STRUCTURE_TYPE_SWAPCHAIN_PRESENT_BARRIER_CREATE_INFO_NV

Issues

1) Is there a query interface to check if a swapchain is using the present barrier?

RESOLVED. There is no such query interface. When creating a swapchain, an application can specify to use the present barrier, and if the swapchain is created successfully, this swapchain will be using the present barrier.

2) Do we need an extra interface to set up the present barrier across distributed systems?

RESOLVED. If the required hardware is presented in the system, and all settings for the physical synchronization with other systems are set up, an implementation manages the configuration automatically when creating a swapchain, without any extra calls from the application.

Version History

- Revision 1, 2022-07-20
  - Initial version

VK_NV_ray_tracing

Name String

VK_NV_ray_tracing

Extension Type

Device extension

Registered Extension Number

166

Revision

3

Ratification Status

Not ratified
Extension and Version Dependencies

VK_KHR_get_physical_device_properties2
and
VK_KHR_get_memory_requirements2

Contact

• Eric Werness
  https://github.com/ewerness-nv

Other Extension Metadata

Last Modified Date
2018-11-20

Interactions and External Dependencies

• This extension requires SPV_NV_ray_tracing
• This extension provides API support for GL_NV_ray_tracing

Contributors

• Eric Werness, NVIDIA
• Ashwin Lele, NVIDIA
• Robert Stepinski, NVIDIA
• Nuno Subtil, NVIDIA
• Christoph Kubisch, NVIDIA
• Martin Stich, NVIDIA
• Daniel Koch, NVIDIA
• Jeff Bolz, NVIDIA
• Joshua Barczak, Intel
• Tobias Hector, AMD
• Henrik Rydgard, NVIDIA
• Pascal Gautron, NVIDIA

Description

Rasterization has been the dominant method to produce interactive graphics, but increasing performance of graphics hardware has made ray tracing a viable option for interactive rendering. Being able to integrate ray tracing with traditional rasterization makes it easier for applications to incrementally add ray traced effects to existing applications or to do hybrid approaches with rasterization for primary visibility and ray tracing for secondary queries.

To enable ray tracing, this extension adds a few different categories of new functionality:

• Acceleration structure objects and build commands
• A new pipeline type with new shader domains
• An indirection table to link shader groups with acceleration structure items

This extension adds support for the following SPIR-V extension in Vulkan:

• SPV_NV_ray_tracing

New Object Types

• VkAccelerationStructureNV

New Commands

• vkBindAccelerationStructureMemoryNV
• vkCmdBuildAccelerationStructureNV
• vkCmdCopyAccelerationStructureNV
• vkCmdTraceRaysNV
• vkCmdWriteAccelerationStructuresPropertiesNV
• vkCompileDeferredNV
• vkCreateAccelerationStructureNV
• vkCreateRayTracingPipelinesNV
• vkDestroyAccelerationStructureNV
• vkGetAccelerationStructureHandleNV
• vkGetAccelerationStructureMemoryRequirementsNV
• vkGetRayTracingShaderGroupHandlesNV

New Structures

• VkAabbPositionsNV
• VkAccelerationStructureCreateInfoNV
• VkAccelerationStructureInfoNV
• VkAccelerationStructureInstanceNV
• VkAccelerationStructureMemoryRequirementsInfoNV
• VkBindAccelerationStructureMemoryInfoNV
• VkGeometryAABBNV
• VkGeometryDataNV
• VkGeometryNV
• VkGeometryTrianglesNV
• VkRayTracingPipelineCreateInfoNV
• VkRayTracingShaderGroupCreateInfoNV
• VkRayTracingShaderGroupCreateInfoNV
• VkTransformMatrixNV
Extending `VkPhysicalDeviceProperties2`:
- `VkPhysicalDeviceRayTracingPropertiesNV`

Extending `VkWriteDescriptorSet`:
- `VkWriteDescriptorSetAccelerationStructureNV`

If `VK_KHR_get_memory_requirements2` is supported:
- `VkMemoryRequirements2KHR`

**New Enums**
- `VkAccelerationStructureMemoryRequirementsTypeNV`
- `VkAccelerationStructureTypeNV`
- `VkBuildAccelerationStructureFlagBitsNV`
- `VkCopyAccelerationStructureModeNV`
- `VkGeometryFlagBitsNV`
- `VkGeometryInstanceFlagBitsNV`
- `VkGeometryTypeNV`
- `VkRayTracingShaderGroupTypeNV`

**New Bitmasks**
- `VkBuildAccelerationStructureFlagsNV`
- `VkGeometryFlagsNV`
- `VkGeometryInstanceFlagsNV`

**New Enum Constants**
- `VK_NV_RAY_TRACING_EXTENSION_NAME`
- `VK_NV_RAY_TRACING_SPEC_VERSION`
- `VK_SHADER_UNUSED_NV`

Extending `VkAccelerationStructureTypeKHR`:
- `VK_ACCELERATION_STRUCTURE_TYPE_BOTTOM_LEVEL_NV`
- `VK_ACCELERATION_STRUCTURE_TYPE_TOP_LEVEL_NV`

Extending `VkAccessFlagBits`:
- `VK_ACCESS_ACCELERATION_STRUCTURE_READ_BIT_NV`
- `VK_ACCESS_ACCELERATION_STRUCTURE_WRITE_BIT_NV`

Extending `VkBufferUsageFlagBits`:
- `VK_BUFFER_USAGE_RAY_TRACING_BIT_NV`

Extending `VkBuildAccelerationStructureFlagBitsKHR`:
- **VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_COMPACTION_BIT_NV**
- **VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_UPDATE_BIT_NV**
- **VK_BUILD_ACCELERATION_STRUCTURE_LOW_MEMORY_BIT_NV**
- **VK_BUILD_ACCELERATION_STRUCTURE_PREFER_FAST_BUILD_BIT_NV**
- **VK_BUILD_ACCELERATION_STRUCTURE_PREFER_FAST_TRACE_BIT_NV**

- **Extending** `VkCopyAccelerationStructureModeKHR`:
  - **VK_COPY_ACCELERATION_STRUCTURE_MODE_CLONE_NV**
  - **VK_COPY_ACCELERATION_STRUCTURE_MODE_COMPACT_NV**

- **Extending** `VkDescriptorType`:
  - **VK_DESCRIPTOR_TYPE_ACCELERATION_STRUCTURE_NV**

- **Extending** `VkGeometryFlagBitsKHR`:
  - **VK_GEOMETRY_NO_DUPLICATE_ANY_HIT_INVOCATION_BIT_NV**
  - **VK_GEOMETRY_OPAQUE_BIT_NV**

- **Extending** `VkGeometryInstanceFlagBitsKHR`:
  - **VK_GEOMETRY_INSTANCE_FORCE_NO_OPAQUE_BIT_NV**
  - **VK_GEOMETRY_INSTANCE_FORCE_OPAQUE_BIT_NV**
  - **VK_GEOMETRY_INSTANCE_TRIANGLE_CULL_DISABLE_BIT_NV**
  - **VK_GEOMETRY_INSTANCE_TRIANGLE_FRONT_COUNTERCLOCKWISE_BIT_NV**

- **Extending** `VkGeometryTypeKHR`:
  - **VK_GEOMETRY_TYPE_AABBS_NV**
  - **VK_GEOMETRY_TYPE_TRIANGLES_NV**

- **Extending** `VkIndexType`:
  - **VK_INDEX_TYPE_NONE_NV**

- **Extending** `VkObjectType`:
  - **VK_OBJECT_TYPE_ACCELERATION_STRUCTURE_NV**

- **Extending** `VkPipelineBindPoint`:
  - **VK_PIPELINE_BIND_POINT_RAY_TRACING_NV**

- **Extending** `VkPipelineCreateFlagBits`:
  - **VK_PIPELINE_CREATE_DEFER_COMPILE_BIT_NV**

- **Extending** `VkPipelineStageFlagBits`:
  - **VK_PIPELINE_STAGE_ACCELERATION_STRUCTURE_BUILD_BIT_NV**
  - **VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_NV**

- **Extending** `VkQueryType`:
  - **VK_QUERY_TYPE_ACCELERATION_STRUCTURE_COMPACTED_SIZE_NV**

- **Extending** `VkRayTracingShaderGroupTypeKHR`:

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4560
• **Extending VkShaderStageFlagBits:**
  ◦ VK_SHADER_STAGE_ANY_HIT_BIT_NV
  ◦ VK_SHADER_STAGE_CALLABLE_BIT_NV
  ◦ VK_SHADER_STAGE_CLOSEST_HIT_BIT_NV
  ◦ VK_SHADER_STAGE_INTERSECTION_BIT_NV
  ◦ VK_SHADER_STAGE_MISS_BIT_NV
  ◦ VK_SHADER_STAGE_RAYGEN_BIT_NV

• **Extending VkStructureType:**
  ◦ VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_CREATE_INFO_NV
  ◦ VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_INFO_NV
  ◦ VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_MEMORY_REQUIREMENTS_INFO_NV
  ◦ VK_STRUCTURE_TYPE_BIND_ACCELERATION_STRUCTURE_MEMORY_INFO_NV
  ◦ VK_STRUCTURE_TYPE_GEOMETRY_AABB_NV
  ◦ VK_STRUCTURE_TYPE_GEOMETRY_NV
  ◦ VK_STRUCTURE_TYPE_GEOMETRY_TRIANGLES_NV
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_PROPERTIES_NV
  ◦ VK_STRUCTURE_TYPE_RAY_TRACING_PIPELINE_CREATE_INFO_NV
  ◦ VK_STRUCTURE_TYPE_RAY_TRACING_SHADER_GROUP_CREATE_INFO_NV
  ◦ VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET_ACCELERATION_STRUCTURE_NV

If **VK_EXT_debug_report** is supported:

• **Extending VkDebugReportObjectTypeEXT:**
  ◦ VK_DEBUG_REPORT_OBJECT_TYPE_ACCELERATION_STRUCTURE_NV_EXT

**New or Modified Built-In Variables**

• LaunchIdNV
• LaunchSizeNV
• WorldRayOriginNV
• WorldRayDirectionNV
• ObjectRayOriginNV
• ObjectRayDirectionNV
• RayTminNV
• RayTmaxNV
• InstanceCustomIndexNV
• InstanceId
• ObjectToWorldNV
• WorldToObjectNV
• HitTNV
• HitKindNV
• IncomingRayFlagsNV
• (modified)PrimitiveId

New SPIR-V Capabilities
• RayTracingNV

Issues

1) Are there issues?

RESOLVED: Yes.

Sample Code

Example ray generation GLSL shader

```glsl
#version 450 core
#extension GL_NV_ray_tracing : require
layout(set = 0, binding = 0, rgba8) uniform image2D image;
layout(set = 0, binding = 1) uniform accelerationStructureNV as;
layout(location = 0) rayPayloadNV float payload;

void main()
{
    vec4 col = vec4(0, 0, 0, 1);

    vec3 origin = vec3(float(gl_LaunchIDNV.x)/float(gl_LaunchSizeNV.x), float(gl_LaunchIDNV.y)/float(gl_LaunchSizeNV.y), 1.0);
    vec3 dir = vec3(0.0, 0.0, -1.0);

    traceNV(as, 0, 0xff, 0, 1, 0, origin, 0.0, dir, 1000.0, 0);

    col.y = payload;

    imageStore(image, ivec2(gl_LaunchIDNV.xy), col);
}
```
Version History

- Revision 1, 2018-09-11 (Robert Stepinski, Nuno Subtil, Eric Werness)
  - Internal revisions
- Revision 2, 2018-10-19 (Eric Werness)
  - rename to VK_NV_ray_tracing, add support for callables.
  - too many updates to list
- Revision 3, 2018-11-20 (Daniel Koch)
  - update to use InstanceId instead of InstanceIndex as implemented.

VK_NV_ray_tracing_invocation_reorder

Name String

VK_NV_ray_tracing_invocation_reorder

Extension Type

Device extension

Registered Extension Number

491

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_ray_tracing_pipeline

Contact

- Eric Werness ewerness-nv

Other Extension Metadata

Last Modified Date

2022-11-02

Interactions and External Dependencies

- This extension requires SPV_NV_shader_invocation_reorder
- This extension provides API support for GL_NV_shader_invocation_reorder

Contributors

- Eric Werness, NVIDIA
- Ashwin Lele, NVIDIA
Description

The ray tracing pipeline API provides some ability to reorder for locality, but it is useful to have more control over how the reordering happens and what information is included in the reordering. The shader API provides a hit object to contain result information from the hit which can be used as part of the explicit sorting plus options that contain an integer for hint bits to use to add more locality.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceRayTracingInvocationReorderFeaturesNV

- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceRayTracingInvocationReorderPropertiesNV

New Enums

- VkRayTracingInvocationReorderModeNV

New Enum Constants

- VK_NV_RAY_TRACING_INVOCATION_REORDER_EXTENSION_NAME
- VK_NV_RAY_TRACING_INVOCATION_REORDER_SPEC_VERSION
  - Extending VkStructureType:
    - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_INVOCATION_REORDER_FEATURES_NV
    - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_INVOCATION_REORDER_PROPERTIES_NV

HLSL Mapping

HLSL does not provide this functionality natively yet.

However, it is possible to use this functionality via SPIR-V Intrinsics.

The codes for shader invocation reorder are obtained from this page:

```
#define ShaderInvocationReorderNV 5383
#define HitObjectAttributeNV 5385

#define OpHitObjectRecordHitMotionNV 5249
#define OpHitObjectRecordHitWithIndexMotionNV 5250
#define OpHitObjectRecordMissMotionNV 5251
#define OpHitObjectGetWorldToObjectNV 5252
#define OpHitObjectGetObjectToWorldNV 5253
#define OpHitObjectGetObjectRayDirectionNV 5254
#define OpHitObjectGetObjectRayOriginNV 5255
#define OpHitObjectTraceRayMotionNV 5256
```
The capability and extension need to be added:

```cpp
[[vk::ext_capability(ShaderInvocationReorderNV)]]
[[vk::ext_extension("SPV_NV_shader_invocation_reorder")]]
```

The creation of the `HitObject` type can be done like this:

```cpp
[[vk::ext_type_def(HitObjectAttributeNV, OpTypeHitObjectNV)]]
void createHitObjectNV();
#define HitObjectNV vk::ext_type<HitObjectAttributeNV>
```

The payload:

- must be global
- needs the `RayPayloadKHR` attribute as an extra storage class

```cpp
struct [raypayload] HitPayload
{
    float hitT : write(closesthit, miss) : read(caller);
    int instanceIndex : write(closesthit) : read(caller);
    float3 pos : write(closesthit) : read(caller);
}
```
float3 nrm : write(closesthit) : read(caller);
};

#define RayPayloadKHR 5338
[[vk::ext_storage_class(RayPayloadKHR)]] static HitPayload payload;

Here is the declaration of a few invocation reordering functions:

[[vk::ext_instruction(OpHitObjectRecordEmptyNV)]]
void hitObjectRecordEmptyNV([[vk::ext_reference]] HitObjectNV hitObject);

[[vk::ext_instruction(OpHitObjectTraceRayNV)]]
void hitObjectTraceRayNV(
  [[vk::ext_reference]] HitObjectNV hitObject,
  RaytracingAccelerationStructure as,
  uint RayFlags,
  uint CullMask,
  uint SBTOffset,
  uint SBTStride,
  uint MissIndex,
  float3 RayOrigin,
  float RayTmin,
  float3 RayDirection,
  float RayTMax,
  [[vk::ext_reference]] [[vk::ext_storage_class(RayPayloadKHR)]] HitPayload payload
);

[[vk::ext_instruction(OpReorderThreadWithHintNV)]]
void reorderThreadWithHintNV(int Hint, int Bits);

[[vk::ext_instruction(OpReorderThreadWithHitObjectNV)]]
void reorderThreadWithHitObjectNV([[vk::ext_reference]] HitObjectNV hitObject);

[[vk::ext_instruction(OpHitObjectExecuteShaderNV)]]
void hitObjectExecuteShaderNV([[vk::ext_reference]] HitObjectNV hitObject,
  [[vk::ext_reference]] [[vk::ext_storage_class(RayPayloadKHR)]] HitPayload payload);

[[vk::ext_instruction(OpHitObjectIsHitNV)]]
bool hitObjectIsHitNV([[vk::ext_reference]] HitObjectNV hitObject);

Using the function in the code, can be done like this

if (USE_SER == 1)
{
  createHitObjectNV();
  HitObjectNV hObj; // hitObjectNV hObj;
  hitObjectRecordEmptyNV(hObj); // Initialize to an empty hit object
  hitObjectTraceRayNV(hObj, topLevelAS, rayFlags, 0xFF, 0, 0, 0, r.Origin, 0.0, r.Direction, INFINITE, payload);
reorderThreadWithHitObjectNV(hObj);
hitObjectExecuteShaderNV(hObj, payload);
}

Note:

• createHitObjectNV() needs to be call at least once. This can be also done in the main entry of the shader.
• Function with a payload parameter, needs to have the payload struct defined before. There are no templated declaration of the function.

Version History

• Revision 1, 2020-09-12 (Eric Werness, Ashwin Lele)
  ◦ Initial external release

VK_NV_ray_tracing_motion_blur

Name String
  VK_NV_ray_tracing_motion_blur

Extension Type
  Device extension

Registered Extension Number
  328

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_ray_tracing_pipeline

Contact
  • Eric Werness

Other Extension Metadata

Last Modified Date
  2021-06-16

Interactions and External Dependencies
  • This extension requires SPV_NV_ray_tracing_motion_blur
  • This extension provides API support for GL_NV_ray_tracing_motion_blur
Description

Ray tracing support in the API provides an efficient mechanism to intersect rays against static geometry, but rendering algorithms often want to support motion, which is more efficiently supported with motion-specific algorithms. This extension adds a set of mechanisms to support fast tracing of moving geometry:

- A ray pipeline trace call which takes a time parameter
- Flags to enable motion support in an acceleration structure
- Support for time-varying vertex positions in a geometry
- Motion instances to move existing instances over time

The motion represented here is parameterized across a normalized timestep between 0.0 and 1.0. A motion trace using `OpTraceRayMotionNV` provides a time within that normalized range to be used when intersecting that ray with geometry. The geometry can be provided with motion by a combination of adding a second vertex position for time of 1.0 using `VkAccelerationStructureGeometryMotionTrianglesDataNV` and providing multiple transforms in the instance using `VkAccelerationStructureMotionInstanceNV`.

New Structures

- `VkAccelerationStructureMatrixMotionInstanceNV`
- `VkAccelerationStructureMotionInstanceNV`
- `VkAccelerationStructureSRTMotionInstanceNV`
- `VkSRTDataNV`

Extending `VkAccelerationStructureCreateInfoKHR`:

- `VkAccelerationStructureMotionInfoNV`

Extending `VkAccelerationStructureGeometryTrianglesDataKHR`:

- `VkAccelerationStructureGeometryMotionTrianglesDataNV`

Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:

- `VkPhysicalDeviceRayTracingMotionBlurFeaturesNV`

New Unions

- `VkAccelerationStructureMotionInstanceDataNV`

New Enums

- `VkAccelerationStructureMotionInstanceTypeNV`
New Bitmasks

- VkAccelerationStructureMotionInfoFlagsNV
- VkAccelerationStructureMotionInstanceFlagsNV

New Enum Constants

- VK_NV_RAY_TRACING_MOTION_BLUR_EXTENSION_NAME
- VK_NV_RAY_TRACING_MOTION_BLUR_SPEC_VERSION
- Extending VkAccelerationStructureCreateFlagBitsKHR:
  - VK_ACCELERATION_STRUCTURE_CREATE_MOTION_BIT_NV
- Extending VkBuildAccelerationStructureFlagBitsKHR:
  - VK_BUILD_ACCELERATION_STRUCTURE_MOTION_BIT_NV
- Extending VkPipelineCreateFlagBits:
  - VK_PIPELINE_CREATE_RAY_TRACING_ALLOW_MOTION_BIT_NV
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_GEOMETRY_MOTION_TRIANGLES_DATA_NV
  - VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_MOTION_INFO_NV
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_RAY_TRACING_MOTION_BLUR_FEATURES_NV

Issues

(1) What size is VkAccelerationStructureMotionInstanceNV?

- Added a note on the structure size and made the stride explicit in the language.

(2) Allow arrayOfPointers for motion TLAS?

- Yes, with a packed encoding to minimize the amount of data sent for metadata.

Version History

- Revision 1, 2020-06-16 (Eric Werness, Ashwin Lele)
  - Initial external release

VK_NV_representative_fragment_test

Name String

VK_NV_representative_fragment_test

Extension Type

Device extension
This extension provides a new representative fragment test that allows implementations to reduce the amount of rasterization and fragment processing work performed for each point, line, or triangle primitive. For any primitive that produces one or more fragments that pass all other early fragment tests, the implementation is permitted to choose one or more “representative” fragments for processing and discard all other fragments. For draw calls rendering multiple points, lines, or triangles arranged in lists, strips, or fans, the representative fragment test is performed independently for each of those primitives.

This extension is useful for applications that use an early render pass to determine the full set of primitives that would be visible in the final scene. In this render pass, such applications would set up a fragment shader that enables early fragment tests and writes to an image or shader storage buffer to record the ID of the primitive that generated the fragment. Without this extension, the shader would record the ID separately for each visible fragment of each primitive. With this extension, fewer stores will be performed, particularly for large primitives.

The representative fragment test has no effect if early fragment tests are not enabled via the
fragment shader. The set of fragments discarded by the representative fragment test is implementation-dependent and may vary from frame to frame. In some cases, the representative fragment test may not discard any fragments for a given primitive.

New Structures

- Extending `VkGraphicsPipelineCreateInfo`:
  - `VkPipelineRepresentativeFragmentTestStateCreateInfoNV`
- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceRepresentativeFragmentTestFeaturesNV`

New Enum Constants

- `VK_NV_REPRESENTATIVE_FRAGMENT_TEST_EXTENSION_NAME`
- `VK_NV_REPRESENTATIVE_FRAGMENT_TEST_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_REPRESENTATIVE_FRAGMENT_TEST_FEATURES_NV`
  - `VK_STRUCTURE_TYPE_PIPELINE_REPRESENTATIVE_FRAGMENT_TEST_STATE_CREATE_INFO_NV`

Issues

1. Is the representative fragment test guaranteed to have any effect?

**RESOLVED**: No. As specified, we only guarantee that each primitive with at least one fragment that passes prior tests will have one fragment passing the representative fragment tests. We do not guarantee that any particular fragment will fail the test.

In the initial implementation of this extension, the representative fragment test is treated as an optimization that may be completely disabled for some pipeline states. This feature was designed for a use case where the fragment shader records information on individual primitives using shader storage buffers or storage images, with no writes to color or depth buffers.

2. Will the set of fragments that pass the representative fragment test be repeatable if you draw the same scene over and over again?

**RESOLVED**: No. The set of fragments that pass the representative fragment test is implementation-dependent and may vary due to the timing of operations performed by the GPU.

3. What happens if you enable the representative fragment test with writes to color and/or depth render targets enabled?

**RESOLVED**: If writes to the color or depth buffer are enabled, they will be performed for any fragments that survive the relevant tests. Any fragments that fail the representative fragment test will not update color buffers. For the use cases intended for this feature, we do not expect color or depth writes to be enabled.

4. How do derivatives and automatic texture LOD computations work with the representative fragment test?
RESOLVED: If a fragment shader uses derivative functions or texture lookups using automatic LOD computation, derivatives will be computed identically whether or not the representative fragment test is enabled. For the use cases intended for this feature, we do not expect the use of derivatives in the fragment shader.

Version History

- Revision 2, 2018-09-13 (pbrown)
  - Add issues.
- Revision 1, 2018-08-22 (Kedarnath Thangudu)
  - Internal Revisions

VK_NV_sample_mask_override_coverage

Name String

VK_NV_sample_mask_override_coverage

Extension Type

Device extension

Registered Extension Number

95

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

Contact

- Piers Daniell pdaniell-nv

Other Extension Metadata

Last Modified Date

2016-12-08

IP Status

No known IP claims.

Interactions and External Dependencies

- This extension requires SPV_NV_sample_mask_override_coverage
- This extension provides API support for GL_NV_sample_mask_override_coverage
Contributors

• Daniel Koch, NVIDIA
• Jeff Bolz, NVIDIA

Description

This extension adds support for the following SPIR-V extension in Vulkan:

• SPV_NV_sample_mask_override_coverage

The extension provides access to the OverrideCoverageNV decoration under the SampleMaskOverrideCoverageNV capability. Adding this decoration to a variable with the SampleMask builtin decoration allows the shader to modify the coverage mask and affect which samples are used to process the fragment.

When using GLSL source-based shader languages, the override_coverage layout qualifier from GL_NV_sample_mask_override_coverage maps to the OverrideCoverageNV decoration. To use the override_coverage layout qualifier in GLSL the GL_NV_sample_mask_override_coverage extension must be enabled. Behavior is described in the GL_NV_sample_mask_override_coverage extension spec.

New Enum Constants

• VK_NV_SAMPLE_MASK_OVERRIDE_COVERAGE_EXTENSION_NAME
• VK_NV_SAMPLE_MASK_OVERRIDE_COVERAGE_SPEC_VERSION

New Variable Decoration

• OverrideCoverageNV in SampleMask

New SPIR-V Capabilities

• SampleMaskOverrideCoverageNV

Version History

• Revision 1, 2016-12-08 (Piers Daniell)
  ◦ Internal revisions

VK_NV_scissor_exclusive

Name String

  VK_NV_scissor_exclusive

Extension Type

  Device extension

Registered Extension Number

  206
This extension adds support for an exclusive scissor test to Vulkan. The exclusive scissor test behaves like the scissor test, except that the exclusive scissor test fails for pixels inside the corresponding rectangle and passes for pixels outside the rectangle. If the same rectangle is used for both the scissor and exclusive scissor tests, the exclusive scissor test will pass if and only if the scissor test fails.

Version 2 of this extension introduces `VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV` and `vkCmdSetExclusiveScissorEnableNV`. Applications that use this dynamic state must ensure the implementation advertises at least `specVersion 2` of this extension.

**New Commands**

- `vkCmdSetExclusiveScissorEnableNV`
- `vkCmdSetExclusiveScissorNV`
New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceExclusiveScissorFeaturesNV`

- Extending `VkPipelineViewportStateCreateInfo`:
  - `VkPipelineViewportExclusiveScissorStateCreateInfoNV`

New Enum Constants

- `VK_NV_SCISSOR_EXCLUSIVE_EXTENSION_NAME`
- `VK_NV_SCISSOR_EXCLUSIVE_SPEC_VERSION`

- Extending `VkDynamicState`:
  - `VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_ENABLE_NV`
  - `VK_DYNAMIC_STATE_EXCLUSIVE_SCISSOR_NV`

- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXCLUSIVE_SCISSOR_FEATURES_NV`
  - `VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_EXCLUSIVE_SCISSOR_STATE_CREATE_INFO_NV`

Issues

1) For the scissor test, the viewport state must be created with a matching number of scissor and viewport rectangles. Should we have the same requirement for exclusive scissors?

**RESOLVED:** For exclusive scissors, we relax this requirement and allow an exclusive scissor rectangle count that is either zero or equal to the number of viewport rectangles. If you pass in an exclusive scissor count of zero, the exclusive scissor test is treated as disabled.

Version History

- Revision 2, 2023-01-18 (Piers Daniell)
  - Add dynamic state for explicit exclusive scissor enables
- Revision 1, 2018-07-31 (Pat Brown)
  - Internal revisions

VK_NV_shader_image_footprint

Name String

- `VK_NV_shader_image_footprint`

Extension Type

- Device extension
This extension adds Vulkan support for the SPV_NV_shader_image_footprint SPIR-V extension. That SPIR-V extension provides a new instruction OpImageSampleFootprintNV allowing shaders to determine the set of texels that would be accessed by an equivalent filtered texture lookup.

Instead of returning a filtered texture value, the instruction returns a structure that can be interpreted by shader code to determine the footprint of a filtered texture lookup. This structure includes integer values that identify a small neighborhood of texels in the image being accessed and a bitfield that indicates which texels in that neighborhood would be used. The structure also includes a bitfield where each bit identifies whether any texel in a small aligned block of texels would be fetched by the texture lookup. The size of each block is specified by an access granularity provided by the shader. The minimum granularity supported by this extension is 2x2 (for 2D textures) and 2x2x2 (for 3D textures); the maximum granularity is 256x256 (for 2D textures) or
64x32x32 (for 3D textures). Each footprint query returns the footprint from a single texture level. When using minification filters that combine accesses from multiple mipmap levels, shaders must perform separate queries for the two levels accessed (“fine” and “coarse”). The footprint query also returns a flag indicating if the texture lookup would access texels from only one mipmap level or from two neighboring levels.

This extension should be useful for multi-pass rendering operations that do an initial expensive rendering pass to produce a first image that is then used as a texture for a second pass. If the second pass ends up accessing only portions of the first image (e.g., due to visibility), the work spent rendering the non-accessed portion of the first image was wasted. With this feature, an application can limit this waste using an initial pass over the geometry in the second image that performs a footprint query for each visible pixel to determine the set of pixels that it needs from the first image. This pass would accumulate an aggregate footprint of all visible pixels into a separate “footprint image” using shader atomics. Then, when rendering the first image, the application can kill all shading work for pixels not in this aggregate footprint.

This extension has a number of limitations. The `OpImageSampleFootprintNV` instruction only supports for two- and three-dimensional textures. Footprint evaluation only supports the `CLAMP_TO_EDGE` wrap mode; results are undefined for all other wrap modes. Only a limited set of granularity values and that set does not support separate coverage information for each texel in the original image.

When using SPIR-V generated from the OpenGL Shading Language, the new instruction will be generated from code using the new `textureFootprint*NV` built-in functions from the `GL_NV_shader_texture_footprint` shading language extension.

**New Structures**

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceShaderImageFootprintFeaturesNV`

**New Enum Constants**

- `VK_NV_SHADER_IMAGE_FOOTPRINT_EXTENSION_NAME`
- `VK_NV_SHADER_IMAGE_FOOTPRINT_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_IMAGE_FOOTPRINT_FEATURES_NV`

**New SPIR-V Capability**

- `ImageFootprintNV`

**Issues**

(1) The footprint returned by the SPIR-V instruction is a structure that includes an anchor, an offset, and a mask that represents a 8x8 or 4x4x4 neighborhood of texel groups. But the bits of the mask are not stored in simple pitch order. Why is the footprint built this way?

**RESOLVED**: We expect that applications using this feature will want to use a fixed granularity and
accumulate coverage information from the returned footprints into an aggregate “footprint image” that tracks the portions of an image that would be needed by regular texture filtering. If an application is using a two-dimensional image with 4x4 pixel granularity, we expect that the footprint image will use 64-bit texels where each bit in an 8x8 array of bits corresponds to coverage for a 4x4 block in the original image. Texel (0,0) in the footprint image would correspond to texels (0,0) through (31,31) in the original image.

In the usual case, the footprint for a single access will fully contained in a 32x32 aligned region of the original texture, which corresponds to a single 64-bit texel in the footprint image. In that case, the implementation will return an anchor coordinate pointing at the single footprint image texel, an offset vector of (0,0), and a mask whose bits are aligned with the bits in the footprint texel. For this case, the shader can simply atomically OR the mask bits into the contents of the footprint texel to accumulate footprint coverage.

In the worst case, the footprint for a single access spans multiple 32x32 aligned regions and may require updates to four separate footprint image texels. In this case, the implementation will return an anchor coordinate pointing at the lower right footprint image texel and an offset will identify how many “columns” and “rows” of the returned 8x8 mask correspond to footprint texels to the left and above the anchor texel. If the anchor is (2,3), the 64 bits of the returned mask are arranged spatially as follows, where each 4x4 block is assigned a bit number that matches its bit number in the footprint image texels:

```
+-------------------------+-------------------------+
| -- -- -- -- -- -- -- -- | -- -- -- -- -- -- -- -- |
| -- -- -- -- -- -- -- -- | -- -- -- -- -- -- -- -- |
| -- -- -- -- -- -- -- -- | -- -- -- -- -- -- -- -- |
| -- -- -- -- -- -- -- -- | -- -- -- -- -- -- -- -- |
| -- -- -- -- -- -- 46 47 | 40 41 42 43 44 45 -- -- |
| -- -- -- -- -- -- 54 55 | 48 49 50 51 52 53 -- -- |
| -- -- -- -- -- -- 62 63 | 56 57 58 59 60 61 -- -- |
+-------------------------+-------------------------+
| -- -- -- -- -- -- 06 07 | 00 01 02 03 04 05 -- -- |
| -- -- -- -- -- -- 14 15 | 08 09 10 11 12 13 -- -- |
| -- -- -- -- -- -- 22 23 | 16 17 18 19 20 21 -- -- |
| -- -- -- -- -- -- 30 31 | 24 25 26 27 28 29 -- -- |
| -- -- -- -- -- -- 38 39 | 32 33 34 35 36 37 -- -- |
+-------------------------+-------------------------+
```

To accumulate coverage for each of the four footprint image texels, a shader can AND the returned mask with simple masks derived from the x and y offset values and then atomically OR the updated mask bits into the contents of the corresponding footprint texel.

```c
uint64_t returnedMask = (uint64_t)(footprint.mask.x) | (uint64_t)(footprint.mask.y) << 32);
```
uint64_t rightMask = ((0xFF >> footprint.offset.x) * 0x0101010101010101UL);
uint64_t bottomMask = 0xFFFFFFFFFFFFFFFFUL >> (8 * footprint.offset.y);
uint64_t bottomRight = returnedMask & bottomMask & rightMask;
uint64_t bottomLeft = returnedMask & bottomMask & (~rightMask);
uint64_t topRight = returnedMask & (~bottomMask) & rightMask;
uint64_t topLeft = returnedMask & (~bottomMask) & (~rightMask);

(2) What should an application do to ensure maximum performance when accumulating footprints into an aggregate footprint image?

**RESOLVED**: We expect that the most common usage of this feature will be to accumulate aggregate footprint coverage, as described in the previous issue. Even if you ignore the anisotropic filtering case where the implementation may return a granularity larger than that requested by the caller, each shader invocation will need to use atomic functions to update up to four footprint image texels for each LOD accessed. Having each active shader invocation perform multiple atomic operations can be expensive, particularly when neighboring invocations will want to update the same footprint image texels.

Techniques can be used to reduce the number of atomic operations performed when accumulating coverage include:

- Have logic that detects returned footprints where all components of the returned offset vector are zero. In that case, the mask returned by the footprint function is guaranteed to be aligned with the footprint image texels and affects only a single footprint image texel.
- Have fragment shaders communicate using built-in functions from the `VK_NV_shader_subgroup_partitioned` extension or other shader subgroup extensions. If you have multiple invocations in a subgroup that need to update the same texel (x,y) in the footprint image, compute an aggregate footprint mask across all invocations in the subgroup updating that texel and have a single invocation perform an atomic operation using that aggregate mask.
- When the returned footprint spans multiple texels in the footprint image, each invocation need to perform four atomic operations. In the previous issue, we had an example that computed separate masks for “topLeft”, “topRight”, “bottomLeft”, and “bottomRight”. When the invocations in a subgroup have good locality, it might be the case the “top left” for some invocations might refer to footprint image texel (10,10), while neighbors might have their “top left” texels at (11,10), (10,11), and (11,11). If you compute separate masks for even/odd x and y values instead of left/right or top/bottom, the “odd/odd” mask for all invocations in the subgroup hold coverage for footprint image texel (11,11), which can be updated by a single atomic operation for the entire subgroup.

**Examples**

TBD

**Version History**

- Revision 2, 2018-09-13 (Pat Brown)
  - Add issue (2) with performance tips.
VK_NV_shader_sm_builtins

Name String
VK_NV_shader_sm_builtins

Extension Type
Device extension

Registered Extension Number
155

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
Version 1.1

Contact
• Daniel Koch dgkoch

Other Extension Metadata

Last Modified Date
2019-05-28

Interactions and External Dependencies
• This extension requires SPV_NV_shader_sm_builtins.
• This extension provides API support for GL_NV_shader_sm_builtins

Contributors
• Jeff Bolz, NVIDIA
• Eric Werness, NVIDIA

Description
This extension provides the ability to determine device-specific properties on NVIDIA GPUs. It provides the number of streaming multiprocessors (SMs), the maximum number of warps (subgroups) that can run on an SM, and shader builtins to enable invocations to identify which SM and warp a shader invocation is executing on.

This extension enables support for the SPIR-V ShaderSMBuiltinsNV capability.
These properties and built-ins should typically only be used for debugging purposes.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceShaderSMBuiltinsFeaturesNV
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceShaderSMBuiltinsPropertiesNV

New Enum Constants

- VK_NV_SHADER_SM_BUILTINS_EXTENSION_NAME
- VK_NV_SHADER_SM_BUILTINS_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_SM_BUILTINS_FEATURES_NV
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_SM_BUILTINS_PROPERTIES_NV

New or Modified Built-In Variables

- WarpsPerSMNV
- SMCountNV
- WarpIDNV
- SMIDNV

New SPIR-V Capabilities

- ShaderSMBuiltinsNV

Issues

1. What should we call this extension?

   **RESOLVED:** NV_shader_sm_builtins. Other options considered included:
   - NV_shader_smid - but SMID is really easy to typo/confuse as SIMD.
   - NV_shader_sm_info - but **Info** is typically reserved for input structures

Version History

- Revision 1, 2019-05-28 (Daniel Koch)
  - Internal revisions
VK_NV_shader_subgroup_partitioned

Name String
VK_NV_shader_subgroup_partitioned

Extension Type
Device extension

Registered Extension Number
199

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
Version 1.1

Contact
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Other Extension Metadata

Last Modified Date
2018-03-17

Interactions and External Dependencies
• This extension requires SPV_NV_shader_subgroup_partitioned
• This extension provides API support for GL_NV_shader_subgroup_partitioned

Contributors
• Jeff Bolz, NVIDIA

Description
This extension enables support for a new class of group operations on subgroups via the GL_NV_shader_subgroup_partitioned GLSL extension and SPV_NV_shader_subgroup_partitioned SPIR-V extension. Support for these new operations is advertised via the VK_SUBGROUP_FEATURE_PARTITIONED_BIT_NV bit.

This extension requires Vulkan 1.1, for general subgroup support.

New Enum Constants

• VK_NV_SHADER_SUBGROUP_PARTITIONED_EXTENSION_NAME
• VK_NV_SHADER_SUBGROUP_PARTITIONED_SPEC_VERSION
• Extending VkSubgroupFeatureFlagBits:
  ◦ VK_SUBGROUP_FEATURE_PARTITIONED_BIT_NV

Version History

• Revision 1, 2018-03-17 (Jeff Bolz)
  ◦ Internal revisions

VK_NV_shading_rate_image

Name String
  VK_NV_shading_rate_image

Extension Type
  Device extension

Registered Extension Number
  165

Revision
  3

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_get_physical_device_properties2

Contact
  • Pat Brown @nvpbrown

Other Extension Metadata

Last Modified Date
  2019-07-18

Interactions and External Dependencies
  • This extension requires SPV_NV_shading_rate
  • This extension provides API support for GL_NV_shading_rate_image

Contributors
  • Pat Brown, NVIDIA
  • Carsten Rohde, NVIDIA
  • Jeff Bolz, NVIDIA
  • Daniel Koch, NVIDIA
  • Mathias Schott, NVIDIA
Description

This extension allows applications to use a variable shading rate when processing fragments of rasterized primitives. By default, Vulkan will spawn one fragment shader for each pixel covered by a primitive. In this extension, applications can bind a *shading rate image* that can be used to vary the number of fragment shader invocations across the framebuffer. Some portions of the screen may be configured to spawn up to 16 fragment shaders for each pixel, while other portions may use a single fragment shader invocation for a 4x4 block of pixels. This can be useful for use cases like eye tracking, where the portion of the framebuffer that the user is looking at directly can be processed at high frequency, while distant corners of the image can be processed at lower frequency. Each texel in the shading rate image represents a fixed-size rectangle in the framebuffer, covering 16x16 pixels in the initial implementation of this extension. When rasterizing a primitive covering one of these rectangles, the Vulkan implementation reads a texel in the bound shading rate image and looks up the fetched value in a palette to determine a base shading rate.

In addition to the API support controlling rasterization, this extension also adds Vulkan support for the *SPV_NV_shading_rate* extension to SPIR-V. That extension provides two fragment shader variable decorations that allow fragment shaders to determine the shading rate used for processing the fragment:

- *FragmentSizeNV*, which indicates the width and height of the set of pixels processed by the fragment shader.
- *InvocationsPerPixel*, which indicates the maximum number of fragment shader invocations that could be spawned for the pixel(s) covered by the fragment.

When using SPIR-V in conjunction with the OpenGL Shading Language (GLSL), the fragment shader capabilities are provided by the *GL_NV_shading_rate_image* language extension and correspond to the built-in variables *gl_FragmentSizeNV* and *gl_InvocationsPerPixelNV*, respectively.

New Commands

- *vkCmdBindShadingRateImageNV*
- *vkCmdSetCoarseSampleOrderNV*
- *vkCmdSetViewportShadingRatePaletteNV*

New Structures

- *VkCoarseSampleLocationNV*
- *VkCoarseSampleOrderCustomNV*
- *VkShadingRatePaletteNV*
- Extending *VkPhysicalDeviceFeatures2, VkDeviceCreateInfo*:
  - *VkPhysicalDeviceShadingRateImageFeaturesNV*
- Extending *VkPhysicalDeviceProperties2*:
New Enums

• VkCoarseSampleOrderTypeNV
• VkShadingRatePaletteEntryNV

New Enum Constants

• VK_NV_SHADING_RATE_IMAGE_EXTENSION_NAME
• VK_NV_SHADING_RATE_IMAGE_SPEC_VERSION

Extending VkAccessFlagBits:

• VK_ACCESS_SHADING_RATE_IMAGE_READ_BIT_NV

Extending VkDynamicState:

• VK_DYNAMIC_STATE_VIEWPORT_COARSE_SAMPLE_ORDER_NV
• VK_DYNAMIC_STATE_VIEWPORT_SHADING_RATE_PALETTE_NV

Extending VkImageLayout:

• VK_IMAGE_LAYOUT_SHADING_RATE_OPTIMAL_NV

Extending VkImageUsageFlagBits:

• VK_IMAGE_USAGE_SHADING_RATE_IMAGE_BIT_NV

Extending VkPipelineStageFlagBits:

• VK_PIPELINE_STAGE_SHADING_RATE_IMAGE_BIT_NV

Extending VkStructureType:

• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADING_RATE_IMAGE_FEATURES_NV
• VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADING_RATE_IMAGE_PROPERTIES_NV
• VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_COARSE_SAMPLE_ORDER_STATE_CREATE_INFO_NV
• VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_SHADING_RATE_IMAGE_STATE_CREATE_INFO_NV

Issues

(1) When using shading rates specifying “coarse” fragments covering multiple pixels, we will generate a combined coverage mask that combines the coverage masks of all pixels covered by the fragment. By default, these masks are combined in an implementation-dependent order. Should we provide a mechanism allowing applications to query or specify an exact order?

**RESOLVED**: Yes, this feature is useful for cases where most of the fragment shader can be evaluated once for an entire coarse fragment, but where some per-pixel computations are also
required. For example, a per-pixel alpha test may want to kill all the samples for some pixels in a coarse fragment. This sort of test can be implemented using an output sample mask, but such a shader would need to know which bit in the mask corresponds to each sample in the coarse fragment. We are including a mechanism to allow applications to specify the orders of coverage samples for each shading rate and sample count, either as static pipeline state or dynamically via a command buffer. This portion of the extension has its own feature bit.

We will not be providing a query to determine the implementation-dependent default ordering. The thinking here is that if an application cares enough about the coarse fragment sample ordering to perform such a query, it could instead just set its own order, also using custom per-pixel sample locations if required.

(2) For the pipeline stage `VK_PIPELINE_STAGE_SHADING_RATE_IMAGE_BIT_NV`, should we specify a precise location in the pipeline the shading rate image is accessed (after geometry shading, but before the early fragment tests) or leave it under-specified in case there are other implementations that access the image in a different pipeline location?

**RESOLVED** We are specifying the pipeline stage to be between the final pre-rasterization shader stage (`VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT`) and before the first stage used for fragment processing (`VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT`), which seems to be the natural place to access the shading rate image.

(3) How do centroid-sampled variables work with fragments larger than one pixel?

**RESOLVED** For single-pixel fragments, fragment shader inputs decorated with `Centroid` are sampled at an implementation-dependent location in the intersection of the area of the primitive being rasterized and the area of the pixel that corresponds to the fragment. With multi-pixel fragments, we follow a similar pattern, using the intersection of the primitive and the set of pixels corresponding to the fragment.

One important thing to keep in mind when using such “coarse” shading rates is that fragment attributes are sampled at the center of the fragment by default, regardless of the set of pixels/samples covered by the fragment. For fragments with a size of 4x4 pixels, this center location will be more than two pixels (1.5 * \(\sqrt{2}\)) away from the center of the pixels at the corners of the fragment. When rendering a primitive that covers only a small part of a coarse fragment, sampling a color outside the primitive can produce overly bright or dark color values if the color values have a large gradient. To deal with this, an application can use centroid sampling on attributes where “extrapolation” artifacts can lead to overly bright or dark pixels. Note that this same problem also exists for multisampling with single-pixel fragments, but is less severe because it only affects certain samples of a pixel and such bright/dark samples may be averaged with other samples that do not have a similar problem.

**Version History**

- Revision 3, 2019-07-18 (Mathias Schott)
  - Fully list extension interfaces in this appendix.
- Revision 2, 2018-09-13 (Pat Brown)
  - Miscellaneous edits preparing the specification for publication.
VK_NV_viewport_array2

Name String
VK_NV_viewport_array2

Extension Type
Device extension

Registered Extension Number
97

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies

Contact
• Daniel Koch dgkoch

Other Extension Metadata

Last Modified Date
2017-02-15

Interactions and External Dependencies
• This extension requires SPV_NV_viewport_array2
• This extension provides API support for GL_NV_viewport_array2
• This extension requires the geometryShader and multiViewport features.
• This extension interacts with the tessellationShader feature.

Contributors
• Piers Daniell, NVIDIA
• Jeff Bolz, NVIDIA

Description
This extension adds support for the following SPIR-V extension in Vulkan:

• SPV_NV_viewport_array2

which allows a single primitive to be broadcast to multiple viewports and/or multiple layers. A new shader built-in output ViewportMaskNV is provided, which allows a single primitive to be output to
multiple viewports simultaneously. Also, a new SPIR-V decoration is added to control whether the effective viewport index is added into the variable decorated with the Layer built-in decoration. These capabilities allow a single primitive to be output to multiple layers simultaneously.

This extension allows variables decorated with the Layer and ViewportIndex built-ins to be exported from vertex or tessellation shaders, using the ShaderViewportIndexLayerNV capability.

This extension adds a new ViewportMaskNV built-in decoration that is available for output variables in vertex, tessellation evaluation, and geometry shaders, and a new ViewportRelativeNV decoration that can be added on variables decorated with Layer when using the ShaderViewportMaskNV capability.

When using GLSL source-based shading languages, the glViewportMask[] built-in output variable and viewport_relative layout qualifier from GL_NV_viewport_array2 map to the ViewportMaskNV and ViewportRelativeNV decorations, respectively. Behaviour is described in the GL_NV_viewport_array2 extension specification.

Note
The ShaderViewportIndexLayerNV capability is equivalent to the ShaderViewportIndexLayerEXT capability added by VK_EXT_shader_viewport_index_layer.

**New Enum Constants**

- VK_NV_VIEWPORT_ARRAY2_EXTENSION_NAME
- VK_NV_VIEWPORT_ARRAY2_SPEC_VERSION
- VK_NV_VIEWPORT_ARRAY_2_EXTENSION_NAME
- VK_NV_VIEWPORT_ARRAY_2_SPEC_VERSION

**New or Modified Built-In Variables**

- (modified) Layer
- (modified) ViewportIndex
- ViewportMaskNV

**New Variable Decoration**

- ViewportRelativeNV in Layer

**New SPIR-V Capabilities**

- ShaderViewportIndexLayerNV
- ShaderViewportMaskNV
Version History

- Revision 1, 2017-02-15 (Daniel Koch)
  - Internal revisions

VK_NV_viewport_swizzle

Name String
VK_NV_viewport_swizzle

Extension Type
Device extension

Registered Extension Number
99

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies

Contact
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Other Extension Metadata

Last Modified Date
2016-12-22

Interactions and External Dependencies
- This extension requires multiViewport and geometryShader features to be useful.

Contributors
- Daniel Koch, NVIDIA
- Jeff Bolz, NVIDIA

Description

This extension provides a new per-viewport swizzle that can modify the position of primitives sent to each viewport. New viewport swizzle state is added for each viewport, and a new position vector is computed for each vertex by selecting from and optionally negating any of the four components of the original position vector.

This new viewport swizzle is useful for a number of algorithms, including single-pass cube map rendering (broadcasting a primitive to multiple faces and reorienting the vertex position for each face) and voxel rasterization. The per-viewport component remapping and negation provided by
the swizzle allows application code to re-orient three-dimensional geometry with a view along any of the X, Y, or Z axes. If a perspective projection and depth buffering is required, 1/W buffering should be used, as described in the single-pass cube map rendering example in the “Issues” section below.

New Structures

- VkViewportSwizzleNV
- Extending VkPipelineViewportStateCreateInfo:
  - VkPipelineViewportSwizzleStateCreateInfoNV

New Enums

- VkViewportCoordinateSwizzleNV

New Bitmasks

- VkPipelineViewportSwizzleStateCreateFlagsNV

New Enum Constants

- VK_NV_VIEWPORT_SWIZZLE_EXTENSION_NAME
- VK_NV_VIEWPORT_SWIZZLE_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PIPELINE_VIEWPORT_SWIZZLE_STATE_CREATE_INFO_NV

Issues

1) Where does viewport swizzling occur in the pipeline?

**RESOLVED**: Despite being associated with the viewport, viewport swizzling must happen prior to the viewport transform. In particular, it needs to be performed before clipping and perspective division.

The viewport mask expansion (VK_NV_viewport_array2) and the viewport swizzle could potentially be performed before or after transform feedback, but feeding back several viewports worth of primitives with different swizzles does not seem particularly useful. This specification applies the viewport mask and swizzle after transform feedback, and makes primitive queries only count each primitive once.

2) Any interesting examples of how this extension, VK_NV_viewport_array2, and VK_NV_geometry_shader_passthrough can be used together in practice?

**RESOLVED**: One interesting use case for this extension is for single-pass rendering to a cube map. In this example, the application would attach a cube map texture to a layered FBO where the six cube faces are treated as layers. Vertices are sent through the vertex shader without applying a projection matrix, where the gl_Position output is (x,y,z,1) and the center of the cube map is at 4590.
With unextended Vulkan, one could have a conventional instanced geometry shader that looks something like the following:

```glsl
layout(invocations = 6) in;    // separate invocation per face
layout(triangles) in;
layout(triangle_strip) out;
layout(max_vertices = 3) out;

in Inputs {
    vec2 texcoord;
    vec3 normal;
    vec4 baseColor;
} v[];

out Outputs {
    vec2 texcoord;
    vec3 normal;
    vec4 baseColor;
};

void main()
{
    int face = gl_InvocationID;    // which face am I?

    // Project gl_Position for each vertex onto the cube map face.
    vec4 positions[3];
    for (int i = 0; i < 3; i++) {
        positions[i] = rotate(gl_in[i].gl_Position, face);
    }

    // If the primitive does not project onto this face, we are done.
    if (shouldCull(positions)) {
        return;
    }

    // Otherwise, emit a copy of the input primitive to the appropriate face (using gl_Layer).
    for (int i = 0; i < 3; i++) {
        gl_Layer = face;
        gl_Position = positions[i];
        texcoord = v[i].texcoord;
        normal = v[i].normal;
        baseColor = v[i].baseColor;
        EmitVertex();
    }
}
```

With passthrough geometry shaders, this can be done using a much simpler shader:
The application code is set up so that each of the six cube faces has a separate viewport (numbered 0 to 5). Each face also has a separate swizzle, programmed via the `VkPipelineViewportSwizzleStateCreateInfoNV` pipeline state. The viewport swizzle feature performs the coordinate transformation handled by the `rotate()` function in the original shader. The `viewport_relative` layout qualifier says that the viewport number (0 to 5) is added to the base `gl_Layer` value of 0 to determine which layer (cube face) the primitive should be sent to.

Note that the use of the passed through input `normal` in this example suggests that the fragment shader in this example would perform an operation like per-fragment lighting. The viewport swizzle would transform the position to be face-relative, but `normal` would remain in the original coordinate system. It seems likely that the fragment shader in either version of the example would want to perform lighting in the original coordinate system. It would likely do this by reconstructing the position of the fragment in the original coordinate system using `gl_FragCoord`, a constant or uniform holding the size of the cube face, and the input `gl_ViewportIndex` (or `gl_Layer`), which identifies the cube face. Since the value of `normal` is in the original coordinate system, it would not need to be modified as part of this coordinate transformation.

Note that while the `rotate()` operation in the regular geometry shader above could include an arbitrary post-rotation projection matrix, the viewport swizzle does not support arbitrary math. To get proper projection, 1/W buffering should be used. To do this:

1. Program the viewport swizzles to move the pre-projection W eye coordinate (typically 1.0) into the Z coordinate of the swizzle output and the eye coordinate component used for depth into the W coordinate. For example, the viewport corresponding to the +Z face might use a swizzle of
The $Z$ normalized device coordinate computed after swizzling would then be $z'/w' = 1/Z_{\text{eye}}$.

2. On NVIDIA implementations supporting floating-point depth buffers with values outside $[0,1]$, prevent unwanted near plane clipping by enabling `depthClampEnable`. Ensure that the depth clamp does not mess up depth testing by programming the depth range to very large values, such as $\text{minDepthBounds}=-z$, $\text{maxDepthBounds}=+z$, where $z = 2^{127}$. It should be possible to use IEEE infinity encodings also ($0xFF800000$ for $-\text{INF}$, $0x7F800000$ for $+\text{INF}$). Even when near/far clipping is disabled, primitives extending behind the eye will still be clipped because one or more vertices will have a negative $W$ coordinate and fail $X/Y$ clipping tests.

On other implementations, scale $X$, $Y$, and $Z$ eye coordinates so that vertices on the near plane have a post-swizzle $W$ coordinate of 1.0. For example, if the near plane is at $Z_{\text{eye}} = 1/256$, scale $X$, $Y$, and $Z$ by 256.

3. Adjust depth testing to reflect the fact that $1/W$ values are large near the eye and small away from the eye. Clear the depth buffer to zero (infinitely far away) and use a depth test of `VK_COMPARE_OP_GREATER` instead of `VK_COMPARE_OP_LESS`.

Version History

- Revision 1, 2016-12-22 (Piers Daniell)
  - Internal revisions

**VK_NVX_binary_import**

**Name String**

`VK_NVX_binary_import`

**Extension Type**

Device extension

**Registered Extension Number**

30

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

**Contact**

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Other Extension Metadata

Last Modified Date
2021-04-09

Contributors
- Eric Werness, NVIDIA
- Liam Middlebrook, NVIDIA

Description
This extension allows applications to import CuBIN binaries and execute them.

Note
There is currently no specification language written for this extension. The links to APIs defined by the extension are to stubs that only include generated content such as API declarations and implicit valid usage statements.

New Object Types
- VkCuFunctionNVX
- VkCuModuleNVX

New Commands
- vkCmdCuLaunchKernelNVX
- vkCreateCuFunctionNVX
- vkCreateCuModuleNVX
- vkDestroyCuFunctionNVX
- vkDestroyCuModuleNVX

New Structures
- VkCuFunctionCreateInfoNVX
- VkCuLaunchInfoNVX
- VkCuModuleCreateInfoNVX

New Enum Constants
- VK_NVX_BINARY_IMPORT_EXTENSION_NAME
- VK_NVX_BINARY_IMPORT_SPEC_VERSION

Extending VkObjectType:
- VK_OBJECT_TYPE_CU_FUNCTION_NVX
• VK_OBJECT_TYPE_CU_MODULE_NVX

**Extending VkStructureType:**

• VK_STRUCTURE_TYPE_CU_FUNCTION_CREATE_INFO_NVX
• VK_STRUCTURE_TYPE_CU_LAUNCH_INFO_NVX
• VK_STRUCTURE_TYPE_CU_MODULE_CREATE_INFO_NVX

If **VK_EXT_debug_report** is supported:

• Extending VkDebugReportObjectTypeEXT:

  • VK_DEBUG_REPORT_OBJECT_TYPE_CU_FUNCTION_NVX_EXT
  • VK_DEBUG_REPORT_OBJECT_TYPE_CU_MODULE_NVX_EXT

**Stub API References**

There is currently no specification language written for this type. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

```cpp
// Provided by VK_NVX_binary_import
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkCuFunctionNVX)
```

There is currently no specification language written for this type. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

```cpp
// Provided by VK_NVX_binary_import
VK_DEFINE_NON_DISPATCHABLE_HANDLE(VkCuModuleNVX)
```

There is currently no specification language written for this command. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

```cpp
// Provided by VK_NVX_binary_import
VkResult vkCreateCuFunctionNVX(
    VkDevice device,
    const VkCuFunctionCreateInfoNVX* pCreateInfo,
    const VkAllocationCallbacks* pAllocator,
    VkCuFunctionNVX* pFunction);
```

**Valid Usage (Implicit)**

• VUID-vkCreateCuFunctionNVX-device-parameter
device must be a valid VkDevice handle

• VUID-vkCreateCuFunctionNVX-pCreateInfo-parameter
pCreateInfo must be a valid pointer to a valid VkCuFunctionCreateInfoNVX structure
If `pAllocator` is not `NULL`, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure.

`pFunction` must be a valid pointer to a `VkCuFunctionNVX` handle.

### Return Codes

**Success**
- VK_SUCCESS

**Failure**
- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_INITIALIZATION_FAILED

There is currently no specification language written for this type. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

```c
// Provided by VK_NVX_binary_import
typedef struct VkCuFunctionCreateInfoNVX {
    VkStructureType sType;
    const void* pNext;
    VkCuModuleNVX module;
    const char* pName;
} VkCuFunctionCreateInfoNVX;
```

### Valid Usage (Implicit)

- VUID-VkCuFunctionCreateInfoNVX-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_CU_FUNCTION_CREATE_INFO_NVX`

- VUID-VkCuFunctionCreateInfoNVX-pNext-pNext
  `pNext` must be `NULL`

- VUID-VkCuFunctionCreateInfoNVX-module-parameter
  `module` must be a valid `VkCuModuleNVX` handle

- VUID-VkCuFunctionCreateInfoNVX-pName-parameter
  `pName` must be a null-terminated UTF-8 string

There is currently no specification language written for this command. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

```c
// Provided by VK_NVX_binary_import
void vkDestroyCuFunctionNVX(
    VkDevice                     device,
```
VkCuFunctionNVX function,
const VkAllocationCallbacks* pAllocator);

Valid Usage (Implicit)

- VUID-vkDestroyCuFunctionNVX-device-parameter
device must be a valid VkDevice handle
- VUID-vkDestroyCuFunctionNVX-function-parameter
function must be a valid VkCuFunctionNVX handle
- VUID-vkDestroyCuFunctionNVX-pAllocator-parameter
If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure
- VUID-vkDestroyCuFunctionNVX-function-parent
function must have been created, allocated, or retrieved from device

There is currently no specification language written for this command. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

// Provided by VK_NVX_binary_import
VkResult vkCreateCuModuleNVX(
    VkDevice device, const VkCuModuleCreateInfoNVX* pCreateInfo, const VkAllocationCallbacks* pAllocator, VkCuModuleNVX* pModule);

Valid Usage (Implicit)

- VUID-vkCreateCuModuleNVX-device-parameter
device must be a valid VkDevice handle
- VUID-vkCreateCuModuleNVX-pCreateInfo-parameter
pCreateInfo must be a valid pointer to a valid VkCuModuleCreateInfoNVX structure
- VUID-vkCreateCuModuleNVX-pAllocator-parameter
If pAllocator is not NULL, pAllocator must be a valid pointer to a valid VkAllocationCallbacks structure
- VUID-vkCreateCuModuleNVX-pModule-parameter
pModule must be a valid pointer to a VkCuModuleNVX handle

Return Codes

Success
- VK_SUCCESS
Failure

- VK_ERROR_OUT_OF_HOST_MEMORY
- VK_ERROR_INITIALIZATION_FAILED

There is currently no specification language written for this type. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

```c
// Provided by VK_NVX_binary_import
typedef struct VkCuModuleCreateInfoNVX {
    VkStructureType sType;
    const void* pNext;
    size_t dataSize;
    const void* pData;
} VkCuModuleCreateInfoNVX;
```

Valid Usage (Implicit)

- VUID-VkCuModuleCreateInfoNVX-sType-sType
  `sType` must be `VK_STRUCTURE_TYPE_CU_MODULE_CREATE_INFO_NVX`

- VUID-VkCuModuleCreateInfoNVX-pNext-pNext
  `pNext` must be `NULL`

- VUID-VkCuModuleCreateInfoNVX-pData-parameter
  `pData` must be a valid pointer to an array of `dataSize` bytes

- VUID-VkCuModuleCreateInfoNVX-dataSize-arraylength
  `dataSize` must be greater than 0

There is currently no specification language written for this command. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

```c
// Provided by VK_NVX_binary_import
void vkDestroyCuModuleNVX(
    VkDevice device,  
    VkCuModuleNVX module,  
    const VkAllocationCallbacks* pAllocator);
```

Valid Usage (Implicit)

- VUID-vkDestroyCuModuleNVX-device-parameter
  `device` must be a valid `VkDevice` handle

- VUID-vkDestroyCuModuleNVX-module-parameter
  `module` must be a valid `VkCuModuleNVX` handle

- VUID-vkDestroyCuModuleNVX-pAllocator-parameter
If `pAllocator` is not NULL, `pAllocator` must be a valid pointer to a valid `VkAllocationCallbacks` structure

- VUID-vkDestroyCuModuleNVX-module-parent
  
  module must have been created, allocated, or retrieved from device

There is currently no specification language written for this command. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

```c
// Provided by VK_NVX_binary_import
void vkCmdCuLaunchKernelNVX(
    VkCommandBuffer commandBuffer,
    const VkCuLaunchInfoNVX* pLaunchInfo);
```

### Valid Usage (Implicit)

- VUID-vkCmdCuLaunchKernelNVX-commandBuffer-parameter
  
  `commandBuffer` must be a valid `VkCommandBuffer` handle

- VUID-vkCmdCuLaunchKernelNVX-pLaunchInfo-parameter
  
  `pLaunchInfo` must be a valid pointer to a valid `VkCuLaunchInfoNVX` structure

- VUID-vkCmdCuLaunchKernelNVX-commandBuffer-recording
  
  `commandBuffer` must be in the recording state

- VUID-vkCmdCuLaunchKernelNVX-commandBuffer-cmdpool
  
  The `VkCommandPool` that `commandBuffer` was allocated from must support graphics, or compute operations

- VUID-vkCmdCuLaunchKernelNVX-videocoding
  
  This command must only be called outside of a video coding scope

### Host Synchronization

- Host access to the `VkCommandPool` that `commandBuffer` was allocated from must be externally synchronized

### Command Properties

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</table>

There is currently no specification language written for this type. This section acts only as
// Provided by VK_NVX_binary_import

typedef struct VkCuLaunchInfoNVX {
    VkStructureType sType;
    const void* pNext;
    VkCuFunctionNVX function;
    uint32_t gridDimX;
    uint32_t gridDimY;
    uint32_t gridDimZ;
    uint32_t blockDimX;
    uint32_t blockDimY;
    uint32_t blockDimZ;
    uint32_t sharedMemBytes;
    size_t paramCount;
    const void* const * pParams;
    size_t extraCount;
    const void* const * pExtras;
} VkCuLaunchInfoNVX;

Valid Usage (Implicit)

• VUID-VkCuLaunchInfoNVX-sType-sType
  sType must be VK_STRUCTURE_TYPE_CU_LAUNCH_INFO_NVX

• VUID-VkCuLaunchInfoNVX-pNext-pNext
  pNext must be NULL

• VUID-VkCuLaunchInfoNVX-function-parameter
  function must be a valid VkCuFunctionNVX handle

• VUID-VkCuLaunchInfoNVX-pParams-parameter
  If paramCount is not 0, pParams must be a valid pointer to an array of paramCount bytes

• VUID-VkCuLaunchInfoNVX-pExtras-parameter
  If extraCount is not 0, pExtras must be a valid pointer to an array of extraCount bytes

Version History

• Revision 1, 2021-04-09 (Eric Werness)
  ◦ Internal revisions

VK_NVX_image_view_handle

Name String
  VK_NVX_image_view_handle

Extension Type
  Device extension
Description

This extension allows applications to query an opaque handle from an image view for use as a sampled image or storage image. This provides no direct functionality itself.

New Commands

- vkGetImageViewAddressNVX
- vkGetImageViewHandleNVX

New Structures

- VkImageViewAddressPropertiesNVX
- VkImageViewHandleInfoNVX

New Enum Constants

- VK_NVX_IMAGE_VIEW_HANDLE_EXTENSION_NAME
- VK_NVX_IMAGE_VIEW_HANDLE_SPEC_VERSION

Extending VkStructureType:

- VK_STRUCTURE_TYPE_IMAGE_VIEW_ADDRESS_PROPERTIES_NVX
- VK_STRUCTURE_TYPE_IMAGE_VIEW_HANDLE_INFO_NVX
Version History

- Revision 2, 2020-04-03 (Piers Daniell)
  - Add vkGetImageViewAddressNVX
- Revision 1, 2018-12-07 (Eric Werness)
  - Internal revisions

VK_NVX_multiview_per_view_attributes

Name String
  VK_NVX_multiview_per_view_attributes

Extension Type
  Device extension

Registered Extension Number
  98

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_multiview

Contact
  - Jeff Bolz jeffbolznv

Other Extension Metadata

Last Modified Date
  2017-01-13

IP Status
  No known IP claims.

Interactions and External Dependencies
  - This extension requires SPV_NVX_multiview_per_view_attributes
  - This extension provides API support for GL_NVX_multiview_per_view_attributes
  - This extension interacts with VK_NV_viewport_array2.

Contributors
  - Jeff Bolz, NVIDIA
  - Daniel Koch, NVIDIA
Description

This extension adds a new way to write shaders to be used with multiview subpasses, where the attributes for all views are written out by a single invocation of the pre-rasterization shader stages. Related SPIR-V and GLSL extensions SPV_NVX_multiview_per_view_attributes and GL_NVX_multiview_per_view_attributes introduce per-view position and viewport mask attributes arrays, and this extension defines how those per-view attribute arrays are interpreted by Vulkan. Pipelines using per-view attributes may only execute the pre-rasterization shader stages once for all views rather than once per-view, which reduces redundant shading work.

A subpass creation flag controls whether the subpass uses this extension. A subpass must either exclusively use this extension or not use it at all.

Some Vulkan implementations only support the position attribute varying between views in the X component. A subpass can declare via a second creation flag whether all pipelines compiled for this subpass will obey this restriction.

Shaders that use the new per-view outputs (e.g. gl_PositionPerViewNV) must also write the non-per-view output (gl_Position), and the values written must be such that gl_Position = gl_PositionPerViewNV[gl_ViewIndex] for all views in the subpass. Implementations are free to either use the per-view outputs or the non-per-view outputs, whichever would be more efficient.

If VK_NV_viewport_array2 is not also supported and enabled, the per-view viewport mask must not be used.

New Structures

- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceMultiviewPerViewAttributesPropertiesNVX

New Enum Constants

- VK_NVX_MULTIVIEW_PER_VIEW_ATTRIBUTES_EXTENSION_NAME
- VK_NVX_MULTIVIEW_PER_VIEW_ATTRIBUTES_SPEC_VERSION

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_PER_VIEW_ATTRIBUTES_PROPERTIES_NVX

- Extending VkSubpassDescriptionFlagBits:
  - VK_SUBPASS_DESCRIPTION_PER_VIEW_ATTRIBUTES_BIT_NVX
  - VK_SUBPASS_DESCRIPTION_PER_VIEW_POSITION_X_ONLY_BIT_NVX

New Built-In Variables

- PositionPerViewNV
- ViewportMaskPerViewNV
New SPIR-V Capabilities

- PerViewAttributesNV

Examples

```glsl
#version 450 core

#extension GL_KHX_multiview : enable
#extension GL_NVX_multiview_per_view_attributes : enable

layout(location = 0) in vec4 position;
layout(set = 0, binding = 0) uniform Block { mat4 mvpPerView[2]; } buf;

void main()
{
  // Output both per-view positions and gl_Position as a function of gl_ViewIndex
  gl_PositionPerViewNV[0] = buf.mvpPerView[0] * position;
  gl_Position = buf.mvpPerView[gl_viewIndex] * position;
}
```

Version History

- Revision 1, 2017-01-13 (Jeff Bolz)
  - Internal revisions

VK_QCOM_filter_cubic_clamp

Name String

VK_QCOM_filter_cubic_clamp

Extension Type

Device extension

Registered Extension Number

522

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_EXT_filter_cubic
Description

This extension extends cubic filtering by adding the ability to enable an anti-ringing clamp. Cubic filtering samples from a 4x4 region of texels and computes a cubic weighted average of the region. In some cases, the resulting value is outside the range of any of the texels in the 4x4 region. This is sometimes referred to as “filter overshoot” or “filter ringing” and can occur when there is a sharp discontinuity in the 4x4 region being filtered. For some use cases this “ringing” can produces unacceptable artifacts.

The solution to the ringing problem is to clamp the post-cubic-filtered value to be within the max and min of texel values in the 4x4 region. While such “range clamping” can be performed in shader code, the additional texture fetches and clamping ALU operations can be costly.

Certain Adreno GPUs are able to perform the range clamp in the texture unit during cubic filtering at significant performance/power savings versus a shader-based clamping approach. This extension exposes such hardware functionality.

This extension extends `VkSamplerReductionMode`, adding `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_RANGECLAMP_QCOM` which enables the range clamp operation.

New Structures

- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDeviceCubicClampFeaturesQCOM`

New Enum Constants

- `VK_QCOM_FILTER_CUBIC_CLAMP_EXTENSION_NAME`
- `VK_QCOM_FILTER_CUBIC_CLAMP_SPEC_VERSION`
- Extending `VkSamplerReductionMode`:
• Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CUBIC_CLAMP_FEATURES_QCOM`

**Version History**

- Revision 1, 2023-08-02 (jleger)
  - Initial version

**VK_QCOM_filter_cubic_weights**

**Name String**

`VK_QCOM_filter_cubic_weights`

**Extension Type**

Device extension

**Registered Extension Number**

520

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

`VK_EXT_filter_cubic`

**Contact**

- Jeff Leger `@jackohound`

**Other Extension Metadata**

**Last Modified Date**

2023-06-23

**Contributors**

- Jeff Leger, Qualcomm Technologies, Inc.
- Jonathan Wicks, Qualcomm Technologies, Inc.

**Description**

This extension extends cubic filtering by adding the ability to select a set of weights. Without this extension, the weights used in cubic filtering are limited to those corresponding to a Catmull-Rom spline. This extension adds support for 3 additional spline weights.
This extension adds a new structure that can be added to the pNext chain of VkSamplerCreateInfo that can be used to specify which set of cubic weights are used in cubic filtering. A similar structure can be added to the pNext chain of VkBlitImageInfo2 to specify cubic weights used in a blit operation.

With this extension weights corresponding to the following additional splines can be selected for cubic filtered sampling and blits:

- Zero Tangent Cardinal
- B-Spline
- Mitchell-Netravali

**New Structures**

- Extending VkBlitImageInfo2:
  - VkBlitImageCubicWeightsInfoQCOM
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceCubicWeightsFeaturesQCOM
- Extending VkSamplerCreateInfo:
  - VkSamplerCubicWeightsCreateInfoQCOM

**New Enums**

- VkCubicFilterWeightsQCOM

**New Enum Constants**

- VK_QCOM_FILTER_CUBIC_WEIGHTS_EXTENSION_NAME
- VK_QCOM_FILTER_CUBIC_WEIGHTS_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_BLIT_IMAGE_CUBIC_WEIGHTS_INFO_QCOM
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_CUBIC_WEIGHTS_FEATURES_QCOM
  - VK_STRUCTURE_TYPE_SAMPLER_CUBIC_WEIGHTS_CREATE_INFO_QCOM

**Version History**

- Revision 1, 2023-06-23 (jleger)
  - Initial version

**VK_QCOM_fragment_density_map_offset**

**Name String**

   VK_QCOM_fragment_density_map_offset
Extension Type
Device extension

Registered Extension Number
426

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2
and
VK_EXT_fragment_density_map

Contact
- Matthew Netsch

Other Extension Metadata
Last Modified Date
2021-09-03

Contributors
- Matthew Netsch, Qualcomm Technologies, Inc.
- Jonathan Wicks, Qualcomm Technologies, Inc.
- Jonathan Tinkham, Qualcomm Technologies, Inc.
- Jeff Leger, Qualcomm Technologies, Inc.

Description
This extension allows an application to specify offsets to a fragment density map attachment, changing the framebuffer location where density values are applied to without having to regenerate the fragment density map.

New Structures
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceFragmentDensityMapOffsetFeaturesQCOM
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceFragmentDensityMapOffsetPropertiesQCOM
- Extending VkSubpassEndInfo:
  - VkSubpassFragmentDensityMapOffsetEndInfoQCOM
New Enum Constants

- `VK_QCOM_FRAGMENT_DENSITY_MAP_OFFSET_EXTENSION_NAME`
- `VK_QCOM_FRAGMENT_DENSITY_MAP_OFFSET_SPEC_VERSION`
- Extending `VkImageCreateFlagBits`:
  - `VK_IMAGE_CREATE_FRAGMENT_DENSITY_MAP_OFFSET_BIT_QCOM`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_OFFSET_FEATURES_QCOM`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_DENSITY_MAP_OFFSET_PROPERTIES_QCOM`
  - `VK_STRUCTURE_TYPE_SUBPASS_FRAGMENT_DENSITY_MAP_OFFSET_END_INFO_QCOM`

Version History

- Revision 1, 2021-09-03 (Matthew Netsch)
  - Initial version

**VK_QCOM_image_processing**

Name String

`VK_QCOM_image_processing`

Extension Type

Device extension

Registered Extension Number

441

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

`VK_KHR_format_feature_flags2`

Contact

- Jeff Leger @jackohound

Extension Proposal

`VK_QCOM_image_processing`

Other Extension Metadata
Interactions and External Dependencies

- This extension requires SPV_QCOM_image_processing
- This extension provides API support for GL_QCOM_image_processing

Contributors

- Jeff Leger, Qualcomm Technologies, Inc.
- Ruihao Zhang, Qualcomm Technologies, Inc.

Description

GPUs are commonly used to process images for various applications from 3D graphics to UI and from composition to compute applications. Simple scaling and filtering can be done with bilinear filtering, which comes for free during texture sampling. However, as screen sizes get larger and more use cases rely on GPU such as camera and video post-processing needs, there is increasing demand for GPU to support higher order filtering and other advanced image processing.

This extension introduces a new set of SPIR-V built-in functions for image processing. It exposes the following new imaging operations:

- The `OpImageSampleWeightedQCOM` instruction takes 3 operands: `sampled image`, `weight image`, and texture coordinates. The instruction computes a weighted average of an MxN region of texels in the `sampled image`, using a set of MxN weights in the `weight image`.

- The `OpImageBoxFilterQCOM` instruction takes 3 operands: `sampled image`, `box size`, and texture coordinates. Note that `box size` specifies a floating point width and height in texels. The instruction computes a weighted average of all texels in the `sampled image` that are covered (either partially or fully) by a box with the specified size and centered at the specified texture coordinates.

- The `OpImageBlockMatchSADQCOM` and `OpImageBlockMatchSSDQCOM` instructions each takes 5 operands: `target image`, `target coordinates`, `reference image`, `reference coordinates`, and `block size`. Each instruction computes an error metric, that describes whether a block of texels in the `target image` matches a corresponding block of texels in the `reference image`. The error metric is computed per-component. `OpImageBlockMatchSADQCOM` computes "Sum Of Absolute Difference" and `OpImageBlockMatchSSDQCOM` computes "Sum of Squared Difference".

Each of the image processing instructions operate only on 2D images. The instructions do not support sampling of mipmap, multi-plane, multi-layer, multi-sampled, or depth/stencil images. The instructions can be used in any shader stage.

Implementations of this this extension should support these operations natively at the HW instruction level, offering potential performance gains as well as ease of development.

New Structures

- Extending `VkImageViewCreateInfo`:
• **VkImageViewSampleWeightCreateInfoQCOM**
  
• Extending **VkPhysicalDeviceFeatures2, VkDeviceCreateInfo**:
  
• **VkPhysicalDeviceImageProcessingFeaturesQCOM**
  
• Extending **VkPhysicalDeviceProperties2**:
  
  - **VkPhysicalDeviceImageProcessingPropertiesQCOM**

**New Enum Constants**

- **VK_QCOM_IMAGE_PROCESSING_EXTENSION_NAME**
- **VK_QCOM_IMAGE_PROCESSING_SPEC_VERSION**

• Extending **VkDescriptorType**:
  
  - **VK_DESCRIPTOR_TYPE_BLOCK_MATCH_IMAGE_QCOM**
  - **VK_DESCRIPTOR_TYPE_SAMPLE_WEIGHT_IMAGE_QCOM**

• Extending **VkImageUsageFlagBits**:
  
  - **VK_IMAGE_USAGE_SAMPLE_BLOCK_MATCH_BIT_QCOM**
  - **VK_IMAGE_USAGE_SAMPLE_WEIGHT_BIT_QCOM**

• Extending **VkSamplerCreateFlagBits**:
  
  - **VK_SAMPLER_CREATE_IMAGE_PROCESSING_BIT_QCOM**

• Extending **VkStructureType**:
  
  - **VK_STRUCTURE_TYPE_IMAGE_VIEW_SAMPLE_WEIGHT_CREATE_INFO_QCOM**
  - **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_PROCESSING_FEATURES_QCOM**
  - **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_PROCESSING_PROPERTIES_QCOM**

If **VK_KHR_format_feature_flags2** is supported:

• Extending **VkFormatFeatureFlagBits2**:
  
  - **VK_FORMAT_FEATURE_2_BLOCK_MATCHING_BIT_QCOM**
  - **VK_FORMAT_FEATURE_2_BOX_FILTER_SAMPLED_BIT_QCOM**
  - **VK_FORMAT_FEATURE_2_WEIGHT_IMAGE_BIT_QCOM**
  - **VK_FORMAT_FEATURE_2_WEIGHT_SAMPLED_IMAGE_BIT_QCOM**

**Version History**

- Revision 1, 2022-07-08 (Jeff Leger)

**VK_QCOM_image_processing2**

Name String

**VK_QCOM_image_processing2**

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4611
Extension Type
Device extension

Registered Extension Number
519

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_QCOM_image_processing

Contact
• Jeff Leger @jackohound

Other Extension Metadata

Last Modified Date
2023-03-10

Interactions and External Dependencies
• This extension requires SPV_QCOM_image_processing2
• This extension provides API support for GL_QCOM_image_processing2

Contributors
• Jeff Leger, Qualcomm Technologies, Inc.

Description
This extension enables support for the SPIR-V TextureBlockMatch2QCOM capability. It builds on the functionality of QCOM_image_processing with the addition of 4 new image processing operations.

• The opImageBlockMatchWindowSADQCOM SPIR-V instruction builds upon the functionality of opImageBlockMatchSADQCOM by repeatedly performing block match operations across a 2D window. The “2D windowExtent” and “compareMode” are are specified by VkSamplerBlockMatchWindowCreateInfoQCOM in the sampler used to create the target image. Like OpImageBlockMatchSADQCOM, opImageBlockMatchWindowSADQCOM computes an error metric, that describes whether a block of texels in the target image matches a corresponding block of texels in the reference image. Unlike OpImageBlockMatchSADQCOM, this instruction computes an error metric at each (X,Y) location within the 2D window and returns either the minimum or maximum error. The instruction only supports single-component formats. Refer to the pseudocode below for details.

• The opImageBlockMatchWindowSSDQCOM follows the same pattern, computing the SSD error metric at each location within the 2D window.
The `opImageBlockMatchGatherSADQCOM` builds upon `OpImageBlockMatchSADQCOM`. This instruction computes an error metric, that describes whether a block of texels in the *target image* matches a corresponding block of texels in the *reference image*. The instruction computes the SAD error metric at 4 texel offsets and returns the error metric for each offset in the X,Y,Z, and W components. The instruction only supports single-component texture formats. Refer to the pseudocode below for details.

The `opImageBlockMatchGatherSSDQCOM` follows the same pattern, computing the SSD error metric for 4 offsets.

Each of the above 4 image processing instructions are limited to single-component formats.

Below is the pseudocode for GLSL built-in function `textureWindowBlockMatchSADQCOM`. The pseudocode for `textureWindowBlockMatchSSD` is identical other than replacing all instances of "SAD" with "SSD".

```glsl
vec4 textureBlockMatchWindowSAD( sampler2D target,
    uvec2 targetCoord,
    sampler2D reference,
    uvec2 refCoord,
    uvec2 blocksize) {

    // compareMode (MIN or MAX) comes from the vkSampler associated with `target`
    // uvec2 window comes from the vkSampler associated with `target`
    minSAD = INF;
    maxSAD = -INF;
    uvec2 minCoord;
    uvec2 maxCoord;

    for (uint x=0, x < window.width; x++) {
        for (uint y=0, y < window.height; y++) {
            float SAD = textureBlockMatchSAD(target,
                targetCoord + uvec2(x, y),
                reference,
                refCoord,
                blocksize).x;

            // Note: the below comparison operator will produce undefined results
            // if SAD is a denorm value.
            if (SAD < minSAD) {
                minSAD = SAD;
                minCoord = uvec2(x, y);
            }
            if (SAD > maxSAD) {
                maxSAD = SAD;
                maxCoord = uvec2(x, y);
            }
        }
    }

    if (compareMode=MIN) {
        return vec4(minSAD, minCoord.x, minCoord.y, 0.0);
    } else {
        return vec4(maxSAD, maxCoord.x, maxCoord.y, 0.0);
    }
}
```
Below is the pseudocode for `textureBlockMatchGatherSADQCOM`. The pseudocode for `textureBlockMatchGatherSSD` follows an identical pattern.

```cpp
vec4 textureBlockMatchGatherSAD(sampler2D target, uvec2 targetCoord, sampler2D reference, uvec2 refCoord, uvec2 blocksize) {
    vec4 out;
    for (uint x=0; x<4; x++) {
        float SAD = textureBlockMatchSAD(target, targetCoord + uvec2(x, 0), reference, refCoord, blocksize).x;
        out[x] = SAD;
    }
    return out;
}
```

New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceImageProcessing2FeaturesQCOM`

- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceImageProcessing2PropertiesQCOM`

- Extending `VkSamplerCreateInfo`:
  - `VkSamplerBlockMatchWindowCreateInfoQCOM`

New Enums

- `VkBlockMatchWindowCompareModeQCOM`

New Enum Constants

- `VK_QCOM_IMAGE_PROCESSING_2_EXTENSION_NAME`
- `VK_QCOM_IMAGE_PROCESSING_2_SPEC_VERSION`

- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_PROCESSING_2_FEATURES_QCOM`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_PROCESSING_2_PROPERTIES_QCOM`
  - `VK_STRUCTURE_TYPE_SAMPLER_BLOCK_MATCH_WINDOW_CREATE_INFO_QCOM`
Issues

1) What is the precision of the min/max comparison checks?

**RESOLVED**: Intermediate computations for the new operations are performed at 16-bit floating point precision. If the value of "float SAD" in the above code sample is a 16-bit denorm value, then behavior of the MIN/MAX comparison is undefined.

**Version History**

- Revision 1, 2023-03-10 (Jeff Leger)

**VK_QCOM_multiview_per_view_render_areas**

**Name String**

VK_QCOM_multiview_per_view_render_areas

**Extension Type**

Device extension

**Registered Extension Number**

511

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

**Contact**

- Jeff Leger @jackohound

**Other Extension Metadata**

**Last Modified Date**

2023-01-10

**IP Status**

No known IP claims.

**Interactions and External Dependencies**

- This extension interacts with VK_KHR_dynamic_rendering
- This extension interacts with VK_QCOM_render_pass_transform

**Contributors**

- Jeff Leger, Qualcomm
- Jonathan Tinkham, Qualcomm
Description

Certain use cases (e.g., side-by-side VR rendering) use multiview and render to distinct regions of the framebuffer for each view. On some implementations, there may be a performance benefit for providing per-view render areas to the implementation. Such per-view render areas can be used by the implementation to reduce the pixels that are affected by attachment load, store, and multisample resolve operations.

The extension enables a multiview render pass instance to define per-view render areas. For each view of a multiview render pass instance, only those pixels in the per-view render area are affected by load, store, and resolve operations.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceMultiviewPerViewRenderAreasFeaturesQCOM
- Extending VkRenderPassBeginInfo, VkRenderingInfo:
  - VkMultiviewPerViewRenderAreasRenderPassBeginInfoQCOM

New Enum Constants

- VK_QCOM_MULTIVIEW_PER_VIEW_RENDER_AREAS_EXTENSION_NAME
- VK_QCOM_MULTIVIEW_PER_VIEW_RENDER_AREAS_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_MULTIVIEW_PER_VIEW_RENDER_AREAS_RENDER_PASS_BEGIN_INFO_QCOM
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_PER_VIEW_RENDER_AREAS_FEATURES_QCOM

Issues

1) Do the per-view renderAreas interact with vkGetRenderAreaGranularity?

RESOLVED: There is no change. The granularity returned by vkGetRenderAreaGranularity also applies to the per-view renderAreas.

2) How does this extension interact with VK_QCOM_render_pass_transform?

RESOLVED: When VK_QCOM_render_pass_transform is enabled, the application provides render area in non-rotated coordinates which is rotated by the implementation to the rotated coordinate system. When this extension is used in combination with VK_QCOM_render_pass_transform, then the renderArea provided in VkRenderingInfo::renderArea, VkRenderPassBeginInfo::renderArea, or VkCommandBufferInheritanceRenderPassTransformInfoQCOM::renderArea is rotated by the implementation. The per-view render areas are not rotated.

3) How does this extension interact with VK_QCOM_multiview_per_view_viewports
RESOLVED: There is no direct interaction. The per-view viewports and the per-view renderAreas are orthogonal features.

4) When a per-view renderArea is specified, must multiview rendering for each view of a multiview render pass be contained within the per-view renderArea?

RESOLVED: Yes, and the VK_QCOM_multiview_per_view_viewports may help here since it provides per-view scissors.

5) When per-view render areas are specified, what purpose if any do VkRenderPassBeginInfo::renderArea and VkRenderingInfo::renderArea serve?

RESOLVED: The per-view renderArea effectively overrides the per-renderpass renderArea. The per-view renderArea defines the regions of the attachments that are effected by load, store, and multisample resolve operations. A valid implementation could ignore the per-renderpass renderArea. However, as an aid to the implementation, the application must set the per-renderpass renderArea to an area that is at least as large as the union of all the per-view render areas. Pixels that are within the per-renderpass renderArea but not within any per-view render area must not be affected by load, store, or multisample resolve operations.

Version History

- Revision 1, 2023-01-10 (Jeff Leger)

VK_QCOM_multiview_per_view_viewports

Name String

VK_QCOM_multiview_per_view_viewports

Extension Type

Device extension

Registered Extension Number

489

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Contact

- Jeff Leger jackohound
Other Extension Metadata

Last Modified Date
2022-11-22

IP Status
No known IP claims.

Interactions and External Dependencies
- This extension interacts with VK_KHR_dynamic_rendering
- This extension interacts with VK_EXT_extended_dynamic_state

Contributors
- Jeff Leger, Qualcomm
- Jonathan Tinkham, Qualcomm
- Jonathan Wicks, Qualcomm

Description
Certain use cases for multiview have a need for specifying a separate viewport and scissor for each view, without using shader-based viewport indexing as introduced with VK_EXT_shader_viewport_index_layer.

This extension adds a new way to control ViewportIndex with multiview. When the multiviewPerViewViewports feature is enabled and if the last pre-rasterization shader entry point's interface does not use the ViewportIndex built-in decoration, then each view of a multiview render pass instance will use a viewport and scissor index equal to the ViewIndex.

New Structures
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceMultiviewPerViewViewportsFeaturesQCOM

New Enum Constants
- VK_QCOM_MULTIVIEW_PER_VIEW_VIEWPORTS_EXTENSION_NAME
- VK_QCOM_MULTIVIEW_PER_VIEW_VIEWPORTS_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_PER_VIEW_VIEWPORTS_FEATURES_QCOM

Issues
1) Is it possible to enable/disable the multiviewPerViewViewports feature for individual render pass instances?

RESOLVED: No, when the multiviewPerViewViewports feature is enabled during vkCreateDevice,
then all created render pass instances (including dynamic render passes from
VK_KHR_dynamic_rendering) and all created VkPipelines will have the feature enabled. This approach
was chosen because it simplifies application code and there is no known use case enable/disable
the feature for individual render passes or pipelines.

2) When this extension is used, is the value of ViewportIndex implicitly written by the last pre-
rasterization shader stage and can the value of ViewportIndex be read in the fragment shader?

**RESOLVED**: No, use of the extension extension does not add an implicit write to ViewportIndex in
any shader stage, and additionally, the value of ViewportIndex in the fragment shader is undefined.

**Version History**

- Revision 1, 2022-11-22 (Jeff Leger)

**VK_QCOM_render_pass_shader_resolve**

**Name String**

VK_QCOM_render_pass_shader_resolve

**Extension Type**

Device extension

**Registered Extension Number**

172

**Revision**

4

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

**Contact**

- Bill Licea-Kane wwlk

**Other Extension Metadata**

**Last Modified Date**

2019-11-07

**IP Status**

No known IP claims.

**Interactions and External Dependencies**

None.
**Contributors**
- Srihari Babu Alla, Qualcomm
- Bill Licea-Kane, Qualcomm
- Jeff Leger, Qualcomm

**Description**

This extension allows a shader resolve to replace fixed-function resolve.

Fixed-function resolve is limited in function to simple filters of multisample buffers to a single sample buffer.

Fixed-function resolve is more performance efficient and/or power efficient than shader resolve for such simple filters.

Shader resolve allows a shader writer to create complex, non-linear filtering of a multisample buffer in the last subpass of a subpass dependency chain.

This extension also provides a bit which can be used to enlarge a sample region dependency to a fragment region dependency, so that a framebuffer-region dependency can replace a framebuffer-global dependency in some cases.

**New Enum Constants**

- `VK_QCOM_RENDER_PASS_SHADER_RESOLVE_EXTENSION_NAME`
- `VK_QCOM_RENDER_PASS_SHADER_RESOLVE_SPEC_VERSION`
- Extending `VkSubpassDescriptionFlagBits`:
  - `VK_SUBPASS_DESCRIPTION_FRAGMENT_REGION_BIT_QCOM`
  - `VK_SUBPASS_DESCRIPTION_SHADER_RESOLVE_BIT_QCOM`

**Issues**

1) Should this extension be named `render_pass_shader_resolve`?

**RESOLVED** Yes.

This is part of a suite of small extensions to render pass.

Following the style guide, instead of following `VK_KHR_create_renderpass2`.

2) Should the `VK_SAMPLE_COUNT_1_BIT` be required for each `pColorAttachment` and the `DepthStencilAttachment`?

**RESOLVED** No.

While this may not be a common use case, and while most fixed-function resolve hardware has this limitation, there is little reason to require a shader resolve to resolve to a single sample buffer.
3) Should a shader resolve subpass be the last subpass in a render pass?

**RESOLVED** Yes.

To be more specific, it should be the last subpass in a subpass dependency chain.

4) Do we need the `VK_SUBPASS_DESCRIPTION_FRAGMENT_REGION_BIT_QCOM` bit?

**RESOLVED** Yes.

This applies when an input attachment's sample count is equal to `rasterizationSamples`. Further, if `sampleShading` is enabled (explicitly or implicitly) then `minSampleShading` must equal 0.0.

However, this bit may be set on any subpass, it is not restricted to a shader resolve subpass.

**Version History**

- **Revision 1, 2019-06-28 (wwlk)**
  - Initial draft

- **Revision 2, 2019-11-06 (wwlk)**
  - General clean-up/spec updates
  - Added issues

- **Revision 3, 2019-11-07 (wwlk)**
  - Typos
  - Additional issues
  - Clarified that a shader resolve subpass is the last subpass in a subpass dependency chain

- **Revision 4, 2020-01-06 (wwlk)**
  - Change resolution of Issue 1 (`render_pass`, not `renderpass`)

**VK_QCOM_render_pass_store_ops**

**Name String**

`VK_QCOM_render_pass_store_ops`

**Extension Type**

Device extension

**Registered Extension Number**

302

**Revision**

2

**Ratification Status**

Not ratified
Description

Render pass attachments can be read-only for the duration of a render pass.

Examples include input attachments and depth attachments where depth tests are enabled but depth writes are not enabled.

In such cases, there can be no contents generated for an attachment within the render area.

This extension adds a new VkAttachmentStoreOp VK_ATTACHMENT_STORE_OP_NONE_QCOM specifying that the contents within the render area may not be written to memory, but that the prior contents of the attachment in memory are preserved. However, if any contents were generated within the render area during rendering, the contents of the attachment will be undefined inside the render area.

Note

The VkAttachmentStoreOp VK_ATTACHMENT_STORE_OP_STORE may force an implementation to assume that the attachment was written and force an implementation to flush data to memory or to a higher level cache. The VkAttachmentStoreOp VK_ATTACHMENT_STORE_OP_NONE_QCOM may allow an implementation to assume that the attachment was not written and allow an implementation to avoid such a flush.

New Enum Constants

- VK_QCOM_RENDER_PASS_STORE_OPS_EXTENSION_NAME
- VK_QCOM_RENDER_PASS_STORE_OPS_SPEC_VERSION

Extending VkAttachmentStoreOp:
- VK_ATTACHMENT_STORE_OP_NONE_QCOM

Version History

- Revision 1, 2019-12-20 (wwlk)
  - Initial version
• Revision 2, 2020-03-25 (wwlk)
  ◦ Minor renaming

**VK_QCOM_render_pass_transform**

**Name String**
  `VK_QCOM_render_pass_transform`

**Extension Type**
  Device extension

**Registered Extension Number**
  283

**Revision**
  3

**Ratification Status**
  Not ratified

**Extension and Version Dependencies**
  • `VK_KHR_swapchain`
  • `VK_KHR_surface`

**Contact**
  • Jeff Leger (@jackohound)

**Other Extension Metadata**

**Last Modified Date**
  2022-07-21

**Interactions and External Dependencies**
  • This extension requires `VK_KHR_swapchain`
  • This extension interacts with `VK_EXT_fragment_density_map`
  • This extension interacts with `VK_KHR_fragment_shading_rate`
  • This extension interacts with `VK_QCOM_tile_properties`

**Contributors**
  • Jeff Leger, Qualcomm Technologies, Inc.
  • Brandon Light, Qualcomm Technologies, Inc.
  • Matthew Netsch, Qualcomm Technologies, Inc.
Description

This extension provides a mechanism for applications to enable driver support for render pass transform.

Mobile devices can be rotated and mobile applications need to render properly when a device is held in a landscape or portrait orientation. When the current orientation differs from the device’s native orientation, a rotation is required so that the “up” direction of the rendered scene matches the current orientation.

If the Display Processing Unit (DPU) does not natively support rotation, the Vulkan presentation engine can handle this rotation in a separate composition pass. Alternatively, the application can render frames “pre-rotated” to avoid this extra pass. The latter is preferred to reduce power consumption and achieve the best performance because it avoids tasking the GPU with extra work to perform the copy/rotate operation.

Unlike OpenGL ES, the burden of pre-rotation in Vulkan falls on the application. To implement pre-rotation, applications render into swapchain images matching the device native aspect ratio of the display and “pre-rotate” the rendering content to match the device’s current orientation. The burden is more than adjusting the Model View Projection (MVP) matrix in the vertex shader to account for rotation and aspect ratio. The coordinate systems of scissors, viewports, derivatives and several shader built-ins may need to be adapted to produce the correct result.

It is difficult for some game engines to manage this burden; many chose to simply accept the performance/power overhead of performing rotation in the presentation engine.

This extension allows applications to achieve the performance benefits of pre-rotated rendering by moving much of the above-mentioned burden to the graphics driver. The following is unchanged with this extension:

• Applications create a swapchain matching the native orientation of the display. Applications must also set the VkSwapchainCreateInfoKHR::preTransform equal to the currentTransform as returned by vkGetPhysicalDeviceSurfaceCapabilitiesKHR.

The following is changed with this extension:

• At vkCmdBeginRenderPass, the application provides extension struct VkRenderPassTransformBeginInfoQCOM specifying the render pass transform parameters.
• At vkBeginCommandBuffer for secondary command buffers, the application provides extension struct VkCommandBufferInheritanceRenderPassTransformInfoQCOM specifying the render pass transform parameters.
• The renderArea, viewports, scissors, and fragmentSize are all provided in the current (non-rotated) coordinate system. The implementation will transform those into the native (rotated) coordinate system.
• The implementation is responsible for transforming shader built-ins (FragCoord, PointCoord, SamplePosition, PrimitiveShadingRateKHR, interpolateAt(), dFdx, dFdy, fWidth) into the rotated coordinate system.
• The implementation is responsible for transforming position to the rotated coordinate system.
If this extension is used with VK_QCOM_tile_properties, then
vkGetFramebufferTilePropertiesQCOM and vkGetDynamicRenderingTilePropertiesQCOM
return tile properties in the rotated coordinate space.

New Structures

- Extending VkCommandBufferInheritanceInfo:
  - VkCommandBufferInheritanceRenderPassTransformInfoQCOM
- Extending VkRenderPassBeginInfo:
  - VkRenderPassTransformBeginInfoQCOM

New Enum Constants

- VK_QCOM_RENDER_PASS_TRANSFORM_EXTENSION_NAME
- VK_QCOM_RENDER_PASS_TRANSFORM_SPEC_VERSION
- Extending VkRenderPassCreateFlagBits:
  - VK_RENDER_PASS_CREATE_TRANSFORM_BIT_QCOM
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_RENDER_PASS_TRANSFORM_INFO_QCOM
  - VK_STRUCTURE_TYPE_RENDER_PASS_TRANSFORM_BEGIN_INFO_QCOM

Issues

1) Some early Adreno drivers (October 2019 through March 2020) advertised support for this
extension but expected VK_STRUCTURE_TYPE values different from those in the vulkan headers. To
cover all Adreno devices on the market, applications need to detect the driver version and use the
appropriate VK_STRUCTURE_TYPE values from the table below.

The driver version reported in VkPhysicalDeviceProperties.driverVersion is a uint32_t type. You
can decode the uint32_t value into a major.minor.patch version as shown below:

```c
uint32_t major = ((driverVersion) >> 22);
uint32_t minor = ((driverVersion) >> 12) & 0x3ff;
uint32_t patch = ((driverVersion) & 0xfff);
```

If the Adreno major.minor.patch version is greater than or equal to 512.469.0, then simply use
the VK_STRUCTURE_TYPE values as defined in vulkan_core.h. If the version is less than or equal to
512.468.0, then use the alternate values for the two VK_STRUCTURE_TYPEs in the table below.

Table 98. Adreno Driver Requirements

<table>
<thead>
<tr>
<th>Adreno Driver Version</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>512.468.0 and earlier</td>
<td>512.469.0 and later</td>
</tr>
<tr>
<td>VK_STRUCTURE_TYPE_RENDER_PASS_TRANSFORM_BEGIN_INFO_QCOM</td>
<td>1000282000</td>
</tr>
<tr>
<td>VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_RENDER_PASS_TRANSFORM_INFO_QCOM</td>
<td>1000282001</td>
</tr>
</tbody>
</table>

2) Should the extension support only rotations (e.g. 90, 180, 270-degrees), or also mirror transforms (e.g. vertical flips)? Mobile use cases only require rotation. Other display systems such as projectors might require a flipped transform.

**RESOLVED:** In this version of the extension, the functionality is restricted to 90, 180, and 270-degree rotations to address mobile use cases.

3) How does this extension interact with VK_EXT_fragment_density_map?

**RESOLVED** Some implementations may not be able to support a render pass that enables both render pass transform and fragment density maps. For simplicity, this extension disallows enabling both features within a single render pass.

4) What should this extension be named?

We considered names such as “rotated_rendering”, “pre_rotation” and others. Since the functionality is limited to a render pass, it seemed the name should include “render_pass”. While the current extension is limited to rotations, it could be extended to other transforms (like mirror) in the future.

**RESOLVED** The name “render_pass_transform” seems like the most accurate description of the introduced functionality.

5) How does this extension interact with VK_KHR_fragment_shading_rate?

**RESOLVED:** For the same reasons as issue 3, this extension disallows enabling both pFragmentShadingRateAttachment and render pass transform within a single render pass.

However, pipeline shading rate and primitive shading rate are supported, and their respective fragmentSize and PrimitiveShadingRateKHR are provided in the current (non-rotated) coordinate system. The implementation is responsible for transforming them to the rotated coordinate system.

The set of supported shading rates **may** be different per transform. Supported rates queried from vkGetPhysicalDeviceFragmentShadingRatesKHR are in the native (rotated) coordinate system. This means that the application **must** swap the x/y of the reported rates to get the set of rates supported for 90 and 270 degree rotation.
Version History

- Revision 1, 2020-02-05 (Jeff Leger)
- Revision 2, 2021-03-09 (Matthew Netsch)
  - Adds interactions with VK_KHR_fragment_shading_rate
- Revision 3, 2022-07-11 (Arpit Agarwal)
  - Adds interactions with VK_QCOM_tile_properties

VK_QCOM_rotated_copy_commands

Name String

VK_QCOM_rotated_copy_commands

Extension Type

Device extension

Registered Extension Number

334

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_swapchain
and
VK_KHR_copy_commands2

Contact

- Jeff Leger jackohound

Other Extension Metadata

Last Modified Date

2020-09-18

Interactions and External Dependencies

- None

Contributors

- Jeff Leger, Qualcomm Technologies, Inc.

Description

This extension extends adds an optional rotation transform to copy commands
vkCmdBlitImage2KHR, vkCmdCopyImageToBuffer2KHR and vkCmdCopyBufferToImage2KHR. When copying between two resources, where one resource contains rotated content and the other does not, a rotated copy may be desired. This extension may be used in combination with VK_QCOM_render_pass_transform which adds rotated render passes.

This extension adds an extension structure to the following commands: vkCmdBlitImage2KHR, vkCmdCopyImageToBuffer2KHR and vkCmdCopyBufferToImage2KHR

**Issues**

1) What is an appropriate name for the added extension structure? The style guide says “Structures which extend other structures through the pNext chain should reflect the name of the base structure they extend.”, but in this case a single extension structure is used to extend three base structures (vkCmdBlitImage2KHR, vkCmdCopyImageToBuffer2KHR and vkCmdCopyBufferToImage2KHR). Creating three identical structures with unique names seemed undesirable.

**RESOLVED**: Deviate from the style guide for extension structure naming.

2) Should this extension add a rotation capability to vkCmdCopyImage2KHR?

**RESOLVED**: No. Use of rotated vkCmdBlitImage2KHR can fully address this use case.

3) Should this extension add a rotation capability to vkCmdResolveImage2KHR?

**RESOLVED** No. Use of vkCmdResolveImage2KHR is very slow and extremely bandwidth intensive on Qualcomm’s GPU architecture and use of pResolveAttachments in vkRenderPass is the strongly preferred approach. Therefore, we choose not to introduce a rotation capability to vkCmdResolveImage2KHR.

**New Structures**

- Extending VkBufferImageCopy2, VkImageBlit2:
  - VkCopyCommandTransformInfoQCOM

**New Enum Constants**

- VK_QCOM_ROTATED_COPY_COMMANDS_EXTENSION_NAME
- VK_QCOM_ROTATED_COPY_COMMANDS_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_COPY_COMMAND_TRANSFORM_INFO_QCOM

**Version History**

- Revision 1, 2020-09-19 (Jeff Leger)
**VK_QCOM_tile_properties**

**Name String**

VK_QCOM_tile_properties

**Extension Type**

Device extension

**Registered Extension Number**

485

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

VK_KHR_get_physical_device_properties2

**Contact**

- Jeff Leger @jackohound

**Extension Proposal**

VK_QCOM_tile_properties

**Other Extension Metadata**

**Last Modified Date**

2022-07-11

**Interactions and External Dependencies**

- This extension interacts with VK_EXT_subpass_merge_feedback

**Contributors**

- Jonathan Wicks, Qualcomm Technologies, Inc.
- Jonathan Tinkham, Qualcomm Technologies, Inc.
- Arpit Agarwal, Qualcomm Technologies, Inc.
- Jeff Leger, Qualcomm Technologies, Inc.

**Description**

This extension allows an application to query the tile properties. This extension supports both renderpasses and dynamic rendering.

**New Commands**

- vkGetDynamicRenderingTilePropertiesQCOM
New Structures

- VkTilePropertiesQCOM
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceTilePropertiesFeaturesQCOM

If VK_KHR_dynamic_rendering is supported:

- VkRenderingInfoKHR

New Enum Constants

- VK_QCOM_TILE_PROPERTIES_EXTENSION_NAME
- VK_QCOM_TILE_PROPERTIES_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TILE_PROPERTIES_FEATURES_QCOM
  - VK_STRUCTURE_TYPE_TILE_PROPERTIES_QCOM

Version History

- Revision 1, 2022-07-11 (Arpit Agarwal)
  - Initial version

VK_QCOM_ycbcr_dgamma

Name String

  VK_QCOM_ycbcr_dgamma

Extension Type

  Device extension

Registered Extension Number

  521

Revision

  1

Ratification Status

  Not ratified

Extension and Version Dependencies

Contact

  • Jeff Leger  jackohound
Other Extension Metadata

Last Modified Date
2023-07-31

IP Status
No known IP claims.

Interactions and External Dependencies
None

Contributors
• Jeff Leger, Qualcomm
• Jonathan Wicks, Qualcomm

Description
This extension allows implementations to expose support for “sRGB EOTF” also known as “sRGB degamma”, used in combination with images using 8-bit Y’C_bC_r formats. In addition, the degamma can be selectively applied to the Y (luma) or CrCb (chroma).

`VK_KHR_sampler_ycbcr_conversion` adds support for Y’C_bC_r conversion, but allows texture sampling in a non-linear space which can cause artifacts. This extension allows implementations to expose sRGB degamma for Y’C_bC_r formats, which is performed during texture filtering, allowing texture filtering to operate in a linear space.

New Structures

- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDeviceYcbcrDegammaFeaturesQCOM`
- Extending `VkSamplerYcbcrConversionCreateInfo`:
  - `VkSamplerYcbcrConversionYcbcrDegammaCreateInfoQCOM`

New Enum Constants

- `VK_QCOM_YCBCR_DEGAMMA_EXTENSION_NAME`
- `VK_QCOM_YCBCR_DEGAMMA_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_YCBCR_DEGAMMA_FEATURES_QCOM`
  - `VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_YCBCR_DEGAMMA_CREATE_INFO_QCOM`

Issues

1) Which Y’C_bC_r formats support the degamma feature?

**RESOLVED**: For implementations that support the extension, each format that contains 8-bit R, G,
and B components and supports either `VK_FORMAT_FEATURE_MIDPOINT_CHROMA_SAMPLES_BIT` or `VK_FORMAT_FEATURE_COSITED_CHROMA_SAMPLES_BIT` must support degamma.

Since non-compressed Vulkan sRGB formats are already limited to 8-bit components, and since Adreno supports degamma for all 8bit Y'C_bC_r formats, this extension does not introduce a new `VK_FORMAT_FEATURE_*` bit for the degamma feature.

2) On which Y'C_bC_r components is the degamma applied?

**RESOLVED**: While degamma is expected to be applied to only the Y (luma) component, the extension provides the ability to selectively enable degamma for both the Y (luma) and/or CbCr (chroma) components.

3) Should degamma be enabled for the sampler object or for the image view object?

**RESOLVED**: Both. This extension extends `VkSamplerYcbcrConversionCreateInfo` and the specification already requires that both sampler and view objects must be created with an *identical* `VkSamplerYcbcrConversionCreateInfo` in their pNext chains.

4) Why apply the “sRGB” transfer function directly to Y'C_bC_r data when it would be more correct to use the “ITU transfer function”, and do so only after the values have been converted into non-linear R'G'B'?

**RESOLVED**: Y'C_bC_r is frequently stored according to standards (e.g. BT.601 and BT.709) that specify that the conversion between linear and non-linear should use the ITU Transfer function. The ITU transfer function is mathematically different from the sRGB transfer function and while sRGB and ITU define similar curves, the difference is significant. Performing the “sRGB degamma” prior to range expansion can introduce artifacts if the content uses `VK_SAMPLER_YCBCR_RANGE_ITU_NARROW` encoding. Nevertheless, using sRGB can make sense for certain use-cases where camera YCbCr images are known to be encoded with sRGB (or a pure gamma 2.2) transfer function and are known to use full-range encoding.

For those use-cases, this extension leverages the GPU ability to enable sRGB degamma at little cost, and can improve quality because texture filtering is able to occur in linear space.

**Version History**

- Revision 1, 2023-07-31 (Jeff Leger)

**VK_QNX_external_memory_screen_buffer**

**Name String**

VK_QNX_external_memory_screen_buffer

**Extension Type**

Device extension

**Registered Extension Number**

530
Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_sampler_ycbcr_conversion
and
VK_KHR_external_memory
and
VK_KHR_dedicated_allocation
or
Version 1.1
and
VK_EXT_queue_family_foreign

Contact
• Mike Gorchak mgorchak-blackberry
• Aaron Ruby aruby-blackberry

Other Extension Metadata

Last Modified Date
2023-05-17

IP Status
No known IP claims.

Contributors
• Mike Gorchak, QNX / Blackberry Limited
• Aaron Ruby, QNX / Blackberry Limited

Description
This extension enables an application to import QNX Screen _screen_buffer objects created outside of the Vulkan device into Vulkan memory objects, where they can be bound to images and buffers.

Some _screen_buffer images have implementation-defined external formats that may not correspond to Vulkan formats. Sampler Y’C_bC_r conversion can be used to sample from these images and convert them to a known color space.

_screen_buffer is strongly typed, so naming the handle type is redundant. The internal layout and therefore size of a _screen_buffer image may depend on native usage flags that do not have corresponding Vulkan counterparts.
New Commands

- vkGetScreenBufferPropertiesQNX

New Structures

- VkScreenBufferPropertiesQNX
- Extending VkImageCreateInfo, VkSamplerYcbcrConversionCreateInfo:
  - VkExternalFormatQNX
- Extending VkMemoryAllocateInfo:
  - VkImportScreenBufferInfoQNX
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceExternalMemoryScreenBufferFeaturesQNX
- Extending VkScreenBufferPropertiesQNX:
  - VkScreenBufferFormatPropertiesQNX

New Enum Constants

- VK_QNX_EXTERNAL_MEMORY_SCREEN_BUFFER_EXTENSION_NAME
- VK_QNX_EXTERNAL_MEMORY_SCREEN_BUFFER_SPEC_VERSION
- Extending VkExternalMemoryHandleTypeFlagBits:
  - VK_EXTERNAL_MEMORY_HANDLE_TYPE_SCREEN_BUFFER_BIT_QNX
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_EXTERNAL_FORMAT_QNX
  - VK_STRUCTURE_TYPE_IMPORT_SCREEN_BUFFER_INFO_QNX
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_MEMORY_SCREEN_BUFFER_FEATURES_QNX
  - VK_STRUCTURE_TYPE_SCREEN_BUFFER_FORMAT_PROPERTIES_QNX
  - VK_STRUCTURE_TYPE_SCREEN_BUFFER_PROPERTIES_QNX

Issues

Version History

- Revision 1, 2023-05-17 (Mike Gorchak)
  - Initial version

VK_QNX_screen_surface

Name String

- VK_QNX_screen_surface
The `VK_QNX_screen_surface` extension is an instance extension. It provides a mechanism to create a `VkSurfaceKHR` object (defined by the `VK_KHR_surface` extension) that refers to a QNX Screen window, as well as a query to determine support for rendering to a QNX Screen compositor.

**New Commands**
- `vkCreateScreenSurfaceQNX`
- `vkGetPhysicalDeviceScreenPresentationSupportQNX`

**New Structures**
- `VkScreenSurfaceCreateInfoQNX`

**New Bitmasks**
- `VkScreenSurfaceCreateFlagsQNX`
New Enum Constants

- VK_QNX_SCREEN_SURFACE_EXTENSION_NAME
- VK_QNX_SCREEN_SURFACE_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_SCREEN_SURFACE_CREATE_INFO_QNX

Version History

- Revision 1, 2021-01-11 (Mike Gorchak)
  - Initial draft.

VK_SEC_amigo_profiling

Name String

VK_SEC_amigo_profiling

Extension Type

Device extension

Registered Extension Number

486

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Contact

- Ralph Potter r_potter

Other Extension Metadata

Last Modified Date

2022-07-29

IP Status

No known IP claims.

Contributors

- Ralph Potter, Samsung
- Sangrak Oh, Samsung
Description

This extension is intended to communicate information from layered API implementations such as ANGLE to internal proprietary system schedulers. It has no behavioural implications beyond enabling more intelligent behaviour from the system scheduler.

Application developers should avoid using this extension. It is documented solely for the benefit of tools and layer developers, who may need to manipulate `pNext` chains that include these structures.

**Note**

There is currently no specification language written for this extension. The links to APIs defined by the extension are to stubs that only include generated content such as API declarations and implicit valid usage statements.

**Note**

This extension is only intended for use in specific embedded environments with known implementation details, and is therefore undocumented.

New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceAmigoProfilingFeaturesSEC`
- Extending `VkSubmitInfo`:
  - `VkAmigoProfilingSubmitInfoSEC`

New Enum Constants

- `VK_SEC_AMIGO_PROFILING_EXTENSION_NAME`
- `VK_SEC_AMIGO_PROFILING_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_AMIGO_PROFILING_SUBMIT_INFO_SEC`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_AMIGO_PROFILING_FEATURES_SEC`

Stub API References

There is currently no specification language written for this type. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

```c
// Provided by VK_SEC_amigo_profiling
typedef struct VkPhysicalDeviceAmigoProfilingFeaturesSEC {
    VkStructureType sType;
    void* pNext;
    VkBool32 amigoProfiling;
} VkPhysicalDeviceAmigoProfilingFeaturesSEC;
```
Valid Usage (Implicit)

• VUID-VkPhysicalDeviceAmigoProfilingFeaturesSEC-sType-sType
  
  sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_AMIGO_PROFILING_FEATURES_SEC

There is currently no specification language written for this type. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

// Provided by VK_SEC_amigo_profiling
typedef struct VkAmigoProfilingSubmitInfoSEC {
    VkStructureType sType;
    const void* pNext;
    uint64_t firstDrawTimestamp;
    uint64_t swapBufferTimestamp;
} VkAmigoProfilingSubmitInfoSEC;

Valid Usage (Implicit)

• VUID-VkAmigoProfilingSubmitInfoSEC-sType-sType
  
  sType must be VK_STRUCTURE_TYPE_AMIGO_PROFILING_SUBMIT_INFO_SEC

Version History

• Revision 1, 2022-07-29 (Ralph Potter)
  ◦ Initial specification

VK_VALVE_descriptor_set_host_mapping

Name String

  VK_VALVE_descriptor_set_host_mapping

Extension Type

  Device extension

Registered Extension Number

  421

Revision

  1

Ratification Status

  Not ratified
Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Special Use

• D3D support

Contact

• Hans-Kristian Arntzen

Other Extension Metadata

Last Modified Date

2022-02-22

IP Status

No known IP claims.

Contributors

• Hans-Kristian Arntzen, Valve

Description

This extension allows applications to directly query a host pointer for a VkDescriptorSet which can be used to copy descriptors between descriptor sets without the use of an API command. Memory offsets and sizes for descriptors can be queried from a VkDescriptorSetLayout as well.

Note

There is currently no specification language written for this extension. The links to APIs defined by the extension are to stubs that only include generated content such as API declarations and implicit valid usage statements.

Note

This extension is only intended for use in specific embedded environments with known implementation details, and is therefore undocumented.

New Commands

• vkGetDescriptorSetHostMappingVALVE
• vkGetDescriptorSetLayoutHostMappingInfoVALVE

New Structures

• VkDescriptorSetBindingReferenceVALVE
• VkDescriptorSetLayoutHostMappingInfoVALVE
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  • VkPhysicalDeviceDescriptorSetHostMappingFeaturesVALVE
New Enum Constants

- VK_VALVE_DESCRIPTOR_SET_HOST_MAPPING_EXTENSION_NAME
- VK_VALVE_DESCRIPTOR_SET_HOST_MAPPING_SPEC_VERSION

Extending VkStructureType:

- VK_STRUCTURE_TYPE_DESCRIPTOR_SET_BINDING_REFERENCE_VALVE
- VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_HOST_MAPPING_INFO_VALVE
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_SET_HOST_MAPPING_FEATURES_VALVE

Stub API References

There is currently no specification language written for this command. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

```c
// Provided by VK_VALVE_descriptor_set_host_mapping
void vkGetDescriptorSetLayoutHostMappingInfoVALVE(
    VkDevice device,
    const VkDescriptorSetBindingReferenceVALVE* pBindingReference,
    VkDescriptorSetLayoutHostMappingInfoVALVE* pHostMapping);
```

Valid Usage (Implicit)

- VUID-vkGetDescriptorSetLayoutHostMappingInfoVALVE-device-parameter 
  device must be a valid VkDevice handle

- VUID-vkGetDescriptorSetLayoutHostMappingInfoVALVE-pBindingReference-parameter 
  pBindingReference must be a valid pointer to a valid VkDescriptorSetBindingReferenceVALVE structure

- VUID-vkGetDescriptorSetLayoutHostMappingInfoVALVE-pHostMapping-parameter 
  pHostMapping must be a valid pointer to a VkDescriptorSetLayoutHostMappingInfoVALVE structure

There is currently no specification language written for this command. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

```c
// Provided by VK_VALVE_descriptor_set_host_mapping
void vkGetDescriptorSetHostMappingVALVE(
    VkDevice device,
    VkDescriptorSet descriptorSet,
    void** ppData);
```
Valid Usage (Implicit)

- VUID-vkGetDescriptorSetHostMappingVALVE-device-parameter
device must be a valid VkDevice handle
- VUID-vkGetDescriptorSetHostMappingVALVE-descriptorSet-parameter
descriptorSet must be a valid VkDescriptorSet handle
- VUID-vkGetDescriptorSetHostMappingVALVE-ppData-parameter
ppData must be a valid pointer to a pointer value
- VUID-vkGetDescriptorSetHostMappingVALVE-descriptorSet-parent
descriptorSet must have been created, allocated, or retrieved from device

There is currently no specification language written for this type. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

```c
// Provided by VK_VALVE_descriptor_set_host_mapping
typedef struct VkPhysicalDeviceDescriptorSetHostMappingFeaturesVALVE {
    VkStructureType sType;
    void* pNext;
    VkBool32 descriptorSetHostMapping;
} VkPhysicalDeviceDescriptorSetHostMappingFeaturesVALVE;
```

Valid Usage (Implicit)

- VUID-VkPhysicalDeviceDescriptorSetHostMappingFeaturesVALVE-sType-sType
sType must be VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_SET_HOST_MAPPING_FEATURES_VALVE

There is currently no specification language written for this type. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

```c
// Provided by VK_VALVE_descriptor_set_host_mapping
typedef struct VkDescriptorSetBindingReferenceVALVE {
    VkStructureType sType;
    const void* pNext;
    VkDescriptorSetLayout descriptorSetLayout;
    uint32_t binding;
} VkDescriptorSetBindingReferenceVALVE;
```

Valid Usage (Implicit)

- VUID-VkDescriptorSetBindingReferenceVALVE-sType-sType
sType must be VK_STRUCTURE_TYPE_DESCRIPTOR_SET_BINDING_REFERENCE_VALVE
There is currently no specification language written for this type. This section acts only as placeholder and to avoid dead links in the specification and reference pages.

```c
// Provided by VK_VALVE_descriptor_set_host_mapping
typedef struct VkDescriptorSetLayoutHostMappingInfoVALVE {
    VkStructureType sType;
    void* pNext;
    size_t descriptorOffset;
    uint32_t descriptorSize;
} VkDescriptorSetLayoutHostMappingInfoVALVE;
```

**Valid Usage (Implicit)**

- VUID-VkDescriptorSetLayoutHostMappingInfoVALVE-sType-sType
  *sType must be* `VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_HOST_MAPPING_INFO_VALVE`
- VUID-VkDescriptorSetLayoutHostMappingInfoVALVE-pNext-pNext
  *pNext must be NULL*

**Version History**

- Revision 1, 2022-02-22 (Hans-Kristian Arntzen)
  - Initial specification

**List of Provisional Extensions**

- `VK_KHR_portability_subset`
- `VK_KHR_video_encode_queue`
- `VK_EXT_video_encode_h264`
- `VK_EXT_video_encode_h265`
- `VK_AMDX_shader_enqueue`
- `VK_NV_displacement_micromap`
VK_KHR_portability_subset

Name String
VK_KHR_portability_subset

Extension Type
Device extension

Registered Extension Number
164

Revision
1

Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2

- This is a provisional extension and must be used with caution. See the description of provisional header files for enablement and stability details.

Contact
- Bill Hollings billhollings

Other Extension Metadata

Last Modified Date
2020-07-21

IP Status
No known IP claims.

Contributors
- Bill Hollings, The Brenwill Workshop Ltd.
- Daniel Koch, NVIDIA
- Dzmitry Malyshau, Mozilla
- Chip Davis, CodeWeavers
- Dan Ginsburg, Valve
- Mike Weiblen, LunarG
- Neil Trevett, NVIDIA
- Alexey Knyazev, Independent
Description

The **VK_KHR_portability_subset** extension allows a non-conformant Vulkan implementation to be built on top of another non-Vulkan graphics API, and identifies differences between that implementation and a fully-conformant native Vulkan implementation.

This extension provides Vulkan implementations with the ability to mark otherwise-required capabilities as unsupported, or to establish additional properties and limits that the application should adhere to in order to guarantee portable behaviour and operation across platforms, including platforms where Vulkan is not natively supported.

The goal of this specification is to document, and make queryable, capabilities which are required to be supported by a fully-conformant Vulkan 1.0 implementation, but may be optional for an implementation of the Vulkan 1.0 Portability Subset.

The intent is that this extension will be advertised only on implementations of the Vulkan 1.0 Portability Subset, and not on conformant implementations of Vulkan 1.0. Fully-conformant Vulkan implementations provide all the required capabilities, and so will not provide this extension. Therefore, the existence of this extension can be used to determine that an implementation is likely not fully conformant with the Vulkan spec.

If this extension is supported by the Vulkan implementation, the application must enable this extension.

This extension defines several new structures that can be chained to the existing structures used by certain standard Vulkan calls, in order to query for non-conformant portable behavior.

New Structures

- Extending **VkPhysicalDeviceFeatures2, VkDeviceCreateInfo**:
  - **VkPhysicalDevicePortabilitySubsetFeaturesKHR**

- Extending **VkPhysicalDeviceProperties2**:
  - **VkPhysicalDevicePortabilitySubsetPropertiesKHR**

New Enum Constants

- **VK_KHR_PORTABILITY_SUBSET_EXTENSION_NAME**
- **VK_KHR_PORTABILITY_SUBSET_SPEC_VERSION**

- Extending **VkStructureType**:
  - **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PORTABILITY_SUBSET_FEATURES_KHR**
  - **VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PORTABILITY_SUBSET_PROPERTIES_KHR**

Issues

None.
Version History

- Revision 1, 2020-07-21 (Bill Hollings)
  - Initial draft.

VK_KHR_video_encode_queue

Name String

VK_KHR_video_encode_queue

Extension Type

Device extension

Registered Extension Number

300

Revision

10

Ratification Status

Ratified

Extension and Version Dependencies

VK_KHR_video_queue
and
VK_KHR_synchronization2

- This is a provisional extension and must be used with caution. See the description of provisional header files for enablement and stability details.

Contact

- Ahmed Abdelkhalek @aabdelkh

Other Extension Metadata

Last Modified Date

2023-07-19

IP Status

No known IP claims.

Contributors

- Ahmed Abdelkhalek, AMD
- Damien Kessler, NVIDIA
- George Hao, AMD
- Jake Beju, AMD
- Peter Fang, AMD
Description

This extension builds upon the VK_KHR_video_queue extension by adding common APIs specific to video encoding and thus enabling implementations to expose queue families supporting video encode operations.

More specifically, it adds video encode specific capabilities and a new command buffer command that allows recording video encode operations against a video session.

This extension is to be used in conjunction with other codec specific video encode extensions that enable encoding video sequences of specific video compression standards.

New Commands

- vkCmdEncodeVideoKHR
- vkGetEncodedVideoSessionParametersKHR
- vkGetPhysicalDeviceVideoEncodeQualityLevelPropertiesKHR

New Structures

- VkPhysicalDeviceVideoEncodeQualityLevelInfoKHR
- VkVideoEncodeInfoKHR
- VkVideoEncodeQualityLevelPropertiesKHR
- VkVideoEncodeRateControlLayerInfoKHR
- VkVideoEncodeSessionParametersFeedbackInfoKHR
- VkVideoEncodeSessionParametersGetInfoKHR
- Extending VkQueryPoolCreateInfo:
  - VkQueryPoolVideoEncodeFeedbackCreateInfoKHR
- Extending VkVideoCapabilitiesKHR:
  - VkVideoEncodeCapabilitiesKHR
- Extending VkVideoCodingControlInfoKHR, VkVideoBeginCodingInfoKHR:
- `VkVideoEncodeRateControlInfoKHR`

- **Extending** `VkVideoCodingControlInfoKHR`, `VkVideoSessionParametersCreateInfoKHR`:
  - `VkVideoEncodeQualityLevelInfoKHR`

- **Extending** `VkVideoProfileInfoKHR`, `VkQueryPoolCreateInfo`:
  - `VkVideoEncodeUsageInfoKHR`

### New Enums

- `VkVideoEncodeCapabilityFlagBitsKHR`
- `VkVideoEncodeContentFlagBitsKHR`
- `VkVideoEncodeFeedbackFlagBitsKHR`
- `VkVideoEncodeRateControlModeFlagBitsKHR`
- `VkVideoEncodeTuningModeKHR`
- `VkVideoEncodeUsageFlagBitsKHR`

### New Bitmasks

- `VkVideoEncodeCapabilityFlagsKHR`
- `VkVideoEncodeContentFlagsKHR`
- `VkVideoEncodeFeedbackFlagsKHR`
- `VkVideoEncodeFlagsKHR`
- `VkVideoEncodeRateControlFlagsKHR`
- `VkVideoEncodeRateControlModeFlagsKHR`
- `VkVideoEncodeUsageFlagsKHR`

### New Enum Constants

- `VK_KHR_VIDEO_ENCODE_QUEUE_EXTENSION_NAME`
- `VK_KHR_VIDEO_ENCODE_QUEUE_SPEC_VERSION`

- **Extending** `VkAccessFlagBits2`:
  - `VK_ACCESS_2_VIDEO_ENCODE_READ_BIT_KHR`
  - `VK_ACCESS_2_VIDEO_ENCODE_WRITE_BIT_KHR`

- **Extending** `VkBufferUsageFlagBits`:
  - `VK_BUFFER_USAGE_VIDEO_ENCODE_DST_BIT_KHR`
  - `VK_BUFFER_USAGE_VIDEO_ENCODE_SRC_BIT_KHR`

- **Extending** `VkFormatFeatureFlagBits`:
  - `VK_FORMAT_FEATURE_VIDEO_ENCODE_DPB_BIT_KHR`
  - `VK_FORMAT_FEATURE_VIDEO_ENCODE_INPUT_BIT_KHR`
• Extending `VkImageLayout`:
  ◦ `VK_IMAGE_LAYOUT_VIDEO_ENCODE_DPB_KHR`
  ◦ `VK_IMAGE_LAYOUT_VIDEO_ENCODE_DST_KHR`
  ◦ `VK_IMAGE_LAYOUT_VIDEO_ENCODE_SRC_KHR`

• Extending `VkImageUsageFlagBits`:
  ◦ `VK_IMAGE_USAGE_VIDEO_ENCODE_DPB_BIT_KHR`
  ◦ `VK_IMAGE_USAGE_VIDEO_ENCODE_DST_BIT_KHR`
  ◦ `VK_IMAGE_USAGE_VIDEO_ENCODE_SRC_BIT_KHR`

• Extending `VkPipelineStageFlagBits2`:
  ◦ `VK_PIPELINE_STAGE_2_VIDEO_ENCODE_BIT_KHR`

• Extending `VkQueryResultStatusKHR`:
  ◦ `VK_QUERY_RESULT_STATUS_INSUFFICIENT_BITSTREAM_BUFFER_RANGE_KHR`

• Extending `VkQueryType`:
  ◦ `VK_QUERY_TYPE_VIDEO_ENCODE_FEEDBACK_KHR`

• Extending `VkQueueFlagBits`:
  ◦ `VK_QUEUE_VIDEO_ENCODE_BIT_KHR`

• Extending `VkResult`:
  ◦ `VK_ERROR_INVALID_VIDEO_STD_PARAMETERS_KHR`

• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VIDEO_ENCODE_QUALITY_LEVEL_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_QUERY_POOL_VIDEO_ENCODE_FEEDBACK_CREATE_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_VIDEO_ENCODE_CAPABILITIES_KHR`
  ◦ `VK_STRUCTURE_TYPE_VIDEO_ENCODE_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_VIDEO_ENCODE_QUALITY_LEVEL_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_VIDEO_ENCODE_QUALITY_LEVEL_PROPERTIES_KHR`
  ◦ `VK_STRUCTURE_TYPE_VIDEO_ENCODE_RATE_CONTROL_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_VIDEO_ENCODE_RATE_CONTROL_LAYER_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_VIDEO_ENCODE_SESSION_PARAMETERS_FEEDBACK_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_VIDEO_ENCODE_SESSION_PARAMETERS_GET_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_VIDEO_ENCODE_USAGE_INFO_KHR`

• Extending `VkVideoCodingControlFlagBitsKHR`:
  ◦ `VK_VIDEO_CODING_CONTROL_ENCODE_QUALITY_LEVEL_BIT_KHR`
  ◦ `VK_VIDEO_CODING_CONTROL_ENCODE_RATE_CONTROL_BIT_KHR`

• Extending `VkVideoSessionCreateFlagBitsKHR`:
  ◦ `VK_VIDEO_SESSION_CREATE_ALLOW_ENCODE_PARAMETER_OPTIMIZATIONS_BIT_KHR`
If VK_KHR_format_feature_flags2 is supported:

- Extending VkFormatFeatureFlagBits2:
  - VK_FORMAT_FEATURE_2_VIDEO_ENCODE_DPB_BIT_KHR
  - VK_FORMAT_FEATURE_2_VIDEO_ENCODE_INPUT_BIT_KHR

**Issues**

1) Why is there no VK_PIPELINE_STAGE_VIDEO_ENCODE_BIT_KHR?

**RESOLVED:** This extension requires VK_KHR_synchronization2 because the new access flags introduced did not fit in the 32-bit enum VkAccessFlagBits. Accordingly, all new pipeline stage and access flags have been added to the corresponding 64-bit enum and no new flags have been added to the legacy 32-bit enums. While the new pipeline stage flag introduced uses bit #27 which would also fit in the legacy VkPipelineStageFlagBits enum, there is no real benefit to include it. Instead the bit is marked reserved.

**Version History**

- Revision 1, 2018-07-23 (Ahmed Abdelkhalek)
  - Initial draft
- Revision 1.1, 10/29/2019 (Tony Zlatinski)
  - Updated the reserved spec tokens and renamed VkVideoEncoderKHR to VkVideoSessionKHR
- Revision 1.6, Jan 08 2020 (Tony Zlatinski)
  - API unify with the video_decode_queue spec
- Revision 2, March 29 2021 (Tony Zlatinski)
  - Spec and API updates.
- Revision 3, 2021-09-30 (Jon Leech)
  - Add interaction with VK_KHR_format_feature_flags2 to vk.xml
- Revision 4, 2022-02-10 (Ahmed Abdelkhalek)
  - Updates to encode capability interface
- Revision 5, 2022-03-31 (Ahmed Abdelkhalek)
  - Remove redundant VkVideoEncodeInfoKHR.codedExtent
- Revision 6, 2022-07-18 (Daniel Rakos)
  - Remove VkVideoEncodeRateControlFlagBitsKHR and VkVideoEncodeFlagBitsKHR as they contain no defined flags for now
  - Add VK_VIDEO_CODING_CONTROL_ENCODE_RATE_CONTROL_BIT_KHR and VK_VIDEO_CODING_CONTROL_ENCODE_RATE_CONTROL_LAYER_BIT_KHR to indicate rate control and rate control layer change requests, respectively, in video coding control operations
- Revision 7, 2022-08-12 (Daniel Rakos)
  - Add VkVideoEncodeUsageInfoKHR structure and related flags
Revision 8, 2023-03-06 (Daniel Rakos)

- Replace `VK_QUERY_TYPE_VIDEO_ENCODE_BITSTREAM_BUFFER_RANGE_KHR` queries with more generic `VK_QUERY_TYPE_VIDEO_ENCODE_FEEDBACK_KHR` queries that can be extended in the future with more feedback values.
- Rename `dstBitstreamBuffer`, `dstBitstreamBufferOffset`, and `dstBitstreamBufferMaxRange` in `VkVideoEncodeInfoKHR` to `dstBuffer`, `dstBufferOffset`, and `dstBufferRange`, respectively, for consistency with the naming convention in the video decode extensions.
- Change the type of `rateControlLayerCount` and `qualityLevelCount` in `VkVideoEncodeCapabilitiesKHR` from `uint8_t` to `uint32_t` and rename them to `maxRateControlLayers` and `maxQualityLevels`, respectively.
- Change the type of `averageBitrate` and `maxBitrate` in `VkVideoEncodeRateControlLayerInfoKHR` from `uint32_t` to `uint64_t`.
- Fixed the definition of rate control flag bits and added the new `VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DEFAULT_KHR` constant to indicate implementation-specific automatic rate control.
- Change the type of `VkVideoEncodeRateControlInfoKHR::layerCount` from `uint8_t` to `uint32_t`.
- Rename `pLayerConfigs` to `pLayers` in `VkVideoEncodeRateControlInfoKHR`.

Revision 9, 2023-03-28 (Daniel Rakos)

- Removed `VK_VIDEO_CODING_CONTROL_ENCODE_RATE_CONTROL_LAYER_BIT_KHR` and the ability to change the state of individual rate control layers.
- Added new `VK_VIDEO_ENCODE_FEEDBACK_BITSTREAM_HAS_OVERRIDES_BIT_KHR` flag to video encode feedback queries.
- Added a new video session create flag `VK_VIDEO_SESSION_CREATE_ALLOW_ENCODE_PARAMETER_OPTIMIZATIONS_BIT_KHR` to opt-in to video session and encoding parameter optimizations.
- Added the `vkGetEncodedVideoSessionParametersKHR` command to enable retrieving encoded video session parameter data.
- Moved `virtualBufferSizeInMs` and `initialVirtualBufferSizeInMs` from `VkVideoEncodeRateControlLayerInfoKHR` to `VkVideoEncodeRateControlInfoKHR`.
- Added `maxBitrate` capability.
- Renamed `inputImageDataFillAlignment` capability to `encodeInputPictureGranularity` to better reflect its purpose.
- Added new `vkGetPhysicalDeviceVideoEncodeQualityLevelPropertiesKHR` command and related structures to enable querying recommended settings for video encode quality levels.
- Added `VK_VIDEO_CODING_CONTROL_ENCODE_QUALITY_LEVEL_BIT_KHR` flag and `VkVideoEncodeQualityLevelInfoKHR` structure to allow controlling video encode quality level and removed `qualityLevel` from the encode operation parameters.

Revision 10, 2023-07-19 (Daniel Rakos)

- Added `VK_QUERY_RESULT_STATUS_INSUFFICIENT_BITSTREAM_BUFFER_RANGE_KHR` query result status code and the related capability flag.
VK_EXT_video_encode_h264

Name String
VK_EXT_video_encode_h264

Extension Type
Device extension

Registered Extension Number
39

Revision
12

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_video_encode_queue

- This is a provisional extension and must be used with caution. See the description of provisional header files for enablement and stability details.

Contact
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Other Extension Metadata

Last Modified Date
2023-07-19

IP Status
No known IP claims.

Contributors
- Ahmed Abdelkhalek, AMD
- George Hao, AMD
- Jake Beju, AMD
- Peter Fang, AMD
- Ping Liu, Intel
- Srinath Kumarapuram, NVIDIA
- Tony Zlatinski, NVIDIA
- Ravi Chaudhary, NVIDIA
• Yang Liu, AMD
• Daniel Rakos, RasterGrid
• Aidan Fabius, Core Avionics & Industrial Inc.

**Description**

This extension builds upon the [VK_KHR_video_encode_queue](https://www.khronos.org/registry/vulkan/specs/1.3-extensions/man/html/khr_video.html) extension by adding support for encoding elementary video stream sequences compliant with the H.264/AVC video compression standard.

**New Structures**

- `VkVideoEncodeH264FrameSizeEXT`
- `VkVideoEncodeH264NaluSliceInfoEXT`
- `VkVideoEncodeH264QpEXT`
- Extending `VkVideoBeginCodingInfoKHR`:
  - `VkVideoEncodeH264GopRemainingFrameInfoEXT`
- Extending `VkVideoCapabilitiesKHR`:
  - `VkVideoEncodeH264CapabilitiesEXT`
- Extending `VkVideoCodingControlInfoKHR, VkVideoBeginCodingInfoKHR`:
  - `VkVideoEncodeH264RateControlInfoEXT`
- Extending `VkVideoEncodeInfoKHR`:
  - `VkVideoEncodeH264PictureInfoEXT`
- Extending `VkVideoEncodeQualityLevelPropertiesKHR`:
  - `VkVideoEncodeH264QualityLevelPropertiesEXT`
- Extending `VkVideoEncodeRateControlLayerInfoKHR`:
  - `VkVideoEncodeH264RateControlLayerInfoEXT`
- Extending `VkVideoEncodeSessionParametersFeedbackInfoKHR`:
  - `VkVideoEncodeH264SessionParametersFeedbackInfoEXT`
- Extending `VkVideoEncodeSessionParametersGetInfoKHR`:
  - `VkVideoEncodeH264SessionParametersGetInfoEXT`
- Extending `VkVideoProfileInfoKHR, VkQueryPoolCreateInfo`:
  - `VkVideoEncodeH264ProfileInfoEXT`
- Extending `VkVideoReferenceSlotInfoKHR`:
  - `VkVideoEncodeH264DpbSlotInfoEXT`
- Extending `VkVideoSessionCreateInfoKHR`:
  - `VkVideoEncodeH264SessionCreateInfoEXT`
- Extending `VkVideoSessionParametersCreateInfoKHR`:
• VkVideoEncodeH264SessionParametersCreateInfoEXT

Extending VkVideoSessionParametersUpdateInfoKHR:
  • VkVideoEncodeH264SessionParametersAddInfoEXT

New Enums
  • VkVideoEncodeH264CapabilityFlagBitsEXT
  • VkVideoEncodeH264RateControlFlagBitsEXT
  • VkVideoEncodeH264StdFlagBitsEXT

New Bitmasks
  • VkVideoEncodeH264CapabilityFlagsEXT
  • VkVideoEncodeH264RateControlFlagsEXT
  • VkVideoEncodeH264StdFlagsEXT

New Enum Constants
  • VK_EXT_VIDEO_ENCODE_H264_EXTENSION_NAME
  • VK_EXT_VIDEO_ENCODE_H264_SPEC_VERSION

Extending VkStructureType:
  • VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_CAPABILITIES_EXT
  • VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_DPB_SLOT_INFO_EXT
  • VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_GOP_REMAINING_FRAME_INFO_EXT
  • VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_NALU_SLICE_INFO_EXT
  • VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_PICTURE_INFO_EXT
  • VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_PROFILE_INFO_EXT
  • VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_QUALITY_LEVEL_PROPERTIES_EXT
  • VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_RATE_CONTROL_INFO_EXT
  • VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_RATE_CONTROL_LAYER_INFO_EXT
  • VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_CREATE_INFO_EXT
  • VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_PARAMETERS_ADD_INFO_EXT
  • VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_PARAMETERS_CREATE_INFO_EXT
  • VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_PARAMETERS_FEEDBACK_INFO_EXT
  • VK_STRUCTURE_TYPE_VIDEO_ENCODE_H264_SESSION_PARAMETERS_GET_INFO_EXT

Extending VkVideoCodecOperationFlagBitsKHR:
  • VK_VIDEO_CODEC_OPERATION_ENCODE_H264_BIT_EXT
Version History

- Revision 0, 2018-7-23 (Ahmed Abdelkhalek)
  - Initial draft
- Revision 0.5, 2020-02-13 (Tony Zlatinski)
  - General Spec cleanup
  - Added DPB structures
  - Change the VCL frame encode structure
  - Added a common Non-VCL Picture Paramarameters structure
- Revision 1, 2021-03-29 (Tony Zlatinski)
  - Spec and API updates
- Revision 2, August 1 2021 (Srinath Kumarapuram)
  - Rename VkVideoEncodeH264CapabilitiesFlagsEXT to VkVideoEncodeH264CapabilityFlagsEXT and VkVideoEncodeH264CapabilitiesFlagsEXT to VkVideoEncodeH264CapabilityFlagsEXT, following Vulkan naming conventions.
- Revision 3, 2021-12-08 (Ahmed Abdelkhalek)
  - Rate control updates
- Revision 4, 2022-02-04 (Ahmed Abdelkhalek)
  - Align VkVideoEncodeH264VclFrameInfoEXT structure to similar one in VK_EXT_video_encode_h265 extension
- Revision 5, 2022-02-10 (Ahmed Abdelkhalek)
  - Updates to encode capability interface
- Revision 6, 2022-03-16 (Ahmed Abdelkhalek)
  - Relocate Std header version reporting/requesting from this extension to VK_KHR_video_queue extension.
  - Remove redundant maxPictureSizeInMbs from VkVideoEncodeH264SessionCreateInfoEXT.
  - Remove the now empty VkVideoEncodeH264SessionCreateInfoEXT.
- Revision 7, 2022-04-06 (Ahmed Abdelkhalek)
  - Add capability flag to report support to use B frame in L1 reference list.
  - Add capability flag to report support for disabling SPS direct_8x8_inference_flag.
- Revision 8, 2022-07-18 (Daniel Rakos)
  - Replace VkVideoEncodeH264RateControlStructureFlagBitsEXT bit enum with VkVideoEncodeH264RateControlStructureEXT enum
  - Rename VkVideoEncodeH264ProfileEXT to VkVideoEncodeH264ProfileInfoEXT
  - Rename VkVideoEncodeH264ReferenceListsEXT to VkVideoEncodeH264ReferenceListsInfoEXT
  - Rename VkVideoEncodeH264EmitPictureParametersEXT to VkVideoEncodeH264EmitPictureParametersInfoEXT
- Rename VkVideoEncodeH264NaluSliceEXT to VkVideoEncodeH264NaluSliceInfoEXT

**Revision 9, 2022-09-18 (Daniel Rakos)**

- Rename spsStdCount, pSpsStd, ppsStdCount, and pPpsStd to stdSPSCount, pStdSPSs, stdPPSCount, and pStdPPSs, respectively, in VkVideoEncodeH264SessionParametersAddInfoEXT
- Rename maxSpsStdCount and maxPpsStdCount to stdMaxSPSCount and stdMaxPPSCount, respectively, in VkVideoEncodeH264SessionParametersCreateInfoEXT

- **Revision 10, 2023-03-06 (Daniel Rakos)**

  - Removed VkVideoEncodeH264EmitPictureParametersInfoEXT
  - Changed member types in VkVideoEncodeH264CapabilitiesEXT and VkVideoEncodeH264ReferenceListsInfoEXT from uint8_t to uint32_t
  - Changed the type of VkVideoEncodeH264RateControlInfoEXT::temporalLayerCount and VkVideoEncodeH264RateControlLayerInfoEXT::temporalLayerId from uint8_t to uint32_t
  - Removed VkVideoEncodeH264InputModeFlagsEXT and VkVideoEncodeH264OutputModeFlagsEXT as we only support frame-in-frame-out mode for now
  - Rename pCurrentPictureInfo in VkVideoEncodeH264VclFrameInfoEXT to pStdPictureInfo
  - Rename pSliceHeaderStd in VkVideoEncodeH264NaluSliceInfoEXT to pStdSliceHeader
  - Rename pReferenceFinalLists in VkVideoEncodeH264VclFrameInfoEXT and VkVideoEncodeH264NaluSliceInfoEXT to pStdReferenceFinalLists
  - Removed the slotIndex member of VkVideoEncodeH264DpbSlotInfoEXT and changed it to be chained to VkVideoReferenceSlotInfoKHR
  - Replaced VkVideoEncodeH264ReferenceListsInfoEXT with the new Video Std header structure StdVideoEncodeH264ReferenceLists that also includes data previously part of the now removed StdVideoEncodeH264RefMemMgmtCtrlOperations structure
  - Added new capability flag VK_VIDEO_ENCODE_H264_CAPABILITY_DIFFERENT_REFERENCE_FINAL_LISTS_BIT_EXT

**Revision 11, 2023-05-22 (Daniel Rakos)**

- Renamed VkVideoEncodeH264VclFrameInfoEXT to VkVideoEncodeH264PictureInfoEXT
- Added VkVideoEncodeH264PictureInfoEXT::generatePrefixNalu and VK_VIDEO_ENCODE_H264_CAPABILITY_GENERATE_PREFIX_NALU_BIT_EXT to enable the generation of H.264 prefix NALUs when supported by the implementation
- Removed VkVideoEncodeH264RateControlLayerInfoEXT::temporalLayerId
- Added expectDyadicTemporalLayerPattern capability
- Added the VkVideoEncodeH264SessionParametersGetInfoEXT structure to identify the H.264 parameter sets to retrieve encoded parameter data for, and the VkVideoEncodeH264SessionParametersFeedbackInfoEXT structure to retrieve H.264 parameter set override information when using the new vkGetEncodedVideoSessionParametersKHR command
- Added VkVideoEncodeH264NaluSliceInfoEXT::constantQp to specify per-slice constant QP when rate control mode is VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DISABLED_BIT_KHR
- Added `VkVideoEncodeH264QualityLevelPropertiesEXT` for retrieving H.264 specific quality level recommendations

- Replaced `VkVideoEncodeH264RateControlStructureEXT` enum with the flags type `VkVideoEncodeH264RateControlFlagsEXT` and bits defined in `VkVideoEncodeH264RateControlFlagBitsEXT` and added HRD compliance flag

- Removed `useInitialRcQp` and `initialRcQp` members of `VkVideoEncodeH264RateControlLayerInfoEXT`

- Added `prefersGopRemainingFrames` and `requiresGopRemainingFrames`, and the new `VkVideoEncodeH264GopRemainingFrameInfoEXT` structure to allow specifying remaining frames of each type in the rate control GOP

- Added `maxTemporalLayers`, `maxQp`, and `minQp` capabilities

- Added `maxLevelIdc` capability and new `VkVideoEncodeH264SessionCreateInfoEXT` structure to specify upper bounds on the H.264 level of the produced video bitstream

- Moved capability flags specific to codec syntax restrictions from `VkVideoEncodeH264CapabilityFlagsEXT` to the new `VkVideoEncodeH264StdFlagsEXT` which is now included as a separate `stdSyntaxFlags` member in `VkVideoEncodeH264CapabilitiesEXT`

- Removed codec syntax override values from `VkVideoEncodeH264CapabilitiesEXT`

- Removed `VkVideoEncodeH264NaluSliceInfoEXT::mbCount` and `VK_VIDEO_ENCODE_H264_CAPABILITY_SLICE_MB_COUNT_BIT_EXT`

- Replaced `VK_VIDEO_ENCODE_H264_CAPABILITY_MULTIPLE_SLICES_PER_FRAME_BIT_EXT` with the new `maxSliceCount` capability

- Removed capability flag `VK_VIDEO_ENCODE_H264_CAPABILITY_DIFFERENT_REFERENCE_FINAL_LISTS_BIT_EXT` and removed `pStdReferenceFinalLists` members from the `VkVideoEncodeH264PictureInfoEXT` and `VkVideoEncodeH264NaluSliceInfoEXT` structures as reference lists info is now included in `pStdPictureInfo`

- Added capability flag `VK_VIDEO_ENCODE_H264_CAPABILITY_B_FRAME_IN_L0_LIST_BIT_EXT`

- Revision 12, 2023-07-19 (Daniel Rakos)

- Added video std capability flags `VK_VIDEO_ENCODE_H264_STD_SLICE_QP_DELTA_BIT_EXT` and `VK_VIDEO_ENCODE_H264_STD_DIFFERENT_SLICE_QP_DELTA_BIT_EXT`

- Fixed optionality of the array members of `VkVideoEncodeH264SessionParametersAddInfoEXT`

- Fixed optionality of `VkVideoEncodeH264RateControlInfoEXT::flags`

**VK_EXT_video_encode_h265**

**Name String**

`VK_EXT_video_encode_h265`

**Extension Type**

Device extension
This extension builds upon the VK_KHR_video_encode_queue extension by adding support for encoding elementary video stream sequences compliant with the H.265/HEVC video compression standard.
New Structures

- VkVideoEncodeH265FrameSizeEXT
- VkVideoEncodeH265NaluSliceSegmentInfoEXT
- VkVideoEncodeH265QpEXT

Extending VkVideoBeginCodingInfoKHR:
- VkVideoEncodeH265GopRemainingFrameInfoEXT

Extending VkVideoCapabilitiesKHR:
- VkVideoEncodeH265CapabilitiesEXT

Extending VkVideoCodingControlInfoKHR, VkVideoBeginCodingInfoKHR:
- VkVideoEncodeH265RateControlInfoEXT

Extending VkVideoEncodeInfoKHR:
- VkVideoEncodeH265PictureInfoEXT

Extending VkVideoEncodeQualityLevelPropertiesKHR:
- VkVideoEncodeH265QualityLevelPropertiesEXT

Extending VkVideoEncodeRateControlLayerInfoKHR:
- VkVideoEncodeH265RateControlLayerInfoEXT

Extending VkVideoEncodeSessionParametersFeedbackInfoKHR:
- VkVideoEncodeH265SessionParametersFeedbackInfoEXT

Extending VkVideoEncodeSessionParametersGetInfoKHR:
- VkVideoEncodeH265SessionParametersGetInfoEXT

Extending VkVideoProfileInfoKHR, VkQueryPoolCreateInfo:
- VkVideoEncodeH265ProfileInfoEXT

Extending VkVideoReferenceSlotInfoKHR:
- VkVideoEncodeH265DpbSlotInfoEXT

Extending VkVideoSessionCreateInfoKHR:
- VkVideoEncodeH265SessionCreateInfoEXT

Extending VkVideoSessionParametersCreateInfoKHR:
- VkVideoEncodeH265SessionParametersCreateInfoEXT

Extending VkVideoSessionParametersUpdateInfoKHR:
- VkVideoEncodeH265SessionParametersAddInfoEXT

New Enums

- VkVideoEncodeH265CapabilityFlagBitsEXT
- VkVideoEncodeH265CntbSizeFlagBitsEXT
New Bitmasks

- VkVideoEncodeH265CapabilityFlagsEXT
- VkVideoEncodeH265CtbSizeFlagsEXT
- VkVideoEncodeH265RateControlFlagsEXT
- VkVideoEncodeH265StdFlagsEXT
- VkVideoEncodeH265TransformBlockSizeFlagsEXT

New Enum Constants

- VK_EXT_VIDEO_ENCODE_H265_EXTENSION_NAME
- VK_EXT_VIDEO_ENCODE_H265_SPEC_VERSION

Extending VkStructureType:
- VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_CAPABILITIES_EXT
- VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_OPB_SLOT_INFO_EXT
- VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_GOP_REMAINING_FRAME_INFO_EXT
- VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_NALU_SLICE_SEGMENT_INFO_EXT
- VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_PICTURE_INFO_EXT
- VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_PROFILE_INFO_EXT
- VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_QUALITY_LEVEL_PROPERTIES_EXT
- VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_RATE_CONTROL_INFO_EXT
- VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_RATE_CONTROL_LAYER_INFO_EXT
- VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_CREATE_INFO_EXT
- VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_PARAMETERS_ADD_INFO_EXT
- VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_PARAMETERS_CREATE_INFO_EXT
- VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_PARAMETERS_FEEDBACK_INFO_EXT
- VK_STRUCTURE_TYPE_VIDEO_ENCODE_H265_SESSION_PARAMETERS_GET_INFO_EXT

Extending VkVideoCodecOperationFlagBitsKHR:
- VK_VIDEO_CODEC_OPERATION_ENCODE_H265_BIT_EXT

Version History

- Revision 0, 2019-11-14 (Ahmed Abdelkhalek)
  - Initial draft
• Revision 0.5, 2020-02-13 (Tony Zlatinski)
  ◦ General Spec cleanup
  ◦ Added DPB structures
  ◦ Change the VCL frame encode structure
  ◦ Added a common Non-VCL Picture Parameters structure

• Revision 2, Oct 10 2021 (Srinath Kumarapuram)
  ◦ Vulkan Video Encode h.265 update and spec edits

• Revision 3, 2021-12-08 (Ahmed Abdelkhalek)
  ◦ Rate control updates

• Revision 4, 2022-01-11 (Ahmed Abdelkhalek)
  ◦ Replace occurrences of “slice” by “slice segment” and rename structures/enums to reflect this.

• Revision 5, 2022-02-10 (Ahmed Abdelkhalek)
  ◦ Updates to encode capability interface

• Revision 6, 2022-03-16 (Ahmed Abdelkhalek)
  ◦ Relocate Std header version reporting/requesting from this extension to VK_KHR_video_queue extension.
  ◦ Remove the now empty VkVideoEncodeH265SessionCreateInfoEXT.

• Revision 7, 2022-03-24 (Ahmed Abdelkhalek)
  ◦ Add capability flags to report support to disable transform skip and support to use B frame in L1 reference list.

• Revision 8, 2022-07-18 (Daniel Rakos)
  ◦ Replace VkVideoEncodeH265RateControlStructureFlagBitsEXT bit enum with VkVideoEncodeH265RateControlStructureEXT enum
  ◦ Rename VkVideoEncodeH265ProfileEXT to VkVideoEncodeH265ProfileInfoEXT
  ◦ Rename VkVideoEncodeH265ReferenceListsEXT to VkVideoEncodeH265ReferenceListsInfoEXT
  ◦ Rename VkVideoEncodeH265EmitPictureParametersEXT to VkVideoEncodeH265EmitPictureParametersInfoEXT
  ◦ Rename VkVideoEncodeH265NaluSliceSegmentEXT to VkVideoEncodeH265NaluSliceSegmentInfoEXT

• Revision 9, 2022-09-18 (Daniel Rakos)
  ◦ Rename vpsStdCount, pVpsStd, spsStdCount, pSpsStd, ppsStdCount, and pPpsStd to stdVPSCount, pStdVPSs, stdSPSCount, pStdSPSs, stdPPSCount, and pStdPPSs, respectively, in VkVideoEncodeH265SessionParametersAddInfoEXT
  ◦ Rename maxVpsStdCount, maxSpsStdCount, and maxPpsStdCount to maxStdVPSCount, maxStdSPSCount, and maxStdPPSCount, respectively, in VkVideoEncodeH265SessionParametersCreateInfoEXT

• Revision 10, 2023-03-06 (Daniel Rakos)
- Removed `VkVideoEncodeH265EmitPictureParametersInfoEXT`
- Changed member types in `VkVideoEncodeH265CapabilitiesEXT` and `VkVideoEncodeH265ReferenceListsInfoEXT` from `uint8_t` to `uint32_t`
- Changed the type of `VkVideoEncodeH265RateControlInfoEXT::subLayerCount` and `VkVideoEncodeH264RateControlLayerInfoEXT::temporalId` from `uint8_t` to `uint32_t`
- Removed `VkVideoEncodeH265InputModeFlagsEXT` and `VkVideoEncodeH265OutputModeFlagsEXT` as we only support frame-in-frame-out mode for now
- Rename `pCurrentPictureInfo` in `VkVideoEncodeH265VclFrameInfoEXT` to `pStdPictureInfo`
- Rename `pSliceSegmentHeaderStd` in `VkVideoEncodeH265NaluSliceSegmentInfoEXT` to `pStdSliceSegmentHeader`
- Rename `pReferenceFinalLists` in `VkVideoEncodeH264VclFrameInfoEXT` and `VkVideoEncodeH264NaluSliceInfoEXT` to `pStdReferenceFinalLists`
- Removed the `slotIndex` member of `VkVideoEncodeH265DpbSlotInfoEXT` and changed it to be chained to `VkVideoReferenceSlotInfoKHR`
- Replaced `VkVideoEncodeH265ReferenceListsInfoEXT` with the new Video Std header structure `StdVideoEncodeH265ReferenceLists`
- Added new capability flag `VK_VIDEO_ENCODE_H265_CAPABILITY_DIFFERENT_REFERENCE_FINAL_LISTS_BIT_EXT`

Revision 11, 2023-05-26 (Daniel Rakos)

- Renamed `VkVideoEncodeH265VclFrameInfoEXT` to `VkVideoEncodeH265PictureInfoEXT`
- Removed `VkVideoEncodeH265RateControlLayerInfoEXT::temporalId`
- Added `expectDyadicTemporalSubLayerPattern` capability
- Added the `VkVideoEncodeH265SessionParametersGetInfoEXT` structure to identify the H.265 parameter sets to retrieve encoded parameter data for, and the `VkVideoEncodeH265SessionParametersFeedbackInfoEXT` structure to retrieve H.265 parameter set override information when using the new `vkGetEncodedVideoSessionParametersKHR` command
- Added `VkVideoEncodeH265NaluSliceSegmentInfoEXT::constantQp` to specify per-slice segment constant QP when rate control mode is `VK_VIDEO_ENCODE_RATE_CONTROL_MODE_DISABLED_BIT_KHR`
- Added `VkVideoEncodeH265QualityLevelPropertiesEXT` for retrieving H.265 specific quality level recommendations
- Replaced `VkVideoEncodeH265RateControlStructureEXT` enum with the flags type `VkVideoEncodeH265RateControlFlagsEXT` and bits defined in `VkVideoEncodeH265RateControlFlagBitsEXT` and added HRD compliance flag
- Removed `useInitialRcQp` and `initialRcQp` members of `VkVideoEncodeH265RateControlLayerInfoEXT`
- Added `prefersGopRemainingFrames` and `requiresGopRemainingFrames`, and the new `VkVideoEncodeH265GopRemainingFrameInfoEXT` structure to allow specifying remaining frames of each type in the rate control GOP
- Renamed `maxSubLayersCount` capability to `maxSubLayerCount`
- Added `maxQp`, and `minQp` capabilities
- Added `maxLevelIdc` capability and new `VkVideoEncodeH265SessionCreateInfoEXT` structure to specify upper bounds on the H.265 level of the produced video bitstream
- Moved capability flags specific to codec syntax restrictions from `VkVideoEncodeH265CapabilityFlagsEXT` to the new `VkVideoEncodeH265StdFlagsEXT` which is now included as a separate `stdSyntaxFlags` member in `VkVideoEncodeH265CapabilitiesEXT`
- Added `std` prefix to codec syntax capabilities in `VkVideoEncodeH265CapabilitiesEXT`
- Removed `VkVideoEncodeH265NaluSliceSegmentInfoEXT::ctbCount` and `VK_VIDEO_ENCODE_H265_CAPABILITY_SLICE_SEGMENT_CTB_COUNT_BIT_EXT`
- Replaced `VK_VIDEO_ENCODE_H265_CAPABILITY_MULTIPLE_SLICE_SEGMENTS_PER_FRAME_BIT_EXT` with the new `maxSliceSegmentCount` capability
- Added `maxTiles` capability
- Removed codec syntax min/max capabilities from `VkVideoEncodeH265CapabilitiesEXT`
- Removed codec syntax capability flag `VK_VIDEO_ENCODE_H265_CAPABILITY_DIFFERENT_REFERENCE_FINAL_LISTS_BIT_EXT` and removed `pStdReferenceFinalLists` members from the `VkVideoEncodeH265PictureInfoEXT` and `VkVideoEncodeH265NaluSliceSegmentInfoEXT` structures as reference lists info is now included in `pStdPictureInfo`
- Added capability flag `VK_VIDEO_ENCODE_H265_CAPABILITY_B_FRAME_IN_L0_LIST_BIT_EXT`  

**Revision 12, 2023-07-19 (Daniel Rakos)**

- Added video std capability flags `VK_VIDEO_ENCODE_H265_STD_SLICE_QP_DELTA_BIT_EXT` and `VK_VIDEO_ENCODE_H265_STD_DIFFERENT_SLICE_QP_DELTA_BIT_EXT`
- Fixed optionality of the array members of `VkVideoEncodeH265SessionParametersAddInfoEXT`
- Fixed optionality of `VkVideoEncodeH265RateControlInfoEXT::flags`

### VK_AMDX_shader_enqueue

**Name String**

`VK_AMDX_shader_enqueue`

**Extension Type**

Device extension

**Registered Extension Number**

135

**Revision**

1

**Ratification Status**

Not ratified
Extension and Version Dependencies

VK_KHR_get_physical_device_properties2
and
VK_KHR_synchronization2
and
VK_KHR_pipeline_library
and
VK_KHR_spirv_1_4

- This is a provisional extension and must be used with caution. See the description of provisional header files for enablement and stability details.

Contact

- Tobias Hector tobshi

Extension Proposal

VK_AMDX_shader_enqueue

Other Extension Metadata

Last Modified Date

2021-07-22

Interactions and External Dependencies

- This extension requires SPV_AMDX_shader_enqueue.

Provisional

This extension is provisional and should not be used in production applications. The functionality may change in ways that break backwards compatibility between revisions, and before final release.

Contributors

- Tobias Hector, AMD
- Matthaeus Chajdas, AMD
- Maciej Jesionowski, AMD
- Robert Martin, AMD
- Qun Lin, AMD
- Rex Xu, AMD
- Dominik Witczak, AMD
- Karthik Srinivasan, AMD
- Nicolai Haehnle, AMD
- Stuart Smith, AMD
Description

This extension adds the ability for developers to enqueue compute shader workgroups from other compute shaders.

New Commands

- `vkCmdDispatchGraphAMDX`
- `vkCmdDispatchGraphIndirectAMDX`
- `vkCmdDispatchGraphIndirectCountAMDX`
- `vkCmdInitializeGraphScratchMemoryAMDX`
- `vkCreateExecutionGraphPipelinesAMDX`
- `vkGetExecutionGraphPipelineNodeIndexAMDX`
- `vkGetExecutionGraphPipelineScratchSizeAMDX`

New Structures

- `VkDispatchGraphCountInfoAMDX`
- `VkDispatchGraphInfoAMDX`
- `VkExecutionGraphPipelineCreateInfoAMDX`
- `VkExecutionGraphPipelineScratchSizeAMDX`

Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
- `VkPhysicalDeviceShaderEnqueueFeaturesAMDX`

Extending `VkPhysicalDeviceProperties2`:
- `VkPhysicalDeviceShaderEnqueuePropertiesAMDX`

Extending `VkPipelineShaderStageCreateInfo`:
- `VkPipelineShaderStageNodeCreateInfoAMDX`

New Unions

- `VkDeviceOrHostAddressConstAMDX`

New Enum Constants

- `VK_AMDX_SHADER_ENQUEUE_EXTENSION_NAME`
- `VK_AMDX_SHADER_ENQUEUE_SPEC_VERSION`
- `VK_SHADER_INDEX_UNUSED_AMDX`

Extending `VkBufferUsageFlagBits`:
- `VK_BUFFER_USAGE_EXECUTION_GRAPH_SCRATCH_BIT_AMDX`

Extending `VkPipelineBindPoint`:
• VT_PIPELINE_BIND_POINT_EXECUTION_GRAPH_AMD

**Extending VkStructureType:**

• VT_STRUCTURE_TYPE_EXECUTION_GRAPH_PIPELINE_CREATE_INFO_AMD
• VT_STRUCTURE_TYPE_EXECUTION_GRAPH_PIPELINE_SCRATCH_SIZE_AMD
• VT_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ENQUEUE_FEATURES_AMD
• VT_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ENQUEUE_PROPERTIES_AMD
• VT_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_NODE_CREATE_INFO_AMD

If VK_KHR_maintenance5 is supported:

• Extending VkBufferUsageFlagBits2KHR:
  • VT_BUFFER_USAGE_2_EXECUTION_GRAPH_SCRATCH_BIT_AMD

**Version History**

• Revision 1, 2021-07-22 (Tobias Hector)
  • Initial revision

**VT_NV_displacement_micromap**

**Name String**

VT_NV_displacement_micromap

**Extension Type**

Device extension

**Registered Extension Number**

398

**Revision**

2

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

VT_EXT_opacity_micromap

• This is a provisional extension and must be used with caution. See the description of provisional header files for enablement and stability details.

**Contact**

• Christoph Kubisch pixeljetstream
• Eric Werness ewerness-nv
Other Extension Metadata

Last Modified Date
2023-03-17

Interactions and External Dependencies
TBD

Contributors
• Christoph Kubisch, NVIDIA
• Eric Werness, NVIDIA

Description
Ray tracing can very efficiently render from geometry which has very fine detail, but when using only a basic triangle representation, memory consumption can be an issue. This extension adds the ability to add a displacement map to add more detail to triangles in an acceleration structure with an efficient in-memory format. The format is externally visible to allow the application to compress its internal geometry representations into the compressed format ahead of time. This format adds displacements along a defined vector to subtriangle vertices which are subdivided from the main triangles.

This extension provides:

• a new VkMicromapTypeEXT format for the displacement micromap,
• a structure to extend VkAccelerationStructureGeometryTrianglesDataKHR to attach a displacement micromap to the geometry of the acceleration structure,
• enums extending VkBuildAccelerationStructureFlagBitsKHR to allow for updates.

New Structures
• Extending VkAccelerationStructureGeometryTrianglesDataKHR:
  ◦ VkAccelerationStructureTrianglesDisplacementMicromapNV
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceDisplacementMicromapFeaturesNV
• Extending VkPhysicalDeviceProperties2:
  ◦ VkPhysicalDeviceDisplacementMicromapPropertiesNV

New Enums
• VkDisplacementMicromapFormatNV

New Enum Constants
• VK_NV_DISPLACEMENT_MICROMAP_EXTENSION_NAME
• **VK_NV_DISPLACEMENT_MICROMAP_SPEC_VERSION**

• **Extending** `VkBuildAccelerationStructureFlagBitsKHR`:
  ◦ `VK_BUILD_ACCELERATION_STRUCTURE_ALLOW_DISPLACEMENT_MICROMAP_UPDATE_NV`

• **Extending** `VkMicromapTypeEXT`:
  ◦ `VK_MICROMAP_TYPE_DISPLACEMENT_MICROMAP_NV`

• **Extending** `VkPipelineCreateFlagBits`:
  ◦ `VK_PIPELINE_CREATE_RAY_TRACING_DISPLACEMENT_MICROMAP_BIT_NV`

• **Extending** `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_ACCELERATION_STRUCTURE_TRIANGLES_DISPLACEMENT_MICROMAP_NV`
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DISPLACEMENT_MICROMAP_FEATURES_NV`
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DISPLACEMENT_MICROMAP_PROPERTIES_NV`

**Issues**

(1) What is the status of this extension?

• Provisional and expected to change. The broad structure and encoding format are stable, but there will likely be changes to the structures, enumerant values, and shader interface.

**Version History**

• Revision 1, 2023-03-17 (Eric Werness)
  ◦ Initial public revision

• Revision 2, 2023-07-07 (Eric Werness)
  ◦ Add shader support for decode intrinsics

**List of Deprecated Extensions**

• `VK_KHR_16bit_storage`
• `VK_KHR_8bit_storage`
• `VK_KHR_bind_memory2`
• `VK_KHR_buffer_device_address`
• `VK_KHR_copy_commands2`
• `VK_KHR_create_renderpass2`
• `VK_KHR_dedicated_allocation`
• `VK_KHR_depth_stencil_resolve`
• `VK_KHR_descriptor_update_template`
• `VK_KHR_device_group`
• `VK_KHR_device_group_creation`
- VK_KHR_draw_indirect_count
- VK_KHR_driver_properties
- VK_KHR_dynamic_rendering
- VK_KHR_external_fence
- VK_KHR_external_fence_capabilities
- VK_KHR_external_memory
- VK_KHR_external_memory_capabilities
- VK_KHR_external_semaphore
- VK_KHR_external_semaphore_capabilities
- VK_KHR_format_feature_flags2
- VK_KHR_get_memory_requirements2
- VK_KHR_get_physical_device_properties2
- VK_KHR_image_format_list
- VK_KHR_imageless_framebuffer
- VK_KHR_maintenance1
- VK_KHR_maintenance2
- VK_KHR_maintenance3
- VK_KHR_maintenance4
- VK_KHR_multiview
- VK_KHR_relaxed_block_layout
- VK_KHR_sampler_mirror_clamp_to_edge
- VK_KHR_sampler_ycbcr_conversion
- VK_KHR_separate_depth_stencil_layouts
- VK_KHR_shader_atomic_int64
- VK_KHR_shader_draw_parameters
- VK_KHR_shader_float16_int8
- VK_KHR_shader_float_controls
- VK_KHR_shader_integer_dot_product
- VK_KHR_shader_non_semantic_info
- VK_KHR_shader_subgroup_extended_types
- VK_KHR_shader_terminate_invocation
- VK_KHR_spirv_1_4
- VK_KHR_storage_buffer_storage_class
- VK_KHR_synchronization2
- VK_KHR_timeline_semaphore
- VK_KHR_uniform_buffer_standard_layout
- VK_KHR_variable_pointers
- VK_KHR_vulkan_memory_model
- VK_KHR_zero_initialize_workgroup_memory
- VK_EXT_4444_formats
- VK_EXT_buffer_device_address
- VK_EXT_debug_marker
- VK_EXT_debug_report
- VK_EXT_descriptor_indexing
- VK_EXT_extended_dynamic_state
- VK_EXT_extended_dynamic_state2
- VK_EXT_global_priority
- VK_EXT_global_priority_query
- VK_EXT_host_query_reset
- VK_EXT_image_robustness
- VK_EXT_inline_uniform_block
- VK_EXT_pipeline_creation_cache_control
- VK_EXT_pipeline_creation_feedback
- VK_EXT_private_data
- VK_EXT_sampler_filter_minmax
- VK_EXT_scalar_block_layout
- VK_EXT_separate_stencil_usage
- VK_EXT_shader_demote_to_helper_invocation
- VK_EXT_shader_subgroup_ballot
- VK_EXT_shader_subgroup_vote
- VK_EXT_shader_viewport_index_layer
- VK_EXT_subgroup_size_control
- VK_EXT_texel_buffer_alignment
- VK_EXT_texture_compression_astc_hdr
- VK_EXT_tooling_info
- VK_EXT_validation_flags
- VK_EXT_ycbcr_2plane_444_formats
- VK_AMD_draw_indirect_count
- VK_AMD_gpu_shader_half_float
- VK_AMD_gpu_shader_int16
• VK_AMD_negative_viewport_height
• VK_ARM_rasterization_order_attachment_access
• VK_IMG_format_pvrtc
• VK_MVK_ios_surface
• VK_MVK_macos_surface
• VK_NV_dedicated_allocation
• VK_NV_external_memory
• VK_NV_external_memory_capabilities
• VK_NV_external_memory_win32
• VK_NV_fragment_shader_barycentric
• VK_NV_gls1_shader
• VK_NV_win32_keyed_mutex
• VK_VALVEmutable_descriptor_type
VK_KHR_16bit_storage

**Name String**

VK_KHR_16bit_storage

**Extension Type**

Device extension

**Registered Extension Number**

84

**Revision**

1

**Ratification Status**

Ratified

**Extension and Version Dependencies**

VK_KHR_get_physical_device_properties2
and
VK_KHR_storage_buffer_storage_class

**Deprecation state**

*Promoted* to Vulkan 1.1

**Contact**

• Jan-Harald Fredriksen (janharaldfredriksen-arm)

**Other Extension Metadata**

**Last Modified Date**

2017-09-05

**IP Status**

No known IP claims.

**Interactions and External Dependencies**

• Promoted to Vulkan 1.1 Core
• This extension requires SPV_KHR_16bit_storage
• This extension provides API support for GL_EXT_shader_16bit_storage

**Contributors**

• Alexander Galazin, ARM
• Jan-Harald Fredriksen, ARM
• Joerg Wagner, ARM
• Neil Henning, Codeplay
Description

The VK_KHR_16bit_storage extension allows use of 16-bit types in shader input and output interfaces, and push constant blocks. This extension introduces several new optional features which map to SPIR-V capabilities and allow access to 16-bit data in Block-decorated objects in the Uniform and the StorageBuffer storage classes, and objects in the PushConstant storage class. This extension allows 16-bit variables to be declared and used as user-defined shader inputs and outputs but does not change location assignment and component assignment rules.

Promotion to Vulkan 1.1

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. However, if Vulkan 1.1 is supported and this extension is not, the storageBuffer16BitAccess capability is optional. The original type, enum and command names are still available as aliases of the core functionality.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDevice16BitStorageFeaturesKHR

New Enum Constants

- VK_KHR_16BIT_STORAGE_EXTENSION_NAME
- VK_KHR_16BIT_STORAGE_SPEC_VERSION

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_16BIT_STORAGE_FEATURES_KHR

New SPIR-V Capabilities

- StorageBuffer16BitAccess
- UniformAndStorageBuffer16BitAccess
- StoragePushConstant16
- StorageInputOutput16

Version History

- Revision 1, 2017-03-23 (Alexander Galazin)
  - Initial draft
VK_KHR_8bit_storage

Name String
   VK_KHR_8bit_storage

Extension Type
   Device extension

Registered Extension Number
   178

Revision
   1

Ratification Status
   Ratified

Extension and Version Dependencies
   VK_KHR_get_physical_device_properties2
   and
   VK_KHR_storage_buffer_storage_class

Deprecation state
   • Promoted to Vulkan 1.2

Contact
   • Alexander Galazin ♦alegal-arm

Other Extension Metadata

Last Modified Date
   2018-02-05

Interactions and External Dependencies
   • Promoted to Vulkan 1.2 Core
   • This extension requires SPV_KHR_8bit_storage
   • This extension provides API support for GL_EXT_shader_16bit_storage

IP Status
   No known IP claims.

Contributors
   • Alexander Galazin, Arm

Description

The VK_KHR_8bit_storage extension allows use of 8-bit types in uniform and storage buffers, and push constant blocks. This extension introduces several new optional features which map to SPIR-V
capabilities and allow access to 8-bit data in Block-decorated objects in the Uniform and the StorageBuffer storage classes, and objects in the PushConstant storage class.

The StorageBuffer8BitAccess capability must be supported by all implementations of this extension. The other capabilities are optional.

**Promotion to Vulkan 1.2**

Functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. However, if Vulkan 1.2 is supported and this extension is not, the StorageBuffer8BitAccess capability is optional. The original type, enum and command names are still available as aliases of the core functionality.

**New Structures**

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDevice8BitStorageFeaturesKHR

**New Enum Constants**

- VK_KHR_8BIT_STORAGE_EXTENSION_NAME
- VK_KHR_8BIT_STORAGE_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_8BIT_STORAGE_FEATURES_KHR

**New SPIR-V Capabilities**

- StorageBuffer8BitAccess
- UniformAndStorageBuffer8BitAccess
- StoragePushConstant8

**Version History**

- Revision 1, 2018-02-05 (Alexander Galazin)
  - Initial draft

**VK_KHR_bind_memory2**

**Name String**

VK_KHR_bind_memory2

**Extension Type**

Device extension

**Registered Extension Number**

158
Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

Deprecation state

• Promoted to Vulkan 1.1

Contact

• Tobias Hector @tobski

Other Extension Metadata

Last Modified Date

2017-09-05

IP Status

No known IP claims.

Interactions and External Dependencies

• Promoted to Vulkan 1.1 Core

Contributors

• Jeff Bolz, NVIDIA
• Tobias Hector, Imagination Technologies

Description

This extension provides versions of vkBindBufferMemory and vkBindImageMemory that allow multiple bindings to be performed at once, and are extensible.

This extension also introduces VK_IMAGE_CREATE_ALIAS_BIT_KHR, which allows “identical” images that alias the same memory to interpret the contents consistently, even across image layout changes.

Promotion to Vulkan 1.1

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Commands

• vkBindBufferMemory2KHR
• vkBindImageMemory2KHR
New Structures

- VkBindBufferMemoryInfoKHR
- VkBindImageMemoryInfoKHR

New Enum Constants

- VK_KHR_BIND_MEMORY_2_EXTENSION_NAME
- VK_KHR_BIND_MEMORY_2_SPEC_VERSION

Extending VkImageCreateInfo:
- VK_IMAGE_CREATE_ALIAS_BIT_KHR

Extending VkStructureType:
- VK_STRUCTURE_TYPE_BIND_BUFFER_MEMORY_INFO_KHR
- VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_INFO_KHR

Version History

- Revision 1, 2017-05-19 (Tobias Hector)
  - Pulled bind memory functions into their own extension

VK_KHR_buffer_device_address

Name String
  VK_KHR_buffer_device_address

Extension Type
  Device extension

Registered Extension Number
  258

Revision
  1

Ratification Status
  Ratified

Extension and Version Dependencies
  VK_KHR_get_physical_device_properties2
  and
  VK_KHR_device_group
  or
  Version 1.1
Deprecation state

- Promoted to Vulkan 1.2

Contact

- Jeff Bolz 🌐jeffbolznv

Other Extension Metadata

Last Modified Date
2019-06-24

IP Status
No known IP claims.

Interactions and External Dependencies

- Promoted to Vulkan 1.2 Core
- This extension requires SPV_KHR_physical_storage_buffer
- This extension provides API support for GL_EXT_buffer_reference and GL_EXT_buffer_reference2 and GL_EXT_buffer_reference_uvec2

Contributors

- Jeff Bolz, NVIDIA
- Neil Henning, AMD
- Tobias Hector, AMD
- Faith Ekstrand, Intel
- Baldur Karlsson, Valve
- Jan-Harald Fredriksen, Arm

Description

This extension allows the application to query a 64-bit buffer device address value for a buffer, which can be used to access the buffer memory via the PhysicalStorageBuffer storage class in the GL_EXT_buffer_reference GLSL extension and SPV_KHR_physical_storage_buffer SPIR-V extension.

Another way to describe this extension is that it adds “pointers to buffer memory in shaders”. By calling vkGetBufferDeviceAddress with a VkBuffer, it will return a VkDeviceAddress value which represents the address of the start of the buffer.

vkGetBufferOpaqueCaptureAddress and vkGetDeviceMemoryOpaqueCaptureAddress allow opaque addresses for buffers and memory objects to be queried for the current process. A trace capture and replay tool can then supply these addresses to be used at replay time to match the addresses used when the trace was captured. To enable tools to insert these queries, new memory allocation flags must be specified for memory objects that will be bound to buffers accessed via the PhysicalStorageBuffer storage class. Note that this mechanism is intended only to support capture/replay tools, and is not recommended for use in other applications.
There are various use cases this extension is designed for. It is required for ray tracing, useful for DX12 portability, and by allowing buffer addresses to be stored in memory it enables more complex data structures to be created.

This extension can also be used to hardcode a dedicated debug channel into all shaders by querying a pointer at startup and pushing that into shaders as a run-time constant (e.g. specialization constant) that avoids impacting other descriptor limits.

There are examples of usage in the `GL_EXT_buffer_reference` spec for how to use this in a high-level shading language such as GLSL. The `GL_EXT_buffer_reference2` and `GL_EXT_buffer_reference_uvec2` extensions were also added to help cover a few additional edge cases.

**Promotion to Vulkan 1.2**

All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. However, if Vulkan 1.2 is supported and this extension is not, the `bufferDeviceAddress` feature is optional. The original type, enum and command names are still available as aliases of the core functionality.

**Promotion to Vulkan 1.3**

Support for the `bufferDeviceAddress` feature is mandatory in Vulkan 1.3, regardless of whether this extension is supported.

**New Commands**

- `vkGetBufferDeviceAddressKHR`
- `vkGetBufferOpaqueCaptureAddressKHR`
- `vkGetDeviceMemoryOpaqueCaptureAddressKHR`

**New Structures**

- `VkBufferDeviceAddressInfoKHR`
- `VkDeviceMemoryOpaqueCaptureAddressInfoKHR`
- Extending `VkBufferCreateInfo`:
  - `VkBufferOpaqueCaptureAddressCreateInfoKHR`
- Extending `VkMemoryAllocateInfo`:
  - `VkMemoryOpaqueCaptureAddressAllocateInfoKHR`
- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceBufferDeviceAddressFeaturesKHR`

**New Enum Constants**

- `VK_KHR_BUFFER_DEVICE_ADDRESS_EXTENSION_NAME`
- `VK_KHR_BUFFER_DEVICE_ADDRESS_SPEC_VERSION`
• Extending `VkBufferCreateFlagBits`:
  ◦ `VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT_KHR`

• Extending `VkBufferUsageFlagBits`:
  ◦ `VK_BUFFER_USAGE_SHADER_DEVICE_ADDRESS_BIT_KHR`

• Extending `VkMemoryAllocateFlagBits`:
  ◦ `VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_BIT_KHR`
  ◦ `VK_MEMORY_ALLOCATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT_KHR`

• Extending `VkResult`:
  ◦ `VK_ERROR_INVALID_OPAQUE_CAPTURE_ADDRESS_KHR`

• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_BUFFER_DEVICE_ADDRESS_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_BUFFER_OPAQUE_CAPTURE_ADDRESS_CREATE_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_DEVICE_MEMORY_OPAQUE_CAPTURE_ADDRESS_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_MEMORY_OPAQUE_CAPTURE_ADDRESS_ALLOCATE_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BUFFER_DEVICE_ADDRESS_FEATURES_KHR`

### New SPIR-V Capabilities

• `PhysicalStorageBufferAddresses`

### Version History

• Revision 1, 2019-06-24 (Jan-Harald Fredriksen)
  ◦ Internal revisions based on VK_EXT_buffer_device_address

### VK_KHR_copy_commands2

**Name String**

`VK_KHR_copy_commands2`

**Extension Type**

Device extension

**Registered Extension Number**

338

**Revision**

1

**Ratification Status**

Ratified
Extension and Version Dependencies

VK_KHR_get_physical_device_properties2
or
Version 1.1

Deprecation state

• Promoted to Vulkan 1.3

Contact

• Jeff Leger jackohound

Other Extension Metadata

Last Modified Date

2020-07-06

Interactions and External Dependencies

• Promoted to Vulkan 1.3 Core

Interactions and External Dependencies

• None

Contributors

• Jeff Leger, Qualcomm
• Tobias Hector, AMD
• Jan-Harald Fredriksen, ARM
• Tom Olson, ARM

Description

This extension provides extensible versions of the Vulkan buffer and image copy commands. The new commands are functionally identical to the core commands, except that their copy parameters are specified using extensible structures that can be used to pass extension-specific information.

The following extensible copy commands are introduced with this extension: vkCmdCopyBuffer2KHR, vkCmdCopyImage2KHR, vkCmdCopyBufferToImage2KHR, vkCmdCopyImageToBuffer2KHR, vkCmdBlitImage2KHR, and vkCmdResolveImage2KHR. Each command contains an *Info2KHR structure parameter that includes sType/pNext members. Lower level structures describing each region to be copied are also extended with sType/pNext members.

New Commands

• vkCmdBlitImage2KHR
• vkCmdCopyBuffer2KHR
• vkCmdCopyBufferToImage2KHR
• vkCmdCopyImage2KHR
• vkCmdCopyImageToBuffer2KHR
New Structures

- VkBlitImageInfo2KHR
- VkBufferCopy2KHR
- VkBufferImageCopy2KHR
- VkCopyBufferInfo2KHR
- VkCopyBufferToImageInfo2KHR
- VkCopyImageInfo2KHR
- VkCopyImageToBufferInfo2KHR
- VkImageBlit2KHR
- VkImageCopy2KHR
- VkImageResolve2KHR
- VkResolveImageInfo2KHR

New Enum Constants

- VK_KHR_COPY_COMMANDS_2_EXTENSION_NAME
- VK_KHR_COPY_COMMANDS_2_SPEC_VERSION

Extending VkStructureType:

- VK_STRUCTURE_TYPE_BLIT_IMAGE_INFO_2_KHR
- VK_STRUCTURE_TYPE_BUFFER_COPY_2_KHR
- VK_STRUCTURE_TYPE_BUFFER_IMAGE_COPY_2_KHR
- VK_STRUCTURE_TYPE_COPY_BUFFER_INFO_2_KHR
- VK_STRUCTURE_TYPE_COPY_BUFFER_TO_IMAGE_INFO_2_KHR
- VK_STRUCTURE_TYPE_COPY_IMAGE_INFO_2_KHR
- VK_STRUCTURE_TYPE_COPY_IMAGE_TO_BUFFER_INFO_2_KHR
- VK_STRUCTURE_TYPE_IMAGE_BLIT_2_KHR
- VK_STRUCTURE_TYPE_IMAGE_COPY_2_KHR
- VK_STRUCTURE_TYPE_IMAGE_RESOLVE_2_KHR
- VK_STRUCTURE_TYPE_RESOLVE_IMAGE_INFO_2_KHR

Promotion to Vulkan 1.3

Functionality in this extension is included in core Vulkan 1.3, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.
Version History

- Revision 1, 2020-07-06 (Jeff Leger)
  - Internal revisions

**VK_KHR_create_renderpass2**

Name String

`VK_KHR_create_renderpass2`

Extension Type

Device extension

Registered Extension Number

110

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

- `VK_KHR_multiview`
- `VK_KHR_maintenance2`

Deprecation state

- *Promoted to* Vulkan 1.2

Contact

- Tobias Hector [tobias](mailto:tobias)

**Other Extension Metadata**

Last Modified Date

2018-02-07

Interactions and External Dependencies

- Promoted to Vulkan 1.2 Core

Contributors

- Tobias Hector
- Jeff Bolz

Description

This extension provides a new entry point to create render passes in a way that can be easily
extended by other extensions through the substructures of render pass creation. The Vulkan 1.0 render pass creation sub-structures do not include sType/pNext members. Additionally, the render pass begin/next/end commands have been augmented with new extensible structures for passing additional subpass information.

The VkRenderPassMultiviewCreateInfo and VkInputAttachmentAspectReference structures that extended the original VkRenderPassCreateInfo are not accepted into the new creation functions, and instead their parameters are folded into this extension as follows:

- Elements of VkRenderPassMultiviewCreateInfo::pViewMasks are now specified in VkSubpassDescription2KHR::viewMask.
- Elements of VkRenderPassMultiviewCreateInfo::pViewOffsets are now specified in VkSubpassDependency2KHR::viewOffset.
- VkRenderPassMultiviewCreateInfo::correlationMaskCount and VkRenderPassMultiviewCreateInfo::pCorrelationMasks are directly specified in VkRenderPassCreateInfo2KHR.
- VkInputAttachmentAspectReference::aspectMask is now specified in the relevant input attachment reference in VkAttachmentReference2KHR::aspectMask

The details of these mappings are explained fully in the new structures.

**Promotion to Vulkan 1.2**

All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

**New Commands**

- vkCmdBeginRenderPass2KHR
- vkCmdEndRenderPass2KHR
- vkCmdNextSubpass2KHR
- vkCreateRenderPass2KHR

**New Structures**

- VkAttachmentDescription2KHR
- VkAttachmentReference2KHR
- VkRenderPassCreateInfo2KHR
- VkSubpassBeginInfoKHR
- VkSubpassDependency2KHR
- VkSubpassDescription2KHR
- VkSubpassEndInfoKHR
New Enum Constants

- VK_KHR_CREATE_RENDERPASS_2_EXTENSION_NAME
- VK_KHR_CREATE_RENDERPASS_2_SPEC_VERSION

Extending VkStructureType:

- VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_2_KHR
- VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_2_KHR
- VK_STRUCTURE_TYPE_RENDER_PASS_CREATE_INFO_2_KHR
- VK_STRUCTURE_TYPE_SUBPASS_BEGIN_INFO_KHR
- VK_STRUCTURE_TYPE_SUBPASS_DEPENDENCY_2_KHR
- VK_STRUCTURE_TYPE_SUBPASS_DESCRIPTION_2_KHR
- VK_STRUCTURE_TYPE_SUBPASS_END_INFO_KHR

Version History

- Revision 1, 2018-02-07 (Tobias Hector)
  - Internal revisions

VK_KHR_dedicated_allocation

Name String

VK_KHR_dedicated_allocation

Extension Type

Device extension

Registered Extension Number

128

Revision

3

Ratification Status

Ratified

Extension and Version Dependencies

VK_KHR_get_memory_requirements2

Deprecation state

- Promoted to Vulkan 1.1

Contact

- James Jones cubanismo
Other Extension Metadata

Last Modified Date
2017-09-05

IP Status
No known IP claims.

Interactions and External Dependencies
- Promoted to Vulkan 1.1 Core

Contributors
- Jeff Bolz, NVIDIA
- Faith Ekstrand, Intel

Description
This extension enables resources to be bound to a dedicated allocation, rather than suballocated. For any particular resource, applications can query whether a dedicated allocation is recommended, in which case using a dedicated allocation may improve the performance of access to that resource. Normal device memory allocations must support multiple resources per allocation, memory aliasing and sparse binding, which could interfere with some optimizations. Applications should query the implementation for when a dedicated allocation may be beneficial by adding a VkMemoryDedicatedRequirementsKHR structure to the pNext chain of the VkMemoryRequirements2 structure passed as the pMemoryRequirements parameter of a call to vkGetBufferMemoryRequirements2 or vkGetImageMemoryRequirements2. Certain external handle types and external images or buffers may also depend on dedicated allocations on implementations that associate image or buffer metadata with OS-level memory objects.

This extension adds a two small structures to memory requirements querying and memory allocation: a new structure that flags whether an image/buffer should have a dedicated allocation, and a structure indicating the image or buffer that an allocation will be bound to.

Promotion to Vulkan 1.1

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Structures
- Extending VkMemoryAllocateInfo:
  - VkMemoryDedicatedAllocateInfoKHR
- Extending VkMemoryRequirements2:
  - VkMemoryDedicatedRequirementsKHR
New Enum Constants

- VK_KHR_DEDICATED_ALLOCATION_EXTENSION_NAME
- VK_KHR_DEDICATED_ALLOCATION_SPEC_VERSION

Extending VkStructureType:
- VK_STRUCTURE_TYPE_MEMORY_DEDICATED_ALLOCATE_INFO_KHR
- VK_STRUCTURE_TYPE_MEMORY_DEDICATED_REQUIREMENTS_KHR

Examples

```c
// Create an image with a dedicated allocation based on the implementation's preference

VkImageCreateInfo imageCreateInfo = {
    // Image creation parameters
};

VkImage image;
VkResult result = vkCreateImage(
    device,
    &imageCreateInfo,
    NULL, // pAllocator
    &image);

VkMemoryDedicatedRequirementsKHR dedicatedRequirements = {
    .sType = VK_STRUCTURE_TYPE_MEMORY_DEDICATED_REQUIREMENTS_KHR,
    .pNext = NULL,
};

VkMemoryRequirements2 memoryRequirements = {
    .sType = VK_STRUCTURE_TYPE_MEMORY_REQUIREMENTS_2,
    .pNext = &dedicatedRequirements,
};

const VkImageMemoryRequirementsInfo2 imageRequirementsInfo = {
    .sType = VK_STRUCTURE_TYPE_IMAGE_MEMORY_REQUIREMENTS_INFO_2,
    .pNext = NULL,
    .image = image
};

vkGetImageMemoryRequirements2(
    device,
    &imageRequirementsInfo,
    &memoryRequirements);
```
if (dedicatedRequirements.prefersDedicatedAllocation) {
    // Allocate memory with VkMemoryDedicatedAllocateInfoKHR::image
    // pointing to the image we are allocating the memory for

    VkMemoryDedicatedAllocateInfoKHR dedicatedInfo =
    {
        .sType = VK_STRUCTURE_TYPE_MEMORY_DEDICATED_ALLOCATE_INFO_KHR,
        .pNext = NULL,
        .image = image,
        .buffer = VK_NULL_HANDLE,
    };

    VkMemoryAllocateInfo memoryAllocateInfo =
    {
        .sType = VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO,
        .pNext = &dedicatedInfo,
        .allocationSize = memoryRequirements.size,
        .memoryTypeIndex = FindMemoryTypeIndex(memoryRequirements.memoryTypeBits),
    };

    VkDeviceMemory memory;
    vkAllocateMemory(
        device,
        &memoryAllocateInfo,
        NULL,       // pAllocator
        &memory);

    // Bind the image to the memory

    vkBindImageMemory(
        device,
        image,
        memory,
        0);
} else {
    // Take the normal memory sub-allocation path
}

Version History

- Revision 1, 2017-02-27 (James Jones)
  - Copy content from VK_NV_dedicated_allocation
  - Add some references to external object interactions to the overview.
- Revision 2, 2017-03-27 (Faith Ekstrand)
  - Rework the extension to be query-based
- Revision 3, 2017-07-31 (Faith Ekstrand)
Clarify that memory objects allocated with VkMemoryDedicatedAllocateInfoKHR can only have the specified resource bound and no others.

**VK_KHR_depth_stencil_resolve**

**Name String**

VK_KHR_depth_stencil_resolve

**Extension Type**

Device extension

**Registered Extension Number**

200

**Revision**

1

**Ratification Status**

Ratified

**Extension and Version Dependencies**

VK_KHR_create_renderpass2

**Deprecation state**

• Promoted to Vulkan 1.2

**Contact**

• Jan-Harald Fredriksen janharald

**Other Extension Metadata**

**Last Modified Date**

2018-04-09

**Interactions and External Dependencies**

• Promoted to Vulkan 1.2 Core

**Contributors**

• Jan-Harald Fredriksen, Arm
• Andrew Garrard, Samsung Electronics
• Soowan Park, Samsung Electronics
• Jeff Bolz, NVIDIA
• Daniel Rakos, AMD

**Description**

This extension adds support for automatically resolving multisampled depth/stencil attachments in
a subpass in a similar manner as for color attachments.

Multisampled color attachments can be resolved at the end of a subpass by specifying `pResolveAttachments` entries corresponding to the `pColorAttachments` array entries. This does not allow for a way to map the resolve attachments to the depth/stencil attachment. The `vkCmdResolveImage` command does not allow for depth/stencil images. While there are other ways to resolve the depth/stencil attachment, they can give sub-optimal performance. Extending the `VkSubpassDescription2` in this extension allows an application to add a `pDepthStencilResolveAttachment`, that is similar to the color `pResolveAttachments`, that the `pDepthStencilAttachment` can be resolved into.

Depth and stencil samples are resolved to a single value based on the resolve mode. The set of possible resolve modes is defined in the `VkResolveModeFlagBits` enum. The `VK_RESOLVE_MODE_SAMPLE_ZERO_BIT` mode is the only mode that is required of all implementations (that support the extension or support Vulkan 1.2 or higher). Some implementations may also support averaging (the same as color sample resolve) or taking the minimum or maximum sample, which may be more suitable for depth/stencil resolve.

**Promotion to Vulkan 1.2**

All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

**New Structures**

- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceDepthStencilResolvePropertiesKHR`
- Extending `VkSubpassDescription2`:
  - `VkSubpassDescriptionDepthStencilResolveKHR`

**New Enums**

- `VkResolveModeFlagBitsKHR`

**New Bitmasks**

- `VkResolveModeFlagsKHR`

**New Enum Constants**

- `VK_KHR_DEPTH_STENCIL_RESOLVE_EXTENSION_NAME`
- `VK_KHR_DEPTH_STENCIL_RESOLVE_SPEC_VERSION`
- Extending `VkResolveModeFlagBits`:
  - `VK_RESOLVE_MODE_AVERAGE_BIT_KHR`
  - `VK_RESOLVE_MODE_MAX_BIT_KHR`
  - `VK_RESOLVE_MODE_MIN_BIT_KHR`
VK_RESOLVE_MODE_NONE_KHR
VK_RESOLVE_MODE_SAMPLE_ZERO_BIT_KHR

Extending VkStructureType:

◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DEPTH_STENCIL_RESOLVE_PROPERTIES_KHR
◦ VK_STRUCTURE_TYPE_SUBPASS_DESCRIPTION_DEPTH_STENCIL_RESOLVE_KHR

Version History

• Revision 1, 2018-04-09 (Jan-Harald Fredriksen)
  ◦ Initial revision

VK_KHR_descriptor_update_template

Name String

VK_KHR_descriptor_update_template

Extension Type

Device extension

Registered Extension Number

86

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

Deprecation state

• Promoted to Vulkan 1.1

Contact

• Markus Tavenrath mtavenrath

Other Extension Metadata

Last Modified Date

2017-09-05

IP Status

No known IP claims.

Interactions and External Dependencies

• Interacts with VK_KHR_push_descriptor
• Promoted to Vulkan 1.1 Core
Contributors

- Jeff Bolz, NVIDIA
- Michael Worcester, Imagination Technologies

Description

Applications may wish to update a fixed set of descriptors in a large number of descriptor sets very frequently, i.e. during initialization phase or if it is required to rebuild descriptor sets for each frame. For those cases it is also not unlikely that all information required to update a single descriptor set is stored in a single struct. This extension provides a way to update a fixed set of descriptors in a single `VkDescriptorSet` with a pointer to a user defined data structure describing the new descriptors.

Promotion to Vulkan 1.1

`vkCmdPushDescriptorSetWithTemplateKHR` is included as an interaction with `VK_KHR_push_descriptor`. If Vulkan 1.1 and `VK_KHR_push_descriptor` are supported, this is included by `VK_KHR_push_descriptor`.

The base functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Object Types

- `VkDescriptorUpdateTemplateKHR`

New Commands

- `vkCreateDescriptorUpdateTemplateKHR`
- `vkDestroyDescriptorUpdateTemplateKHR`
- `vkUpdateDescriptorSetWithTemplateKHR`

If `VK_KHR_push_descriptor` is supported:

- `vkCmdPushDescriptorSetWithTemplateKHR`

New Structures

- `VkDescriptorUpdateTemplateCreateInfoKHR`
- `VkDescriptorUpdateTemplateEntryKHR`

New Enums

- `VkDescriptorUpdateTemplateTypeKHR`
New Bitmasks

- VkDescriptorUpdateTemplateCreateFlagsKHR

New Enum Constants

- VK_KHR_DESCRIPTOR_UPDATE_TEMPLATE_EXTENSION_NAME
- VK_KHR_DESCRIPTOR_UPDATE_TEMPLATE_SPEC_VERSION

Extending VkDescriptorUpdateTemplateType:
  - VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_DESCRIPTOR_SET_KHR

Extending VkObjectType:
  - VK_OBJECT_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_KHR

Extending VkStructureType:
  - VK_STRUCTURE_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_CREATE_INFO_KHR

If VK_EXT_debug_report is supported:

Extending VkDebugReportObjectTypeEXT:
  - VK_DEBUG_REPORT_OBJECT_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_KHR_EXT

If VK_KHR_push_descriptor is supported:

Extending VkDescriptorUpdateTemplateType:
  - VK_DESCRIPTOR_UPDATE_TEMPLATE_TYPE_PUSH_DESCRIPTORS_KHR

Version History

- Revision 1, 2016-01-11 (Markus Tavenrath)
  - Initial draft

VK_KHR_device_group

Name String

- VK_KHR_device_group

Extension Type

- Device extension

Registered Extension Number

- 61

Revision

- 4
Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_device_group_creation

Deprecation state
• Promoted to Vulkan 1.1

Contact
• Jeff Bolz jeffbolznv

Other Extension Metadata

Last Modified Date
2017-10-10

IP Status
No known IP claims.

Interactions and External Dependencies
• This extension requires SPV_KHR_device_group
• Promoted to Vulkan 1.1 Core

Contributors
• Jeff Bolz, NVIDIA
• Tobias Hector, Imagination Technologies

Description
This extension provides functionality to use a logical device that consists of multiple physical devices, as created with the VK_KHR_device_group_creation extension. A device group can allocate memory across the subdevices, bind memory from one subdevice to a resource on another subdevice, record command buffers where some work executes on an arbitrary subset of the subdevices, and potentially present a swapchain image from one or more subdevices.

Promotion to Vulkan 1.1
The following enums, types and commands are included as interactions with VK_KHR_swapchain:

• VK_STRUCTURE_TYPE_DEVICE_GROUP_PRESENT_CAPABILITIES_KHR
• VK_STRUCTURE_TYPE_IMAGE_SWAPCHAIN_CREATE_INFO_KHR
• VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_SWAPCHAIN_INFO_KHR
• VK_STRUCTURE_TYPE_ACQUIRE_NEXT_IMAGE_INFO_KHR
• VK_STRUCTURE_TYPE_DEVICE_GROUP_PRESENT_INFO_KHR
• VK_STRUCTURE_TYPE_DEVICE_GROUP_SWAPCHAIN_CREATE_INFO_KHR
• VK_SWAPCHAIN_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT_KHR
• VkDeviceGroupPresentModeFlagBitsKHR
• VkDeviceGroupPresentCapabilitiesKHR
• VkImageSwapchainCreateInfoKHR
• VkBindImageMemorySwapchainInfoKHR
• VkAcquireNextImageInfoKHR
• VkDeviceGroupPresentInfoKHR
• VkDeviceGroupSwapchainCreateInfoKHR
• vkGetDeviceGroupPresentCapabilitiesKHR
• vkGetDeviceGroupSurfacePresentModesKHR
• vkGetPhysicalDevicePresentRectanglesKHR
• vkAcquireNextImage2KHR

If Vulkan 1.1 and VK_KHR_swapchain are supported, these are included by VK_KHR_swapchain.

The base functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

**New Commands**

• vkCmdDispatchBaseKHR
• vkCmdSetDeviceMaskKHR
• vkGetDeviceGroupPeerMemoryFeaturesKHR

If VK_KHR_surface is supported:

• vkGetDeviceGroupPresentCapabilitiesKHR
• vkGetDeviceGroupSurfacePresentModesKHR
• vkGetPhysicalDevicePresentRectanglesKHR

If VK_KHR_swapchain is supported:

• vkAcquireNextImage2KHR

**New Structures**

• Extending VkBindSparseInfo:
  ◦ VkDeviceGroupBindSparseInfoKHR

• Extending VkCommandBufferBeginInfo:
  ◦ VkDeviceGroupCommandBufferBeginInfoKHR

• Extending VkMemoryAllocateInfo:
  ◦ VkMemoryAllocateFlagsInfoKHR
• Extending `VkRenderPassBeginInfo`, `VkRenderingInfo`:
  ◦ `VkDeviceGroupRenderPassBeginInfoKHR`

• Extending `VkSubmitInfo`:
  ◦ `VkDeviceGroupSubmitInfoKHR`

If `VK_KHR_bind_memory2` is supported:

• Extending `VkBindBufferMemoryInfo`:
  ◦ `VkBindBufferMemoryDeviceGroupInfoKHR`

• Extending `VkBindImageMemoryInfo`:
  ◦ `VkBindImageMemoryDeviceGroupInfoKHR`

If `VK_KHR_surface` is supported:

• `VkDeviceGroupPresentCapabilitiesKHR`

If `VK_KHR_swapchain` is supported:

• `VkAcquireNextImageInfoKHR`

• Extending `VkBindImageMemoryInfo`:
  ◦ `VkBindImageMemorySwapchainInfoKHR`

• Extending `VkImageCreateInfo`:
  ◦ `VkImageSwapchainCreateInfoKHR`

• Extending `VkPresentInfoKHR`:
  ◦ `VkDeviceGroupPresentInfoKHR`

• Extending `VkSwapchainCreateInfoKHR`:
  ◦ `VkDeviceGroupSwapchainCreateInfoKHR`

**New Enums**

• `VkMemoryAllocateFlagBitsKHR`

• `VkPeerMemoryFeatureFlagBitsKHR`

If `VK_KHR_surface` is supported:

• `VkDeviceGroupPresentModeFlagBitsKHR`

**New Bitmasks**

• `VkMemoryAllocateFlagsKHR`

• `VkPeerMemoryFeatureFlagsKHR`

If `VK_KHR_surface` is supported:
• VkDeviceGroupPresentModeFlagsKHR

New Enum Constants

• VK_KHR_DEVICE_GROUP_EXTENSION_NAME
• VK_KHR_DEVICE_GROUP_SPEC_VERSION

Extending VkDependencyFlagBits:
  ◦ VK_DEPENDENCY_DEVICE_GROUP_BIT_KHR

Extending VkMemoryAllocateFlagBits:
  ◦ VK_MEMORY_ALLOCATE_DEVICE_MASK_BIT_KHR

Extending VkPeerMemoryFeatureFlagBits:
  ◦ VK_PEER_MEMORY_FEATURE_COPY_DST_BIT_KHR
  ◦ VK_PEER_MEMORY_FEATURE_COPY_SRC_BIT_KHR
  ◦ VK_PEER_MEMORY_FEATURE_GENERIC_DST_BIT_KHR
  ◦ VK_PEER_MEMORY_FEATURE_GENERIC_SRC_BIT_KHR

Extending VkPipelineCreateFlagBits:
  ◦ VK_PIPELINE_CREATE_DISPATCH_BASE_KHR
  ◦ VK_PIPELINE_CREATE_VIEW_INDEX_FROM_DEVICE_INDEX_BIT_KHR

Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_DEVICE_GROUP_BIND_SPARSE_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_DEVICE_GROUP_COMMAND_BUFFER_BEGIN_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_DEVICE_GROUP_RENDER_PASS_BEGIN_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_DEVICE_GROUP_SUBMIT_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_FLAGS_INFO_KHR

If VK_KHR_bind_memory2 is supported:

• Extending VkImageCreateFlagBits:
  ◦ VK_IMAGE_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT_KHR

• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_BIND_BUFFER_MEMORY_DEVICE_GROUP_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_DEVICE_GROUP_INFO_KHR

If VK_KHR_surface is supported:

• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_DEVICE_GROUP_PRESENT_CAPABILITIES_KHR

If VK_KHR_swapchain is supported:
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_ACQUIRE_NEXT_IMAGE_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_BIND_IMAGE_MEMORY_SWAPCHAIN_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_DEVICE_GROUP_PRESENT_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_DEVICE_GROUP_SWAPCHAIN_CREATE_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_IMAGE_SWAPCHAIN_CREATE_INFO_KHR

• Extending VkSwapchainCreateFlagBitsKHR:
  ◦ VK_SWAPCHAIN_CREATE_SPLIT_INSTANCE_BIND_REGIONS_BIT_KHR

New Built-in Variables

• DeviceIndex

New SPIR-V Capabilities

• DeviceGroup

Version History

• Revision 1, 2016-10-19 (Jeff Bolz)
  ◦ Internal revisions

• Revision 2, 2017-05-19 (Tobias Hector)
  ◦ Removed extended memory bind functions to VK_KHR_bind_memory2, added dependency
    on that extension, and device-group-specific structs for those functions.

• Revision 3, 2017-10-06 (Ian Elliott)
  ◦ Corrected Vulkan 1.1 interactions with the WSI extensions. All Vulkan 1.1 WSI interactions
    are with the VK_KHR_swapchain extension.

• Revision 4, 2017-10-10 (Jeff Bolz)
  ◦ Rename “SFR” bits and structure members to use the phrase “split instance bind regions”.

VK_KHR_device_group_creation

Name String

VK_KHR_device_group_creation

Extension Type

Instance extension

Registered Extension Number

71

Revision

1
Ratification Status
Ratified

Extension and Version Dependencies

Deprecation state
• Promoted to Vulkan 1.1

Contact
• Jeff Bolz @jeffbolznv

Other Extension Metadata

Last Modified Date
2016-10-19

IP Status
No known IP claims.

Interactions and External Dependencies
• Promoted to Vulkan 1.1 Core

Contributors
• Jeff Bolz, NVIDIA

Description
This extension provides instance-level commands to enumerate groups of physical devices, and to create a logical device from a subset of one of those groups. Such a logical device can then be used with new features in the VK_KHR_device_group extension.

Promotion to Vulkan 1.1
All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Commands
• vkEnumeratePhysicalDeviceGroupsKHR

New Structures
• VkPhysicalDeviceGroupPropertiesKHR
• Extending VkDeviceCreateInfo:
  • VkDeviceGroupDeviceCreateInfoKHR

New Enum Constants
• VK_KHR_DEVICE_GROUP_CREATION_EXTENSION_NAME
Examples

```c
VkDeviceCreateInfo devCreateInfo = { VK_STRUCTURE_TYPE_DEVICE_CREATE_INFO };  // (not shown) fill out devCreateInfo as usual.
uint32_t deviceGroupCount = 0;
VkPhysicalDeviceGroupPropertiesKHR *props = NULL;

// Query the number of device groups
vkEnumeratePhysicalDeviceGroupsKHR(g_vkInstance, &deviceGroupCount, NULL);

// Allocate and initialize structures to query the device groups
props = (VkPhysicalDeviceGroupPropertiesKHR *)malloc(deviceGroupCount * sizeof(VkPhysicalDeviceGroupPropertiesKHR));
for (i = 0; i < deviceGroupCount; ++i) {
    props[i].sType = VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GROUP_PROPERTIES_KHR;
    props[i].pNext = NULL;
}
vkEnumeratePhysicalDeviceGroupsKHR(g_vkInstance, &deviceGroupCount, props);

// If the first device group has more than one physical device. create
// a logical device using all of the physical devices.
VkDeviceGroupDeviceCreateInfoKHR deviceGroupInfo = {
    VK_STRUCTURE_TYPE_DEVICE_GROUP_DEVICE_CREATE_INFO_KHR 
};
if (props[0].physicalDeviceCount > 1) {
    deviceGroupInfo.physicalDeviceCount = props[0].physicalDeviceCount;
    deviceGroupInfo.pPhysicalDevices = props[0].physicalDevices;
    devCreateInfo.pNext = &deviceGroupInfo;
}

vkCreateDevice(props[0].physicalDevices[0], &devCreateInfo, NULL, &g_vkDevice);
free(props);
```

Version History

- Revision 1, 2016-10-19 (Jeff Bolz)
  - Internal revisions
VK_KHR_draw_indirect_count

Name String

VK_KHR_draw_indirect_count

Extension Type

Device extension

Registered Extension Number

170

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

Deprecation state

• Promoted to Vulkan 1.2

Contact

• Piers Daniell pdaniell-nv

Other Extension Metadata

Last Modified Date

2017-08-25

Interactions and External Dependencies

• Promoted to Vulkan 1.2 Core

IP Status

No known IP claims.

Contributors

• Matthaeus G. Chajdas, AMD
• Derrick Owens, AMD
• Graham Sellers, AMD
• Daniel Rakos, AMD
• Dominik Witczak, AMD
• Piers Daniell, NVIDIA

Description

This extension is based off the VK_AMD_draw_indirect_count extension. This extension allows an application to source the number of draws for indirect drawing calls from a buffer.
Applications might want to do culling on the GPU via a compute shader prior to drawing. This enables the application to generate an arbitrary number of drawing commands and execute them without host intervention.

**Promotion to Vulkan 1.2**

All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. However, if Vulkan 1.2 is supported and this extension is not, the entry points `vkCmdDrawIndirectCount` and `vkCmdDrawIndexedIndirectCount` are optional. The original type, enum and command names are still available as aliases of the core functionality.

**New Commands**

- `vkCmdDrawIndexedIndirectCountKHR`
- `vkCmdDrawIndirectCountKHR`

**New Enum Constants**

- `VK_KHR_DRAW_INDIRECT_COUNT_EXTENSION_NAME`
- `VK_KHR_DRAW_INDIRECT_COUNT_SPEC_VERSION`

**Version History**

- Revision 1, 2017-08-25 (Piers Daniell)
  - Initial draft based off VK_AMD_draw_indirect_count

**VK_KHR_driver_properties**

**Name String**

`VK_KHR_driver_properties`

**Extension Type**

Device extension

**Registered Extension Number**

197

**Revision**

1

**Ratification Status**

Ratified

**Extension and Version Dependencies**

- `VK_KHR_get_physical_device_properties2`
Deprecation state
• Promoted to Vulkan 1.2

Contact
• Daniel Rakos drakos-amd

Other Extension Metadata

Last Modified Date
2018-04-11

Interactions and External Dependencies
• Promoted to Vulkan 1.2 Core

IP Status
No known IP claims.

Contributors
• Baldur Karlsson
• Matthaeus G. Chajdas, AMD
• Piers Daniell, NVIDIA
• Alexander Galazin, Arm
• Jesse Hall, Google
• Daniel Rakos, AMD

Description
This extension provides a new physical device query which allows retrieving information about the driver implementation, allowing applications to determine which physical device corresponds to which particular vendor’s driver, and which conformance test suite version the driver implementation is compliant with.

Promotion to Vulkan 1.2
All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Structures
• VkConformanceVersionKHR
• Extending VkPhysicalDeviceProperties2:
  ◦ VkPhysicalDeviceDriverPropertiesKHR

New Enums
• VkDriverIdKHR
New Enum Constants

- VK_KHR_DRIVER_PROPERTIES_EXTENSION_NAME
- VK_KHR_DRIVER_PROPERTIES_SPEC_VERSION
- VK_MAX_DRIVER_INFO_SIZE_KHR
- VK_MAX_DRIVER_NAME_SIZE_KHR

Extending VkDriverId:

- VK_DRIVER_ID_AMD_OPEN_SOURCE_KHR
- VK_DRIVER_ID_AMD_PROPRIETARY_KHR
- VK_DRIVER_ID_ARM_PROPRIETARY_KHR
- VK_DRIVER_ID_BROADCOM_PROPRIETARY_KHR
- VK_DRIVER_ID_GGP_PROPRIETARY_KHR
- VK_DRIVER_ID_GOOGLE_SWIFTSHADER_KHR
- VK_DRIVER_ID_IMAGINATION_PROPRIETARY_KHR
- VK_DRIVER_ID_INTEL_OPEN_SOURCE_MESA_KHR
- VK_DRIVER_ID_INTEL_PROPRIETARY_WINDOWS_KHR
- VK_DRIVER_ID_MESA_RADV_KHR
- VK_DRIVER_ID_NVIDIA_PROPRIETARY_KHR
- VK_DRIVER_ID_QUALCOMM_PROPRIETARY_KHR

Extending VkStructureType:

- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DRIVER_PROPERTIES_KHR

Version History

- Revision 1, 2018-04-11 (Daniel Rakos)
  - Internal revisions

VK_KHR_dynamic_rendering

Name String

VK_KHR_dynamic_rendering

Extension Type

Device extension

Registered Extension Number

45

Revision

1
Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_depth_stencil_resolve
and
VK_KHR_get_physical_device_properties2

Deprecation state
• Promoted to Vulkan 1.3

Contact
• Tobias Hector @tobski

Extension Proposal
VK_KHR_dynamic_rendering

Other Extension Metadata

Last Modified Date
2021-10-06

Interactions and External Dependencies
• Promoted to Vulkan 1.3 Core

Contributors
• Tobias Hector, AMD
• Arseny Kapoulkine, Roblox
• François Duranleau, Gameloft
• Stuart Smith, AMD
• Hai Nguyen, Google
• Jean-François Roy, Google
• Jeff Leger, Qualcomm
• Jan-Harald Fredriksen, Arm
• Piers Daniell, Nvidia
• James Fitzpatrick, Imagination
• Piotr Byszewski, Mobica
• Jesse Hall, Google
• Mike Blumenkrantz, Valve

Description
This extension allows applications to create single-pass render pass instances without needing to create render pass objects or framebuffers. Dynamic render passes can also span across multiple
primary command buffers, rather than relying on secondary command buffers.

This extension also incorporates \texttt{VK_ATTACHMENT_STORE_OP_NONE_KHR} from \texttt{VK_QCOM_render_pass_store_ops}, enabling applications to avoid unnecessary synchronization when an attachment is not written during a render pass.

**New Commands**

- \texttt{vkCmdBeginRenderingKHR}
- \texttt{vkCmdEndRenderingKHR}

**New Structures**

- \texttt{VkRenderingAttachmentInfoKHR}
- \texttt{VkRenderingInfoKHR}
- Extending \texttt{VkCommandBufferInheritanceInfo}:
  - \texttt{VkCommandBufferInheritanceRenderingInfoKHR}
- Extending \texttt{VkGraphicsPipelineCreateInfo}:
  - \texttt{VkPipelineRenderingCreateInfoKHR}
- Extending \texttt{VkPhysicalDeviceFeatures2, VkDeviceCreateInfo}:
  - \texttt{VkPhysicalDeviceDynamicRenderingFeaturesKHR}

If \texttt{VK_AMD_mixed_attachment_samples} is supported:

- Extending \texttt{VkCommandBufferInheritanceInfo, VkGraphicsPipelineCreateInfo}:
  - \texttt{VkAttachmentSampleCountInfoAMD}

If \texttt{VK_EXT_fragment_density_map} is supported:

- Extending \texttt{VkRenderingInfo}:
  - \texttt{VkRenderingFragmentDensityMapAttachmentInfoEXT}

If \texttt{VK_KHR_fragment_shading_rate} is supported:

- Extending \texttt{VkRenderingInfo}:
  - \texttt{VkRenderingFragmentShadingRateAttachmentInfoKHR}

If \texttt{VK_NV_framebuffer_mixed_samples} is supported:

- Extending \texttt{VkCommandBufferInheritanceInfo, VkGraphicsPipelineCreateInfo}:
  - \texttt{VkAttachmentSampleCountInfoNV}

If \texttt{VK_NVX_multiview_per_view_attributes} is supported:

- Extending \texttt{VkCommandBufferInheritanceInfo, VkGraphicsPipelineCreateInfo, VkRenderingInfo}:
  - \texttt{VkMultiviewPerViewAttributesInfoNVX}
New Enums

- VkRenderingFlagBitsKHR

New Bitmasks

- VkRenderingFlagsKHR

New Enum Constants

- VK_KHR_DYNAMIC_RENDERING_EXTENSION_NAME
- VK_KHR_DYNAMIC_RENDERING_SPEC_VERSION

Extending VkAttachmentStoreOp:
- VK_ATTACHMENT_STORE_OP_NONE_KHR

Extending VkStructureType:
- VK_STRUCTURE_TYPE_COMMAND_BUFFER_INHERITANCE_RENDERING_INFO_KHR
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DYNAMIC_RENDERING_FEATURES_KHR
- VK_STRUCTURE_TYPE_PIPELINE_RENDERING_CREATE_INFO_KHR
- VK_STRUCTURE_TYPE_RENDERING_ATTACHMENT_INFO_KHR
- VK_STRUCTURE_TYPE_RENDERING_INFO_KHR

If VK_AMD_mixed_attachment_samples is supported:

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_ATTACHMENT_SAMPLE_COUNT_INFO_AMD

If VK_EXT_fragment_density_map is supported:

- Extending VkPipelineCreateFlagBits:
  - VK_PIPELINE_CREATE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT
  - VK_PIPELINE_RASTERIZATION_STATE_CREATE_FRAGMENT_DENSITY_MAP_ATTACHMENT_BIT_EXT

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_RENDERING_FRAGMENT_DENSITY_MAP_ATTACHMENT_INFO_EXT

If VK_KHR_fragment_shading_rate is supported:

- Extending VkPipelineCreateFlagBits:
  - VK_PIPELINE_CREATE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR
  - VK_PIPELINE_RASTERIZATION_STATE_CREATE_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_RENDERING_FRAGMENT_SHADING_RATE_ATTACHMENT_INFO_KHR

If VK_NV_framebuffer_mixed_samples is supported:
• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_ATTACHMENT_SAMPLE_COUNT_INFO_NV`

If `VK_NVX_multiview_per_view_attributes` is supported:

• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_MULTIVIEW_PER_VIEW_ATTRIBUTES_INFO_NVX`

**Promotion to Vulkan 1.3**

Functionality in this extension is included in core Vulkan 1.3, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

**Version History**

• Revision 1, 2021-10-06 (Tobias Hector)
  ◦ Initial revision

**VK_KHR_external_fence**

**Name String**

`VK_KHR_external_fence`

**Extension Type**

Device extension

**Registered Extension Number**

114

**Revision**

1

**Ratification Status**

Ratified

**Extension and Version Dependencies**

`VK_KHR_external_fence_capabilities`

**Deprecation state**

• *Promoted to* Vulkan 1.1

**Contact**

• Jesse Hall [critsec](#)

**Other Extension Metadata**

**Last Modified Date**

2017-05-08
IP Status
No known IP claims.

Interactions and External Dependencies
• Promoted to Vulkan 1.1 Core

Contributors
• Jesse Hall, Google
• James Jones, NVIDIA
• Jeff Juliano, NVIDIA
• Cass Everitt, Oculus
• Contributors to `VK_KHR_external_semaphore`

Description
An application using external memory may wish to synchronize access to that memory using fences. This extension enables an application to create fences from which non-Vulkan handles that reference the underlying synchronization primitive can be exported.

Promotion to Vulkan 1.1
All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Structures
• Extending `VkFenceCreateInfo`:
  ◦ `VkExportFenceCreateInfoKHR`

New Enums
• `VkFenceImportFlagBitsKHR`

New Bitmasks
• `VkFenceImportFlagsKHR`

New Enum Constants
• `VK_KHR_EXTERNAL_FENCE_EXTENSION_NAME`
• `VK_KHR_EXTERNAL_FENCE_SPEC_VERSION`
• Extending `VkFenceImportFlagBits`:
  ◦ `VK_FENCE_IMPORT_TEMPORARY_BIT_KHR`
• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_EXPORT_FENCE_CREATE_INFO_KHR`
Issues

This extension borrows concepts, semantics, and language from VK_KHR_external_semaphore. That extension's issues apply equally to this extension.

Version History

- Revision 1, 2017-05-08 (Jesse Hall)
  - Initial revision

VK_KHR_external_fence_capabilities

Name String

VK_KHR_external_fence_capabilities

Extension Type

Instance extension

Registered Extension Number

113

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Deprecation state

- Promoted to Vulkan 1.1

Contact

- Jesse Hall @critsec

Other Extension Metadata

Last Modified Date

2017-05-08

IP Status

No known IP claims.

Interactions and External Dependencies

- Promoted to Vulkan 1.1 Core

Contributors

- Jesse Hall, Google
Description

An application may wish to reference device fences in multiple Vulkan logical devices or instances, in multiple processes, and/or in multiple APIs. This extension provides a set of capability queries and handle definitions that allow an application to determine what types of “external” fence handles an implementation supports for a given set of use cases.

Promotion to Vulkan 1.1

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Commands

• vkGetPhysicalDeviceExternalFencePropertiesKHR

New Structures

• VkExternalFencePropertiesKHR
• VkPhysicalDeviceExternalFenceInfoKHR
• Extending VkPhysicalDeviceProperties2:
  ◦ VkPhysicalDeviceIDPropertiesKHR

New Enums

• VkExternalFenceFeatureFlagBitsKHR
• VkExternalFenceHandleTypeFlagBitsKHR

New Bitmasks

• VkExternalFenceFeatureFlagsKHR
• VkExternalFenceHandleTypeFlagsKHR

New Enum Constants

• VK_KHR_EXTERNAL_SEMAPHORE_CAPABILITIES_EXTENSION_NAME
• VK_KHR_EXTERNAL_SEMAPHORE_CAPABILITIES_SPEC_VERSION
• VK_LUID_SIZE_KHR
• Extending VkExternalFenceFeatureFlagBits:
• VK_EXTERNAL_FENCE_FEATURE_EXPORTABLE_BIT_KHR
• VK_EXTERNAL_FENCE_FEATURE_IMPORTABLE_BIT_KHR

• Extending VkExternalFenceHandleTypeFlagBits:
  ◦ VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_FD_BIT_KHR
  ◦ VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_BIT_KHR
  ◦ VK_EXTERNAL_FENCE_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT_KHR
  ◦ VK_EXTERNAL_FENCE_HANDLE_TYPE_SYNC_FD_BIT_KHR

• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_EXTERNAL_FENCE_PROPERTIES_KHR
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_FENCE_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ID_PROPERTIES_KHR

Version History
• Revision 1, 2017-05-08 (Jesse Hall)
  ◦ Initial version

VK_KHR_external_memory

Name String
VK_KHR_external_memory

Extension Type
Device extension

Registered Extension Number
73

Revision
1

Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_external_memory_capabilities

Deprecation state
• Promoted to Vulkan 1.1

Contact
• James Jones cubanismo
Other Extension Metadata

Last Modified Date
2016-10-20

IP Status
No known IP claims.

Interactions and External Dependencies
- Interacts with \texttt{VK_KHR_dedicated_allocation}.
- Interacts with \texttt{VK_NV_dedicated_allocation}.
- Promoted to Vulkan 1.1 Core

Contributors
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- Ian Elliott, Google
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Description
An application may wish to reference device memory in multiple Vulkan logical devices or instances, in multiple processes, and/or in multiple APIs. This extension enables an application to export non-Vulkan handles from Vulkan memory objects such that the underlying resources can be referenced outside the scope of the Vulkan logical device that created them.

Promotion to Vulkan 1.1
All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Structures
- Extending \texttt{VkBufferCreateInfo}:
  - \texttt{VkExternalMemoryBufferCreateInfoKHR}
- Extending \texttt{VkImageCreateInfo}:
• VkExternalMemoryImageCreateInfoKHR

Extending VkMemoryAllocateInfo:
• VkExportMemoryAllocateInfoKHR

New Enum Constants

• VK_KHR_EXTERNAL_MEMORY_EXTENSION_NAME
• VK_KHR_EXTERNAL_MEMORY_SPEC_VERSION
• VK_QUEUE_FAMILY_EXTERNAL_KHR

Extending VkResult:
• VK_ERROR_INVALID_EXTERNAL_HANDLE_KHR

Extending VkStructureType:
• VK_STRUCTURE_TYPE_EXPORT_MEMORY_ALLOCATE_INFO_KHR
• VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_BUFFER_CREATE_INFO_KHR
• VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_IMAGE_CREATE_INFO_KHR

Issues

1) How do applications correlate two physical devices across process or Vulkan instance boundaries?

**RESOLVED:** New device ID fields have been introduced by VK_KHR_external_memory_capabilities. These fields, combined with the existing VkPhysicalDeviceProperties::driverVersion field can be used to identify compatible devices across processes, drivers, and APIs. VkPhysicalDeviceProperties::pipelineCacheUUID is not sufficient for this purpose because despite its description in the specification, it need only identify a unique pipeline cache format in practice. Multiple devices may be able to use the same pipeline cache data, and hence it would be desirable for all of them to have the same pipeline cache UUID. However, only the same concrete physical device can be used when sharing memory, so an actual unique device ID was introduced. Further, the pipeline cache UUID was specific to Vulkan, but correlation with other, non-extensible APIs is required to enable interoperation with those APIs.

2) If memory objects are shared between processes and APIs, is this considered aliasing according to the rules outlined in the Memory Aliasing section?

**RESOLVED:** Yes. Applications must take care to obey all restrictions imposed on aliased resources when using memory across multiple Vulkan instances or other APIs.

3) Are new image layouts or metadata required to specify image layouts and layout transitions compatible with non-Vulkan APIs, or with other instances of the same Vulkan driver?

**RESOLVED:** Separate instances of the same Vulkan driver running on the same GPU should have identical internal layout semantics, so applications have the tools they need to ensure views of images are consistent between the two instances. Other APIs will fall into two categories: Those that are Vulkan-compatible, and those that are Vulkan-incompatible. Vulkan-incompatible APIs will
require the image to be in the GENERAL layout whenever they are accessing them.

Note this does not attempt to address cross-device transitions, nor transitions to engines on the same device which are not visible within the Vulkan API. Both of these are beyond the scope of this extension.

4) Is a new barrier flag or operation of some type needed to prepare external memory for handoff to another Vulkan instance or API and/or receive it from another instance or API?

**RESOLVED**: Yes. Some implementations need to perform additional cache management when transitioning memory between address spaces and other APIs, instances, or processes which may operate in a separate address space. Options for defining this transition include:

- A new structure that can be added to the `pNext` list in `VkMemoryBarrier`, `VkBufferMemoryBarrier`, and `VkImageMemoryBarrier`.
- A new bit in `VkAccessFlags` that can be set to indicate an “external” access.
- A new bit in `VkDependencyFlags`.
- A new special queue family that represents an “external” queue.

A new structure has the advantage that the type of external transition can be described in as much detail as necessary. However, there is not currently a known need for anything beyond differentiating between external and internal accesses, so this is likely an over-engineered solution. The access flag bit has the advantage that it can be applied at buffer, image, or global granularity, and semantically it maps pretty well to the operation being described. Additionally, the API already includes `VK_ACCESS_MEMORY_READ_BIT` and `VK_ACCESS_MEMORY_WRITE_BIT` which appear to be intended for this purpose. However, there is no obvious pipeline stage that would correspond to an external access, and therefore no clear way to use `VK_ACCESS_MEMORY_READ_BIT` or `VK_ACCESS_MEMORY_WRITE_BIT`. `VkDependencyFlags` and `VkPipelineStageFlags` operate at command granularity rather than image or buffer granularity, which would make an entire pipeline barrier an internal→external or external→internal barrier. This may not be a problem in practice, but seems like the wrong scope. Another downside of `VkDependencyFlags` is that it lacks inherent directionality: there are no `src` and `dst` variants of it in the barrier or dependency description semantics, so two bits might need to be added to describe both internal→external and external→internal transitions. Transitioning a resource to a special queue family corresponds well with the operation of transitioning to a separate Vulkan instance, in that both operations ideally include scheduling a barrier on both sides of the transition: Both the releasing and the acquiring queue or process. Using a special queue family requires adding an additional reserved queue family index. Re-using `VK_QUEUE_FAMILY_IGNORED` would have left it unclear how to transition a concurrent usage resource from one process to another, since the semantics would have likely been equivalent to the currently-ignored transition of `VK_QUEUE_FAMILY_IGNORED`→`VK_QUEUE_FAMILY_IGNORED`. Fortunately, creating a new reserved queue family index is not invasive.

Based on the above analysis, the approach of transitioning to a special “external” queue family was chosen.

5) Do internal driver memory arrangements and/or other internal driver image properties need to be exported and imported when sharing images across processes or APIs.
Some vendors claim this is necessary on their implementations, but it was determined that the security risks of allowing opaque metadata to be passed from applications to the driver were too high. Therefore, implementations which require metadata will need to associate it with the objects represented by the external handles, and rely on the dedicated allocation mechanism to associate the exported and imported memory objects with a single image or buffer.

6) Most prior interoperation and cross-process sharing APIs have been based on image-level sharing. Should Vulkan sharing be based on memory-object sharing or image sharing?

RESOLVED: These extensions have assumed memory-level sharing is the correct granularity. Vulkan is a lower-level API than most prior APIs, and as such attempts to closely align with to the underlying primitives of the hardware and system-level drivers it abstracts. In general, the resource that holds the backing store for both images and buffers of various types is memory. Images and buffers are merely metadata containing brief descriptions of the layout of bits within that memory.

Because memory object-based sharing is aligned with the overall Vulkan API design, it enables the full range of Vulkan capabilities with external objects. External memory can be used as backing for sparse images, for example, whereas such usage would be awkward at best with a sharing mechanism based on higher-level primitives such as images. Further, aligning the mechanism with the API in this way provides some hope of trivial compatibility with future API enhancements. If new objects backed by memory objects are added to the API, they too can be used across processes with minimal additions to the base external memory APIs.

Earlier APIs implemented interop at a higher level, and this necessitated entirely separate sharing APIs for images and buffers. To co-exist and interoperate with those APIs, the Vulkan external sharing mechanism must accommodate their model. However, if it can be agreed that memory-based sharing is the more desirable and forward-looking design, legacy interoperation constraints can be considered another reason to favor memory-based sharing: while native and legacy driver primitives that may be used to implement sharing may not be as low-level as the API here suggests, raw memory is still the least common denominator among the types. Image-based sharing can be cleanly derived from a set of base memory-object sharing APIs with minimal effort, whereas image-based sharing does not generalize well to buffer or raw-memory sharing. Therefore, following the general Vulkan design principle of minimalism, it is better to expose interoperability with image-based native and external primitives via the memory sharing API, and place sufficient limits on their usage to ensure they can be used only as backing for equivalent Vulkan images. This provides a consistent API for applications regardless of which platform or external API they are targeting, which makes development of multi-API and multi-platform applications simpler.

7) Should Vulkan define a common external handle type and provide Vulkan functions to facilitate cross-process sharing of such handles rather than relying on native handles to define the external objects?

RESOLVED: No. Cross-process sharing of resources is best left to native platforms. There are myriad security and extensibility issues with such a mechanism, and attempting to re-solve all those issues within Vulkan does not align with Vulkan’s purpose as a graphics API. If desired, such a mechanism could be built as a layer or helper library on top of the opaque native handle defined in this family of extensions.
8) Must implementations provide additional guarantees about state implicitly included in memory objects for those memory objects that may be exported?

**RESOLVED:** Implementations must ensure that sharing memory objects does not transfer any information between the exporting and importing instances and APIs other than that required to share the data contained in the memory objects explicitly shared. As specific examples, data from previously freed memory objects that used the same underlying physical memory, and data from memory objects using adjacent physical memory must not be visible to applications importing an exported memory object.

9) Must implementations validate external handles the application provides as inputs to memory import operations?

**RESOLVED:** Implementations must return an error to the application if the provided memory handle cannot be used to complete the requested import operation. However, implementations need not validate handles are of the exact type specified by the application.

**Version History**

- Revision 1, 2016-10-20 (James Jones)
  - Initial version

**VK_KHR_external_memory_capabilities**

**Name String**

`VK_KHR_external_memory_capabilities`

**Extension Type**

Instance extension

**Registered Extension Number**

72

**Revision**

1

**Ratification Status**

Ratified

**Extension and Version Dependencies**

`VK_KHR_get_physical_device_properties2`

**Deprecation state**

- *Promoted* to Vulkan 1.1

**Contact**

- James Jones [cubanismo]
Other Extension Metadata

Last Modified Date
2016-10-17

IP Status
No known IP claims.

Interactions and External Dependencies
• Interacts with VK_KHR_dedicated_allocation.
• Interacts with VK_NV_dedicated_allocation.
• Promoted to Vulkan 1.1 Core

Contributors
• Ian Elliott, Google
• Jesse Hall, Google
• James Jones, NVIDIA

Description
An application may wish to reference device memory in multiple Vulkan logical devices or instances, in multiple processes, and/or in multiple APIs. This extension provides a set of capability queries and handle definitions that allow an application to determine what types of “external” memory handles an implementation supports for a given set of use cases.

Promotion to Vulkan 1.1
All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Commands
• vkGetPhysicalDeviceExternalBufferPropertiesKHR

New Structures
• VkExternalBufferPropertiesKHR
• VkExternalMemoryPropertiesKHR
• VkPhysicalDeviceExternalBufferInfoKHR
• Extending VkImageFormatProperties2:
  ◦ VkExternalImageFormatPropertiesKHR
• Extending VkPhysicalDeviceImageFormatInfo2:
  ◦ VkPhysicalDeviceExternalImageFormatInfoKHR
• Extending VkPhysicalDeviceProperties2:
New Enums

- VkExternalMemoryFeatureFlagBitsKHR
- VkExternalMemoryHandleTypeFlagBitsKHR

New Bitmasks

- VkExternalMemoryFeatureFlagsKHR
- VkExternalMemoryHandleTypeFlagsKHR

New Enum Constants

- VK_KHR_EXTERNAL_MEMORY_CAPABILITIES_EXTENSION_NAME
- VK_KHR_EXTERNAL_MEMORY_CAPABILITIES_SPEC_VERSION
- VK_LUID_SIZE_KHR

Extending VkExternalMemoryFeatureFlagBits:

- VK_EXTERNAL_MEMORY_FEATURE_DEDICATED_ONLY_BIT_KHR
- VK_EXTERNAL_MEMORY_FEATURE_EXPORTABLE_BIT_KHR
- VK_EXTERNAL_MEMORY_FEATURE_IMPORTABLE_BIT_KHR

Extending VkExternalMemoryHandleTypeFlagBits:

- VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_BIT_KHR
- VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_TEXTURE_KMT_BIT_KHR
- VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_HEAP_BIT_KHR
- VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D12_RESOURCE_BIT_KHR
- VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_FD_BIT_KHR
- VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT_KHR
- VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT_KHR

Extending VkStructureType:

- VK_STRUCTURE_TYPE_EXTERNAL_BUFFER_PROPERTIES_KHR
- VK_STRUCTURE_TYPE_EXTERNAL_IMAGE_FORMAT_PROPERTIES_KHR
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_BUFFER_INFO_KHR
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_IMAGE_FORMAT_INFO_KHR
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ID_PROPERTIES_KHR

Issues

1) Why do so many external memory capabilities need to be queried on a per-memory-handle-type basis?
PROPOSED RESOLUTION: This is because some handle types are based on OS-native objects that have far more limited capabilities than the very generic Vulkan memory objects. Not all memory handle types can name memory objects that support 3D images, for example. Some handle types cannot even support the deferred image and memory binding behavior of Vulkan and require specifying the image when allocating or importing the memory object.

2) Do the VkExternalImageFormatPropertiesKHR and VkExternalBufferPropertiesKHR structs need to include a list of memory type bits that support the given handle type?

PROPOSED RESOLUTION: No. The memory types that do not support the handle types will simply be filtered out of the results returned by vkGetImageMemoryRequirements and vkGetBufferMemoryRequirements when a set of handle types was specified at image or buffer creation time.

3) Should the non-opaque handle types be moved to their own extension?

PROPOSED RESOLUTION: Perhaps. However, defining the handle type bits does very little and does not require any platform-specific types on its own, and it is easier to maintain the bitfield values in a single extension for now. Presumably more handle types could be added by separate extensions though, and it would be midly weird to have some platform-specific ones defined in the core spec and some in extensions.

4) Do we need a D3D11_TILEPOOL type?

PROPOSED RESOLUTION: No. This is technically possible, but the synchronization is awkward. D3D11 surfaces must be synchronized using shared mutexes, and these synchronization primitives are shared by the entire memory object, so D3D11 shared allocations divided among multiple buffer and image bindings may be difficult to synchronize.

5) Should the Windows 7-compatible handle types be named “KMT” handles or “GLOBAL_SHARE” handles?

PROPOSED RESOLUTION: KMT, simply because it is more concise.

6) How do applications identify compatible devices and drivers across instance, process, and API boundaries when sharing memory?

PROPOSED RESOLUTION: New device properties are exposed that allow applications to correctly correlate devices and drivers. A device and driver UUID that must both match to ensure sharing compatibility between two Vulkan instances, or a Vulkan instance and an extensible external API are added. To allow correlating with Direct3D devices, a device LUID is added that corresponds to a DXGI adapter LUID. A driver ID is not needed for Direct3D because mismatched driver component versions are not currently supported on the Windows OS. Should support for such configurations be introduced at the OS level, further Vulkan extensions would be needed to correlate userspace component builds.

Version History

• Revision 1, 2016-10-17 (James Jones)
  ◦ Initial version
VK_KHR_external_semaphore

Name String
VK_KHR_external_semaphore

Extension Type
Device extension

Registered Extension Number
78

Revision
1

Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_external_semaphore_capabilities

Deprecation state
• Promoted to Vulkan 1.1

Contact
• James Jones cubanismo

Other Extension Metadata

Last Modified Date
2016-10-21

IP Status
No known IP claims.

Interactions and External Dependencies
• Promoted to Vulkan 1.1 Core

Contributors
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• Jesse Hall, Google
• Tobias Hector, Imagination Technologies
• James Jones, NVIDIA
• Jeff Juliano, NVIDIA
• Matthew Netsch, Qualcomm Technologies, Inc.
• Ray Smith, ARM
• Lina Versace, Google
Description

An application using external memory may wish to synchronize access to that memory using semaphores. This extension enables an application to create semaphores from which non-Vulkan handles that reference the underlying synchronization primitive can be exported.

Promotion to Vulkan 1.1

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Structures

- Extending VkSemaphoreCreateInfo:
  - VkExportSemaphoreCreateInfoKHR

New Enums

- VkSemaphoreImportFlagBitsKHR

New Bitmasks

- VkSemaphoreImportFlagsKHR

New Enum Constants

- VK_KHR_EXTERNAL_SEMAPHORE_EXTENSION_NAME
- VK_KHR_EXTERNAL_SEMAPHORE_SPEC_VERSION

- Extending VkSemaphoreImportFlagBits:
  - VK_SEMAPHORE_IMPORT_TEMPORARY_BIT_KHR

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_EXPORT_SEMAPHORE_CREATE_INFO_KHR

Issues

1) Should there be restrictions on what side effects can occur when waiting on imported semaphores that are in an invalid state?

**RESOLVED:** Yes. Normally, validating such state would be the responsibility of the application, and the implementation would be free to enter an undefined state if valid usage rules were violated. However, this could cause security concerns when using imported semaphores, as it would require the importing application to trust the exporting application to ensure the state is valid. Requiring this level of trust is undesirable for many potential use cases.

2) Must implementations validate external handles the application provides as input to semaphore state import operations?
RESOLVED: Implementations must return an error to the application if the provided semaphore state handle cannot be used to complete the requested import operation. However, implementations need not validate handles are of the exact type specified by the application.

Version History

• Revision 1, 2016-10-21 (James Jones)
  ◦ Initial revision

VK_KHR_external_semaphore_capabilities

Name String

VK_KHR_external_semaphore_capabilities

Extension Type

Instance extension

Registered Extension Number

77

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Deprecation state

• Promoted to Vulkan 1.1

Contact

• James Jones cubanismo

Other Extension Metadata

Last Modified Date

2016-10-20

IP Status

No known IP claims.

Interactions and External Dependencies

• Promoted to Vulkan 1.1 Core

Contributors

• Jesse Hall, Google
Description

An application may wish to reference device semaphores in multiple Vulkan logical devices or instances, in multiple processes, and/or in multiple APIs. This extension provides a set of capability queries and handle definitions that allow an application to determine what types of “external” semaphore handles an implementation supports for a given set of use cases.

Promotion to Vulkan 1.1

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Commands

- vkGetPhysicalDeviceExternalSemaphorePropertiesKHR

New Structures

- VkExternalSemaphorePropertiesKHR
- VkPhysicalDeviceExternalSemaphoreInfoKHR
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceIDPropertiesKHR

New Enums

- VkExternalSemaphoreFeatureFlagBitsKHR
- VkExternalSemaphoreHandleTypeFlagBitsKHR

New Bitmasks

- VkExternalSemaphoreFeatureFlagsKHR
- VkExternalSemaphoreHandleTypeFlagsKHR

New Enum Constants

- VK_KHR_EXTERNAL_SEMAPHORE_CAPABILITIES_EXTENSION_NAME
- VK_KHR_EXTERNAL_SEMAPHORE_CAPABILITIES_SPEC_VERSION
- VK_LUID_SIZE_KHR
- Extending VkExternalSemaphoreFeatureFlagBits:
  - VK_EXTERNAL_SEMAPHORE_FEATURE_EXPORTABLE_BIT_KHR
  - VK_EXTERNAL_SEMAPHORE_FEATURE_IMPORTABLE_BIT_KHR
• Extending `VkExternalSemaphoreHandleTypeFlagBits`:
  ◦ `VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_D3D12_FENCE_BIT_KHR`
  ◦ `VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_FD_BIT_KHR`
  ◦ `VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_BIT_KHR`
  ◦ `VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_OPAQUE_WIN32_KMT_BIT_KHR`
  ◦ `VK_EXTERNAL_SEMAPHORE_HANDLE_TYPE_SYNC_FD_BIT_KHR`

• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_EXTERNAL_SEMAPHORE_PROPERTIES_KHR`
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTERNAL_SEMAPHORE_INFO_KHR`
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ID_PROPERTIES_KHR`

Version History

• Revision 1, 2016-10-20 (James Jones)
  ◦ Initial revision

**VK_KHR_format_feature_flags2**

Name String

`VK_KHR_format_feature_flags2`

Extension Type

Device extension

Registered Extension Number

361

Revision

2

Ratification Status

Ratified

Extension and Version Dependencies

`VK_KHR_get_physical_device_properties2`

Deprecation state

• *Promoted to* Vulkan 1.3

Contact

• Lionel Landwerlin @landwerlin
Other Extension Metadata

Last Modified Date
2021-07-01

Interactions and External Dependencies
- Promoted to Vulkan 1.3 Core

IP Status
No known IP claims.

Contributors
- Lionel Landwerlin, Intel
- Faith Ekstrand, Intel
- Tobias Hector, AMD
- Spencer Fricke, Samsung Electronics
- Graeme Leese, Broadcom
- Jan-Harald Fredriksen, ARM

Description
This extension adds a new VkFormatFeatureFlagBits2KHR 64bits format feature flag type to extend the existing VkFormatFeatureFlagBits which is limited to 31 flags. At the time of this writing 29 bits of VkFormatFeatureFlagBits are already used.

Because VkFormatProperties2 is already defined to extend the Vulkan 1.0 vkGetPhysicalDeviceFormatProperties entry point, this extension defines a new VkFormatProperties3KHR to extend the VkFormatProperties.

On top of replicating all the bits from VkFormatFeatureFlagBits, VkFormatFeatureFlagBits2KHR adds the following bits:

- VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT_KHR and VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT_KHR indicate that an implementation supports respectively reading and writing a given VkFormat through storage operations without specifying the format in the shader.
- VK_FORMAT_FEATURE_2_SAMPLED_IMAGE_DEPTH_COMPARISON_BIT_KHR indicates that an implementation supports depth comparison performed by OpImage*Dref* instructions on a given VkFormat. Previously the result of executing a OpImage*Dref* instruction on an image view, where the format was not one of the depth/stencil formats with a depth component, was undefined. This bit clarifies on which formats such instructions can be used.

Prior to version 2 of this extension, implementations exposing the shaderStorageImageReadWithoutFormat and shaderStorageImageWriteWithoutFormat features may not report VK_FORMAT_FEATURE_2_STORAGE_READ_WITHOUT_FORMAT_BIT_KHR and VK_FORMAT_FEATURE_2_STORAGE_WRITE_WITHOUT_FORMAT_BIT_KHR in VkFormatProperties3KHR::bufferFeatures. Despite this, buffer reads/writes are supported as intended by the original
features.

New Structures

• Extending VkFormatProperties2:
  ◦ VkFormatProperties3KHR

New Enums

• VkFormatFeatureFlagBits2KHR

New Bitmasks

• VkFormatFeatureFlags2KHR

New Enum Constants

• VK_KHR_FORMAT_FEATURE_FLAGS_2_EXTENSION_NAME
• VK_KHR_FORMAT_FEATURE_FLAGS_2_SPEC_VERSION
  ◦ Extending VkStructureType:
    ◦ VK_STRUCTURE_TYPE_FORMAT_PROPERTIES_3_KHR

Promotion to Vulkan 1.3

Functionality in this extension is included in core Vulkan 1.3, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

Version History

• Revision 2, 2022-07-20 (Lionel Landwerlin)
  ◦ Clarify that VK_FORMAT_FEATURE_2_STORAGE_(READ|WRITE)_WITHOUT_FORMAT_BIT also apply to buffer views.
• Revision 1, 2020-07-21 (Lionel Landwerlin)
  ◦ Initial draft

VK_KHR_get_memory_requirements2

Name String

VK_KHR_get_memory_requirements2

Extension Type

Device extension

Registered Extension Number

147
Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

Deprecation state

- Promoted to Vulkan 1.1

Contact

- Faith Ekstrand gfxstrand

Other Extension Metadata

Last Modified Date

2017-09-05

IP Status

No known IP claims.

Interactions and External Dependencies

- Promoted to Vulkan 1.1 Core

Contributors

- Faith Ekstrand, Intel
- Jeff Bolz, NVIDIA
- Jesse Hall, Google

Description

This extension provides new queries for memory requirements of images and buffers that can be easily extended by other extensions, without introducing any further entry points. The Vulkan 1.0 VkMemoryRequirements and VkSparseImageMemoryRequirements structures do not include sType and pNext members. This extension wraps them in new structures with these members, so an application can query a chain of memory requirements structures by constructing the chain and letting the implementation fill them in. A new command is added for each vkGet*MemoryRequirements command in core Vulkan 1.0.

Promotion to Vulkan 1.1

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Commands

- vkGetBufferMemoryRequirements2KHR
• vkGetImageMemoryRequirements2KHR
• vkGetImageSparseMemoryRequirements2KHR

New Structures

• VkBufferMemoryRequirementsInfo2KHR
• VkImageMemoryRequirementsInfo2KHR
• VkImageSparseMemoryRequirementsInfo2KHR
• VkMemoryRequirements2KHR
• VkSparseImageMemoryRequirements2KHR

New Enum Constants

• VK_KHR_GET_MEMORY_REQUIREMENTS_2_EXTENSION_NAME
• VK_KHR_GET_MEMORY_REQUIREMENTS_2_SPEC_VERSION

Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_BUFFER_MEMORY_REQUIREMENTS_INFO_2_KHR
  ◦ VK_STRUCTURE_TYPE_IMAGE_MEMORY_REQUIREMENTS_INFO_2_KHR
  ◦ VK_STRUCTURE_TYPE_IMAGE_SPARSE_MEMORY_REQUIREMENTS_INFO_2_KHR
  ◦ VK_STRUCTURE_TYPE_MEMORY_REQUIREMENTS_2_KHR
  ◦ VK_STRUCTURE_TYPE_SPARSE_IMAGE_MEMORY_REQUIREMENTS_2_KHR

Version History

• Revision 1, 2017-03-23 (Faith Ekstrand)
  ◦ Internal revisions

VK_KHR_get_physical_device_properties2

Name String
  VK_KHR_get_physical_device_properties2

Extension Type
  Instance extension

Registered Extension Number
  60

Revision
  2

Ratification Status
  Ratified
Extension and Version Dependencies

Deprecation state

• Promoted to Vulkan 1.1

Contact

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Other Extension Metadata

Last Modified Date

2017-09-05

IP Status

No known IP claims.

Interactions and External Dependencies

• Promoted to Vulkan 1.1 Core

Contributors

• Jeff Bolz, NVIDIA
  • Ian Elliott, Google

Description

This extension provides new queries for device features, device properties, and format properties that can be easily extended by other extensions, without introducing any further queries. The Vulkan 1.0 feature/limit/formatproperty structures do not include sType/pNext members. This extension wraps them in new structures with sType/pNext members, so an application can query a chain of feature/limit/formatproperty structures by constructing the chain and letting the implementation fill them in. A new command is added for each vkGetPhysicalDevice* command in core Vulkan 1.0. The new feature structure (and a pNext chain of extending structures) can also be passed in to device creation to enable features.

This extension also allows applications to use the physical-device components of device extensions before vkCreateDevice is called.

Promotion to Vulkan 1.1

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Commands

• vkGetPhysicalDeviceFeatures2KHR
• vkGetPhysicalDeviceFormatProperties2KHR
• vkGetPhysicalDeviceImageFormatProperties2KHR
• vkGetPhysicalDeviceMemoryProperties2KHR
New Structures

- VkFormatProperties2KHR
- VkImageFormatProperties2KHR
- VkPhysicalDeviceImageFormatInfo2KHR
- VkPhysicalDeviceMemoryProperties2KHR
- VkPhysicalDeviceProperties2KHR
- VkPhysicalDeviceSparseImageFormatInfo2KHR
- VkQueueFamilyProperties2KHR
- VkSparseImageFormatProperties2KHR

Extending VkDeviceCreateInfo:

- VkPhysicalDeviceFeatures2KHR

New Enum Constants

- VK_KHR_GET_PHYSICAL_DEVICE_PROPERTIES_2_EXTENSION_NAME
- VK_KHR_GET_PHYSICAL_DEVICE_PROPERTIES_2_SPEC_VERSION

Extending VkStructureType:

- VK_STRUCTURE_TYPE_FORMAT_PROPERTIES_2_KHR
- VK_STRUCTURE_TYPE_IMAGE_FORMAT_PROPERTIES_2_KHR
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FEATURES_2_KHR
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_FORMAT_INFO_2_KHR
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MEMORY_PROPERTIES_2_KHR
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PROPERTIES_2_KHR
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SPARSE_IMAGE_FORMAT_INFO_2_KHR
- VK_STRUCTURE_TYPE_QUEUE_FAMILY_PROPERTIES_2_KHR
- VK_STRUCTURE_TYPE_SPARSE_IMAGE_FORMAT_PROPERTIES_2_KHR

Examples

```c
// Get features with a hypothetical future extension.
VkHypotheticalExtensionFeaturesKHR hypotheticalFeatures = {
    .sType = VK_STRUCTURE_TYPE_HYPOTHETICAL_FEATURES_KHR,
    .pNext = NULL,
};
```
VkPhysicalDeviceFeatures2KHR features =
{
    .sType = VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FEATURES_2_KHR,
    .pNext = &hypotheticalFeatures,
};

// After this call, features and hypotheticalFeatures have been filled out.
vkGetPhysicalDeviceFeatures2KHR(physicalDevice, &features);

// Properties/limits can be chained and queried similarly.

// Enable some features:
VkHypotheticalExtensionFeaturesKHR enabledHypotheticalFeatures =
{
    .sType = VK_STRUCTURE_TYPE_HYPOTHETICAL_FEATURES_KHR,
    .pNext = NULL,
};

VkPhysicalDeviceFeatures2KHR enabledFeatures =
{
    .sType = VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FEATURES_2_KHR,
    .pNext = &enabledHypotheticalFeatures,
};

enabledFeatures.features.xyz = VK_TRUE;
enabledHypotheticalFeatures.abc = VK_TRUE;

VkDeviceCreateInfo deviceCreateInfo =
{
    .sType = VK_STRUCTURE_TYPE_DEVICE_CREATE_INFO,
    .pNext = &enabledFeatures,
    ... 
    .pEnabledFeatures = NULL,
};

VkDevice device;
vkCreateDevice(physicalDevice, &deviceCreateInfo, NULL, &device);

Version History

• Revision 1, 2016-09-12 (Jeff Bolz)
  ◦ Internal revisions
• Revision 2, 2016-11-02 (Ian Elliott)
  ◦ Added ability for applications to use the physical-device components of device extensions
    before vkCreateDevice is called.
VK_KHR_image_format_list

Name String
VK_KHR_image_format_list

Extension Type
Device extension

Registered Extension Number
148

Revision
1

Ratification Status
Ratified

Extension and Version Dependencies

Deprecation state
• Promoted to Vulkan 1.2

Contact
• Faith Ekstrand gfxstrand

Other Extension Metadata

Last Modified Date
2017-03-20

Interactions and External Dependencies
• Promoted to Vulkan 1.2 Core

IP Status
No known IP claims.

Contributors
• Faith Ekstrand, Intel
• Jan-Harald Fredriksen, ARM
• Jeff Bolz, NVIDIA
• Jeff Leger, Qualcomm
• Neil Henning, Codeplay

Description
On some implementations, setting the VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT on image creation can cause access to that image to perform worse than an equivalent image created without VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT because the implementation does not know what view formats
This extension allows an application to provide the list of all formats that can be used with an image when it is created. The implementation may then be able to create a more efficient image that supports the subset of formats required by the application without having to support all formats in the format compatibility class of the image format.

**Promotion to Vulkan 1.2**

All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

**New Structures**

- Extending `VkImageCreateInfo`, `VkSwapchainCreateInfoKHR`, `VkPhysicalDeviceImageFormatInfo2`:
  - `VkImageFormatListCreateInfoKHR`

**New Enum Constants**

- `VK_KHR_IMAGE_FORMAT_LIST_EXTENSION_NAME`
- `VK_KHR_IMAGE_FORMAT_LIST_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_IMAGE_FORMAT_LIST_CREATE_INFO_KHR`

**Version History**

- Revision 1, 2017-03-20 (Faith Ekstrand)
  - Initial revision

**VK_KHR_imageless_framebuffer**

**Name String**

`VK_KHR_imageless_framebuffer`

**Extension Type**

Device extension

**Registered Extension Number**

109

**Revision**

1

**Ratification Status**

Ratified
Extension and Version Dependencies

- VK_KHR_maintenance2
- VK_KHR_image_format_list
- VK_KHR_get_physical_device_properties2

Deprecation state

- Promoted to Vulkan 1.2

Contact

- Tobias Hector @tobias

Other Extension Metadata

Last Modified Date

2018-12-14

Interactions and External Dependencies

- Promoted to Vulkan 1.2 Core

Contributors

- Tobias Hector
- Graham Wihldal

Description

This extension allows framebuffers to be created without the need for creating images first, allowing more flexibility in how they are used, and avoiding the need for many of the confusing compatibility rules.

Framebuffers are now created with a small amount of additional metadata about the image views that will be used in VkFramebufferAttachmentsCreateInfoKHR, and the actual image views are provided at render pass begin time via VkRenderPassAttachmentBeginInfoKHR.

Promotion to Vulkan 1.2

All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Structures

- VkFramebufferAttachmentImageInfoKHR
- Extending VkFramebufferCreateInfo:
  - VkFramebufferAttachmentsCreateInfoKHR
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceImagelessFramebufferFeaturesKHR
• Extending VkRenderPassBeginInfo:
  ◦ VkRenderPassAttachmentBeginInfoKHR

**New Enum Constants**

• VK_KHR_IMAGELESS_FRAMEBUFFER_EXTENSION_NAME
• VK_KHR_IMAGELESS_FRAMEBUFFER_SPEC_VERSION

• Extending VkFramebufferCreateFlagBits:
  ◦ VK_FRAMEBUFFER_CREATE_IMAGELESS_BIT_KHR

• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_FRAMEBUFFER_ATTACHMENTS_CREATE_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_FRAMEBUFFER_ATTACHMENT_IMAGE_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGELESS_FRAMEBUFFER_FEATURES_KHR
  ◦ VK_STRUCTURE_TYPE_RENDER_PASS_ATTACHMENT_BEGIN_INFO_KHR

**Version History**

• Revision 1, 2018-12-14 (Tobias Hector)
  ◦ Internal revisions

**VK_KHR_maintenance1**

**Name String**

VK_KHR_maintenance1

**Extension Type**

Device extension

**Registered Extension Number**

70

**Revision**

2

**Ratification Status**

Ratified

**Extension and Version Dependencies**

**Deprecation state**

• Promoted to Vulkan 1.1

**Contact**

• Piers Daniell pdaniell-nv
Other Extension Metadata

Last Modified Date
2018-03-13

Interactions and External Dependencies
• Promoted to Vulkan 1.1 Core

Contributors
• Dan Ginsburg, Valve
• Daniel Koch, NVIDIA
• Daniel Rakos, AMD
• Jan-Harald Fredriksen, ARM
• Faith Ekstrand, Intel
• Jeff Bolz, NVIDIA
• Jesse Hall, Google
• John Kessenich, Google
• Michael Worcester, Imagination Technologies
• Neil Henning, Codeplay Software Ltd.
• Piers Daniell, NVIDIA
• Slawomir Grajewski, Intel
• Tobias Hector, Imagination Technologies
• Tom Olson, ARM

Description

VK_KHR_maintenance1 adds a collection of minor features that were intentionally left out or overlooked from the original Vulkan 1.0 release.

The new features are as follows:

• Allow 2D and 2D array image views to be created from 3D images, which can then be used as color framebuffer attachments. This allows applications to render to slices of a 3D image.

• Support vkCmdCopyImage between 2D array layers and 3D slices. This extension allows copying from layers of a 2D array image to slices of a 3D image and vice versa.

• Allow negative height to be specified in the VkViewport::height field to perform y-inversion of the clip-space to framebuffer-space transform. This allows apps to avoid having to use gl_Position.y = -gl_Position.y in shaders also targeting other APIs.

• Allow implementations to express support for doing just transfers and clears of image formats that they otherwise support no other format features for. This is done by adding new format feature flags VK_FORMAT_FEATURE_TRANSFER_SRC_BIT_KHR and VK_FORMAT_FEATURE_TRANSFER_DST_BIT_KHR.
• Support `vkCmdFillBuffer` on transfer-only queues. Previously `vkCmdFillBuffer` was defined to only work on command buffers allocated from command pools which support graphics or compute queues. It is now allowed on queues that just support transfer operations.

• Fix the inconsistency of how error conditions are returned between the `vkCreateGraphicsPipelines` and `vkCreateComputePipelines` functions and the `vkAllocateDescriptorSets` and `vkAllocateCommandBuffers` functions.

• Add new `VK_ERROR_OUT_OF_POOL_MEMORY_KHR` error so implementations can give a more precise reason for `vkAllocateDescriptorSets` failures.

• Add a new command `vkTrimCommandPoolKHR` which gives the implementation an opportunity to release any unused command pool memory back to the system.

**Promotion to Vulkan 1.1**

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

**New Commands**

• `vkTrimCommandPoolKHR`

**New Bitmasks**

• `VkCommandPoolTrimFlagsKHR`

**New Enum Constants**

• `VK_KHR_MAINTENANCE1_EXTENSION_NAME`
• `VK_KHR_MAINTENANCE1_SPEC_VERSION`
• `VK_KHR_MAINTENANCE_1_EXTENSION_NAME`
• `VK_KHR_MAINTENANCE_1_SPEC_VERSION`

• Extending `VkFormatFeatureFlagBits`:
  ◦ `VK_FORMAT_FEATURE_TRANSFER_DST_BIT_KHR`
  ◦ `VK_FORMAT_FEATURE_TRANSFER_SRC_BIT_KHR`

• Extending `VkImageCreateFlagBits`:
  ◦ `VK_IMAGE_CREATE_2D_ARRAY_COMPATIBLE_BIT_KHR`

• Extending `VkResult`:
  ◦ `VK_ERROR_OUT_OF_POOL_MEMORY_KHR`

**Issues**

1. Are viewports with zero height allowed?

  **RESOLVED**: Yes, although they have low utility.
Version History

- Revision 1, 2016-10-26 (Piers Daniell)
  - Internal revisions
- Revision 2, 2018-03-13 (Jon Leech)
  - Add issue for zero-height viewports

VK_KHR_maintenance2

Name String

VK_KHR_maintenance2

Extension Type

Device extension

Registered Extension Number

118

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

Deprecation state

- Promoted to Vulkan 1.1

Contact

- Michael Worcester michaelworcester

Other Extension Metadata

Last Modified Date

2017-09-05

Interactions and External Dependencies

- Promoted to Vulkan 1.1 Core

Contributors

- Michael Worcester, Imagination Technologies
- Stuart Smith, Imagination Technologies
- Jeff Bolz, NVIDIA
- Daniel Koch, NVIDIA
- Jan-Harald Fredriksen, ARM
- Daniel Rakos, AMD
Description

VK_KHR_maintenance2 adds a collection of minor features that were intentionally left out or overlooked from the original Vulkan 1.0 release.

The new features are as follows:

- Allow the application to specify which aspect of an input attachment might be read for a given subpass.
- Allow implementations to express the clipping behavior of points.
- Allow creating images with usage flags that may not be supported for the base image’s format, but are supported for image views of the image that have a different but compatible format.
- Allow creating uncompressed image views of compressed images.
- Allow the application to select between an upper-left and lower-left origin for the tessellation domain space.
- Adds two new image layouts for depth stencil images to allow either the depth or stencil aspect to be read-only while the other aspect is writable.

Input Attachment Specification

Input attachment specification allows an application to specify which aspect of a multi-aspect image (e.g. a depth/stencil format) will be accessed via a subpassLoad operation.

On some implementations there may be a performance penalty if the implementation does not know (at vkCreateRenderPass time) which aspect(s) of multi-aspect images can be accessed as input attachments.

Promotion to Vulkan 1.1

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Structures

- VkInputAttachmentAspectReferenceKHR
- Extending VkImageViewCreateInfo:
  - VkImageViewUsageCreateInfoKHR
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDevicePointClippingPropertiesKHR
- Extending VkPipelineTessellationStateCreateInfo:
  - VkPipelineTessellationDomainOriginStateCreateInfoKHR
• Extending VkRenderPassCreateInfo:
  ◦ VkRenderPassInputAttachmentAspectCreateInfoKHR

New Enums

• VkPointClippingBehaviorKHR
• VkTessellationDomainOriginKHR

New Enum Constants

• VK_KHR_MAINTENANCE2_EXTENSION_NAME
• VK_KHR_MAINTENANCE2_SPEC_VERSION
• VK_KHR_MAINTENANCE_2_EXTENSION_NAME
• VK_KHR_MAINTENANCE_2_SPEC_VERSION

• Extending VkImageCreateFlagBits:
  ◦ VK_IMAGE_CREATE_BLOCK_TEXEL_VIEW_COMPATIBLE_BIT_KHR
  ◦ VK_IMAGE_CREATE_EXTENDED_USAGE_BIT_KHR

• Extending VkImageLayout:
  ◦ VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_STENCIL_READ_ONLY_OPTIMAL_KHR
  ◦ VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_STENCIL_ATTACHMENT_OPTIMAL_KHR

• Extending VkPointClippingBehavior:
  ◦ VK_POINT_CLIPPING_BEHAVIOR_ALL_CLIP_PLANES_KHR
  ◦ VK_POINT_CLIPPING_BEHAVIOR_USER_CLIP_PLANES_ONLY_KHR

• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_IMAGE_VIEW_USAGE_CREATE_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_POINT_CLIPPING_PROPERTIES_KHR
  ◦ VK_STRUCTURE_TYPE_PIPELINE_TESSELLATION_DOMAIN_ORIGIN_STATE_CREATE_INFO_KHR
  ◦ VK_STRUCTURE_TYPE_RENDER_PASS_INPUT_ATTACHMENT_ASPECT_CREATE_INFO_KHR

• Extending VkTessellationDomainOrigin:
  ◦ VK_TESSELLATION_DOMAIN_ORIGIN_LOWER_LEFT_KHR
  ◦ VK_TESSELLATION_DOMAIN_ORIGIN_UPPER_LEFT_KHR

Input Attachment Specification Example

Consider the case where a render pass has two subpasses and two attachments.

Attachment 0 has the format VK_FORMAT_D24_UNORM_S8_UINT, attachment 1 has some color format.

Subpass 0 writes to attachment 0, subpass 1 reads only the depth information from attachment 0 (using inputAttachmentRead) and writes to attachment 1.
 VkInputAttachmentAspectReferenceKHR references[] = {
    {.
        subpass = 1,
        inputAttachmentIndex = 0,
        .aspectMask = VK_IMAGE_ASPECT_DEPTH_BIT
    }
};

 VkRenderPassInputAttachmentAspectCreateInfoKHR specifyAspects = {
    .sType = VK_STRUCTURE_TYPE_RENDER_PASS_INPUT_ATTACHMENT_ASPECT_CREATE_INFO_KHR,
    .pNext = NULL,
    .aspectReferenceCount = 1,
    .pAspectReferences = references
};

 VkRenderPassCreateInfo createInfo = {
    ...
    .pNext = &specifyAspects,
    ...
};

 vkCreateRenderPass(...);

Issues
1) What is the default tessellation domain origin?

RESOLVED: Vulkan 1.0 originally inadvertently documented a lower-left origin, but the conformance tests and all implementations implemented an upper-left origin. This extension adds a control to select between lower-left (for compatibility with OpenGL) and upper-left, and we retroactively fix unextended Vulkan to have a default of an upper-left origin.

Version History

- Revision 1, 2017-04-28

VK_KHR_maintenance3

Name String
VK_KHR_maintenance3

Extension Type
Device extension

Registered Extension Number
169
**Description**

`VK_KHR_maintenance3` adds a collection of minor features that were intentionally left out or overlooked from the original Vulkan 1.0 release.

The new features are as follows:

- A limit on the maximum number of descriptors that are supported in a single descriptor set layout. Some implementations have a limit on the total size of descriptors in a set, which cannot be expressed in terms of the limits in Vulkan 1.0.
- A limit on the maximum size of a single memory allocation. Some platforms have kernel interfaces that limit the maximum size of an allocation.

**Promotion to Vulkan 1.1**

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

**New Commands**

- `vkGetDescriptorSetLayoutSupportKHR`
New Structures

- VkDescriptorSetLayoutSupportKHR
- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceMaintenance3PropertiesKHR

New Enum Constants

- VK_KHR_MAINTENANCE3_EXTENSION_NAME
- VK_KHR_MAINTENANCE3_SPEC_VERSION
- VK_KHR_MAINTENANCE_3_EXTENSION_NAME
- VK_KHR_MAINTENANCE_3_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_SUPPORT_KHR
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_3_PROPERTIES_KHR

Version History

- Revision 1, 2017-08-22

VK_KHR_maintenance4

Name String

VK_KHR_maintenance4

Extension Type

Device extension

Registered Extension Number

414

Revision

2

Ratification Status

Ratified

Extension and Version Dependencies

Version 1.1

Deprecation state

- Promoted to Vulkan 1.3

Contact

- Piers Daniell pdaniell-nv
Other Extension Metadata

Last Modified Date
2021-10-25

Interactions and External Dependencies

- Promoted to Vulkan 1.3 Core
- Requires SPIR-V 1.2 for LocalSizeId

Contributors

- Lionel Duc, NVIDIA
- Faith Ekstrand, Intel
- Spencer Fricke, Samsung
- Tobias Hector, AMD
- Lionel Landwerlin, Intel
- Graeme Leese, Broadcom
- Tom Olson, Arm
- Stu Smith, AMD
- Yiwei Zhang, Google

Description

VK_KHR_maintenance4 adds a collection of minor features, none of which would warrant an entire extension of their own.

The new features are as follows:

- Allow the application to destroy their VkPipelineLayout object immediately after it was used to create another object. It is no longer necessary to keep its handle valid while the created object is in use.

- Add a new maxBufferSize implementation-defined limit for the maximum size VkBuffer that can be created.

- Add support for the SPIR-V 1.2 LocalSizeId execution mode, which can be used as an alternative to LocalSize to specify the local workgroup size with specialization constants.

- Add a guarantee that images created with identical creation parameters will always have the same alignment requirements.

- Add new vkGetDeviceBufferMemoryRequirementsKHR, vkGetDeviceImageMemoryRequirementsKHR, and vkGetDeviceImageSparseMemoryRequirementsKHR to allow the application to query the image memory requirements without having to create an image object and query it.

- Relax the requirement that push constants must be initialized before they are dynamically accessed.

- Relax the interface matching rules to allow a larger output vector to match with a smaller input
vector, with additional values being discarded.

- Add a guarantee for buffer memory requirement that the size memory requirement is never greater than the result of aligning create size with the alignment memory requirement.

**New Commands**

- `vkGetDeviceBufferMemoryRequirementsKHR`
- `vkGetDeviceImageMemoryRequirementsKHR`
- `vkGetDeviceImageSparseMemoryRequirementsKHR`

**New Structures**

- `VkDeviceBufferMemoryRequirementsKHR`
- `VkDeviceImageMemoryRequirementsKHR`
- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceMaintenance4FeaturesKHR`
- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceMaintenance4PropertiesKHR`

**New Enum Constants**

- `VK_KHR_MAINTENANCE_4_EXTENSION_NAME`
- `VK_KHR_MAINTENANCE_4_SPEC_VERSION`
- Extending `VkImageAspectFlagBits`:
  - `VK_IMAGE_ASPECT_NONE_KHR`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_DEVICE_BUFFER_MEMORY_REQUIREMENTS_KHR`
  - `VK_STRUCTURE_TYPE_DEVICE_IMAGE_MEMORY_REQUIREMENTS_KHR`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_4_FEATURES_KHR`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MAINTENANCE_4_PROPERTIES_KHR`

**Promotion to Vulkan 1.3**

Functionality in this extension is included in core Vulkan 1.3, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

**Issues**

None.
Version History

- Revision 1, 2021-08-18 (Piers Daniell)
  - Internal revisions
- Revision 2, 2021-10-25 (Yiwei Zhang)
  - More guarantees on buffer memory requirements

VK_KHR_multiview

Name String

VK_KHR_multiview

Extension Type

Device extension

Registered Extension Number

54

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Deprecation state

- Promoted to Vulkan 1.1

Contact

- Jeff Bolz @jeffbolznv

Other Extension Metadata

Last Modified Date

2016-10-28

IP Status

No known IP claims.

Interactions and External Dependencies

- Promoted to Vulkan 1.1 Core
- This extension requires SPV_KHR_multiview
- This extension provides API support for GL_EXT_multiview
Contributors

- Jeff Bolz, NVIDIA

Description

This extension has the same goal as the OpenGL ES \texttt{GL_OVR_multiview} extension. Multiview is a rendering technique originally designed for VR where it is more efficient to record a single set of commands to be executed with slightly different behavior for each “view”.

It includes a concise way to declare a render pass with multiple views, and gives implementations freedom to render the views in the most efficient way possible. This is done with a multiview configuration specified during render pass creation with the \texttt{VkRenderPassMultiviewCreateInfo} passed into \texttt{VkRenderPassCreateInfo::pNext}.

This extension enables the use of the \texttt{SPV_KHR_multiview} shader extension, which adds a new \texttt{ViewIndex} built-in type that allows shaders to control what to do for each view. If using GLSL there is also the \texttt{GL_EXT_multiview} extension that introduces a \texttt{highp int gl_ViewIndex}; built-in variable for vertex, tessellation, geometry, and fragment shaders.

Promotion to Vulkan 1.1

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Structures

- Extending \texttt{VkPhysicalDeviceFeatures2, VkDeviceCreateInfo}:
  - \texttt{VkPhysicalDeviceMultiviewFeaturesKHR}
- Extending \texttt{VkPhysicalDeviceProperties2}:
  - \texttt{VkPhysicalDeviceMultiviewPropertiesKHR}
- Extending \texttt{VkRenderPassCreateInfo}:
  - \texttt{VkRenderPassMultiviewCreateInfoKHR}

New Enum Constants

- \texttt{VK_KHR_MULTIVIEW_EXTENSION_NAME}
- \texttt{VK_KHR_MULTIVIEW_SPEC_VERSION}
- Extending \texttt{VkDependencyFlagBits}:
  - \texttt{VK_DEPENDENCY_VIEW_LOCAL_BIT_KHR}
- Extending \texttt{VkStructureType}:
  - \texttt{VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_FEATURES_KHR}
  - \texttt{VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MULTIVIEW_PROPERTIES_KHR}
  - \texttt{VK_STRUCTURE_TYPE_RENDER_PASS_MULTIVIEW_CREATE_INFO_KHR}
New Built-In Variables

- ViewIndex

New SPIR-V Capabilities

- MultiView

Version History

- Revision 1, 2016-10-28 (Jeff Bolz)
  - Internal revisions

VK_KHR_relaxed_block_layout

Name String

VK_KHR_relaxed_block_layout

Extension Type

Device extension

Registered Extension Number

145

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

Deprecation state

- Promoted to Vulkan 1.1

Contact

- John Kessenich (johnkslang)

Other Extension Metadata

Last Modified Date

2017-03-26

IP Status

No known IP claims.

Interactions and External Dependencies

- Promoted to Vulkan 1.1 Core
Contributors

- John Kessenich, Google

Description

The \texttt{VK_KHR_relaxed_block_layout} extension allows implementations to indicate they can support more variation in block \texttt{Offset} decorations. For example, placing a vector of three floats at an offset of $16 \times N + 4$.

See \texttt{Offset and Stride Assignment} for details.

Promotion to Vulkan 1.1

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Enum Constants

- \texttt{VK_KHR_RELAXED_BLOCK_LAYOUT_EXTENSION_NAME}
- \texttt{VK_KHR_RELAXED_BLOCK_LAYOUT_SPEC_VERSION}

Version History

- Revision 1, 2017-03-26 (JohnK)

\texttt{VK_KHR_sampler_mirror_clamp_to_edge}

Name String

\texttt{VK_KHR_sampler_mirror_clamp_to_edge}

Extension Type

Device extension

Registered Extension Number

15

Revision

3

Ratification Status

Ratified

Extension and Version Dependencies

Deprecation state

- Promoted to Vulkan 1.2

Contact

- Tobias Hector \texttt{tobski}
Other Extension Metadata

Last Modified Date
2019-08-17

Interactions and External Dependencies
• Promoted to Vulkan 1.2 Core

Contributors
• Tobias Hector, Imagination Technologies
• Jon Leech, Khronos

Description
VK_KHR_sampler_mirror_clamp_to_edge extends the set of sampler address modes to include an additional mode (VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE) that effectively uses a texture map twice as large as the original image in which the additional half of the new image is a mirror image of the original image.

This new mode relaxes the need to generate images whose opposite edges match by using the original image to generate a matching “mirror image”. This mode allows the texture to be mirrored only once in the negative s, t, and r directions.

Promotion to Vulkan 1.2
All functionality in this extension is included in core Vulkan 1.2. However, if Vulkan 1.2 is supported and this extension is not, the VkSamplerAddressMode VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE is optional. Since the original extension did not use an author suffix on the enum VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE_KHR, it is used by both core and extension implementations.

New Enum Constants
• VK_KHR_SAMPLER_MIRROR_CLAMP_TO_EDGE_EXTENSION_NAME
• VK_KHR_SAMPLER_MIRROR_CLAMP_TO_EDGE_SPEC_VERSION
• Extending VkSamplerAddressMode:
  ◦ VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE
  ◦ VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE_KHR

Example
Creating a sampler with the new address mode in each dimension

```cpp
VkSamplerCreateInfo createInfo = {
    .sType = VK_STRUCTURE_TYPE_SAMPLER_CREATE_INFO,
    // Other members set to application-desired values
};
```
createInfo.addressModeU = VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE;
createInfo.addressModeV = VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE;
createInfo.addressModeW = VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE;

VkSampler sampler;
VkResult result = vkCreateSampler(
    device,
    &createInfo,
    &sampler);

**Issues**

1) Why are both KHR and core versions of the `VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE` token present?

**RESOLVED**: This functionality was intended to be required in Vulkan 1.0. We realized shortly before public release that not all implementations could support it, and moved the functionality into an optional extension, but did not apply the KHR extension suffix. Adding a KHR-suffixed alias of the non-suffixed enum has been done to comply with our own naming rules.

In a related change, before spec revision 1.1.121 this extension was hardwiring into the spec Makefile so it was always included with the Specification, even in the core-only versions. This has now been reverted, and it is treated as any other extension.

**Version History**

- Revision 1, 2016-02-16 (Tobias Hector)
  - Initial draft
- Revision 2, 2019-08-14 (Jon Leech)
  - Add KHR-suffixed alias of non-suffixed enum.
- Revision 3, 2019-08-17 (Jon Leech)
  - Add an issue explaining the reason for the extension API not being suffixed with KHR.

**VK_KHR_sampler_ycbcr_conversion**

**Name String**

`VK_KHR_sampler_ycbcr_conversion`

**Extension Type**

Device extension

**Registered Extension Number**

157
Revision
14

Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_maintenance1
and
VK_KHR_bind_memory2
and
VK_KHR_get_memory_requirements2
and
VK_KHR_get_physical_device_properties2

Deprecation state
• Promoted to Vulkan 1.1

Contact
• Andrew Garrard fluppeteer

Other Extension Metadata

Last Modified Date
2017-08-11

IP Status
No known IP claims.

Interactions and External Dependencies
• Promoted to Vulkan 1.1 Core

Contributors
• Andrew Garrard, Samsung Electronics
• Tobias Hector, Imagination Technologies
• James Jones, NVIDIA
• Daniel Koch, NVIDIA
• Daniel Rakos, AMD
• Romain Guy, Google
• Jesse Hall, Google
• Tom Cooksey, ARM Ltd
• Jeff Leger, Qualcomm Technologies, Inc
• Jan-Harald Fredriksen, ARM Ltd
• Jan Outters, Samsung Electronics
Description

The use of Y′CbCr sampler conversion is an area in 3D graphics not used by most Vulkan developers. It is mainly used for processing inputs from video decoders and cameras. The use of the extension assumes basic knowledge of Y′CbCr concepts.

This extension provides the ability to perform specified color space conversions during texture sampling operations for the Y′CbCr color space natively. It also adds a selection of multi-planar formats, image aspect plane, and the ability to bind memory to the planes of an image collectively or separately.

Promotion to Vulkan 1.1

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted. However, if Vulkan 1.1 is supported and this extension is not, the samplerYcbcrConversion capability is optional. The original type, enum and command names are still available as aliases of the core functionality.

New Object Types

- VkSamplerYcbcrConversionKHR

New Commands

- vkCreateSamplerYcbcrConversionKHR
- vkDestroySamplerYcbcrConversionKHR

New Structures

- VkSamplerYcbcrConversionCreateInfoKHR
- Extending VkBindImageMemoryInfo:
  - VkBindImagePlaneMemoryInfoKHR
- Extending VkImageFormatProperties2:
  - VkSamplerYcbcrConversionImageFormatPropertiesKHR
- Extending VkImageMemoryRequirementsInfo2:
  - VkImagePlaneMemoryRequirementsInfoKHR
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceSamplerYcbcrConversionFeaturesKHR
• Extending VkSamplerCreateInfo, VkImageViewCreateInfo:
  ◦ VkSamplerYcbcrConversionInfoKHR

New Enums

• VkChromaLocationKHR
• VkSamplerYcbcrModelConversionKHR
• VkSamplerYcbcrRangeKHR

New Enum Constants

• VK_KHR_SAMPLER_YCBCR_CONVERSION_EXTENSION_NAME
• VK_KHR_SAMPLER_YCBCR_CONVERSION_SPEC_VERSION

Extending VkChromaLocation:
  ◦ VK_CHROMA_LOCATION_COSITED_EVEN_KHR
  ◦ VK_CHROMA_LOCATION_MIDPOINT_KHR

Extending VkFormat:
  ◦ VK_FORMAT_B10X6G10X6R10X6G10X6_422_UNORM_4PACK16_KHR
  ◦ VK_FORMAT_B12X4G12X4R12X4G12X4_422_UNORM_4PACK16_KHR
  ◦ VK_FORMAT_B16G16R16G16_422_UNORM_KHR
  ◦ VK_FORMAT_B8G8R8G8_422_UNORM_KHR
  ◦ VK_FORMAT_G10X6B10X6G10X6R10X6_422_UNORM_4PACK16_KHR
  ◦ VK_FORMAT_G10X6_B10X6R10X6_2PLANE_420_UNORM_3PACK16_KHR
  ◦ VK_FORMAT_G10X6_B10X6R10X6_2PLANE_422_UNORM_3PACK16_KHR
  ◦ VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_420_UNORM_3PACK16_KHR
  ◦ VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_422_UNORM_3PACK16_KHR
  ◦ VK_FORMAT_G10X6_B10X6_R10X6_3PLANE_444_UNORM_3PACK16_KHR
  ◦ VK_FORMAT_G12X4B12X4G12X4R12X4_422_UNORM_4PACK16_KHR
  ◦ VK_FORMAT_G12X4_B12X4R12X4_2PLANE_420_UNORM_3PACK16_KHR
  ◦ VK_FORMAT_G12X4_B12X4R12X4_2PLANE_422_UNORM_3PACK16_KHR
  ◦ VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_420_UNORM_3PACK16_KHR
  ◦ VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_422_UNORM_3PACK16_KHR
  ◦ VK_FORMAT_G12X4_B12X4_R12X4_3PLANE_444_UNORM_3PACK16_KHR
  ◦ VK_FORMAT_G16B16G16R16_422_UNORM_KHR
  ◦ VK_FORMAT_G16_B16R16_2PLANE_420_UNORM_KHR
  ◦ VK_FORMAT_G16_B16R16_2PLANE_422_UNORM_KHR
  ◦ VK_FORMAT_G16_B16_R16_3PLANE_420_UNORM_KHR
*Extending* VkFormatFeatureFlagBits:
- VK_FORMAT_FEATURE_COSITED_CHROMA_SAMPLES_BIT_KHR
- VK_FORMAT_FEATURE_DISJOINT_BIT_KHR
- VK_FORMAT_FEATURE_MIDPOINT_CHROMA_SAMPLES_BIT_KHR
- VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_BIT_KHR
- VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_CHROMA_RECONSTRUCTION_EXPLICIT_FORCEABLE_BIT_KHR
- VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_LINEAR_FILTER_BIT_KHR
- VK_FORMAT_FEATURE_SAMPLED_IMAGE_YCBCR_CONVERSION_SEPARATE_RECONSTRUCTION_FILTER_BIT_KHR

*Extending* VkImageAspectFlagBits:
- VK_IMAGE_ASPECT_PLANE_0_BIT_KHR
- VK_IMAGE_ASPECT_PLANE_1_BIT_KHR
- VK_IMAGE_ASPECT_PLANE_2_BIT_KHR

*Extending* VkImageCreateFlagBits:
- VK_IMAGE_CREATE_DISJOINT_BIT_KHR

*Extending* VkObjectType:
- VK_OBJECT_TYPE_SAMPLER_YCBCR_CONVERSION_KHR

*Extending* VkSamplerYcbcrModelConversion:
- VK_SAMPLER_YCBCR_MODEL_CONVERSION_RGB_IDENTITY_KHR
- VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_2020_KHR
- VK_SAMPLER_YCBCR_MODEL_CONVERSION_YCBCR_601_KHR
Extending `VkSamplerYcbcrRange`:
- `VK_SAMPLER_YCBCR_RANGE_ITU_FULL_KHR`
- `VK_SAMPLER_YCBCR_RANGE_ITU_NARROW_KHR`

Extending `VkStructureType`:
- `VK_STRUCTURE_TYPE_BIND_IMAGE_PLANE_MEMORY_INFO_KHR`
- `VK_STRUCTURE_TYPE_IMAGE_PLANE_MEMORY_REQUIREMENTS_INFO_KHR`
- `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SAMPLER_YCBCR_CONVERSION_FEATURES_KHR`
- `VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_CREATE_INFO_KHR`
- `VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_IMAGE_FORMAT_PROPERTIES_KHR`
- `VK_STRUCTURE_TYPE_SAMPLER_YCBCR_CONVERSION_INFO_KHR`

If `VK_EXT_debug_report` is supported:

Extending `VkDebugReportObjectTypeEXT`:
- `VK_DEBUG_REPORT_OBJECT_TYPE_SAMPLER_YCBCR_CONVERSION_EXT`
- `VK_DEBUG_REPORT_OBJECT_TYPE_SAMPLER_YCBCR_CONVERSION_KHR_EXT`

Version History:

- Revision 1, 2017-01-24 (Andrew Garrard)
  - Initial draft
- Revision 2, 2017-01-25 (Andrew Garrard)
  - After initial feedback
- Revision 3, 2017-01-27 (Andrew Garrard)
  - Higher bit depth formats, renaming, swizzle
- Revision 4, 2017-02-22 (Andrew Garrard)
  - Added query function, formats as RGB, clarifications
- Revision 5, 2017-04-?? (Andrew Garrard)
  - Simplified query and removed output conversions
- Revision 6, 2017-04-24 (Andrew Garrard)
  - Tidying, incorporated new image query, restored transfer functions
- Revision 7, 2017-04-25 (Andrew Garrard)
  - Added cosited option/midpoint requirement for formats, “bypassConversion”
- Revision 8, 2017-04-25 (Andrew Garrard)
  - Simplified further
• Revision 9, 2017-04-27 (Andrew Garrard)
  ◦ Disjoint no more

• Revision 10, 2017-04-28 (Andrew Garrard)
  ◦ Restored disjoint

• Revision 11, 2017-04-29 (Andrew Garrard)
  ◦ Now Ycbcr conversion, and KHR

• Revision 12, 2017-06-06 (Andrew Garrard)
  ◦ Added conversion to image view creation

• Revision 13, 2017-07-13 (Andrew Garrard)
  ◦ Allowed cosited-only chroma samples for formats

• Revision 14, 2017-08-11 (Andrew Garrard)
  ◦ Reflected quantization changes in BT.2100-1

**VK_KHR_separate_depth_stencil_layouts**

**Name String**

VK_KHR_separate_depth_stencil_layouts

**Extension Type**

Device extension

**Registered Extension Number**

242

**Revision**

1

**Ratification Status**

Ratified

**Extension and Version Dependencies**

VK_KHR_get_physical_device_properties2
and
VK_KHR_create_renderpass2

**Deprecation state**

• Promoted to Vulkan 1.2

**Contact**

• Piers Daniell [pdaniell-nv](https://github.com/pdaniell-nv)

**Other Extension Metadata**
Interactions and External Dependencies

- Promoted to Vulkan 1.2 Core

Contributors

- Daniel Koch, NVIDIA
- Jeff Bolz, NVIDIA
- Jesse Barker, Unity
- Tobias Hector, AMD

Description

This extension allows image memory barriers for depth/stencil images to have just one of the `VK_IMAGE_ASPECT_DEPTH_BIT` or `VK_IMAGE_ASPECT_STENCIL_BIT` aspect bits set, rather than require both. This allows their layouts to be set independently. To support depth/stencil images with different layouts for the depth and stencil aspects, the depth/stencil attachment interface has been updated to support a separate layout for stencil.

Promotion to Vulkan 1.2

All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Structures

- Extending `VkAttachmentDescription2`:
  - `VkAttachmentDescriptionStencilLayoutKHR`
- Extending `VkAttachmentReference2`:
  - `VkAttachmentReferenceStencilLayoutKHR`
- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceSeparateDepthStencilLayoutsFeaturesKHR`

New Enum Constants

- `VK_KHR_SEPARATE_DEPTH_STENCIL_LAYOUTS_EXTENSION_NAME`
- `VK_KHR_SEPARATE_DEPTH_STENCIL_LAYOUTS_SPEC_VERSION`
- Extending `VkImageLayout`:
  - `VK_IMAGE_LAYOUT_DEPTH_ATTACHMENT_OPTIMAL_KHR`
  - `VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL_KHR`
  - `VK_IMAGE_LAYOUT_STENCIL_ATTACHMENT_OPTIMAL_KHR`
  - `VK_IMAGE_LAYOUT_STENCIL_READ_ONLY_OPTIMAL_KHR`
• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_ATTACHMENT_DESCRIPTION_STENCIL_LAYOUT_KHR`
  ◦ `VK_STRUCTURE_TYPE_ATTACHMENT_REFERENCE_STENCIL_LAYOUT_KHR`
  ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SEPARATE_DEPTH_STENCIL_LAYOUTS_FEATURES_KHR`

**Version History**

• Revision 1, 2019-06-25 (Piers Daniell)
  ◦ Internal revisions

**VK_KHR_shader_atomic_int64**

**Name String**

`VK_KHR_shader_atomic_int64`

**Extension Type**

Device extension

**Registered Extension Number**

181

**Revision**

1

**Ratification Status**

Ratified

**Extension and Version Dependencies**

`VK_KHR_get_physical_device_properties2`

**Deprecation state**

• Promoted to Vulkan 1.2

**Contact**

• Aaron Hagan 🌐ahagan

**Other Extension Metadata**

**Last Modified Date**

2018-07-05

**Interactions and External Dependencies**

• Promoted to Vulkan 1.2 Core
  • This extension provides API support for `GL_ARB_gpu_shader_int64` and `GL_EXT_shader_atomic_int64`
Contributors

- Aaron Hagan, AMD
- Daniel Rakos, AMD
- Jeff Bolz, NVIDIA
- Neil Henning, Codeplay

Description

This extension advertises the SPIR-V **Int64Atomics** capability for Vulkan, which allows a shader to contain 64-bit atomic operations on signed and unsigned integers. The supported operations include OpAtomicMin, OpAtomicMax, OpAtomicAnd, OpAtomicOr, OpAtomicXor, OpAtomicAdd, OpAtomicExchange, and OpAtomicCompareExchange.

Promotion to Vulkan 1.2

All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. However, if Vulkan 1.2 is supported and this extension is not, the `shaderBufferInt64Atomics` capability is optional. The original type, enum and command names are still available as aliases of the core functionality.

New Structures

- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDeviceShaderAtomicInt64FeaturesKHR`

New Enum Constants

- `VK_KHR_SHADER_ATOMIC_INT64_EXTENSION_NAME`
- `VK_KHR_SHADER_ATOMIC_INT64_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_ATOMIC_INT64_FEATURES_KHR`

New SPIR-V Capabilities

- `Int64Atomics`

Version History

- Revision 1, 2018-07-05 (Aaron Hagan)
  - Internal revisions

**VK_KHR_shader_draw_parameters**

Name String

`VK_KHR_shader_draw_parameters`
Extension Type
  Device extension

Registered Extension Number
  64

Revision
  1

Ratification Status
  Ratified

Extension and Version Dependencies

Deprecation state
  • Promoted to Vulkan 1.1

Contact
  • Daniel Koch dgkoch

Other Extension Metadata

Last Modified Date
  2017-09-05

IP Status
  No known IP claims.

Interactions and External Dependencies
  • This extension requires SPV_KHR_shader_draw_parameters
  • This extension provides API support for GL_ARB_shader_draw_parameters
  • Promoted to Vulkan 1.1 Core

Contributors
  • Daniel Koch, NVIDIA Corporation
  • Jeff Bolz, NVIDIA
  • Daniel Rakos, AMD
  • Jan-Harald Fredriksen, ARM
  • John Kessenich, Google
  • Stuart Smith, IMG

Description

This extension adds support for the following SPIR-V extension in Vulkan:
  • SPV_KHR_shader_draw_parameters
The extension provides access to three additional built-in shader variables in Vulkan:

- **BaseInstance**, containing the `firstInstance` parameter passed to drawing commands,
- **BaseVertex**, containing the `firstVertex` or `vertexOffset` parameter passed to drawing commands, and
- **DrawIndex**, containing the index of the draw call currently being processed from an indirect drawing call.

When using GLSL source-based shader languages, the following variables from `GL_ARB_shader_draw_parameters` can map to these SPIR-V built-in decorations:

- `in int gl_BaseInstanceARB;` → **BaseInstance**,
- `in int gl_BaseVertexARB;` → **BaseVertex**, and
- `in int gl_DrawIDARB;` → **DrawIndex**.

**Promotion to Vulkan 1.1**

All functionality in this extension is included in core Vulkan 1.1. However, the `shaderDrawParameters` feature bit was added to distinguish whether it is actually available or not.

**New Enum Constants**

- `VK_KHR_SHADER_DRAW_PARAMETERS_EXTENSION_NAME`
- `VK_KHR_SHADER_DRAW_PARAMETERS_SPEC_VERSION`

**New Built-In Variables**

- **BaseInstance**
- **BaseVertex**
- **DrawIndex**

**New SPIR-V Capabilities**

- `DrawParameters`

**Issues**

1) Is this the same functionality as `GL_ARB_shader_draw_parameters`?

**RESOLVED**: It is actually a superset, as it also adds in support for arrayed drawing commands.

In GL for `GL_ARB_shader_draw_parameters`, `gl_BaseVertexARB` holds the integer value passed to the parameter to the command that resulted in the current shader invocation. In the case where the command has no `baseVertex` parameter, the value of `gl_BaseVertexARB` is zero. This means that `gl_BaseVertexARB = baseVertex` (for `glDrawElements` commands with `baseVertex`) or 0. In particular there are no `glDrawArrays` commands that take a `baseVertex` parameter.
Now in Vulkan, we have `BaseVertex = vertexOffset` (for indexed drawing commands) or `firstVertex` (for arrayed drawing commands), and so Vulkan’s version is really a superset of GL functionality.

**Version History**

- Revision 1, 2016-10-05 (Daniel Koch)
  - Internal revisions

**VK_KHR_shader_float16_int8**

**Name String**

`VK_KHR_shader_float16_int8`

**Extension Type**

Device extension

**Registered Extension Number**

83

**Revision**

1

**Ratification Status**

Ratified

**Extension and Version Dependencies**

`VK_KHR_get_physical_device_properties2`

**Deprecation state**

- *Promoted to* Vulkan 1.2

**Contact**

- Alexander Galazin [alegal-arm](mailto:alegal-arm)

**Other Extension Metadata**

**Last Modified Date**

2018-03-07

**Interactions and External Dependencies**

- Promoted to Vulkan 1.2 Core
- This extension interacts with `VK_KHR_8bit_storage`
- This extension interacts with `VK_KHR_16bit_storage`
- This extension interacts with `VK_KHR_shader_float_controls`
- This extension provides API support for `GL_EXT_shader_explicit_arithmetic_types`
IP Status

No known IP claims.

Contributors

- Alexander Galazin, Arm
- Jan-Harald Fredriksen, Arm
- Jeff Bolz, NVIDIA
- Graeme Leese, Broadcom
- Daniel Rakos, AMD

Description

The VK_KHR_shader_float16_int8 extension allows use of 16-bit floating-point types and 8-bit integer types in shaders for arithmetic operations.

It introduces two new optional features shaderFloat16 and shaderInt8 which directly map to the Float16 and the Int8 SPIR-V capabilities. The VK_KHR_shader_float16_int8 extension also specifies precision requirements for half-precision floating-point SPIR-V operations. This extension does not enable use of 8-bit integer types or 16-bit floating-point types in any shader input and output interfaces and therefore does not supersede the VK_KHR_8bit_storage or VK_KHR_16bit_storage extensions.

Promotion to Vulkan 1.2

All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. However, if Vulkan 1.2 is supported and this extension is not, both the shaderFloat16 and shaderInt8 capabilities are optional. The original type, enum and command names are still available as aliases of the core functionality.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceFloat16Int8FeaturesKHR
  - VkPhysicalDeviceShaderFloat16Int8FeaturesKHR

New Enum Constants

- VK_KHR_SHADER_FLOAT16_INT8_EXTENSION_NAME
- VK_KHR_SHADER_FLOAT16_INT8_SPEC_VERSION

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FLOAT16_INT8_FEATURES_KHR
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_FLOAT16_INT8_FEATURES_KHR
**Version History**

- Revision 1, 2018-03-07 (Alexander Galazin)
  - Initial draft

**VK_KHR_shader_float_controls**

**Name String**

VK_KHR_shader_float_controls

**Extension Type**

Device extension

**Registered Extension Number**

198

**Revision**

4

**Ratification Status**

Ratified

**Extension and Version Dependencies**

VK_KHR_get_physical_device_properties2

**Deprecation state**

- Promoted to Vulkan 1.2

**Contact**

- Alexander Galazin @alegal-arm

**Other Extension Metadata**

**Last Modified Date**

2018-09-11

**Interactions and External Dependencies**

- Promoted to Vulkan 1.2 Core
  - This extension requires SPV_KHR_float_controls

**IP Status**

No known IP claims.

**Contributors**

- Alexander Galazin, Arm
- Jan-Harald Fredriksen, Arm
- Jeff Bolz, NVIDIA
Description

The `VK_KHR_shader_float_controls` extension enables efficient use of floating-point computations through the ability to query and override the implementation's default behavior for rounding modes, denormals, signed zero, and infinity.

Promotion to Vulkan 1.2

All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Structures

- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceFloatControlsPropertiesKHR`

New Enums

- `VkShaderFloatControlsIndependenceKHR`

New Enum Constants

- `VK_KHR_SHADER_FLOAT_CONTROLS_EXTENSION_NAME`
- `VK_KHR_SHADER_FLOAT_CONTROLS_SPEC_VERSION`
- Extending `VkShaderFloatControlsIndependence`:
  - `VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_32_BIT_ONLY_KHR`
  - `VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_ALL_KHR`
  - `VK_SHADER_FLOAT_CONTROLS_INDEPENDENCE_NONE_KHR`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FLOAT_CONTROLS_PROPERTIES_KHR`

New SPIR-V Capabilities

- `DenormPreserve`
- `DenormFlushToZero`
- `SignedZeroInfNanPreserve`
- `RoundingModeRTE`
- `RoundingModeRTZ`
Issues

1) Which instructions must flush denorms?

**RESOLVED:** Only floating-point conversion, floating-point arithmetic, floating-point relational (except `OpIsNaN`, `OpIsInf`), and floating-point GLSL.std.450 extended instructions must flush denormals.

2) What is the denorm behavior for intermediate results?

**RESOLVED:** When a SPIR-V instruction is implemented as a sequence of other instructions:

- in the `DenormFlushToZero` execution mode, the intermediate instructions may flush denormals, the final result of the sequence must not be denormal.
- in the `DenormPreserve` execution mode, denormals must be preserved throughout the whole sequence.

3) Do denorm and rounding mode controls apply to `OpSpecConstantOp`?

**RESOLVED:** Yes, except when the opcode is `OpQuantizeToF16`.

4) The SPIR-V specification says that `OpConvertFToU` and `OpConvertFToS` unconditionally round towards zero. Do the rounding mode controls specified through the execution modes apply to them?

**RESOLVED:** No, these instructions unconditionally round towards zero.

5) Do any of the “Pack” GLSL.std.450 instructions count as conversion instructions and have the rounding mode applied?

**RESOLVED:** No, only instructions listed in “section 3.32.11. Conversion Instructions” of the SPIR-V specification count as conversion instructions.

6) When using inf/nan-ignore mode, what is expected of `OpIsNan` and `OpIsInf`?

**RESOLVED:** These instructions must always accurately detect inf/nan if it is passed to them.

Version 4 API incompatibility

The original versions of `VK_KHR_shader_float_controls` shipped with booleans named “separateDenormSettings” and “separateRoundingModeSettings”, which at first glance could have indicated “they can all be set independently, or not”. However the spec language as written indicated that the 32-bit value could always be set independently, and only the 16- and 64-bit controls needed to be the same if these values were `VK_FALSE`.

As a result of this slight disparity, and lack of test coverage for this facet of the extension, we ended up with two different behaviors in the wild, where some implementations worked as written, and others worked based on the naming. As these are hard limits in hardware with reasons for exposure as written, it was not possible to standardise on a single way to make this work within the existing API.
No known users of this part of the extension exist in the wild, and as such the Vulkan WG took the
unusual step of retroactively changing the once boolean value into a tri-state enum, breaking
source compatibility. This was however done in such a way as to retain ABI compatibility, in case
any code using this did exist; with the numerical values 0 and 1 retaining their original specified
meaning, and a new value signifying the additional “all need to be set together” state. If any
applications exist today, compiled binaries will continue to work as written in most cases, but will
need changes before the code can be recompiled.

Version History

- Revision 4, 2019-06-18 (Tobias Hector)
  - Modified settings restrictions, see Version 4 API incompatibility
- Revision 3, 2018-09-11 (Alexander Galazin)
  - Minor restructuring
- Revision 2, 2018-04-17 (Alexander Galazin)
  - Added issues and resolutions
- Revision 1, 2018-04-11 (Alexander Galazin)
  - Initial draft

VK_KHR_shader_integer_dot_product

Name String

VK_KHR_shader_integer_dot_product

Extension Type

Device extension

Registered Extension Number

281

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Deprecation state

- Promoted to Vulkan 1.3

Contact

- Kevin Petit kpet

4768
Extension Proposal

VK_KHR_shader_integer_dot_product

Other Extension Metadata

Last Modified Date
2021-06-16

Interactions and External Dependencies

• Promoted to Vulkan 1.3 Core
• This extension requires SPV_KHR_integer_dot_product.
• This extension interacts with VK_KHR_shader_float16_int8.

IP Status
No known IP claims.

Contributors

• Kévin Petit, Arm Ltd.
• Jeff Bolz, NVidia
• Spencer Fricke, Samsung
• Jesse Hall, Google
• John Kessenich, Google
• Graeme Leese, Broadcom
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• Stuart Brady, Arm Ltd.
• Pablo Cascon, Arm Ltd.
• Tobias Hector, AMD
• Jeff Leger, Qualcomm
• Ruihao Zhang, Qualcomm
• Pierre Boudier, NVidia
• Jon Leech, The Khronos Group
• Tom Olson, Arm Ltd.

Description

This extension adds support for the integer dot product SPIR-V instructions defined in SPV_KHR_integer_dot_product. These instructions are particularly useful for neural network inference and training but find uses in other general-purpose compute applications as well.

New Structures

• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
• VkPhysicalDeviceShaderIntegerDotProductFeaturesKHR

• Extending VkPhysicalDeviceProperties2:
  • VkPhysicalDeviceShaderIntegerDotProductPropertiesKHR

New Enum Constants

• VK_KHR_SHADER_INTEGER_DOT_PRODUCT_EXTENSION_NAME
• VK_KHR_SHADER_INTEGER_DOT_PRODUCT_SPEC_VERSION

• Extending VkStructureType:
  • VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_INTEGER_DOT_PRODUCT_FEATURES_KHR
  • VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_INTEGER_DOT_PRODUCT_PROPERTIES_KHR

Promotion to Vulkan 1.3

Functionality in this extension is included in core Vulkan 1.3, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New SPIR-V Capabilities

• DotProductInputAllKHR
• DotProductInput4x8BitKHR
• DotProductInput4x8BitPackedKHR
• DotProductKHR

Version History

• Revision 1, 2021-06-16 (Kévin Petit)
  • Initial revision

VK_KHR_shader_non_semantic_info

Name String
  VK_KHR_shader_non_semantic_info

Extension Type
  Device extension

Registered Extension Number
  294

Revision
  1
Ratification Status
   Ratified

Extension and Version Dependencies

Deprecation state
   • Promoted to Vulkan 1.3

Contact
   • Baldur Karlsson @baldurk

Other Extension Metadata

Last Modified Date
   2019-10-16

Interactions and External Dependencies
   • Promoted to Vulkan 1.3 Core
   • This extension requires SPV_KHR_non_semantic_info

IP Status
   No known IP claims.

Contributors
   • Baldur Karlsson, Valve

Description

This extension allows the use of the SPV_KHR_non_semantic_info extension in SPIR-V shader modules.

New Enum Constants

   • VK_KHR_SHADER_NON_SEMANTIC_INFO_EXTENSION_NAME
   • VK_KHR_SHADER_NON_SEMANTIC_INFO_SPEC_VERSION

Promotion to Vulkan 1.3

Functionality in this extension is included in core Vulkan 1.3 Because the extension has no API controlling its functionality, this results only in a change to the SPIR-V Extensions table.

Version History

   • Revision 1, 2019-10-16 (Baldur Karlsson)
     ◦ Initial revision

VK_KHR_shader_subgroup_extended_types
Name String
  VK_KHR_shader_subgroup_extended_types

Extension Type
  Device extension

Registered Extension Number
  176

Revision
  1

Ratification Status
  Ratified

Extension and Version Dependencies
  Version 1.1

Deprecation state
  • Promoted to Vulkan 1.2

Contact
  • Neil Henning sheredom

Other Extension Metadata

Last Modified Date
  2019-01-08

IP Status
  No known IP claims.

Interactions and External Dependencies
  • Promoted to Vulkan 1.2 Core
  • This extension provides API support for GLSL_EXT_shader_subgroup_extended_types

Contributors
  • Jeff Bolz, NVIDIA
  • Jan-Harald Fredriksen, Arm
  • Neil Henning, AMD
  • Daniel Koch, NVIDIA
  • Jeff Leger, Qualcomm
  • Graeme Leese, Broadcom
  • David Neto, Google
  • Daniel Rakos, AMD
Description

This extension enables the Non Uniform Group Operations in SPIR-V to support 8-bit integer, 16-bit integer, 64-bit integer, 16-bit floating-point, and vectors of these types.

Promotion to Vulkan 1.2

All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceShaderSubgroupExtendedTypesFeaturesKHR

New Enum Constants

- VK_KHR_SHADER_SUBGROUP_EXTENDED_TYPES_EXTENSION_NAME
- VK_KHR_SHADER_SUBGROUP_EXTENDED_TYPES_SPEC_VERSION

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_SUBGROUP_EXTENDED_TYPES_FEATURES_KHR

Version History

- Revision 1, 2019-01-08 (Neil Henning)
  - Initial draft

VK_KHR_shader_terminate_invocation

Name String

VK_KHR_shader_terminate_invocation

Extension Type

Device extension

Registered Extension Number

216

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

or
Version 1.1

Deprecation state
• Promoted to Vulkan 1.3

Contact
• Jesse Hall @critsec

Other Extension Metadata

Last Modified Date
2020-08-11

Interactions and External Dependencies
• Promoted to Vulkan 1.3 Core
• Requires the SPV_KHR_terminate_invocation SPIR-V extension.

IP Status
No known IP claims.

Contributors
• Alan Baker, Google
• Jeff Bolz, NVIDIA
• Jesse Hall, Google
• Ralph Potter, Samsung
• Tom Olson, Arm

Description
This extension adds Vulkan support for the SPV_KHR_terminate_invocation SPIR-V extension. That SPIR-V extension provides a new instruction, OpTerminateInvocation, which causes a shader invocation to immediately terminate and sets the coverage of shaded samples to 0; only previously executed instructions will have observable effects. The OpTerminateInvocation instruction, along with the OpDemoteToHelperInvocation instruction from the VK_EXT_shader_demote_to_helper_invocation extension, together replace the OpKill instruction, which could behave like either of these instructions. OpTerminateInvocation provides the behavior required by the GLSL discard statement, and should be used when available by GLSL compilers and applications that need the GLSL discard behavior.

New Structures
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceShaderTerminateInvocationFeaturesKHR
New Enum Constants

- `VK_KHR_SHADER_TERMINATE_INVOCATION_EXTENSION_NAME`
- `VK_KHR_SHADER_TERMINATE_INVOCATION_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_TERMINATE_INVOCATION_FEATURES_KHR`

Promotion to Vulkan 1.3

Functionality in this extension is included in core Vulkan 1.3, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

Version History

- Revision 1, 2020-08-11 (Jesse Hall)

VK_KHR_spirv_1_4

Name String

- `VK_KHR_spirv_1_4`

Extension Type

- Device extension

Registered Extension Number

- 237

Revision

- 1

Ratification Status

- Ratified

Extension and Version Dependencies

- Version 1.1
- and
- `VK_KHR_shader_float_controls`

Deprecation state

- Promoted to Vulkan 1.2

Contact

- Jesse Hall [critsec](#)

Other Extension Metadata
Description

This extension allows the use of SPIR-V 1.4 shader modules. SPIR-V 1.4's new features primarily make it an easier target for compilers from high-level languages, rather than exposing new hardware functionality.

SPIR-V 1.4 incorporates features that are also available separately as extensions. SPIR-V 1.4 shader modules do not need to enable those extensions with the `OpExtension` opcode, since they are integral parts of SPIR-V 1.4.

SPIR-V 1.4 introduces new floating point execution mode capabilities, also available via `SPV_KHR_float_controls`. Implementations are not required to support all of these new capabilities; support can be queried using `VkPhysicalDeviceFloatControlsPropertiesKHR` from the `VK_KHR_shader_float_controls` extension.

Promotion to Vulkan 1.2

All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Enum Constants

- `VK_KHR_SPIRV_1_4_EXTENSION_NAME`
- `VK_KHR_SPIRV_1_4_SPEC_VERSION`

Issues

1. Should we have an extension specific to this SPIR-V version, or add a version-generic query for
SPIR-V version? SPIR-V 1.4 does not need any other API changes.

**RESOLVED:** Just expose SPIR-V 1.4.

Most new SPIR-V versions introduce optionally-required capabilities or have implementation-defined limits, and would need more API and specification changes specific to that version to make them available in Vulkan. For example, to support the subgroup capabilities added in SPIR-V 1.3 required introducing `VkPhysicalDeviceSubgroupProperties` to allow querying the supported group operation categories, maximum supported subgroup size, etc. While we could expose the parts of a new SPIR-V version that do not need accompanying changes generically, we will still end up writing extensions specific to each version for the remaining parts. Thus the generic mechanism will not reduce future spec-writing effort. In addition, making it clear which parts of a future version are supported by the generic mechanism and which cannot be used without specific support would be difficult to get right ahead of time.

2. Can different stages of the same pipeline use shaders with different SPIR-V versions?

**RESOLVED:** Yes.

Mixing SPIR-V versions 1.0-1.3 in the same pipeline has not been disallowed, so it would be inconsistent to disallow mixing 1.4 with previous versions. SPIR-V 1.4 does not introduce anything that should cause new difficulties here.

3. Must Vulkan extensions corresponding to SPIR-V extensions that were promoted to core in 1.4 be enabled in order to use that functionality in a SPIR-V 1.4 module?

**RESOLVED:** No, with caveats.

The SPIR-V 1.4 module does not need to declare the SPIR-V extensions, since the functionality is now part of core, so there is no need to enable the Vulkan extension that allows SPIR-V modules to declare the SPIR-V extension. However, when the functionality that is now core in SPIR-V 1.4 is optionally supported, the query for support is provided by a Vulkan extension, and that query can only be used if the extension is enabled.

This applies to any SPIR-V version; specifically for SPIR-V 1.4 this only applies to the functionality from `SPV_KHR_float_controls`, which was made available in Vulkan by `VK_KHR_shader_float_controls`. Even though the extension was promoted in SPIR-V 1.4, the capabilities are still optional in implementations that support `VK_KHR_spirv_1_4`.

A SPIR-V 1.4 module does not need to enable `SPV_KHR_float_controls` in order to use the capabilities, so if the application has *a priori* knowledge that the implementation supports the capabilities, it does not need to enable `VK_KHR_shader_float_controls`. However, if it does not have this knowledge and has to query for support at runtime, it must enable `VK_KHR_shader_float_controls` in order to use `VkPhysicalDeviceFloatControlsPropertiesKHR`.

**Version History**

- Revision 1, 2019-04-01 (Jesse Hall)
  - Internal draft versions
VK_KHR_storage_buffer_storage_class

Name String
VK_KHR_storage_buffer_storage_class

Extension Type
Device extension

Registered Extension Number
132

Revision
1

Ratification Status
Ratified

Extension and Version Dependencies
Deprecation state
• Promoted to Vulkan 1.1

Contact
• Alexander Galazin @alegal-arm

Other Extension Metadata

Last Modified Date
2017-09-05

IP Status
No known IP claims.

Interactions and External Dependencies
• This extension requires SPV_KHR_storage_buffer_storage_class
• Promoted to Vulkan 1.1 Core

Contributors
• Alexander Galazin, ARM
• David Neto, Google

Description
This extension adds support for the following SPIR-V extension in Vulkan:

• SPV_KHR_storage_buffer_storage_class

This extension provides a new SPIR-V StorageBuffer storage class. A Block-decorated object in this class is equivalent to a BufferBlock-decorated object in the Uniform storage class.
Promotion to Vulkan 1.1

All functionality in this extension is included in core Vulkan 1.1.

New Enum Constants

- VK_KHR_STORAGE_BUFFER_STORAGE_CLASS_EXTENSION_NAME
- VK_KHR_STORAGE_BUFFER_STORAGE_CLASS_SPEC_VERSION

Version History

- Revision 1, 2017-03-23 (Alexander Galazin)
  - Initial draft

VK_KHR_synchronization2

Name String

VK_KHR_synchronization2

Extension Type

Device extension

Registered Extension Number

315

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

or

Version 1.1

Deprecation state

• Promoted to Vulkan 1.3

Contact

- Tobias Hector tobki

Other Extension Metadata

Last Modified Date

2020-12-03
Interactions and External Dependencies

- Promoted to Vulkan 1.3 Core
- Interacts with VK_KHR_create_renderpass2

Contributors

- Tobias Hector

Description

This extension modifies the original core synchronization APIs to simplify the interface and improve usability of these APIs. It also adds new pipeline stage and access flag types that extend into the 64-bit range, as we have run out within the 32-bit range. The new flags are identical to the old values within the 32-bit range, with new stages and bits beyond that.

Pipeline stages and access flags are now specified together in memory barrier structures, making the connection between the two more obvious. Additionally, scoping the pipeline stages into the barrier structs allows the use of the MEMORY_READ and MEMORY_WRITE flags without sacrificing precision. The per-stage access flags should be used to disambiguate specific accesses in a given stage or set of stages - for instance, between uniform reads and sampling operations.

Layout transitions have been simplified as well; rather than requiring a different set of layouts for depth/stencil/color attachments, there are generic VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL_KHR and VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR layouts which are contextually applied based on the image format. For example, for a depth format image, VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR is equivalent to VK_IMAGE_LAYOUT_DEPTH_READ_ONLY_OPTIMAL_KHR. VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR also functionally replaces VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL.

Events are now more efficient, because they include memory dependency information when you set them on the device. Previously, this information was only known when waiting on an event, so the dependencies could not be satisfied until the wait occurred. That sometimes meant stalling the pipeline when the wait occurred. The new API provides enough information for implementations to satisfy these dependencies in parallel with other tasks.

Queue submission has been changed to wrap command buffers and semaphores in extensible structures, which incorporate changes from Vulkan 1.1, VK_KHR_device_group, and VK_KHR_timeline_semaphore. This also adds a pipeline stage to the semaphore signal operation, mirroring the existing pipeline stage specification for wait operations.

Other miscellaneous changes include:

- Events can now be specified as interacting only with the device, allowing more efficient access to the underlying object.
- Image memory barriers that do not perform an image layout transition can be specified by setting oldLayout equal to newLayout.
  - E.g. the old and new layout can both be set to VK_IMAGE_LAYOUT_UNDEFINED, without discarding data in the image.
- Queue family ownership transfer parameters are simplified in some cases.
• Where two synchronization commands need to be matched up (queue transfer operations, events), the dependency information specified in each place must now match completely for consistency.

• Extensions with commands or functions with a VkPipelineStageFlags or VkPipelineStageFlagBits parameter have had those APIs replaced with equivalents using VkPipelineStageFlags2KHR.

• The new event and barrier interfaces are now more extensible for future changes.

• Relevant pipeline stage masks can now be specified as empty with the new VK_PIPELINE_STAGE_NONE_KHR and VK_PIPELINE_STAGE_2_NONE_KHR values.

• VkMemoryBarrier2KHR can be chained to VkSubpassDependency2, overriding the original 32-bit stage and access masks.

New Base Types

• VkFlags64

New Commands

• vkCmdPipelineBarrier2KHR
• vkCmdResetEvent2KHR
• vkCmdSetEvent2KHR
• vkCmdWaitEvents2KHR
• vkCmdWriteTimestamp2KHR
• vkQueueSubmit2KHR

If VK_AMD_buffer_marker is supported:

• vkCmdWriteBufferMarker2AMD

If VK_NV_device_diagnostic_checkpoints is supported:

• vkGetQueueCheckpointData2NV

New Structures

• VkBufferMemoryBarrier2KHR
• VkCommandBufferSubmitInfoKHR
• VkDependencyInfoKHR
• VkImageMemoryBarrier2KHR
• VkSemaphoreSubmitInfoKHR
• VkSubmitInfo2KHR

• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceSynchronization2FeaturesKHR
• Extending VkSubpassDependency2:
  ◦ VkMemoryBarrier2KHR

If VK_NV_device_diagnostic_checkpoints is supported:

  • VkCheckpointData2NV
  • Extending VkQueueFamilyProperties2:
    ◦ VkQueueFamilyCheckpointProperties2NV

New Enums

  • VkAccessFlagBits2KHR
  • VkPipelineStageFlagBits2KHR
  • VkSubmitFlagBitsKHR

New Bitmasks

  • VkAccessFlags2KHR
  • VkPipelineStageFlags2KHR
  • VkSubmitFlagsKHR

New Enum Constants

  • VK_KHR_SYNCHRONIZATION_2_EXTENSION_NAME
  • VK_KHR_SYNCHRONIZATION_2_SPEC_VERSION
  • Extending VkAccessFlagBits:
    ◦ VK_ACCESS_NONE_KHR
  • Extending VkEventCreateFlagBits:
    ◦ VK_EVENT_CREATE_DEVICE_ONLY_BIT_KHR
  • Extending VkImageLayout:
    ◦ VK_IMAGE_LAYOUT_ATTACHMENT_OPTIMAL_KHR
    ◦ VK_IMAGE_LAYOUT_READ_ONLY_OPTIMAL_KHR
  • Extending VkPipelineStageFlagBits:
    ◦ VK_PIPELINE_STAGE_NONE_KHR
  • Extending VkStructureType:
    ◦ VK_STRUCTURE_TYPE_BUFFER_MEMORY_BARRIER_2_KHR
    ◦ VK_STRUCTURE_TYPE_COMMAND_BUFFER_SUBMIT_INFO_KHR
    ◦ VK_STRUCTURE_TYPE_DEPENDENCY_INFO_KHR
    ◦ VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER_2_KHR
    ◦ VK_STRUCTURE_TYPE_MEMORY_BARRIER_2_KHR
If **VK_EXT_blend_operation_advanced** is supported:

- Extending **VkAccessFlagBits2**:
  - **VK_ACCESS_2_COLOR_ATTACHMENT_READ_NONCOHERENT_BIT_EXT**

If **VK_EXT_conditional_rendering** is supported:

- Extending **VkAccessFlagBits2**:
  - **VK_ACCESS_2_CONDITIONAL_RENDERING_READ_BIT_EXT**
- Extending **VkPipelineStageFlagBits2**:
  - **VK_PIPELINE_STAGE_2_CONDITIONAL_RENDERING_BIT_EXT**

If **VK_EXT_fragment_density_map** is supported:

- Extending **VkAccessFlagBits2**:
  - **VK_ACCESS_2_FRAGMENT_DENSITY_MAP_READ_BIT_EXT**
- Extending **VkPipelineStageFlagBits2**:
  - **VK_PIPELINE_STAGE_2_FRAGMENT_DENSITY_PROCESS_BIT_EXT**

If **VK_EXT_mesh_shader** is supported:

- Extending **VkPipelineStageFlagBits2**:
  - **VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_EXT**
  - **VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_EXT**

If **VK_EXT_transform_feedback** is supported:

- Extending **VkAccessFlagBits2**:
  - **VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_READ_BIT_EXT**
  - **VK_ACCESS_2_TRANSFORM_FEEDBACK_COUNTER_WRITE_BIT_EXT**
  - **VK_ACCESS_2_TRANSFORM_FEEDBACK_WRITE_BIT_EXT**
- Extending **VkPipelineStageFlagBits2**:
  - **VK_PIPELINE_STAGE_2_TRANSFORM_FEEDBACK_BIT_EXT**

If **VK_KHR_acceleration_structure** is supported:

- Extending **VkAccessFlagBits2**:
  - **VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_KHR**
  - **VK_ACCESS_2_ACCELERATION_STRUCTURE_WRITE_BIT_KHR**
• Extending `VkPipelineStageFlagBits2`:
  ◦ `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_KHR`

If `VK_KHR_fragment_shading_rate` is supported:

• Extending `VkAccessFlagBits2`:
  ◦ `VK_ACCESS_2_FRAGMENT_SHADING_RATE_ATTACHMENT_READ_BIT_KHR`

• Extending `VkPipelineStageFlagBits2`:
  ◦ `VK_PIPELINE_STAGE_2_FRAGMENT_SHADING_RATE_ATTACHMENT_BIT_KHR`

If `VK_KHR_ray_tracing_pipeline` is supported:

• Extending `VkPipelineStageFlagBits2`:
  ◦ `VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_KHR`

If `VK_NV_device_diagnostic_checkpoints` is supported:

• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_CHECKPOINT_DATA_2_NV`
  ◦ `VK_STRUCTURE_TYPE_QUEUE_FAMILY_CHECKPOINT_PROPERTIES_2_NV`

If `VK_NV_device_generated_commands` is supported:

• Extending `VkAccessFlagBits2`:
  ◦ `VK_ACCESS_2_COMMAND_PREPROCESS_READ_BIT_NV`
  ◦ `VK_ACCESS_2_COMMAND_PREPROCESS_WRITE_BIT_NV`

• Extending `VkPipelineStageFlagBits2`:
  ◦ `VK_PIPELINE_STAGE_2_COMMAND_PREPROCESS_BIT_NV`

If `VK_NV_mesh_shader` is supported:

• Extending `VkPipelineStageFlagBits2`:
  ◦ `VK_PIPELINE_STAGE_2_MESH_SHADER_BIT_NV`
  ◦ `VK_PIPELINE_STAGE_2_TASK_SHADER_BIT_NV`

If `VK_NV_ray_tracing` is supported:

• Extending `VkAccessFlagBits2`:
  ◦ `VK_ACCESS_2_ACCELERATION_STRUCTURE_READ_BIT_NV`
  ◦ `VK_ACCESS_2_ACCELERATION_STRUCTURE_WRITE_BIT_NV`

• Extending `VkPipelineStageFlagBits2`:
  ◦ `VK_PIPELINE_STAGE_2_ACCELERATION_STRUCTURE_BUILD_BIT_NV`
  ◦ `VK_PIPELINE_STAGE_2_RAY_TRACING_SHADER_BIT_NV`
If `VK_NV_shading_rate_image` is supported:

- Extending `VkAccessFlagBits2`:
  - `VK_ACCESS_2_SHADING_RATE_IMAGE_READ_BIT_NV`
- Extending `VkPipelineStageFlagBits2`:
  - `VK_PIPELINE_STAGE_2_SHADING_RATE_IMAGE_BIT_NV`

**Promotion to Vulkan 1.3**

Functionality in this extension is included in core Vulkan 1.3, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

**Examples**

See [https://github.com/KhronosGroup/Vulkan-Docs/wiki/Synchronization-Examples](https://github.com/KhronosGroup/Vulkan-Docs/wiki/Synchronization-Examples)

**Version History**

- Revision 1, 2020-12-03 (Tobias Hector)
  - Internal revisions

**VK_KHR_timeline_semaphore**

**Name String**

`VK_KHR_timeline_semaphore`

**Extension Type**

Device extension

**Registered Extension Number**

208

**Revision**

2

**Ratification Status**

Ratified

**Extension and Version Dependencies**

`VK_KHR_get_physical_device_properties2`

**Deprecation state**

- *Promoted to* Vulkan 1.2

**Contact**

- Faith Ekstrand 🌐gfxstrand
Other Extension Metadata

Last Modified Date
2019-06-12

IP Status
No known IP claims.

Interactions and External Dependencies
• This extension interacts with VK_KHR_external_semaphore_capabilities
• This extension interacts with VK_KHR_external_semaphore
• This extension interacts with VK_KHR_external_semaphore_win32
• Promoted to Vulkan 1.2 Core

Contributors
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• Yuriy O'Donnell, Epic Games
• Faith Ekstrand, Intel
• Jesse Hall, Google
• James Jones, NVIDIA
• Jeff Juliano, NVIDIA
• Daniel Rakos, AMD
• Ray Smith, Arm

Description
This extension introduces a new type of semaphore that has an integer payload identifying a point in a timeline. Such timeline semaphores support the following operations:

• Host query - A host operation that allows querying the payload of the timeline semaphore.
• Host wait - A host operation that allows a blocking wait for a timeline semaphore to reach a specified value.
• Host signal - A host operation that allows advancing the timeline semaphore to a specified value.
• Device wait - A device operation that allows waiting for a timeline semaphore to reach a specified value.
• Device signal - A device operation that allows advancing the timeline semaphore to a specified value.

Promotion to Vulkan 1.2
All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.
New Commands

- vkGetSemaphoreCounterValueKHR
- vkSignalSemaphoreKHR
- vkWaitSemaphoresKHR

New Structures

- VkSemaphoreSignalInfoKHR
- VkSemaphoreWaitInfoKHR

Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceTimelineSemaphoreFeaturesKHR

Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceTimelineSemaphorePropertiesKHR

Extending VkSemaphoreCreateInfo, VkPhysicalDeviceExternalSemaphoreInfo:
  - VkSemaphoreTypeCreateInfoKHR

Extending VkSubmitInfo, VkBindSparseInfo:
  - VkTimelineSemaphoreSubmitInfoKHR

New Enums

- VkSemaphoreTypeKHR
- VkSemaphoreWaitFlagBitsKHR

New Bitmasks

- VkSemaphoreWaitFlagsKHR

New Enum Constants

- VK_KHR_TIMELINE_SEMAPHORE_EXTENSION_NAME
- VK_KHR_TIMELINE_SEMAPHORE_SPEC_VERSION

Extending VkSemaphoreType:
  - VK_SEMAPHORE_TYPE_BINARY_KHR
  - VK_SEMAPHORE_TYPE_TIMELINE_KHR

Extending VkSemaphoreWaitFlagBits:
  - VK_SEMAPHORE_WAIT_ANY_BIT_KHR

Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TIMELINE_SEMAPHORE_FEATURES_KHR
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TIMELINE_SEMAPHORE_PROPERTIES_KHR
Issues

1) Do we need a new object type for this?

**RESOLVED:** No, we just introduce a new type of semaphore object, as VK_KHR_external_semaphore_win32 already uses semaphores as the destination for importing D3D12 fence objects, which are semantically close/identical to the proposed synchronization primitive.

2) What type of payload the new synchronization primitive has?

**RESOLVED:** A 64-bit unsigned integer that can only be set to strictly increasing values by signal operations and is not changed by wait operations.

3) Does the new synchronization primitive have the same signal-before-wait requirement as the existing semaphores do?

**RESOLVED:** No. Timeline semaphores support signaling and waiting entirely asynchronously. It is the responsibility of the client to avoid deadlock.

4) Does the new synchronization primitive allow resetting its payload?

**RESOLVED:** No, allowing the payload value to “go backwards” is problematic. Applications looking for reset behavior should create a new instance of the synchronization primitive instead.

5) How do we enable host waits on the synchronization primitive?

**RESOLVED:** Both a non-blocking query of the current payload value of the synchronization primitive, and a blocking wait operation are provided.

6) How do we enable device waits and signals on the synchronization primitive?

**RESOLVED:** Similar to VK_KHR_external_semaphore_win32, this extension introduces a new structure that can be chained to VkSubmitInfo to specify the values signaled semaphores should be set to, and the values waited semaphores need to reach.

7) Can the new synchronization primitive be used to synchronize presentation and swapchain image acquisition operations?

**RESOLVED:** Some implementations may have problems with supporting that directly, thus it is not allowed in this extension.

8) Do we want to support external sharing of the new synchronization primitive type?

**RESOLVED:** Yes. Timeline semaphore specific external sharing capabilities can be queried using vkGetPhysicalDeviceExternalSemaphoreProperties by chaining the new
VkSemaphoreTypeCreateInfoKHR structure to its pExternalSemaphoreInfo structure. This allows having a different set of external semaphore handle types supported for timeline semaphores vs. binary semaphores.

9) Do we need to add a host signal operation for the new synchronization primitive type?

**RESOLVED**: Yes. This helps in situations where one host thread submits a workload but another host thread has the information on when the workload is ready to be executed.

10) How should the new synchronization primitive interact with the ordering requirements of the original VkSemaphore?

**RESOLVED**: Prior to calling any command which may cause a wait operation on a binary semaphore, the client must ensure that the semaphore signal operation that has been submitted for execution and any semaphore signal operations on which it depends (if any) must have also been submitted for execution.

11) Should we have separate feature bits for different sub-features of timeline semaphores?

**RESOLVED**: No. The only feature which cannot be supported universally is timeline semaphore import/export. For import/export, the client is already required to query available external handle types via vkGetPhysicalDeviceExternalSemaphoreProperties and provide the semaphore type by adding a VkSemaphoreTypeCreateInfoKHR structure to the pNext chain ofVkPhysicalDeviceExternalSemaphoreInfo so no new feature bit is required.

### Version History

- Revision 1, 2018-05-10 (Faith Ekstrand)
  - Initial version
- Revision 2, 2019-06-12 (Faith Ekstrand)
  - Added an initialValue parameter to timeline semaphore creation

### VK_KHR_uniform_buffer_standard_layout

**Name String**

VK_KHR_uniform_buffer_standard_layout

**Extension Type**

Device extension

**Registered Extension Number**

254

**Revision**

1

**Ratification Status**

Ratified
Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Deprecation state

• *Promoted* to **Vulkan 1.2**

Contact

• Graeme Leese Øgnl21

Other Extension Metadata

Last Modified Date

2019-01-25

Interactions and External Dependencies

• Promoted to Vulkan 1.2 Core

Contributors

• Graeme Leese, Broadcom
• Jeff Bolz, NVIDIA
• Tobias Hector, AMD
• Faith Ekstrand, Intel
• Neil Henning, AMD

Description

This extension enables tighter array and struct packing to be used with uniform buffers.

It modifies the alignment rules for uniform buffers, allowing for tighter packing of arrays and structures. This allows, for example, the std430 layout, as defined in GLSL to be supported in uniform buffers.

Promotion to Vulkan 1.2

All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Structures

• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceUniformBufferStandardLayoutFeaturesKHR

New Enum Constants

• VK_KHR_UNIFORM_BUFFER_STANDARD_LAYOUT_EXTENSION_NAME
• VK_KHR_UNIFORM_BUFFER_STANDARD_LAYOUT_SPEC_VERSION
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_UNIFORM_BUFFER_STANDARD_LAYOUT_FEATURES_KHR

Version History

• Revision 1, 2019-01-25 (Graeme Leese)
  ◦ Initial draft

VK_KHR_variable_pointers

Name String
VK_KHR_variable_pointers

Extension Type
Device extension

Registered Extension Number
121

Revision
1

Ratification Status
Ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2
  and
VK_KHR_storage_buffer_storage_class

Deprecation state
• Promoted to Vulkan 1.1

Contact
• Jesse Hall critsec

Other Extension Metadata

Last Modified Date
2017-09-05

IP Status
No known IP claims.

Interactions and External Dependencies
• This extension requires SPV_KHR_variable_pointers
• Promoted to Vulkan 1.1 Core
Contributors

- John Kessenich, Google
- Neil Henning, Codeplay
- David Neto, Google
- Daniel Koch, Nvidia
- Graeme Leese, Broadcom
- Weifeng Zhang, Qualcomm
- Stephen Clarke, Imagination Technologies
- Faith Ekstrand, Intel
- Jesse Hall, Google

Description

The `VK_KHR_variable_pointers` extension allows implementations to indicate their level of support for the `SPV_KHR_variable_pointers` SPIR-V extension. The SPIR-V extension allows shader modules to use invocation-private pointers into uniform and/or storage buffers, where the pointer values can be dynamic and non-uniform.

The `SPV_KHR_variable_pointers` extension introduces two capabilities. The first, `VariablePointersStorageBuffer`, must be supported by all implementations of this extension. The second, `VariablePointers`, is optional.

Promotion to Vulkan 1.1

All functionality in this extension is included in core Vulkan 1.1, with the KHR suffix omitted, however support for the `variablePointersStorageBuffer` feature is made optional. The original type, enum and command names are still available as aliases of the core functionality.

New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceVariablePointerFeaturesKHR`
  - `VkPhysicalDeviceVariablePointersFeaturesKHR`

New Enum Constants

- `VK_KHR_VARIABLE_POINTERS_EXTENSION_NAME`
- `VK_KHR_VARIABLE_POINTERS_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL DEVICE_VARIABLE PointersFeaturesKHR`
  - `VK_STRUCTURE_TYPE_PHYSICAL DEVICE VARIABLE_POINTER FEATURES KHR`
New SPIR-V Capabilities

- VariablePointers
- VariablePointersStorageBuffer

Issues

1) Do we need an optional property for the SPIR-V VariablePointersStorageBuffer capability or should it be mandatory when this extension is advertised?

RESOLVED: Add it as a distinct feature, but make support mandatory. Adding it as a feature makes the extension easier to include in a future core API version. In the extension, the feature is mandatory, so that presence of the extension guarantees some functionality. When included in a core API version, the feature would be optional.

2) Can support for these capabilities vary between shader stages?

RESOLVED: No, if the capability is supported in any stage it must be supported in all stages.

3) Should the capabilities be features or limits?

RESOLVED: Features, primarily for consistency with other similar extensions.

Version History

- Revision 1, 2017-03-14 (Jesse Hall and John Kessenich)
  - Internal revisions

VK_KHR_vulkan_memory_model

Name String

VK_KHR_vulkan_memory_model

Extension Type

Device extension

Registered Extension Number

212

Revision

3

Ratification Status

Ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2
Deprecation state

- Promoted to Vulkan 1.2

Contact

- Jeff Bolz (jeffbolznv)

Other Extension Metadata

Last Modified Date

2018-12-10

IP Status

No known IP claims.

Interactions and External Dependencies

- Promoted to Vulkan 1.2 Core
- This extension requires SPV_KHR_vulkan_memory_model

Contributors

- Jeff Bolz, NVIDIA
- Alan Baker, Google
- Tobias Hector, AMD
- David Neto, Google
- Robert Simpson, Qualcomm Technologies, Inc.
- Brian Sumner, AMD

Description

The VK_KHR_vulkan_memory_model extension allows use of the features guarded by the VulkanMemoryModel, VulkanMemoryModelDeviceScope, and VulkanMemoryModelAvailabilityVisibilityChains capabilities in shader modules. The Vulkan Memory Model formally defines how to synchronize memory accesses to the same memory locations performed by multiple shader invocations.

Note

Version 3 of the spec added a member (vulkanMemoryModelAvailabilityVisibilityChains) to VkPhysicalDeviceVulkanMemoryModelFeaturesKHR, which is an incompatible change from version 2.

Promotion to Vulkan 1.2

All functionality in this extension is included in core Vulkan 1.2, with the KHR suffix omitted. However, if Vulkan 1.2 is supported and this extension is not, the vulkanMemoryModel capability is optional. The original type, enum and command names are still available as aliases of the core functionality.
New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceVulkanMemoryModelFeaturesKHR`

New Enum Constants

- `VK_KHR_VULKAN_MEMORY_MODEL_EXTENSION_NAME`
- `VK_KHR_VULKAN_MEMORY_MODEL_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_VULKAN_MEMORY_MODEL_FEATURES_KHR`

New SPIR-V Capabilities

- `VulkanMemoryModelKHR`

Version History

- Revision 1, 2018-06-24 (Jeff Bolz)
  - Initial draft
- Revision 3, 2018-12-10 (Jeff Bolz)
  - Add `vulkanMemoryModelAvailabilityVisibilityChains` member to the `VkPhysicalDeviceVulkanMemoryModelFeaturesKHR` structure.

**VK_KHR_zero_initialize_workgroup_memory**

Name String

`VK_KHR_zero_initialize_workgroup_memory`

Extension Type

Device extension

Registered Extension Number

326

Revision

1

Ratification Status

Ratified

Extension and Version Dependencies

- `VK_KHR_get_physical_device_properties2`

Deprecation state

- *Promoted to* Vulkan 1.3
Description

This extension allows the use of a null constant initializer on shader Workgroup memory variables, allowing implementations to expose any special hardware or instructions they may have. Zero initialization is commonly used by applications running untrusted content (e.g. web browsers) as way of defeating memory-scraping attacks.

New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceZeroInitializeWorkgroupMemoryFeaturesKHR`

New Enum Constants

- `VK_KHR_ZERO_INITIALIZE_WORKGROUP_MEMORY_EXTENSION_NAME`
- `VK_KHR_ZERO_INITIALIZE_WORKGROUP_MEMORY_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_ZERO_INITIALIZE_WORKGROUP_MEMORY_FEATURES_KHR`

Promotion to Vulkan 1.3

Functionality in this extension is included in core Vulkan 1.3, with the KHR suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

Version History

- Revision 1, 2020-11-18 (Alan Baker)
VK_EXT_4444_formats

Name String
VK_EXT_4444_formats

Extension Type
Device extension

Registered Extension Number
341

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2
or
Version 1.1

Deprecation state
• Promoted to Vulkan 1.3

Contact
• Joshua Ashton Joshua-Ashton

Other Extension Metadata

Last Modified Date
2020-07-28

Interactions and External Dependencies
• Promoted to Vulkan 1.3 Core

IP Status
No known IP claims.

Contributors
• Joshua Ashton, Valve
• Faith Ekstrand, Intel

Description
This extension defines the VK_FORMAT_A4R4G4B4_UNORM_PACK16_EXT and
VK_FORMAT_A4B4G4R4_UNORM_PACK16_EXT formats which are defined in other current graphics APIs.

This extension may be useful for building translation layers for those APIs or for porting applications that use these formats without having to resort to swizzles.

When VK_EXT_custom_border_color is used, these formats are not subject to the same restrictions for border color without format as with VK_FORMAT_B4G4R4A4_UNORM_PACK16.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDevice4444FormatsFeaturesEXT

New Enum Constants

- VK_EXT_4444_FORMATS_EXTENSION_NAME
- VK_EXT_4444_FORMATS_SPEC_VERSION

- Extending VkFormat:
  - VK_FORMAT_A4B4G4R4_UNORM_PACK16_EXT
  - VK_FORMAT_A4R4G4B4_UNORM_PACK16_EXT

- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_4444_FORMATS_FEATURES_EXT

Promotion to Vulkan 1.3

This extension has been partially promoted. The format enumerants introduced by the extension are included in core Vulkan 1.3, with the EXT suffix omitted. However, runtime support for these formats is optional in core Vulkan 1.3, while if this extension is supported, runtime support is mandatory. The feature structure is not promoted. The original enum names are still available as aliases of the core functionality.

Version History

- Revision 1, 2020-07-04 (Joshua Ashton)
  - Initial draft

VK_EXT_buffer_device_address

Name String

VK_EXT_buffer_device_address

Extension Type

Device extension

Registered Extension Number

245
Revision
2

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2

Deprecation state
- Deprecated by VK_KHR_buffer_device_address extension
  - Which in turn was promoted to Vulkan 1.2

Contact
- Jeff Bolz jeffbolznv

Other Extension Metadata

Last Modified Date
2019-01-06

IP Status
No known IP claims.

Interactions and External Dependencies
- This extension requires SPV_EXT_physical_storage_buffer
- This extension provides API support for GLSL_EXT_buffer_reference and GLSL_EXT_buffer_reference_uvec2

Contributors
- Jeff Bolz, NVIDIA
- Neil Henning, AMD
- Tobias Hector, AMD
- Faith Ekstrand, Intel
- Baldur Karlsson, Valve

Description
This extension allows the application to query a 64-bit buffer device address value for a buffer, which can be used to access the buffer memory via the PhysicalStorageBufferEXT storage class in the GL_EXT_buffer_reference GLSL extension and SPV_EXT_physical_storage_buffer SPIR-V extension.

It also allows buffer device addresses to be provided by a trace replay tool, so that it matches the address used when the trace was captured.
**New Commands**

- `vkGetBufferDeviceAddressEXT`

**New Structures**

- `VkBufferDeviceAddressInfoEXT`
- Extending `VkBufferCreateInfo`:
  - `VkBufferDeviceAddressCreateInfoEXT`
- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDeviceBufferAddressFeaturesEXT`
  - `VkPhysicalDeviceBufferDeviceAddressFeaturesEXT`

**New Enum Constants**

- `VK_EXT_BUFFER_DEVICE_ADDRESS_EXTENSION_NAME`
- `VK_EXT_BUFFER_DEVICE_ADDRESS_SPEC_VERSION`
- Extending `VkBufferCreateFlagBits`:
  - `VK_BUFFER_CREATE_DEVICE_ADDRESS_CAPTURE_REPLAY_BIT_EXT`
- Extending `VkBufferUsageFlagBits`:
  - `VK_BUFFER_USAGE_SHADER_DEVICE_ADDRESS_BIT_EXT`
- Extending `VkResult`:
  - `VK_ERROR_INVALID_DEVICE_ADDRESS_EXT`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_BUFFER_DEVICE_ADDRESS_CREATE_INFO_EXT`
  - `VK_STRUCTURE_TYPE_BUFFER_DEVICE_ADDRESS_INFO_EXT`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BUFFER_ADDRESS_FEATURES_EXT`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BUFFER_DEVICE_ADDRESS_FEATURES_EXT`

**New SPIR-V Capabilities**

- `PhysicalStorageBufferAddressesEXT`

**Issues**

1) Where is `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BUFFER_ADDRESS_FEATURES_EXT` and `VkPhysicalDeviceBufferAddressFeaturesEXT`?

**RESOLVED:** They were renamed as `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_BUFFER_ADDRESS_FEATURES_EXT` and `VkPhysicalDeviceBufferDeviceAddressFeaturesEXT` accordingly for consistency. Even though, the old names can still be found in the generated header files for compatibility.
Version History

- Revision 1, 2018-11-01 (Jeff Bolz)
  - Internal revisions
- Revision 2, 2019-01-06 (Jon Leech)
  - Minor updates to appendix for publication

VK_EXT_debug_marker

**Name String**

```
VK_EXT_debug_marker
```

**Extension Type**

Device extension

**Registered Extension Number**

23

**Revision**

4

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

```
VK_EXT_debug_report
```

**Deprecation state**

- Promoted to VK_EXT_debug_utils extension

**Special Use**

- Debugging tools

**Contact**

- Baldur Karlsson @baldurk

**Other Extension Metadata**

**Last Modified Date**

2017-01-31

**IP Status**

No known IP claims.

**Contributors**

- Baldur Karlsson
- Dan Ginsburg, Valve
Description

The `VK_EXT_debug_marker` extension is a device extension. It introduces concepts of object naming and tagging, for better tracking of Vulkan objects, as well as additional commands for recording annotations of named sections of a workload to aid organization and offline analysis in external tools.

New Commands

- `vkCmdDebugMarkerBeginEXT`
- `vkCmdDebugMarkerEndEXT`
- `vkCmdDebugMarkerInsertEXT`
- `vkDebugMarkerSetObjectNameEXT`
- `vkDebugMarkerSetObjectTagEXT`

New Structures

- `VkDebugMarkerMarkerInfoEXT`
- `VkDebugMarkerObjectNameInfoEXT`
- `VkDebugMarkerObjectTagInfoEXT`

New Enums

- `VkDebugReportObjectTypeEXT`

New Enum Constants

- `VK_EXT_DEBUG_MARKER_EXTENSION_NAME`
- `VK_EXT_DEBUG_MARKER_SPEC_VERSION`

Extending `VkStructureType`:

- `VK_STRUCTURE_TYPE_DEBUG_MARKER_MARKER_INFO_EXT`
- `VK_STRUCTURE_TYPE_DEBUG_MARKER_OBJECT_NAME_INFO_EXT`
- `VK_STRUCTURE_TYPE_DEBUG_MARKER_OBJECT_TAG_INFO_EXT`

Examples

Example 1

Associate a name with an image, for easier debugging in external tools or with validation layers that can print a friendly name when referring to objects in error messages.
extern VkDevice device;
extern VkImage image;

// Must call extension functions through a function pointer:
PFN_vkDebugMarkerSetObjectNameEXT pfDebugMarkerSetObjectNameEXT = (PFN_vkDebugMarkerSetObjectNameEXT)vkGetDeviceProcAddr(device, "vkDebugMarkerSetObjectNameEXT");

// Set a name on the image
const VkDebugMarkerObjectNameInfoEXT imageNameInfo = {
    .sType = VK_STRUCTURE_TYPE_DEBUG_MARKER_OBJECT_NAME_INFO_EXT,
    .pNext = NULL,
    .objectType = VK_DEBUG_REPORT_OBJECT_TYPE_IMAGE_EXT,
    .object = (uint64_t)image,
    .pObjectName = "Brick Diffuse Texture",
};

pfDebugMarkerSetObjectNameEXT(device, &imageNameInfo);

// A subsequent error might print:
//   Image 'Brick Diffuse Texture' (0xc0dec0dedeadbeef) is used in a
//   command buffer with no memory bound to it.

Example 2
Annotating regions of a workload with naming information so that offline analysis tools can display a more usable visualisation of the commands submitted.

extern VkDevice device;
extern VkCommandBuffer commandBuffer;

// Must call extension functions through a function pointer:
PFN_vkCmdDebugMarkerBeginEXT pfCmdDebugMarkerBeginEXT = (PFN_vkCmdDebugMarkerBeginEXT)vkGetDeviceProcAddr(device, "vkCmdDebugMarkerBeginEXT");
PFN_vkCmdDebugMarkerEndEXT pfCmdDebugMarkerEndEXT = (PFN_vkCmdDebugMarkerEndEXT)vkGetDeviceProcAddr(device, "vkCmdDebugMarkerEndEXT");
PFN_vkCmdDebugMarkerInsertEXT pfCmdDebugMarkerInsertEXT = (PFN_vkCmdDebugMarkerInsertEXT)vkGetDeviceProcAddr(device, "vkCmdDebugMarkerInsertEXT");

// Describe the area being rendered
const VkDebugMarkerMarkerInfoEXT houseMarker = {
    .sType = VK_STRUCTURE_TYPE_DEBUG_MARKER_MARKER_INFO_EXT,
    .pNext = NULL,
    .pMarkerName = "Brick House",
    .color = { 1.0f, 0.0f, 0.0f, 1.0f }
};
// Start an annotated group of calls under the 'Brick House' name
PFN.CmdDebugMarkerBeginEXT(commandBuffer, &houseMarker);
{
    // A mutable structure for each part being rendered
    VkDebugMarkerMarkerInfoEXT housePartMarker =
    {
        .sType = VK_STRUCTURE_TYPE_DEBUG_MARKER_MARKER_INFO_EXT,
        .pNext = NULL,
        .pMarkerName = NULL,
        .color = { 0.0f, 0.0f, 0.0f, 0.0f },
    };

    // Set the name and insert the marker
    housePartMarker.pMarkerName = "Walls";
    PFN.CmdDebugMarkerInsertEXT(commandBuffer, &housePartMarker);

    // Insert the drawcall for the walls
    vkCmdDrawIndexed(commandBuffer, 1000, 1, 0, 0);

    // Insert a recursive region for two sets of windows
    housePartMarker.pMarkerName = "Windows";
    PFN.CmdDebugMarkerBeginEXT(commandBuffer, &housePartMarker);
    {
        vkCmdDrawIndexed(commandBuffer, 75, 6, 1000, 0, 0);
        vkCmdDrawIndexed(commandBuffer, 100, 2, 1450, 0, 0);
    }
    PFN.CmdDebugMarkerEndEXT(commandBuffer);

    housePartMarker.pMarkerName = "Front Door";
    PFN.CmdDebugMarkerInsertEXT(commandBuffer, &housePartMarker);

    vkCmdDrawIndexed(commandBuffer, 350, 1, 1650, 0, 0);

    housePartMarker.pMarkerName = "Roof";
    PFN.CmdDebugMarkerInsertEXT(commandBuffer, &housePartMarker);

    vkCmdDrawIndexed(commandBuffer, 500, 1, 2000, 0, 0);
}
    // End the house annotation started above
    PFN.CmdDebugMarkerEndEXT(commandBuffer);

Issues

1) Should the tag or name for an object be specified using the pNext parameter in the object’s Vk*CreateInfo structure?

**RESOLVED:** No. While this fits with other Vulkan patterns and would allow more type safety and future proofing against future objects, it has notable downsides. In particular passing the name at Vk*CreateInfo time does not allow renaming, prevents late binding of naming information, and
does not allow naming of implicitly created objects such as queues and swapchain images.

2) Should the command annotation functions `vkCmdDebugMarkerBeginEXT` and `vkCmdDebugMarkerEndEXT` support the ability to specify a color?

**RESOLVED:** Yes. The functions have been expanded to take an optional color which can be used at will by implementations consuming the command buffer annotations in their visualisation.

3) Should the functions added in this extension accept an extensible structure as their parameter for a more flexible API, as opposed to direct function parameters? If so, which functions?

**RESOLVED:** Yes. All functions have been modified to take a structure type with extensible `pNext` pointer, to allow future extensions to add additional annotation information in the same commands.

**Version History**

- Revision 1, 2016-02-24 (Baldur Karlsson)
  - Initial draft, based on LunarG marker spec
- Revision 2, 2016-02-26 (Baldur Karlsson)
  - Renamed Dbg to DebugMarker in function names
  - Allow markers in secondary command buffers under certain circumstances
  - Minor language tweaks and edits
- Revision 3, 2016-04-23 (Baldur Karlsson)
  - Reorganise spec layout to closer match desired organisation
  - Added optional color to markers (both regions and inserted labels)
  - Changed functions to take extensible structs instead of direct function parameters
- Revision 4, 2017-01-31 (Baldur Karlsson)
  - Added explicit dependency on `VK_EXT_debug_report`
  - Moved definition of `VkDebugReportObjectTypeEXT` to debug report chapter.
  - Fixed typo in dates in revision history

**VK_EXT_debug_report**

**Name String**

```
VK_EXT_debug_report
```

**Extension Type**

Instance extension

**Registered Extension Number**

12
Revision
10

Ratification Status
Not ratified

Extension and Version Dependencies

Deprecation state
• Deprecated by VK_EXT_debug_utils extension

Special Use
• Debugging tools

Contact
• Courtney Goeltzenleuchter courtney-g

Other Extension Metadata

Last Modified Date
2020-12-14

IP Status
No known IP claims.

Contributors
• Courtney Goeltzenleuchter, LunarG
• Dan Ginsburg, Valve
• Jon Ashburn, LunarG
• Mark Lobodzinski, LunarG

Description
Due to the nature of the Vulkan interface, there is very little error information available to the developer and application. By enabling optional validation layers and using the VK_EXT_debug_report extension, developers can obtain much more detailed feedback on the application’s use of Vulkan. This extension defines a way for layers and the implementation to call back to the application for events of interest to the application.

New Object Types
• VkDebugReportCallbackEXT

New Commands
• vkCreateDebugReportCallbackEXT
• vkDebugReportMessageEXT
• vkDestroyDebugReportCallbackEXT
New Structures

- Extending `VkInstanceCreateInfo`:
  - `VkDebugReportCallbackCreateInfoEXT`

New Function Pointers

- `PFN_vkDebugReportCallbackEXT`

New Enums

- `VkDebugReportFlagBitsEXT`
- `VkDebugReportObjectTypeEXT`

New Bitmasks

- `VkDebugReportFlagsEXT`

New Enum Constants

- `VK_EXT_DEBUG_REPORT_EXTENSION_NAME`
- `VK_EXT_DEBUG_REPORT_SPEC_VERSION`
- Extending `VkObjectType`:
  - `VK_OBJECT_TYPE_DEBUG_REPORT_CALLBACK_EXT`
- Extending `VkResult`:
  - `VK_ERROR_VALIDATION_FAILED_EXT`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_DEBUG_REPORT_CALLBACK_CREATE_INFO_EXT`
  - `VK_STRUCTURE_TYPE_DEBUG_REPORT_CREATE_INFO_EXT`

If Version 1.1 is supported:

- Extending `VkDebugReportObjectTypeEXT`:
  - `VK_DEBUG_REPORT_OBJECT_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_EXT`
  - `VK_DEBUG_REPORT_OBJECT_TYPE_SAMPLER_YCBCR_CONVERSION_EXT`

Examples

`VK_EXT_debug_report` allows an application to register multiple callbacks with the validation layers. Some callbacks may log the information to a file, others may cause a debug break point or other application defined behavior. An application `can` register callbacks even when no validation layers are enabled, but they will only be called for loader and, if implemented, driver events.

To capture events that occur while creating or destroying an instance an application `can` link a `VkDebugReportCallbackCreateInfoEXT` structure to the `pNext` element of the `VkInstanceCreateInfo`. 
structure given to \texttt{vkCreateInstance}.

Example uses: Create three callback objects. One will log errors and warnings to the debug console using Windows \texttt{OutputDebugString}. The second will cause the debugger to break at that callback when an error happens and the third will log warnings to stdout.

```c
VkResult res;
VkDebugReportCallbackEXT cb1, cb2, cb3;

VkDebugReportCallbackCreateInfoEXT callback1 = {
    .sType = VK_STRUCTURE_TYPE_DEBUG_REPORT_CALLBACK_CREATE_INFO_EXT,
    .pNext = NULL,
    .flags = VK_DEBUG_REPORT_ERROR_BIT_EXT | VK_DEBUG_REPORT_WARNING_BIT_EXT,
    .pfnCallback = myOutputDebugString,
    .pUserData = NULL
};
res = vkCreateDebugReportCallbackEXT(instance, &callback1, &cb1);
if (res != VK_SUCCESS)
    /* Do error handling for VK_ERROR_OUT_OF_MEMORY */
#endif

callback.flags = VK_DEBUG_REPORT_ERROR_BIT_EXT;
callback.pfnCallback = myDebugBreak;
callback.pUserData = NULL;
res = vkCreateDebugReportCallbackEXT(instance, &callback, &cb2);
if (res != VK_SUCCESS)
    /* Do error handling for VK_ERROR_OUT_OF_MEMORY */
#endif

VkDebugReportCallbackCreateInfoEXT callback3 = {
    .sType = VK_STRUCTURE_TYPE_DEBUG_REPORT_CALLBACK_CREATE_INFO_EXT,
    .pNext = NULL,
    .flags = VK_DEBUG_REPORT_WARNING_BIT_EXT,
    .pfnCallback = mystdOutLogger,
    .pUserData = NULL
};
res = vkCreateDebugReportCallbackEXT(instance, &callback3, &cb3);
if (res != VK_SUCCESS)
    /* Do error handling for VK_ERROR_OUT_OF_MEMORY */
#endif

/* remove callbacks when cleaning up */
vkDestroyDebugReportCallbackEXT(instance, cb1);
vkDestroyDebugReportCallbackEXT(instance, cb2);
vkDestroyDebugReportCallbackEXT(instance, cb3);
```

\textbf{Note}

In the initial release of the \texttt{VK_EXT_debug_report} extension, the token \texttt{VK_STRUCTURE_TYPE_DEBUG_REPORT_CREATE_INFO_EXT} was used. Starting in version 2 of
the extension branch, `VK_STRUCTURE_TYPE_DEBUG_REPORT_CALLBACK_CREATE_INFO_EXT` is used instead for consistency with Vulkan naming rules. The older enum is still available for backwards compatibility.

**Note**

In the initial release of the `VK_EXT_debug_report` extension, the token `VK_DEBUG_REPORT_OBJECT_TYPE_DEBUG_REPORT_EXT` was used. Starting in version 8 of the extension branch, `VK_DEBUG_REPORT_OBJECT_TYPE_DEBUG_REPORT_CALLBACK_EXT_EXT` is used instead for consistency with Vulkan naming rules. The older enum is still available for backwards compatibility.

**Issues**

1) What is the hierarchy / seriousness of the message flags? E.g. `ERROR > WARN > PERF_WARN` ...

**RESOLVED**: There is no specific hierarchy. Each bit is independent and should be checked via bitwise AND. For example:

```c
if (localFlags & VK_DEBUG_REPORT_ERROR_BIT_EXT) {
    process error message
}
if (localFlags & VK_DEBUG_REPORT_DEBUG_BIT_EXT) {
    process debug message
}
```

The validation layers do use them in a hierarchical way (`ERROR > WARN > PERF, WARN > DEBUG > INFO`) and they (at least at the time of this writing) only set one bit at a time. But it is not a requirement of this extension.

It is possible that a layer may intercept and change, or augment the flags with extension values the application’s debug report handler may not be familiar with, so it is important to treat each flag independently.

2) Should there be a VU requiring `VkDebugReportCallbackCreateInfoEXT::msgFlags` to be non-zero?

**RESOLVED**: It may not be very useful, but we do not need VU statement requiring the `VkDebugReportCallbackCreateInfoEXT::msgFlags` at create-time to be non-zero. One can imagine that apps may prefer it as it allows them to set the mask as desired - including nothing - at runtime without having to check.

3) What is the difference between `VK_DEBUG_REPORT_DEBUG_BIT_EXT` and `VK_DEBUG_REPORT_INFORMATION_BIT_EXT`?

**RESOLVED**: `VK_DEBUG_REPORT_DEBUG_BIT_EXT` specifies information that could be useful debugging the Vulkan implementation itself.

4) How do you compare handles returned by the debug_report callback to the application’s handles?
RESOLVED: Due to the different nature of dispatchable and nondispatchable handles there is no generic way (that we know of) that works for common compilers with 32bit, 64bit, C and C++. We recommend applications use the same cast that the validation layers use:

```cpp
reinterpret_cast<uint64_t&>(dispatchableHandle)
(uint64_t)(nondispatchableHandle)
```

+ This does require that the app treat dispatchable and nondispatchable handles differently.

**Version History**

- **Revision 1, 2015-05-20 (Courtney Goetzenleuchter)**
  - Initial draft, based on LunarG KHR spec, other KHR specs
- **Revision 2, 2016-02-16 (Courtney Goetzenleuchter)**
  - Update usage, documentation
- **Revision 3, 2016-06-14 (Courtney Goetzenleuchter)**
  - Update `VK_EXT_DEBUG_REPORT_SPEC_VERSION` to indicate added support for `vkCreateInstance` and `vkDestroyInstance`
- **Revision 4, 2016-12-08 (Mark Lobodzinski)**
  - Added `Display_KHR`, `DisplayModeKHR` extension objects
  - Added `ObjectTable_NVX`, `IndirectCommandsLayout_NVX` extension objects
  - Bumped spec revision
  - Retroactively added version history
- **Revision 5, 2017-01-31 (Baldur Karlsson)**
  - Moved definition of `VkDebugReportObjectTypeEXT` from debug marker chapter
- **Revision 6, 2017-01-31 (Baldur Karlsson)**
  - Added `VK_DEBUG_REPORT_OBJECT_TYPE_DESCRIPTOR_UPDATE_TEMPLATE_KHR_EXT`
- **Revision 7, 2017-04-20 (Courtney Goeltzenleuchter)**
  - Clarify wording and address questions from developers.
- **Revision 8, 2017-04-21 (Courtney Goeltzenleuchter)**
  - Remove unused enum `VkDebugReportErrorEXT`
- **Revision 9, 2017-09-12 (Tobias Hector)**
  - Added interactions with Vulkan 1.1
- **Revision 10, 2020-12-14 (Courtney Goetzenleuchter)**
  - Add issue 4 discussing matching handles returned by the extension, based on suggestion in public issue 368.
VK_EXT_descriptor_indexing

Name String
VK_EXT_descriptor_indexing

Extension Type
Device extension

Registered Extension Number
162

Revision
2

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2
and
VK_KHR_maintenance3

Deprecation state
• Promoted to Vulkan 1.2

Contact
• Jeff Bolz @jeffbolznv

Other Extension Metadata

Last Modified Date
2017-10-02

Interactions and External Dependencies
• Promoted to Vulkan 1.2 Core
• This extension requires SPV_EXT_descriptor_indexing
• This extension provides API support for GL_EXT_nonuniform_qualifier

Contributors
• Jeff Bolz, NVIDIA
• Daniel Rakos, AMD
• Slawomir Grajewski, Intel
• Tobias Hector, Imagination Technologies

Description
This extension adds several small features which together enable applications to create large
descriptor sets containing substantially all of their resources, and selecting amongst those resources with dynamic (non-uniform) indexes in the shader. There are feature enables and SPIR-V capabilities for non-uniform descriptor indexing in the shader, and non-uniform indexing in the shader requires use of a new `NonUniformEXT` decoration defined in the `SPV_EXT_descriptor_indexing` SPIR-V extension. There are descriptor set layout binding creation flags enabling several features:

- Descriptors can be updated after they are bound to a command buffer, such that the execution of the command buffer reflects the most recent update to the descriptors.
- Descriptors that are not used by any pending command buffers can be updated, which enables writing new descriptors for frame N+1 while frame N is executing.
- Relax the requirement that all descriptors in a binding that is “statically used” must be valid, such that descriptors that are not accessed by a submission need not be valid and can be updated while that submission is executing.
- The final binding in a descriptor set layout can have a variable size (and unsized arrays of resources are allowed in the `GL_EXT_nonuniform_qualifier` and `SPV_EXT_descriptor_indexing` extensions).

Note that it is valid for multiple descriptor arrays in a shader to use the same set and binding number, as long as they are all compatible with the descriptor type in the pipeline layout. This means a single array binding in the descriptor set can serve multiple texture dimensionalities, or an array of buffer descriptors can be used with multiple different block layouts.

There are new descriptor set layout and descriptor pool creation flags that are required to opt in to the update-after-bind functionality, and there are separate `maxPerStage` and `maxDescriptorSet` limits that apply to these descriptor set layouts which may be much higher than the pre-existing limits. The old limits only count descriptors in non-updateAfterBind descriptor set layouts, and the new limits count descriptors in all descriptor set layouts in the pipeline layout.

**New Structures**

- Extending `VkDescriptorSetAllocateInfo`:
  - `VkDescriptorSetVariableDescriptorCountAllocateInfoEXT`
- Extending `VkDescriptorSetLayoutCreateInfo`:
  - `VkDescriptorSetLayoutBindingFlagsCreateInfoEXT`
- Extending `VkDescriptorSetLayoutSupport`:
  - `VkDescriptorSetVariableDescriptorCountLayoutSupportEXT`
- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceDescriptorIndexingFeaturesEXT`
- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceDescriptorIndexingPropertiesEXT`

**New Enums**

- `VkDescriptorBindingFlagBitsEXT`
New Bitmasks

- VkDescriptorBindingFlagsEXT

New Enum Constants

- VK_EXT_DESCRIPTOR_INDEXING_EXTENSION_NAME
- VK_EXT_DESCRIPTOR_INDEXING_SPEC_VERSION

Extending VkDescriptorBindingFlagBits:

- VK_DESCRIPTOR_BINDING_PARTIALLY_BOUND_BIT_EXT
- VK_DESCRIPTOR_BINDING_UPDATE_AFTER_BIND_BIT_EXT
- VK_DESCRIPTOR_BINDING_UPDATE_UNUSED_WHILE_PENDING_BIT_EXT
- VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT_EXT

Extending VkDescriptorPoolCreateFlagBits:

- VK_DESCRIPTOR_POOL_CREATE_UPDATE_AFTER_BIND_BIT_EXT

Extending VkDescriptorSetLayoutCreateFlagBits:

- VK_DESCRIPTOR_SET_LAYOUT_CREATE_UPDATE_AFTER_BIND_POOL_BIT_EXT

Extending VkResult:

- VK_ERROR_FRAGMENTATION_EXT

Extending VkStructureType:

- VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_BINDING_FLAGS_CREATE_INFO_EXT
- VK_STRUCTURE_TYPE_DESCRIPTOR_SET_VARIABLE_DESCRIPTOR_COUNT_ALLOCATE_INFO_EXT
- VK_STRUCTURE_TYPE_DESCRIPTOR_SET_VARIABLE_DESCRIPTOR_COUNT_LAYOUT_SUPPORT_EXT
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_INDEXING_FEATURES_EXT
- VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_DESCRIPTOR_INDEXING_PROPERTIES_EXT

Promotion to Vulkan 1.2

Functionality in this extension is included in core Vulkan 1.2, with the EXT suffix omitted. However, if Vulkan 1.2 is supported and this extension is not, the descriptorIndexing capability is optional. The original type, enum and command names are still available as aliases of the core functionality.

Version History

- Revision 1, 2017-07-26 (Jeff Bolz)
  - Internal revisions
- Revision 2, 2017-10-02 (Jeff Bolz)
  - ???
VK_EXT_extended_dynamic_state

Name String
  VK_EXT_extended_dynamic_state

Extension Type
  Device extension

Registered Extension Number
  268

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_get_physical_device_properties2
  or
  Version 1.1

Deprecation state
  • Promoted to Vulkan 1.3

Contact
  • Piers Daniell pdaniell-nv

Other Extension Metadata

Last Modified Date
  2019-12-09

Interactions and External Dependencies
  • Promoted to Vulkan 1.3 Core

IP Status
  No known IP claims.

Contributors
  • Dan Ginsburg, Valve Corporation
  • Graeme Leese, Broadcom
  • Hans-Kristian Arntzen, Valve Corporation
  • Jan-Harald Fredriksen, Arm Limited
  • Faith Ekstrand, Intel
  • Jeff Bolz, NVIDIA
Description

This extension adds some more dynamic state to support applications that need to reduce the number of pipeline state objects they compile and bind.

New Commands

- `vkCmdBindVertexBuffers2EXT`
- `vkCmdSetCullModeEXT`
- `vkCmdSetDepthBoundsTestEnableEXT`
- `vkCmdSetDepthCompareOpEXT`
- `vkCmdSetDepthTestEnableEXT`
- `vkCmdSetDepthWriteEnableEXT`
- `vkCmdSetFrontFaceEXT`
- `vkCmdSetPrimitiveTopologyEXT`
- `vkCmdSetScissorWithCountEXT`
- `vkCmdSetStencilOpEXT`
- `vkCmdSetStencilTestEnableEXT`
- `vkCmdSetViewportWithCountEXT`

New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceExtendedDynamicStateFeaturesEXT`

New Enum Constants

- `Vk_EXT_EXTENDED_DYNAMIC_STATE_EXTENSION_NAME`
- `Vk_EXT_EXTENDED_DYNAMIC_STATE_SPEC_VERSION`

Extending `VkDynamicState`:

- `VK_DYNAMIC_STATE_CULL_MODE_EXT`
- `VK_DYNAMIC_STATE_DEPTH_BOUNDS_TEST_ENABLE_EXT`
- `VK_DYNAMIC_STATE_DEPTH_COMPARE_OP_EXT`
- `VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE_EXT`
- `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE_EXT`
- `VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE_EXT`
• VK_DYNAMIC_STATE_FRONT_FACE_EXT
• VK_DYNAMIC_STATE_PRIMITIVE_TOPOLOGY_EXT
• VK_DYNAMIC_STATE_SCISSOR_WITH_COUNT_EXT
• VK_DYNAMIC_STATE_STENCIL_OP_EXT
• VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE_EXT
• VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE_EXT
• VK_DYNAMIC_STATE_VIEWPORT_WITH_COUNT_EXT

• Extending VkStructureType:
  • VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTENDED_DYNAMIC_STATE_FEATURES_EXT

Promotion to Vulkan 1.3
This extension has been partially promoted. All dynamic state enumerants and entry points in this
extension are included in core Vulkan 1.3, with the EXT suffix omitted. The feature structure is not
promoted. Extension interfaces that were promoted remain available as aliases of the core
functionality.

Issues
Why are the values of pStrides in vkCmdBindVertexBuffers2 limited to be between 0 and the
maximum extent of the binding, when this restriction is not present for the same static state?
Implementing these edge cases adds overhead to some implementations that would require
significant cost when calling this function, and the intention is that this state should be more or less
free to change.

VK_EXT_vertex_input_dynamic_state allows the stride to be changed freely when supported via
vkCmdSetVertexInputEXT[].

Version History
• Revision 1, 2019-12-09 (Piers Daniell)
  • Internal revisions

VK_EXT_extended_dynamic_state2

Name String
  VK_EXT_extended_dynamic_state2

Extension Type
  Device extension

Registered Extension Number
  378
Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2
or
Version 1.1

Deprecation state
• Promoted to Vulkan 1.3

Contact
• Vikram Kushwaha vkushwaha-nv

Other Extension Metadata

Last Modified Date
2021-04-12

Interactions and External Dependencies
• Promoted to Vulkan 1.3 Core

IP Status
No known IP claims.

Contributors
• Vikram Kushwaha, NVIDIA
• Piers Daniell, NVIDIA
• Jeff Bolz, NVIDIA

Description
This extension adds some more dynamic state to support applications that need to reduce the number of pipeline state objects they compile and bind.

New Commands
• vkCmdSetDepthBiasEnableEXT
• vkCmdSetLogicOpEXT
• vkCmdSetPatchControlPointsEXT
• vkCmdSetPrimitiveRestartEnableEXT
• vkCmdSetRasterizerDiscardEnableEXT
New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceExtendedDynamicState2FeaturesEXT`

New Enum Constants

- `VK_EXT_EXTENDED_DYNAMIC_STATE_2_EXTENSION_NAME`
- `VK_EXT_EXTENDED_DYNAMIC_STATE_2_SPEC_VERSION`
- Extending `VkDynamicState`:
  - `VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE_EXT`
  - `VK_DYNAMIC_STATE_LOGIC_OP_EXT`
  - `VK_DYNAMIC_STATE_PATCH_CONTROL_POINTS_EXT`
  - `VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE_EXT`
  - `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE_EXT`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_EXTENDED_DYNAMIC_STATE_2_FEATURES_EXT`

Promotion to Vulkan 1.3

This extension has been partially promoted. The dynamic state enumerants `VK_DYNAMIC_STATE_DEPTH_BIAS_ENABLE_EXT`, `VK_DYNAMIC_STATE_PRIMITIVE_RESTART_ENABLE_EXT`, and `VK_DYNAMIC_STATE_RASTERIZER_DISCARD_ENABLE_EXT`; and the corresponding entry points in this extension are included in core Vulkan 1.3, with the EXT suffix omitted. The enumerants and entry points for dynamic logic operation and patch control points are not promoted, nor is the feature structure. Extension interfaces that were promoted remain available as aliases of the core functionality.

Version History

- Revision 1, 2021-04-12 (Vikram Kushwaha)
  - Internal revisions

**VK_EXT_global_priority**

Name String

- `VK_EXT_global_priority`

Extension Type

- Device extension

Registered Extension Number

- 175
Revision
   2

Ratification Status
   Not ratified

Extension and Version Dependencies

Deprecation state
   • Promoted to VK_KHR_global_priority extension

Contact
   • Andres Rodriguez @lostgoat

Other Extension Metadata

Last Modified Date
   2017-10-06

IP Status
   No known IP claims.

Contributors
   • Andres Rodriguez, Valve
   • Pierre-Loup Griffais, Valve
   • Dan Ginsburg, Valve
   • Mitch Singer, AMD

Description

In Vulkan, users can specify device-scope queue priorities. In some cases it may be useful to extend this concept to a system-wide scope. This extension provides a mechanism for callers to set their system-wide priority. The default queue priority is VK_QUEUE_GLOBAL_PRIORITY_MEDIUM_EXT.

The driver implementation will attempt to skew hardware resource allocation in favour of the higher-priority task. Therefore, higher-priority work may retain similar latency and throughput characteristics even if the system is congested with lower priority work.

The global priority level of a queue shall take precedence over the per-process queue priority (VkDeviceQueueCreateInfo::pQueuePriorities).

Abuse of this feature may result in starving the rest of the system from hardware resources. Therefore, the driver implementation may deny requests to acquire a priority above the default priority (VK_QUEUE_GLOBAL_PRIORITY_MEDIUM_EXT) if the caller does not have sufficient privileges. In this scenario VK_ERROR_NOT_PERMITTED_EXT is returned.

The driver implementation may fail the queue allocation request if resources required to complete the operation have been exhausted (either by the same process or a different process). In this scenario VK_ERROR_INITIALIZATION_FAILED is returned.
New Structures

• Extending `VkDeviceQueueCreateInfo`:
  ◦ `VkDeviceQueueGlobalPriorityCreateInfoEXT`

New Enums

• `VkQueueGlobalPriorityEXT`

New Enum Constants

• `VK_EXT_GLOBAL_PRIORITY_EXTENSION_NAME`
• `VK_EXT_GLOBAL_PRIORITY_SPEC_VERSION`

• Extending `VkResult`:
  ◦ `VK_ERROR_NOT_PERMITTED_EXT`

• Extending `VkStructureType`:
  ◦ `VK_STRUCTURE_TYPE_DEVICE_QUEUE_GLOBAL_PRIORITY_CREATE_INFO_EXT`

Version History

• Revision 2, 2017-11-03 (Andres Rodriguez)
  ◦ Fixed `VkQueueGlobalPriorityEXT` missing _EXT suffix

• Revision 1, 2017-10-06 (Andres Rodriguez)
  ◦ First version.

**VK_EXT_global_priority_query**

**Name String**

`VK_EXT_global_priority_query`

**Extension Type**

Device extension

**Registered Extension Number**

389

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

`VK_EXT_global_priority` and
Deprecation state

- Promoted to VK_KHR_global_priority extension

Contact

- Yiwei Zhang @zhangyiwei

Other Extension Metadata

Last Modified Date
2021-03-29

IP Status
No known IP claims.

Contributors

- Yiwei Zhang, Google

Description

This device extension allows applications to query the global queue priorities supported by a queue family. It allows implementations to report which global priority levels are treated differently by the implementation, instead of silently mapping multiple requested global priority levels to the same internal priority, or using device creation failure to signal that a requested priority is not supported. It is intended primarily for use by system integration along with certain platform-specific priority enforcement rules.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceGlobalPriorityQueryFeaturesEXT
- Extending VkQueueFamilyProperties2:
  - VkQueueFamilyGlobalPriorityPropertiesEXT

New Enum Constants

- VK_EXT_GLOBAL_PRIORITY_QUERY_EXTENSION_NAME
- VK_EXT_GLOBAL_PRIORITY_QUERY_SPEC_VERSION
- VK_MAX_GLOBAL_PRIORITY_SIZE_EXT
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_GLOBAL_PRIORITY_QUERY_FEATURES_EXT
  - VK_STRUCTURE_TYPE_QUEUE_FAMILY_GLOBAL_PRIORITY_PROPERTIES_EXT
**Issues**

1) Can we additionally query whether a caller is permitted to acquire a specific global queue priority in this extension?

**RESOLVED:** No. Whether a caller has enough privilege goes with the OS, and the Vulkan driver cannot really guarantee that the privilege will not change in between this query and the actual queue creation call.

2) If more than 1 queue using global priority is requested, is there a good way to know which queue is failing the device creation?

**RESOLVED:** No. There is not a good way at this moment, and it is also not quite actionable for the applications to know that because the information may not be accurate. Queue creation can fail because of runtime constraints like insufficient privilege or lack of resource, and the failure is not necessarily tied to that particular queue configuration requested.

**Version History**

- Revision 1, 2021-03-29 (Yiwei Zhang)

**VK_EXT_host_query_reset**

**Name String**

VK_EXT_host_query_reset

**Extension Type**

Device extension

**Registered Extension Number**

262

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

VK_KHR_get_physical_device_properties2

**Deprecation state**

- Promoted to Vulkan 1.2

**Contact**

- Bas Nieuwenhuizen BNieuwenhuizen
Other Extension Metadata

Last Modified Date
2019-03-06

IP Status
No known IP claims.

Interactions and External Dependencies
• Promoted to Vulkan 1.2 Core

Contributors
• Bas Nieuwenhuizen, Google
• Faith Ekstrand, Intel
• Jeff Bolz, NVIDIA
• Piers Daniell, NVIDIA

Description
This extension adds a new function to reset queries from the host.

Promotion to Vulkan 1.2
All functionality in this extension is included in core Vulkan 1.2, with the EXT suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Commands
• vkResetQueryPoolEXT

New Structures
• Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  ◦ VkPhysicalDeviceHostQueryResetFeaturesEXT

New Enum Constants
• VK_EXT_HOST_QUERY_RESET_EXTENSION_NAME
• VK_EXT_HOST_QUERY_RESET_SPEC_VERSION
• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_HOST_QUERY_RESETeatures_EXT

Version History
• Revision 1, 2019-03-12 (Bas Nieuwenhuizen)
  ◦ Initial draft
VK_EXT_image_robustness

Name String
VK_EXT_image_robustness

Extension Type
Device extension

Registered Extension Number
336

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2
or
Version 1.1

Deprecation state
• Promoted to Vulkan 1.3

Contact
• Graeme Leese gnl21

Other Extension Metadata

Last Modified Date
2020-04-27

Interactions and External Dependencies
• Promoted to Vulkan 1.3 Core

IP Status
No known IP claims.

Contributors
• Graeme Leese, Broadcom
• Jan-Harald Fredriksen, ARM
• Jeff Bolz, NVIDIA
• Spencer Fricke, Samsung
• Courtney Goeltzenleuchter, Google
• Slawomir Cygan, Intel
Description

This extension adds stricter requirements for how out of bounds reads from images are handled. Rather than returning undefined values, most out of bounds reads return R, G, and B values of zero and alpha values of either zero or one. Components not present in the image format may be set to zero or to values based on the format as described in Conversion to RGBA.

New Structures

- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceImageRobustnessFeaturesEXT

New Enum Constants

- VK_EXT_IMAGE_ROBUSTNESS_EXTENSION_NAME
- VK_EXT_IMAGE_ROBUSTNESS_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_IMAGE_ROBUSTNESS_FEATURES_EXT

Promotion to Vulkan 1.3

Functionality in this extension is included in core Vulkan 1.3, with the EXT suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

Issues

1. How does this extension differ from VK_EXT_robustness2?

The guarantees provided by this extension are a subset of those provided by the robustImageAccess2 feature of VK_EXT_robustness2. Where this extension allows return values of (0, 0, 0, 0) or (0, 0, 0, 1), robustImageAccess2 requires that a particular value dependent on the image format be returned. This extension provides no guarantees about the values returned for an access to an invalid Lod.

Examples

None.

Version History

- Revision 1, 2020-04-27 (Graeme Leese)
- Initial draft

VK_EXT_inline_uniform_block

Name String

VK_EXT_inline_uniform_block
Extension Type
  Device extension

Registered Extension Number
  139

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies
  VK_KHR_get_physical_device_properties2
  and
  VK_KHR_maintenance1

Deprecation state
  • *Promoted* to Vulkan 1.3

Contact
  • Daniel Rakos  

Other Extension Metadata

Last Modified Date
  2018-08-01

Interactions and External Dependencies
  • Promoted to Vulkan 1.3 Core

IP Status
  No known IP claims.

Contributors
  • Daniel Rakos, AMD
  • Jeff Bolz, NVIDIA
  • Slawomir Grajewski, Intel
  • Neil Henning, Codeplay

Description

This extension introduces the ability to back uniform blocks directly with descriptor sets by storing inline uniform data within descriptor pool storage. Compared to push constants this new construct allows uniform data to be reused across multiple disjoint sets of drawing or dispatching commands and *may* enable uniform data to be accessed with fewer indirections compared to uniforms backed by buffer memory.
New Structures

- Extending `VkDescriptorPoolCreateInfo`:
  - `VkDescriptorPoolInlineUniformBlockCreateInfoEXT`

- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDeviceInlineUniformBlockFeaturesEXT`

- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceInlineUniformBlockPropertiesEXT`

- Extending `VkWriteDescriptorSet`:
  - `VkWriteDescriptorSetInlineUniformBlockEXT`

New Enum Constants

- `VK_EXT_INLINE_UNIFORM_BLOCK_EXTENSION_NAME`
- `VK_EXT_INLINE_UNIFORM_BLOCK_SPEC_VERSION`

- Extending `VkDescriptorType`:
  - `VK_DESCRIPTOR_TYPE_INLINE_UNIFORM_BLOCK_EXT`

- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_DESCRIPTOR_POOL_INLINE_UNIFORM_BLOCK_CREATE_INFO_EXT`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INLINE_UNIFORM_BLOCK_FEATURES_EXT`
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_INLINE_UNIFORM_BLOCK_PROPERTIES_EXT`
  - `VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET_INLINE_UNIFORM_BLOCK_EXT`

Promotion to Vulkan 1.3

Functionality in this extension is included in core Vulkan 1.3, with the EXT suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

Vulkan 1.3 adds additional functionality related to this extension in the form of the `maxInlineUniformTotalSize` limit.

Issues

1) Do we need a new storage class for inline uniform blocks vs. uniform blocks?

**RESOLVED:** No. The *Uniform* storage class is used to allow the same syntax used for both uniform buffers and inline uniform blocks.

2) Is the descriptor array index and array size expressed in terms of bytes or dwords for inline uniform block descriptors?

**RESOLVED:** In bytes, but both **must** be a multiple of 4, similar to how push constant ranges are specified. The `descriptorCount` of `VkDescriptorSetLayoutBinding` thus provides the total number of
bytes a particular binding with an inline uniform block descriptor type can hold, while the `srcArrayElement`, `dstArrayElement`, and `descriptorCount` members of `VkWriteDescriptorSet`, `VkCopyDescriptorSet`, and `VkDescriptorUpdateTemplateEntry` (where applicable) specify the byte offset and number of bytes to write/copy to the binding’s backing store. Additionally, the `stride` member of `VkDescriptorUpdateTemplateEntry` is ignored for inline uniform blocks and a default value of one is used, meaning that the data to update inline uniform block bindings with must be contiguous in memory.

3) What layout rules apply for uniform blocks corresponding to inline constants?

**RESOLVED:** They use the same layout rules as uniform buffers.

4) Do we need to add non-uniform indexing features/properties as introduced by `VK_EXT_descriptor_indexing` for inline uniform blocks?

**RESOLVED:** No, because inline uniform blocks are not allowed to be “arrayed”. A single binding with an inline uniform block descriptor type corresponds to a single uniform block instance and the array indices inside that binding refer to individual offsets within the uniform block (see issue #2). However, this extension does introduce new features/properties about the level of support for update-after-bind inline uniform blocks.

5) Is the `descriptorBindingVariableDescriptorCount` feature introduced by `VK_EXT_descriptor_indexing` supported for inline uniform blocks?

**RESOLVED:** Yes, as long as other inline uniform block specific limits are respected.

6) Do the robustness guarantees of `robustBufferAccess` apply to inline uniform block accesses?

**RESOLVED:** No, similarly to push constants, as they are not backed by buffer memory like uniform buffers.

**Version History**

- Revision 1, 2018-08-01 (Daniel Rakos)
  - Internal revisions

**VK_EXT_pipeline_creation_cache_control**

**Name String**

`VK_EXT_pipeline_creation_cache_control`

**Extension Type**

Device extension

**Registered Extension Number**

298

**Revision**

3
Ratification Status
Not ratified

Extension and Version Dependencies
VK_KHR_get_physical_device_properties2

Deprecation state
• Promoted to Vulkan 1.3

Contact
• Gregory Grebe grgrebe_amd

Other Extension Metadata

Last Modified Date
2020-03-23

Interactions and External Dependencies
• Promoted to Vulkan 1.3 Core

IP Status
No known IP claims.

Contributors
• Gregory Grebe, AMD
• Tobias Hector, AMD
• Matthaeus Chajdas, AMD
• Mitch Singer, AMD
• Spencer Fricke, Samsung Electronics
• Stuart Smith, Imagination Technologies
• Jeff Bolz, NVIDIA Corporation
• Daniel Koch, NVIDIA Corporation
• Dan Ginsburg, Valve Corporation
• Jeff Leger, QUALCOMM
• Michal Pietrasiuk, Intel
• Jan-Harald Fredriksen, Arm Limited

Description
This extension adds flags to Vk*PipelineCreateInfo and VkPipelineCacheCreateInfo structures with the aim of improving the predictability of pipeline creation cost. The goal is to provide information about potentially expensive hazards within the client driver during pipeline creation to the application before carrying them out rather than after.
**Background**

Pipeline creation is a costly operation, and the explicit nature of the Vulkan design means that cost is not hidden from the developer. Applications are also expected to schedule, prioritize, and load balance all calls for pipeline creation. It is strongly advised that applications create pipelines sufficiently ahead of their usage. Failure to do so will result in an unresponsive application, intermittent stuttering, or other poor user experiences. Proper usage of pipeline caches and/or derivative pipelines help mitigate this but is not assured to eliminate disruption in all cases. In the event that an ahead-of-time creation is not possible, considerations should be taken to ensure that the current execution context is suitable for the workload of pipeline creation including possible shader compilation.

Applications making API calls to create a pipeline must be prepared for any of the following to occur:

- OS/kernel calls to be made by the ICD
- Internal memory allocation not tracked by the *pAllocator* passed to `vkCreate*Pipelines`
- Internal thread synchronization or yielding of the current thread's core
- Extremely long (multi-millisecond+), blocking, compilation times
- Arbitrary call stacks depths and stack memory usage

The job or task based game engines that are being developed to take advantage of explicit graphics APIs like Vulkan may behave exceptionally poorly if any of the above scenarios occur. However, most game engines are already built to “stream” in assets dynamically as the user plays the game. By adding control by way of `VkPipelineCreateFlags`, we can require an ICD to report back a failure in critical execution paths rather than forcing an unexpected wait.

Applications can prevent unexpected compilation by setting `VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT_EXT` on `Vk*PipelineCreateInfo::flags`. When set, an ICD must not attempt pipeline or shader compilation to create the pipeline object. In such a case, if the implementation fails to create a pipeline without compilation, the implementation **must** return the result `VK_PIPELINE_COMPILE_REQUIRED_EXT` and return `VK_NULL_HANDLE` for the pipeline.

By default `vkCreate*Pipelines` calls must attempt to create all pipelines before returning. Setting `VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT_EXT` on `Vk*PipelineCreateInfo::flags` can be used as an escape hatch for batched pipeline creates.

Hidden locks also add to the unpredictability of the cost of pipeline creation. The most common case of locks inside the `vkCreate*Pipelines` is internal synchronization of the `VkPipelineCache` object. `VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT_EXT` can be set when calling `vkCreatePipelineCache` to state the cache is **externally synchronized**.

The hope is that armed with this information application and engine developers can leverage existing asset streaming systems to recover from "just-in-time" pipeline creation stalls.
New Structures

- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDevicePipelineCreationCacheControlFeaturesEXT`

New Enums

- `VkPipelineCacheCreateFlagBits`

New Enum Constants

- `VK_EXT_PIPELINE_CREATION_CACHE_CONTROL_EXTENSION_NAME`
- `VK_EXT_PIPELINE_CREATION_CACHE_CONTROL_SPEC_VERSION`

- Extending `VkPipelineCacheCreateFlagBits`:
  - `VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT_EXT`

- Extending `VkPipelineCreateFlagBits`:
  - `VK_PIPELINE_CREATE_EARLY_RETURN_ON_FAILURE_BIT_EXT`
  - `VK_PIPELINE_CREATE_FAIL_ON_PIPELINE_COMPILE_REQUIRED_BIT_EXT`

- Extending `VkResult`:
  - `VK_ERROR_PIPELINE_COMPILE_REQUIRED_EXT`
  - `VK_PIPELINE_COMPILE_REQUIRED_EXT`

- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PIPELINE_CREATION_CACHE_CONTROL_FEATURES_EXT`

Promotion to Vulkan 1.3

Functionality in this extension is included in core Vulkan 1.3, with the EXT suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

Version History

- Revision 1, 2019-11-01 (Gregory Grebe)
  - Initial revision
- Revision 2, 2020-02-24 (Gregory Grebe)
  - Initial public revision
- Revision 3, 2020-03-23 (Tobias Hector)
  - Changed `VK_PIPELINE_COMPILE_REQUIRED_EXT` to a success code, adding an alias for the original `VK_ERROR_PIPELINE_COMPILE_REQUIRED_EXT`. Also updated the xml to include these codes as return values.
VK_EXT_pipeline_creation_feedback

Name String
VK_EXT_pipeline_creation_feedback

Extension Type
Device extension

Registered Extension Number
193

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies

Deprecation state
- Promoted to Vulkan 1.3

Special Use
- Developer tools

Contact
- Jean-Francois Roy @jfroy

Other Extension Metadata

Last Modified Date
2019-03-12

Interactions and External Dependencies
- Promoted to Vulkan 1.3 Core

IP Status
No known IP claims.

Contributors
- Jean-Francois Roy, Google
- Hai Nguyen, Google
- Andrew Ellem, Google
- Bob Fraser, Google
- Sujeevan Rajayogam, Google
- Jan-Harald Fredriksen, ARM
- Jeff Leger, Qualcomm Technologies, Inc.
Description

This extension adds a mechanism to provide feedback to an application about pipeline creation, with the specific goal of allowing a feedback loop between build systems and in-the-field application executions to ensure effective pipeline caches are shipped to customers.

New Structures

- `VkPipelineCreationFeedbackEXT`
- Extending `VkGraphicsPipelineCreateInfo`, `VkComputePipelineCreateInfo`, `VkRayTracingPipelineCreateInfoNV`, `VkRayTracingPipelineCreateInfoKHR`, `VkExecutionGraphPipelineCreateInfoAMDX`:
  - `VkPipelineCreationFeedbackCreateInfoEXT`

New Enums

- `VkPipelineCreationFeedbackFlagBitsEXT`

New Bitmasks

- `VkPipelineCreationFeedbackFlagsEXT`

New Enum Constants

- `VK_EXT_PIPELINE_CREATION_FEEDBACK_EXTENSION_NAME`
- `VK_EXT_PIPELINE_CREATION_FEEDBACK_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PIPELINE_CREATION_FEEDBACK_CREATE_INFO_EXT`

Promotion to Vulkan 1.3

Functionality in this extension is included in core Vulkan 1.3, with the EXT suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

Version History

- Revision 1, 2019-03-12 (Jean-Francois Roy)
  - Initial revision
VK_EXT_private_data

Name String
- VK_EXT_private_data

Extension Type
- Device extension

Registered Extension Number
- 296

Revision
- 1

Ratification Status
- Not ratified

Extension and Version Dependencies
- VK_KHR_get_physical_device_properties2

Deprecation state
- Promoted to Vulkan 1.3

Contact
- Matthew Rusch mattruschnv

Other Extension Metadata

Last Modified Date
- 2020-03-25

Interactions and External Dependencies
- Promoted to Vulkan 1.3 Core

IP Status
- No known IP claims.

Contributors
- Matthew Rusch, NVIDIA
- Nuno Subtil, NVIDIA
- Piers Daniell, NVIDIA
- Jeff Bolz, NVIDIA

Description
This extension is a device extension which enables attaching arbitrary payloads to Vulkan objects. It introduces the idea of private data slots as a means of storing a 64-bit unsigned integer of application defined data. Private data slots can be created or destroyed any time an associated
device is available. Private data slots can be reserved at device creation time, and limiting use to the amount reserved will allow the extension to exhibit better performance characteristics.

**New Object Types**

- VkPrivateDataSlotEXT

**New Commands**

- vkCreatePrivateDataSlotEXT
- vkDestroyPrivateDataSlotEXT
- vkGetPrivateDataEXT
- vkSetPrivateDataEXT

**New Structures**

- VkPrivateDataSlotCreateInfoEXT
- Extending VkDeviceCreateInfo:
  - VkDevicePrivateDataCreateInfoEXT
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDevicePrivateDataFeaturesEXT

**New Bitmasks**

- VkPrivateDataSlotCreateFlagsEXT

**New Enum Constants**

- VK_EXT_PRIVATE_DATA_EXTENSION_NAME
- VK_EXT_PRIVATE_DATA_SPEC_VERSION
- Extending VkObjectType:
  - VK_OBJECT_TYPE_PRIVATE_DATA_SLOT_EXT
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_DEVICE_PRIVATE_DATA_CREATE_INFO_EXT
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_PRIVATE_DATA_FEATURES_EXT
  - VK_STRUCTURE_TYPE_PRIVATE_DATA_SLOT_CREATE_INFO_EXT

**Promotion to Vulkan 1.3**

Functionality in this extension is included in core Vulkan 1.3, with the EXT suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.
Examples

• In progress

Issues

(1) If I have to create a VkPrivateDataSlot to store and retrieve data on an object, how does this extension help me? Will I not need to store the VkPrivateDataSlot mapping with each object, and if I am doing that, I might as well just store the original data!

**RESOLVED:** The VkPrivateDataSlot can be thought of as an opaque index into storage that is reserved in each object. That is, you can use the same VkPrivateDataSlot with each object for a specific piece of information. For example, if a layer wishes to track per-object information, the layer only needs to allocate one VkPrivateDataSlot per device and it can use that private data slot for all of the device’s child objects. This allows multiple layers to store private data without conflicting with each other's and/or the application’s private data.

(2) What if I need to store more than 64-bits of information per object?

**RESOLVED:** The data that you store per object could be a pointer to another object or structure of your own allocation.

Version History

• Revision 1, 2020-01-15 (Matthew Rusch)
  ◦ Initial draft

**VK_EXT_sampler_filter_minmax**

Name String

VK_EXT_sampler_filter_minmax

Extension Type

Device extension

Registered Extension Number

131

Revision

2

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_get_physical_device_properties2

Deprecation state

• *Promoted to* Vulkan 1.2
Description

In unextended Vulkan, minification and magnification filters such as LINEAR allow sampled image lookups to return a filtered texel value produced by computing a weighted average of a collection of texels in the neighborhood of the texture coordinate provided.

This extension provides a new sampler parameter which allows applications to produce a filtered texel value by computing a component-wise minimum (MIN) or maximum (MAX) of the texels that would normally be averaged. The reduction mode is orthogonal to the minification and magnification filter parameters. The filter parameters are used to identify the set of texels used to produce a final filtered value; the reduction mode identifies how these texels are combined.

Promotion to Vulkan 1.2

All functionality in this extension is included in core Vulkan 1.2, with the EXT suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Structures

- Extending VkPhysicalDeviceProperties2:
  - VkPhysicalDeviceSamplerFilterMinmaxPropertiesEXT
- Extending VkSamplerCreateInfo:
  - VkSamplerReductionModeCreateInfoEXT

New Enums

- VkSamplerReductionModeEXT
New Enum Constants

- `VK_EXT_SAMPLER_FILTER_MINMAX_EXTENSION_NAME`
- `VK_EXT_SAMPLER_FILTER_MINMAX_SPEC_VERSION`

Extending `VkFormatFeatureFlagBits`:
- `VK_FORMAT_FEATURE_SAMPLED_IMAGE_FILTER_MINMAX_BIT_EXT`

Extending `VkSamplerReductionMode`:
- `VK_SAMPLER_REDUCTION_MODE_MAX_EXT`
- `VK_SAMPLER_REDUCTION_MODE_MIN_EXT`
- `VK_SAMPLER_REDUCTION_MODE_WEIGHTED_AVERAGE_EXT`

Extending `VkStructureType`:
- `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SAMPLER_FILTER_MINMAX_PROPERTIES_EXT`
- `VK_STRUCTURE_TYPE_SAMPLER_REDUCTION_MODE_CREATE_INFO_EXT`

Version History

- Revision 2, 2017-05-19 (Piers Daniell)
  - Renamed to EXT
- Revision 1, 2017-03-25 (Jeff Bolz)
  - Internal revisions

**VK_EXT_scalar_block_layout**

Name String

`VK_EXT_scalar_block_layout`

Extension Type

Device extension

Registered Extension Number

222

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

`VK_KHR_get_physical_device_properties2`

Deprecation state

• Promoted to Vulkan 1.2
Contact
- Tobias Hector @tobski

Other Extension Metadata

Last Modified Date
2018-11-14

Interactions and External Dependencies
- Promoted to Vulkan 1.2 Core

Contributors
- Jeff Bolz
- Jan-Harald Fredriksen
- Graeme Leese
- Faith Ekstrand
- John Kessenich

Description
This extension enables C-like structure layout for SPIR-V blocks. It modifies the alignment rules for uniform buffers, storage buffers and push constants, allowing non-scalar types to be aligned solely based on the size of their components, without additional requirements.

Promotion to Vulkan 1.2

Functionality in this extension is included in core Vulkan 1.2, with the EXT suffix omitted. However, if Vulkan 1.2 is supported and this extension is not, the scalarBlockLayout capability is optional. The original type, enum and command names are still available as aliases of the core functionality.

New Structures
- Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
  - VkPhysicalDeviceScalarBlockLayoutFeaturesEXT

New Enum Constants
- VK_EXT_SCALAR_BLOCK_LAYOUT_EXTENSION_NAME
- VK_EXT_SCALAR_BLOCK_LAYOUT_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SCALAR_BLOCK_LAYOUT_FEATURES_EXT

Version History
- Revision 1, 2018-11-14 (Tobias Hector)
VK_EXT_separate_stencil_usage

Name String
VK_EXT_separate_stencil_usage

Extension Type
Device extension

Registered Extension Number
247

Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies
Deprecation state
• Promoted to Vulkan 1.2

Contact
• Daniel Rakos drakos-amd

Other Extension Metadata

Last Modified Date
2018-11-08

Interactions and External Dependencies
• Promoted to Vulkan 1.2 Core

IP Status
No known IP claims.

Contributors
• Daniel Rakos, AMD
• Jordan Logan, AMD

Description
This extension allows specifying separate usage flags for the stencil aspect of images with a depth-stencil format at image creation time.
Promotion to Vulkan 1.2

All functionality in this extension is included in core Vulkan 1.2, with the EXT suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

New Structures

- Extending `VkImageCreateInfo`, `VkPhysicalDeviceImageFormatInfo2`:
  - `VkImageStencilUsageCreateInfoEXT`

New Enum Constants

- `VK_EXT_SEPARATE_STENCIL_USAGE_EXTENSION_NAME`
- `VK_EXT_SEPARATE_STENCIL_USAGE_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_IMAGE_STENCIL_USAGE_CREATE_INFO_EXT`

Version History

- Revision 1, 2018-11-08 (Daniel Rakos)
  - Internal revisions.

VK_EXT_shader_demote_to_helper_invocation

Name String

`VK_EXT_shader_demote_to_helper_invocation`

Extension Type

- Device extension

Registered Extension Number

277

Revision

1

Ratification Status

- Not ratified

Extension and Version Dependencies

- `VK_KHR_get_physical_device_properties2`
- Version 1.1

Deprecation state

- Promoted to Vulkan 1.3
Contact
  • Jeff Bolz [jeffbolznv](https://www."

Other Extension Metadata

Last Modified Date
  2019-06-01

Interactions and External Dependencies
  • Promoted to Vulkan 1.3 Core

IP Status
  No known IP claims.

Interactions and External Dependencies
  • This extension requires: `SPV_EXT_demote_to_helper_invocation`
  • This extension provides API support for: `GL_EXT_demote_to_helper_invocation`

Contributors
  • Jeff Bolz, NVIDIA

Description
This extension adds Vulkan support for the `SPV_EXT_demote_to_helper_invocation` SPIR-V extension. That SPIR-V extension provides a new instruction `OpDemoteToHelperInvocationEXT` allowing shaders to “demote” a fragment shader invocation to behave like a helper invocation for its duration. The demoted invocation will have no further side effects and will not output to the framebuffer, but remains active and can participate in computing derivatives and in group operations. This is a better match for the “discard” instruction in HLSL.

New Structures
  • Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
    ◦ `VkPhysicalDeviceShaderDemoteToHelperInvocationFeaturesEXT`

New Enum Constants
  • `VK_EXT_SHADER_DEMOTE_TO_HELPER_INVOCATION_EXTENSION_NAME`
  • `VK_EXT_SHADER_DEMOTE_TO_HELPER_INVOCATION_SPEC_VERSION`
  • Extending `VkStructureType`:
    ◦ `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_SHADER_DEMOTE_TO_HELPER_INVOCATION_FEATURES_EXT`

New SPIR-V Capability
  • `DemoteToHelperInvocationEXT`
Promotion to Vulkan 1.3

Functionality in this extension is included in core Vulkan 1.3, with the EXT suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

Version History

- Revision 1, 2019-06-01 (Jeff Bolz)
  - Initial draft

VK_EXT_shader_subgroup_ballot

Name String

VK_EXT_shader_subgroup_ballot

Extension Type

Device extension

Registered Extension Number

65

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

Deprecation state

- Deprecated by Vulkan 1.2

Contact

- Daniel Koch @dgkoch

Other Extension Metadata

Last Modified Date

2016-11-28

IP Status

No known IP claims.

Interactions and External Dependencies

- This extension requires SPV_KHR_shader_ballot
- This extension provides API support for GL_ARB_shader_ballot

Contributors

- Jeff Bolz, NVIDIA
Description

This extension adds support for the following SPIR-V extension in Vulkan:

- **SPV_KHR_shader_ballot**

This extension provides the ability for a group of invocations, which execute in parallel, to do limited forms of cross-invocation communication via a group broadcast of an invocation value, or broadcast of a bitarray representing a predicate value from each invocation in the group.

This extension provides access to a number of additional built-in shader variables in Vulkan:

- **SubgroupEqMaskKHR**, containing the subgroup mask of the current subgroup invocation,
- **SubgroupGeMaskKHR**, containing the subgroup mask of the invocations greater than or equal to the current invocation,
- **SubgroupGtMaskKHR**, containing the subgroup mask of the invocations greater than the current invocation,
- **SubgroupLeMaskKHR**, containing the subgroup mask of the invocations less than or equal to the current invocation,
- **SubgroupLtMaskKHR**, containing the subgroup mask of the invocations less than the current invocation,

- **SubgroupLocalInvocationId**, containing the index of an invocation within a subgroup, and
- **SubgroupSize**, containing the maximum number of invocations in a subgroup.

Additionally, this extension provides access to the new SPIR-V instructions:

- **OpSubgroupBallotKHR**,  
- **OpSubgroupFirstInvocationKHR**, and  
- **OpSubgroupReadInvocationKHR**,  

When using GLSL source-based shader languages, the following variables and shader functions from GL_ARB_shader_ballot can map to these SPIR-V built-in decorations and instructions:

- `in uint64_t gl_SubGroupEqMaskARB; → SubgroupEqMaskKHR`,  
- `in uint64_t gl_SubGroupGeMaskARB; → SubgroupGeMaskKHR`,  
- `in uint64_t gl_SubGroupGtMaskARB; → SubgroupGtMaskKHR`,  
- `in uint64_t gl_SubGroupLeMaskARB; → SubgroupLeMaskKHR`,  
- `in uint64_t gl_SubGroupLtMaskARB; → SubgroupLtMaskKHR`,  
- `in uint gl_SubGroupInvocationARB; → SubgroupLocalInvocationId`,  
- `uniform uint gl_SubGroupSizeARB; → SubgroupSize`,  
- `ballotARB() → OpSubgroupBallotKHR`,
• `readFirstInvocationARB()` → `OpSubgroupFirstInvocationKHR`, and
• `readInvocationARB()` → `OpSubgroupReadInvocationKHR`.

**Deprecated by Vulkan 1.2**

Most of the functionality in this extension is superseded by the core Vulkan 1.1 subgroup operations. However, Vulkan 1.1 required the `OpGroupNonUniformBroadcast “Id”` to be constant. This restriction was removed in Vulkan 1.2 with the addition of the `subgroupBroadcastDynamicId` feature.

**New Enum Constants**

- `VK_EXT_SHADER_SUBGROUP_BALLOT_EXTENSION_NAME`
- `VK_EXT_SHADER_SUBGROUP_BALLOT_SPEC_VERSION`

**New Built-In Variables**

- `SubgroupEqMaskKHR`
- `SubgroupGeMaskKHR`
- `SubgroupGtMaskKHR`
- `SubgroupLeMaskKHR`
- `SubgroupLtMaskKHR`
- `SubgroupLocalInvocationId`
- `SubgroupSize`

**New SPIR-V Capabilities**

- `SubgroupBallotKHR`

**Version History**

- Revision 1, 2016-11-28 (Daniel Koch)
  - Initial draft

**VK_EXT_shader_subgroup_vote**

**Name String**

- `VK_EXT_shader_subgroup_vote`

**Extension Type**

- Device extension

**Registered Extension Number**

- 66
Revision
1

Ratification Status
Not ratified

Extension and Version Dependencies

Deprecation state
• Deprecated by Vulkan 1.1

Contact
• Daniel Koch 🌟dgkoch

Other Extension Metadata

Last Modified Date
2016-11-28

IP Status
No known IP claims.

Interactions and External Dependencies
• This extension requires SPV_KHR_subgroup_vote
• This extension provides API support for GL_ARB_shader_group_vote

Contributors
• Neil Henning, Codeplay
• Daniel Koch, NVIDIA Corporation

Description

This extension adds support for the following SPIR-V extension in Vulkan:

• SPV_KHR_subgroup_vote

This extension provides new SPIR-V instructions:

• OpSubgroupAllKHR,
• OpSubgroupAnyKHR, and
• OpSubgroupAllEqualKHR.

to compute the composite of a set of boolean conditions across a group of shader invocations that are running concurrently (a subgroup). These composite results may be used to execute shaders more efficiently on a VkPhysicalDevice.

When using GLSL source-based shader languages, the following shader functions from GL_ARB_shader_group_vote can map to these SPIR-V instructions:
• anyInvocationARB() → OpSubgroupAnyKHR,
• allInvocationARB() → OpSubgroupAllKHR, and
• allInvocationEqualARB() → OpSubgroupAllEqualKHR.

The subgroup across which the boolean conditions are evaluated is implementation-dependent, and this extension provides no guarantee over how individual shader invocations are assigned to subgroups. In particular, a subgroup has no necessary relationship with the compute shader local workgroup — any pair of shader invocations in a compute local workgroup may execute in different subgroups as used by these instructions.

Compute shaders operate on an explicitly specified group of threads (a local workgroup), but many implementations will also group non-compute shader invocations and execute them concurrently. When executing code like

```c
if (condition) {
    result = do_fast_path();
} else {
    result = do_general_path();
}
```

where condition diverges between invocations, an implementation might first execute do_fast_path() for the invocations where condition is true and leave the other invocations dormant. Once do_fast_path() returns, it might call do_general_path() for invocations where condition is false and leave the other invocations dormant. In this case, the shader executes both the fast and the general path and might be better off just using the general path for all invocations.

This extension provides the ability to avoid divergent execution by evaluating a condition across an entire subgroup using code like:

```c
if (allInvocationARB(condition)) {
    result = do_fast_path();
} else {
    result = do_general_path();
}
```

The built-in function allInvocationARB() will return the same value for all invocations in the group, so the group will either execute do_fast_path() or do_general_path(), but never both. For example, shader code might want to evaluate a complex function iteratively by starting with an approximation of the result and then refining the approximation. Some input values may require a small number of iterations to generate an accurate result (do_fast_path) while others require a larger number (do_general_path). In another example, shader code might want to evaluate a complex function (do_general_path) that can be greatly simplified when assuming a specific value for one of its inputs (do_fast_path).
Deprecated by Vulkan 1.1

All functionality in this extension is superseded by the core Vulkan 1.1 subgroup operations.

New Enum Constants

- VK_EXT_SHADER_SUBGROUP_VOTE_EXTENSION_NAME
- VK_EXT_SHADER_SUBGROUP_VOTE_SPEC_VERSION

New SPIR-V Capabilities

- SubgroupVoteKHR

Version History

- Revision 1, 2016-11-28 (Daniel Koch)
  - Initial draft

VK_EXT_shader_viewport_index_layer

Name String

VK_EXT_shader_viewport_index_layer

Extension Type

Device extension

Registered Extension Number

163

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

Deprecation state

- Promoted to Vulkan 1.2

Contact

- Daniel Koch @dgkoch

Other Extension Metadata

Last Modified Date

2017-08-08
Interactions and External Dependencies

- Promoted to Vulkan 1.2 Core
- This extension requires **SPV_EXT_shader_viewport_index_layer**
- This extension provides API support for **GL_ARB_shader_viewport_layer_array**, **GL_AMD_vertex_shader_layer**, **GL_AMD_vertex_shader_viewport_index**, and **GL_NV_viewport_array2**
- This extension requires the **multiViewport** feature.
- This extension interacts with the **tessellationShader** feature.

Contributors

- Piers Daniell, NVIDIA
- Jeff Bolz, NVIDIA
- Jan-Harald Fredriksen, ARM
- Daniel Rakos, AMD
- Slawomir Grajewski, Intel

Description

This extension adds support for the **ShaderViewportIndexLayerEXT** capability from the **SPV_EXT_shader_viewport_index_layer** extension in Vulkan.

This extension allows variables decorated with the **Layer** and **ViewportIndex** built-ins to be exported from vertex or tessellation shaders, using the **ShaderViewportIndexLayerEXT** capability.

When using GLSL source-based shading languages, the **glViewportIndex** and **glLayer** built-in variables map to the SPIR-V **ViewportIndex** and **Layer** built-in decorations, respectively. Behaviour of these variables is extended as described in the **GL_ARB_shader_viewport_layer_array** (or the precursor **GL_AMD_vertex_shader_layer**, **GL_AMD_vertex_shader_viewport_index**, and **GL_NV_viewport_array2** extensions).

**Note**

The **ShaderViewportIndexLayerEXT** capability is equivalent to the **ShaderViewportIndexLayerNV** capability added by **VK_NV_viewport_array2**.

Promotion to Vulkan 1.2

All functionality in this extension is included in core Vulkan 1.2.

The single **ShaderViewportIndexLayerEXT** capability from the **SPV_EXT_shader_viewport_index_layer** extension is replaced by the **ShaderViewportIndex** and **ShaderLayer** capabilities from SPIR-V 1.5 which are enabled by the **shaderOutputViewportIndex** and **shaderOutputLayer** features, respectively. Additionally, if Vulkan 1.2 is supported but this extension is not, these capabilities are optional.

Enabling both features is equivalent to enabling the **VK_EXT_shader_viewport_index_layer** extension.
New Enum Constants

• VK_EXT_SHADER_VIEWPORT_INDEX_LAYER_EXTENSION_NAME
• VK_EXT_SHADER_VIEWPORT_INDEX_LAYER_SPEC_VERSION

New or Modified Built-In Variables

• (modified) Layer
• (modified) ViewportIndex

New SPIR-V Capabilities

• ShaderViewportIndexLayerEXT

Version History

• Revision 1, 2017-08-08 (Daniel Koch)
  ◦ Internal drafts

VK_EXT_subgroup_size_control

Name String

VK_EXT_subgroup_size_control

Extension Type

Device extension

Registered Extension Number

226

Revision

2

Ratification Status

Not ratified

Extension and Version Dependencies

Version 1.1

Deprecation state

• Promoted to Vulkan 1.3

Contact

• Neil Henning sheredom

Other Extension Metadata
Interactions and External Dependencies

• Promoted to Vulkan 1.3 Core

Contributors

• Jeff Bolz, NVIDIA
• Faith Ekstrand, Intel
• Sławek Grajewski, Intel
• Jesse Hall, Google
• Neil Henning, AMD
• Daniel Koch, NVIDIA
• Jeff Leger, Qualcomm
• Graeme Leese, Broadcom
• Allan MacKinnon, Google
• Mariusz Merecki, Intel
• Graham Wihlidal, Electronic Arts

Description

This extension enables an implementation to control the subgroup size by allowing a varying subgroup size and also specifying a required subgroup size.

It extends the subgroup support in Vulkan 1.1 to allow an implementation to expose a varying subgroup size. Previously Vulkan exposed a single subgroup size per physical device, with the expectation that implementations will behave as if all subgroups have the same size. Some implementations may dispatch shaders with a varying subgroup size for different subgroups. As a result they could implicitly split a large subgroup into smaller subgroups or represent a small subgroup as a larger subgroup, some of whose invocations were inactive on launch.

To aid developers in understanding the performance characteristics of their programs, this extension exposes a minimum and maximum subgroup size that a physical device supports and a pipeline create flag to enable that pipeline to vary its subgroup size. If enabled, any SubgroupSize decorated variables in the SPIR-V shader modules provided to pipeline creation may vary between the minimum and maximum subgroup sizes.

An implementation is also optionally allowed to support specifying a required subgroup size for a given pipeline stage. Implementations advertise which stages support a required subgroup size, and any pipeline of a supported stage can be passed a VkPipelineShaderStageRequiredSubgroupSizeCreateInfoEXT structure to set the subgroup size for that shader stage of the pipeline. For compute shaders, this requires the developer to query the maxComputeWorkgroupSubgroups and ensure that:

\[ s = \text{WorkGroupSize}_x \times \text{WorkGroupSize}_y \times \text{WorkGroupSize}_z \leq \text{SubgroupSize} \times \text{maxComputeWorkgroupSubgroups} \]
Developers can also specify a new pipeline shader stage create flag that requires the implementation to have fully populated subgroups within local workgroups. This requires the workgroup size in the X dimension to be a multiple of the subgroup size.

**New Structures**

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceSubgroupSizeControlFeaturesEXT`
- Extending `VkPhysicalDeviceProperties2`:
  - `VkPhysicalDeviceSubgroupSizeControlPropertiesEXT`
- Extending `VkPipelineShaderStageCreateInfo`, `VkShaderCreateInfoEXT`:
  - `VkPipelineShaderStageRequiredSubgroupSizeCreateInfoEXT`

**New Enum Constants**

- `VK_EXT_SUBGROUP_SIZE_CONTROL_EXTENSION_NAME`
- `VK_EXT_SUBGROUP_SIZE_CONTROL_SPEC_VERSION`
- Extending `VkPipelineShaderStageCreateFlagBits`:
  - `VK_PIPELINE_SHADER_STAGE_CREATE_ALLOW_VARYING_SUBGROUP_SIZE_BIT_EXT`
  - `VK_PIPELINE_SHADER_STAGE_CREATE_REQUIRE_FULL_SUBGROUPS_BIT_EXT`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_PHYSICALDEVICE_SUBGROUPSIZECONTROLFEATURES_EXT`
  - `VK_STRUCTURE_TYPE_PHYSICALDEVICE_SUBGROUPSIZECONTROLPROPERTIES_EXT`
  - `VK_STRUCTURE_TYPE_PIPELINE_SHADERSTAGEREQUIREDSUBGROUPSIZECREATEINFO_EXT`

**Promotion to Vulkan 1.3**

Functionality in this extension is included in core Vulkan 1.3, with the EXT suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

**Version History**

- Revision 1, 2019-03-05 (Neil Henning)
  - Initial draft
- Revision 2, 2019-07-26 (Faith Ekstrand)
  - Add the missing `VkPhysicalDeviceSubgroupSizeControlFeaturesEXT` for querying subgroup size control features.

**VK_EXT_texel_buffer_alignment**

**Name String**

```
VK_EXT_texel_buffer_alignment
```
Extension Type
   Device extension

Registered Extension Number
   282

Revision
   1

Ratification Status
   Not ratified

Extension and Version Dependencies
   Vk_KHR_get_physical_device_properties2
   or
   Version 1.1

Deprecation state
   • Promoted to Vulkan 1.3

Contact
   • Jeff Bolz jeffbolznv

Other Extension Metadata

Last Modified Date
   2019-06-06

Interactions and External Dependencies
   • Promoted to Vulkan 1.3 Core

IP Status
   No known IP claims.

Contributors
   • Jeff Bolz, NVIDIA

Description

This extension adds more expressive alignment requirements for uniform and storage texel buffers. Some implementations have single texel alignment requirements that cannot be expressed via VkPhysicalDeviceLimits::minTexelBufferOffsetAlignment.

New Structures

   • Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
     ○ VkPhysicalDeviceTexelBufferAlignmentFeaturesEXT
   • Extending VkPhysicalDeviceProperties2:
New Enum Constants

- VK_EXT_TEXEL_BUFFER_ALIGNMENT_EXTENSION_NAME
- VK_EXT_TEXEL_BUFFER_ALIGNMENT_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXEL_BUFFER_ALIGNMENT_FEATURES_EXT
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXEL_BUFFER_ALIGNMENT_PROPERTIES_EXT

Promotion to Vulkan 1.3

Functionality in this extension is included in core Vulkan 1.3, with the EXT suffix omitted. However, only the properties structure is promoted. The feature structure is not promoted and texelBufferAlignment is enabled if using a Vulkan 1.3 instance. The original type name is still available as an alias of the core functionality.

Version History

- Revision 1, 2019-06-06 (Jeff Bolz)
  - Initial draft

VK_EXT_texture_compression_astc_hdr

Name String

VK_EXT_texture_compression_astc_hdr

Extension Type

Device extension

Registered Extension Number

67

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

- VK_KHR_get_physical_device_properties2
- or
- Version 1.1

Deprecation state

- Promoted to Vulkan 1.3
Contact
  • Jan-Harald Fredriksen janharaldfredriksen-arm

Other Extension Metadata

Last Modified Date
  2019-05-28

Interactions and External Dependencies
  • Promoted to Vulkan 1.3 Core

IP Status
  No known issues.

Contributors
  • Jan-Harald Fredriksen, Arm

Description

This extension adds support for textures compressed using the Adaptive Scalable Texture Compression (ASTC) High Dynamic Range (HDR) profile.

When this extension is enabled, the HDR profile is supported for all ASTC formats listed in ASTC Compressed Image Formats.

New Structures
  • Extending VkPhysicalDeviceFeatures2, VkDeviceCreateInfo:
    ◦ VkPhysicalDeviceTextureCompressionASTCHDRFeaturesEXT

New Enum Constants
  • VK_EXT_TEXTURE_COMPRESSION_ASTC_HDR_EXTENSION_NAME
  • VK_EXT_TEXTURE_COMPRESSION_ASTC_HDR_SPEC_VERSION
  • Extending VkFormat:
    ◦ VK_FORMAT_ASTC_10x10_SFLOAT_BLOCK_EXT
    ◦ VK_FORMAT_ASTC_10x5_SFLOAT_BLOCK_EXT
    ◦ VK_FORMAT_ASTC_10x6_SFLOAT_BLOCK_EXT
    ◦ VK_FORMAT_ASTC_10x8_SFLOAT_BLOCK_EXT
    ◦ VK_FORMAT_ASTC_12x10_SFLOAT_BLOCK_EXT
    ◦ VK_FORMAT_ASTC_12x12_SFLOAT_BLOCK_EXT
    ◦ VK_FORMAT_ASTC_4x4_SFLOAT_BLOCK_EXT
    ◦ VK_FORMAT_ASTC_5x4_SFLOAT_BLOCK_EXT
    ◦ VK_FORMAT_ASTC_5x5_SFLOAT_BLOCK_EXT
• VK_FORMAT_ASTC_6x5_SFLOAT_BLOCK_EXT
• VK_FORMAT_ASTC_6x6_SFLOAT_BLOCK_EXT
• VK_FORMAT_ASTC_8x5_SFLOAT_BLOCK_EXT
• VK_FORMAT_ASTC_8x6_SFLOAT_BLOCK_EXT
• VK_FORMAT_ASTC_8x8_SFLOAT_BLOCK_EXT

• Extending VkStructureType:
  • VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TEXTURE_COMPRESSION_ASTC_HDR_FEATURES_EXT

Promotion to Vulkan 1.3

This extension has been partially promoted. Functionality in this extension is included in core Vulkan 1.3, with the EXT suffix omitted. However, the feature is made optional in Vulkan 1.3. The original type, enum and command names are still available as aliases of the core functionality.

Issues

1) Should we add a feature or limit for this functionality?

Yes. It is consistent with the ASTC LDR support to add a feature like textureCompressionASTC_HDR.

The feature is strictly speaking redundant as long as this is just an extension; it would be sufficient to just enable the extension. But adding the feature is more forward-looking if wanted to make this an optional core feature in the future.

2) Should we introduce new format enums for HDR?

Yes. Vulkan 1.0 describes the ASTC format enums as UNORM, e.g. VK_FORMAT_ASTC_4x4_UNORM_BLOCK, so it is confusing to make these contain HDR data. Note that the OpenGL (ES) extensions did not make this distinction because a single ASTC HDR texture may contain both unorm and float blocks. Implementations may not be able to distinguish between LDR and HDR ASTC textures internally and just treat them as the same format, i.e. if this extension is supported then sampling from a VK_FORMAT_ASTC_4x4_UNORM_BLOCK image format may return HDR results. Applications can get predictable results by using the appropriate image format.

Version History

• Revision 1, 2019-05-28 (Jan-Harald Fredriksen)
  • Initial version

VK_EXT_tooling_info

Name String
  VK_EXT_tooling_info

Extension Type
  Device extension
Description

When an error occurs during application development, a common question is "What tools are actually running right now?" This extension adds the ability to query that information directly from the Vulkan implementation.

Outdated versions of one tool might not play nicely with another, or perhaps a tool is not actually running when it should have been. Trying to figure that out can cause headaches as it is necessary to consult each known tool to figure out what is going on—in some cases the tool might not even be known.

Typically, the expectation is that developers will simply print out this information for visual inspection when an issue occurs, however a small amount of semantic information about what the tool is doing is provided to help identify it programmatically. For example, if the advertised limits or features of an implementation are unexpected, is there a tool active which modifies these limits? Or if an application is providing debug markers, but the implementation is not actually doing anything with that information, this can quickly point that out.
New Commands

- vkGetPhysicalDeviceToolPropertiesEXT

New Structures

- VkPhysicalDeviceToolPropertiesEXT

New Enums

- VkToolPurposeFlagBitsEXT

New Bitmasks

- VkToolPurposeFlagsEXT

New Enum Constants

- VK_EXT_TOOLING_INFO_EXTENSION_NAME
- VK_EXT_TOOLING_INFO_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_TOOL_PROPERTIES_EXT

If VK_EXT_debug_marker is supported:

- Extending VkToolPurposeFlagBits:
  - VK_TOOL_PURPOSE_DEBUG_MARKERS_BIT_EXT

If VK_EXT_debug_report is supported:

- Extending VkToolPurposeFlagBits:
  - VK_TOOL_PURPOSE_DEBUG_REPORTING_BIT_EXT

If VK_EXT_debug_utils is supported:

- Extending VkToolPurposeFlagBits:
  - VK_TOOL_PURPOSE_DEBUG_MARKERS_BIT_EXT
  - VK_TOOL_PURPOSE_DEBUG_REPORTING_BIT_EXT

Promotion to Vulkan 1.3

Functionality in this extension is included in core Vulkan 1.3, with the EXT suffix omitted. The original type, enum and command names are still available as aliases of the core functionality.

Examples
Printing Tool Information

```c
uint32_t num_tools;
VkPhysicalDeviceToolPropertiesEXT *pToolProperties;
vkGetPhysicalDeviceToolPropertiesEXT(physicalDevice, &num_tools, NULL);

pToolProperties = 
(VkPhysicalDeviceToolPropertiesEXT*)malloc(sizeof(VkPhysicalDeviceToolPropertiesEXT) * 
num_tools);

vkGetPhysicalDeviceToolPropertiesEXT(physicalDevice, &num_tools, pToolProperties);

for (int i = 0; i < num_tools; ++i) {
    printf("%s:\n", pToolProperties[i].name);
    printf("Version:\n");
    printf("%s:\n", pToolProperties[i].version);
    printf("Description:\n");
    printf("t%s\n", pToolProperties[i].description);
    printf("Purposes:\n");
    printf("t%s\n", VkToolPurposeFlagBitsEXT_to_string(pToolProperties[i].purposes));
    if (strnlen_s(pToolProperties[i].layer,VK_MAX_EXTENSION_NAME_SIZE) > 0) {
        printf("Corresponding Layer:\n");
        printf("t%s\n", pToolProperties[i].layer);
    }
}
```

Issues

1) Why is this information separate from the layer mechanism?

Some tooling may be built into a driver, or be part of the Vulkan loader etc. Tying this information directly to layers would have been awkward at best.

Version History

- Revision 1, 2018-11-05 (Tobias Hector)
  - Initial draft

VK_EXT_validation_flags

Name String

VK_EXT_validation_flags

Extension Type

Instance extension

Registered Extension Number

62
Revision
2

Ratification Status
Not ratified

Extension and Version Dependencies
Deprecation state
• Deprecated by VK_EXT_validation_features extension

Special Use
• Debugging tools

Contact
• Tobin Ehlis tobine

Other Extension Metadata

Last Modified Date
2019-08-19

IP Status
No known IP claims.

Contributors
• Tobin Ehlis, Google
• Courtney Goeltzenleuchter, Google

Description
This extension provides the VkValidationFlagsEXT struct that can be included in the pNext chain of the VkInstanceCreateInfo structure passed as the pCreateInfo parameter of vkCreateInstance. The structure contains an array of VkValidationCheckEXT values that will be disabled by the validation layers.

Deprecation by VK_EXT_validation_features
Functionality in this extension is subsumed into the VK_EXT_validation_features extension.

New Structures
• Extending VkInstanceCreateInfo:
  ◦ VkValidationFlagsEXT

New Enums
• VkValidationCheckEXT
New Enum Constants

- VK_EXT_VALIDATION_FLAGS_EXTENSION_NAME
- VK_EXT_VALIDATION_FLAGS_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_VALIDATION_FLAGS_EXT

Version History

- Revision 2, 2019-08-19 (Mark Lobodzinski)
  - Marked as deprecated
- Revision 1, 2016-08-26 (Courtney Goeltzenleuchter)
  - Initial draft

VK_EXT_ycbcr_2plane_444_formats

Name String

VK_EXT_ycbcr_2plane_444_formats

Extension Type

Device extension

Registered Extension Number

331

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_sampler_ycbcr_conversion

or

Version 1.1

Deprecation state

- Promoted to Vulkan 1.3

Contact

- Tony Zlatinski @tzlatinski

Other Extension Metadata

Last Modified Date

2020-07-28
Interactions and External Dependencies
• Promoted to Vulkan 1.3 Core

IP Status
No known IP claims.

Contributors
• Piers Daniell, NVIDIA
• Ping Liu, Intel

Description
This extension adds some \( Y'CbCr \) formats that are in common use for video encode and decode, but were not part of the \texttt{VK_KHR_sampler_ycbcr_conversion} extension.

New Structures
• Extending \texttt{VkPhysicalDeviceFeatures2, VkDeviceCreateInfo}:
  ◦ \texttt{VkPhysicalDeviceYcbcr2Plane444FormatsFeaturesEXT}

New Enum Constants
• \texttt{VK_EXT_YCBCR_2PLANE_444_FORMATS_EXTENSION_NAME}
• \texttt{VK_EXT_YCBCR_2PLANE_444_FORMATS_SPEC_VERSION}
• Extending \texttt{VkFormat}:
  ◦ \texttt{VK_FORMAT_G10X6_B10X6R10X6_2PLANE_444_UNORM_3PACK16_EXT}
  ◦ \texttt{VK_FORMAT_G12X4_B12X4R12X4_2PLANE_444_UNORM_3PACK16_EXT}
  ◦ \texttt{VK_FORMAT_G16_B16R16_2PLANE_444_UNORM_EXT}
  ◦ \texttt{VK_FORMAT_G8_B8R8_2PLANE_444_UNORM_EXT}
• Extending \texttt{VkStructureType}:
  ◦ \texttt{VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_YCBCR_2_PLANE_444_FORMATS_FEATURES_EXT}

Promotion to Vulkan 1.3
This extension has been partially promoted. The format enumerants introduced by the extension are included in core Vulkan 1.3, with the EXT suffix omitted. However, runtime support for these formats is optional in core Vulkan 1.3, while if this extension is supported, runtime support is mandatory. The feature structure is not promoted. The original enum names are still available as aliases of the core functionality.

Version History
• Revision 1, 2020-03-08 (Piers Daniell)
  ◦ Initial draft
VK_AMD_draw_indirect_count

Name String
   VK_AMD_draw_indirect_count

Extension Type
   Device extension

Registered Extension Number
   34

Revision
   2

Ratification Status
   Not ratified

Extension and Version Dependencies

Deprecation state
   • Promoted to VK_KHR_draw_indirect_count extension
      ◦ Which in turn was promoted to Vulkan 1.2

Contact
   • Daniel Rakos drakos-amd

Other Extension Metadata

Last Modified Date
   2016-08-23

Interactions and External Dependencies
   • Promoted to VK_KHR_draw_indirect_count

IP Status
   No known IP claims.

Contributors
   • Matthaeus G. Chajdas, AMD
   • Derrick Owens, AMD
   • Graham Sellers, AMD
   • Daniel Rakos, AMD
   • Dominik Witczak, AMD

Description

This extension allows an application to source the number of draws for indirect drawing commands from a buffer. This enables applications to generate an arbitrary number of drawing
commands and execute them without host intervention.

**Promotion to VK_KHR_draw_indirect_count**

All functionality in this extension is included in VK_KHR_draw_indirect_count, with the suffix changed to KHR. The original type, enum and command names are still available as aliases of the core functionality.

**New Commands**

- `vkCmdDrawIndexedIndirectCountAMD`
- `vkCmdDrawIndirectCountAMD`

**New Enum Constants**

- `VK_AMD_DRAW_INDIRECT_COUNT_EXTENSION_NAME`
- `VK_AMD_DRAW_INDIRECT_COUNT_SPEC_VERSION`

**Version History**

- Revision 2, 2016-08-23 (Dominik Witczak)
  - Minor fixes
- Revision 1, 2016-07-21 (Matthaeus Chajdas)
  - Initial draft

**VK_AMD_gpu_shader_half_float**

**Name String**

`VK_AMD_gpu_shader_half_float`

**Extension Type**

Device extension

**Registered Extension Number**

37

**Revision**

2

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

**Deprecation state**

- Deprecated by VK_KHR_shader_float16_int8 extension
  - Which in turn was promoted to Vulkan 1.2
Contact

- Dominik Witczak dominikwitczakamd

Other Extension Metadata

Last Modified Date

2019-04-11

IP Status

No known IP claims.

Interactions and External Dependencies

- This extension requires SPV_AMD_gpu_shader_half_float
- This extension provides API support for GL_AMD_gpu_shader_half_float

Contributors

- Daniel Rakos, AMD
- Dominik Witczak, AMD
- Donglin Wei, AMD
- Graham Sellers, AMD
- Qun Lin, AMD
- Rex Xu, AMD

Description

This extension adds support for using half float variables in shaders.

Deprecation by VK_KHR_shader_float16_int8

Functionality in this extension was included in VK_KHR_shader_float16_int8 extension, when VkPhysicalDeviceShaderFloat16Int8FeaturesKHR::shaderFloat16 is enabled.

New Enum Constants

- VK_AMD_GPU_SHADER_HALF_FLOAT_EXTENSION_NAME
- VK_AMD_GPU_SHADER_HALF_FLOAT_SPEC_VERSION

Version History

- Revision 2, 2019-04-11 (Tobias Hector)
  - Marked as deprecated
- Revision 1, 2016-09-21 (Dominik Witczak)
  - Initial draft
VK_AMD_gpu_shader_int16

Name String
VK_AMD_gpu_shader_int16

Extension Type
Device extension

Registered Extension Number
133

Revision
2

Ratification Status
Not ratified

Extension and Version Dependencies

Deprecation state

• Deprecated by VK_KHR_shader_float16_int8 extension
  ◦ Which in turn was promoted to Vulkan 1.2

Contact

• Qun Lin linqun

Other Extension Metadata

Last Modified Date
2019-04-11

IP Status
No known IP claims.

Interactions and External Dependencies

• This extension requires SPV_AMD_gpu_shader_int16
• This extension provides API support for GL_AMD_gpu_shader_int16

Contributors

• Daniel Rakos, AMD
• Dominik Witczak, AMD
• Matthaeus G. Chajdas, AMD
• Rex Xu, AMD
• Timothy Lottes, AMD
• Zhi Cai, AMD
Description

This extension adds support for using 16-bit integer variables in shaders.

Deprecation by VK_KHR_shader_float16_int8

Functionality in this extension was included in VK_KHR_shader_float16_int8 extension, when VkPhysicalDeviceFeatures::shaderInt16 and VkPhysicalDeviceShaderFloat16Int8FeaturesKHR::shaderFloat16 are enabled.

New Enum Constants

• VK_AMD_GPU_SHADER_INT16_EXTENSION_NAME
• VK_AMD_GPU_SHADER_INT16_SPEC_VERSION

Version History

• Revision 2, 2019-04-11 (Tobias Hector)
  ◦ Marked as deprecated
• Revision 1, 2017-06-18 (Dominik Witczak)
  ◦ First version

VK_AMD_negative_viewport_height

Name String
  VK_AMD_negative_viewport_height

Extension Type
  Device extension

Registered Extension Number
  36

Revision
  1

Ratification Status
  Not ratified

Extension and Version Dependencies

Deprecation state
  • Obsoleted by VK_KHR_maintenance1 extension
    ◦ Which in turn was promoted to Vulkan 1.1

Contact
  • Matthaeus G. Chajdas anteru
Other Extension Metadata

Last Modified Date
2016-09-02

IP Status
No known IP claims.

Contributors
- Matthaeus G. Chajdas, AMD
- Graham Sellers, AMD
- Baldur Karlsson

Description
This extension allows an application to specify a negative viewport height. The result is that the viewport transformation will flip along the y-axis.

- Allow negative height to be specified in the `VkViewport::height` field to perform y-inversion of the clip-space to framebuffer-space transform. This allows apps to avoid having to use `gl_Position.y = -gl_Position.y` in shaders also targeting other APIs.

Obsoletion by `VK_KHR_maintenance1` and Vulkan 1.1

Functionality in this extension is included in `VK_KHR_maintenance1` and subsequently Vulkan 1.1. Due to some slight behavioral differences, this extension must not be enabled alongside `VK_KHR_maintenance1`, or in an instance created with version 1.1 or later requested in `VkApplicationInfo::apiVersion`.

New Enum Constants
- `VK_AMD_NEGATIVE_VIEWPORT_HEIGHT_EXTENSION_NAME`
- `VK_AMD_NEGATIVE_VIEWPORT_HEIGHT_SPEC_VERSION`

Version History
- Revision 1, 2016-09-02 (Matthaeus Chajdas)
  - Initial draft

VK_ARM_rasterization_order_attachment_access

Name String
- `VK_ARM_rasterization_order_attachment_access`

Extension Type
- Device extension
Render passes, and specifically subpass dependencies, enable much of the same functionality as the framebuffer fetch and pixel local storage extensions did for OpenGL ES. But certain techniques such as programmable blending are awkward or impractical to implement with these alone, in part because a self-dependency is required every time a fragment will read a value at a given sample coordinate.

This extension extends the mechanism of input attachments to allow access to framebuffer attachments when used as both input and color, or depth/stencil, attachments from one fragment to the next, in rasterization order, without explicit synchronization.

**New Structures**

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceRasterizationOrderAttachmentAccessFeaturesARM`
New Enum Constants

- **VK_ARM_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_EXTENSION_NAME**
- **VK_ARM_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_SPEC_VERSION**

Extending `VkPipelineColorBlendStateCreateFlagBits`:
- **VK_PIPELINE_COLOR_BLEND_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_ACCESS_BIT_ARM**

Extending `VkPipelineDepthStencilStateCreateFlagBits`:
- **VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_ARM**
- **VK_PIPELINE_DEPTH_STENCIL_STATE_CREATE_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_ARM**

Extending `VkStructureType`:
- **VK_STRUCTURE_TYPE_PHYSICALDEVICE_RASTERIZATION_ORDER_ATTACHMENT_ACCESSFEATURES_ARM**

Extending `VkSubpassDescriptionFlagBits`:
- **VK_SUBPASSDESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_COLOR_ACCESS_BIT_ARM**
- **VK_SUBPASSDESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_DEPTH_ACCESS_BIT_ARM**
- **VK_SUBPASSDESCRIPTION_RASTERIZATION_ORDER_ATTACHMENT_STENCIL_ACCESS_BIT_ARM**

Issues

1) Is there any interaction with the `VK_KHR_dynamic_rendering` extension?

No. This extension only affects reads from input attachments. Render pass instances begun with `vkCmdBeginRenderingKHR` do not have input attachments and a different mechanism will be needed to provide similar functionality in this case.

Examples

None.

Version History

- Revision 1, 2021-11-12 (Jan-Harald Fredriksen)
  - Initial draft

**VK_IMG_format_pvrtc**

Name String
- **VK_IMG_format_pvrtc**

Extension Type
- Device extension
**Registered Extension Number**

55

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

**Deprecation state**

- Deprecated without replacement

**Contact**

- Stuart Smith

**Other Extension Metadata**

**Last Modified Date**

2019-09-02

**IP Status**

Imagination Technologies Proprietary

**Contributors**

- Stuart Smith, Imagination Technologies

**Description**

`VK_IMG_format_pvrtc` provides additional texture compression functionality specific to Imagination Technologies PowerVR Texture compression format (called PVRTC).

**Deprecation**

Both PVRTC1 and PVRTC2 are slower than standard image formats on PowerVR GPUs, and support will be removed from future hardware.

**New Enum Constants**

- `VK_IMG_FORMAT_PVRTC_EXTENSION_NAME`
- `VK_IMG_FORMAT_PVRTC_SPEC_VERSION`
- Extending `VkFormat`:
  - `VK_FORMAT_PVRTC1_2BPP_SRGB_BLOCK_IMG`
  - `VK_FORMAT_PVRTC1_2BPP_UNORM_BLOCK_IMG`
  - `VK_FORMAT_PVRTC1_4BPP_SRGB_BLOCK_IMG`
  - `VK_FORMAT_PVRTC1_4BPP_UNORM_BLOCK_IMG`
○ VK_FORMAT_PVRTC2_2BPP_SRGB_BLOCK_IMG
○ VK_FORMAT_PVRTC2_2BPP_UNORM_BLOCK_IMG
○ VK_FORMAT_PVRTC2_4BPP_SRGB_BLOCK_IMG
○ VK_FORMAT_PVRTC2_4BPP_UNORM_BLOCK_IMG

**Version History**

- Revision 1, 2019-09-02 (Stuart Smith)
  - Initial version

**VK_MVK_ios_surface**

**Name String**

VK_MVK_ios_surface

**Extension Type**

Instance extension

**Registered Extension Number**

123

**Revision**

3

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

VK_KHR_surface

**Deprecation state**

- Deprecated by VK_EXT_metal_surface extension

**Contact**

- Bill Hollings @billhollings

**Other Extension Metadata**

**Last Modified Date**

2020-07-31

**IP Status**

No known IP claims.

**Contributors**

- Bill Hollings, The Brenwill Workshop Ltd.
Description

The `VK_MVK_ios_surface` extension is an instance extension. It provides a mechanism to create a `VkSurfaceKHR` object (defined by the `VK_KHR_surface` extension) based on a `UIView`, the native surface type of iOS, which is underpinned by a `CAMetalLayer`, to support rendering to the surface using Apple’s Metal framework.

Deprecation by `VK_EXT_metal_surface`

The `VK_MVK_ios_surface` extension is considered deprecated and has been superseded by the `VK_EXT_metal_surface` extension.

New Commands

- `vkCreateIOSSurfaceMVK`

New Structures

- `VkIOSSurfaceCreateInfoMVK`

New Bitmasks

- `VkIOSSurfaceCreateFlagsMVK`

New Enum Constants

- `VK_MVK_IOS_SURFACE_EXTENSION_NAME`
- `VK_MVK_IOS_SURFACE_SPEC_VERSION`
- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_IOS_SURFACE_CREATE_INFO_MVK`

Version History

- Revision 1, 2017-02-15 (Bill Hollings)
  - Initial draft.
- Revision 2, 2017-02-24 (Bill Hollings)
  - Minor syntax fix to emphasize firm requirement for `UIView` to be backed by a `CAMetalLayer`.
- Revision 3, 2020-07-31 (Bill Hollings)
  - Update documentation on requirements for `UIView`.
  - Mark as deprecated by `VK_EXT_metal_surface`.

`VK_MVK_macos_surface`

Name String

`VK_MVK_macos_surface`
Extension Type
   Instance extension

Registered Extension Number
   124

Revision
   3

Ratification Status
   Not ratified

Extension and Version Dependencies
   VK_KHR_surface

Deprecation state
   • Deprecated by VK_EXT_metal_surface extension

Contact
   • Bill Hollings billhollings

Other Extension Metadata

Last Modified Date
   2020-07-31

IP Status
   No known IP claims.

Contributors
   • Bill Hollings, The Brenwill Workshop Ltd.

Description

The VK_MVK_macos_surface extension is an instance extension. It provides a mechanism to create a VkSurfaceKHR object (defined by the VK_KHR_surface extension) based on an NSView, the native surface type of macOS, which is underpinned by a CAMetalLayer, to support rendering to the surface using Apple’s Metal framework.

Deprecation by VK_EXT_metal_surface

The VK_MVK_macos_surface extension is considered deprecated and has been superseded by the VK_EXT_metal_surface extension.

New Commands
   • vkCreateMacOSSurfaceMVK
New Structures

- VkMacOSSurfaceCreateInfoMVK

New Bitmasks

- VkMacOSSurfaceCreateFlagsMVK

New Enum Constants

- VK_MVK_MACOS_SURFACE_EXTENSION_NAME
- VK_MVK_MACOS_SURFACE_SPEC_VERSION

Extending VkStructureType:
- VK_STRUCTURE_TYPE_MACOS_SURFACE_CREATE_INFO_MVK

Version History

- Revision 1, 2017-02-15 (Bill Hollings)
  - Initial draft.
- Revision 2, 2017-02-24 (Bill Hollings)
  - Minor syntax fix to emphasize firm requirement for NSView to be backed by a CAMetalLayer.
- Revision 3, 2020-07-31 (Bill Hollings)
  - Update documentation on requirements for NSView.
  - Mark as deprecated by VK_EXT_metal_surface.

VK_NV_dedicated_allocation

Name String

- VK_NV_dedicated_allocation

Extension Type

- Device extension

Registered Extension Number

- 27

Revision

- 1

Ratification Status

- Not ratified

Extension and Version Dependencies

Deprecation state

- Deprecated by VK_KHR_dedicated_allocation extension
Which in turn was promoted to Vulkan 1.1

Contact

• Jeff Bolz [jeffbolznv](mailto:jeffbolznv)

Other Extension Metadata

Last Modified Date
2016-05-31

IP Status
No known IP claims.

Contributors

• Jeff Bolz, NVIDIA

Description

This extension allows device memory to be allocated for a particular buffer or image resource, which on some devices can significantly improve the performance of that resource. Normal device memory allocations must support memory aliasing and sparse binding, which could interfere with optimizations like framebuffer compression or efficient page table usage. This is important for render targets and very large resources, but need not (and probably should not) be used for smaller resources that can benefit from suballocation.

This extension adds a few small structures to resource creation and memory allocation: a new structure that flags whether an image/buffer will have a dedicated allocation, and a structure indicating the image or buffer that an allocation will be bound to.

New Structures

• Extending VkBufferCreateInfo:
  • VkDedicatedAllocationBufferCreateInfoNV

• Extending VkImageCreateInfo:
  • VkDedicatedAllocationImageCreateInfoNV

• Extending VkMemoryAllocateInfo:
  • VkDedicatedAllocationMemoryAllocateInfoNV

New Enum Constants

• VK_NV_DEDICATED_ALLOCATION_EXTENSION_NAME
• VK_NV_DEDICATED_ALLOCATION_SPEC_VERSION

• Extending VkStructureType:
  • VK_STRUCTURE_TYPE_DEDICATED_ALLOCATION_BUFFER_CREATE_INFO_NV
  • VK_STRUCTURE_TYPE_DEDICATED_ALLOCATION_IMAGE_CREATE_INFO_NV
Examples

// Create an image with
// VkDedicatedAllocationImageCreateInfoNV::dedicatedAllocation
// set to VK_TRUE

VkDedicatedAllocationImageCreateInfoNV dedicatedImageInfo =
{
    .sType = VK_STRUCTURE_TYPE_DEDICATED_ALLOCATION_IMAGE_CREATE_INFO_NV,
    .pNext = NULL,
    .dedicatedAllocation = VK_TRUE,
};

VkImageCreateInfo imageCreateInfo =
{
    .sType = VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO,
    .pNext = &dedicatedImageInfo
    // Other members set as usual
};

VkImage image;
VkResult result = vkCreateImage(
    device,
    &imageCreateInfo,
    NULL, // pAllocator
    &image);

VkMemoryRequirements memoryRequirements;
vkGetImageMemoryRequirements(
    device,
    image,
    &memoryRequirements);

// Allocate memory with VkDedicatedAllocationMemoryAllocateInfoNV::image
// pointing to the image we are allocating the memory for

VkDedicatedAllocationMemoryAllocateInfoNV dedicatedInfo =
{
    .sType = VK_STRUCTURE_TYPE_DEDICATED_ALLOCATION_MEMORY_ALLOCATE_INFO_NV,
    .pNext = NULL,
    .image = image,
    .buffer = VK_NULL_HANDLE,
};

VkMemoryAllocateInfo memoryAllocateInfo =
{
    .sType = VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO,
    .pNext = &dedicatedInfo,
}
.allocationSize = memoryRequirements.size,
.memoryTypeIndex = FindMemoryTypeIndex(memoryRequirements.memoryTypeBits),
};

VkDeviceMemory memory;
vkAllocateMemory(
    device,
    &memoryAllocateInfo,
    NULL, // pAllocator
    &memory);

// Bind the image to the memory
vkBindImageMemory(
    device,
    image,
    memory,
    0);

Version History

- Revision 1, 2016-05-31 (Jeff Bolz)
  - Internal revisions

VK_NV_external_memory

Name String

VK_NV_external_memory

Extension Type

Device extension

Registered Extension Number

57

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_NV_external_memory_capabilities

Deprecation state

- Deprecated by VK_KHR_external_memory extension
  - Which in turn was promoted to Vulkan 1.1
Applications may wish to export memory to other Vulkan instances or other APIs, or import memory from other Vulkan instances or other APIs to enable Vulkan workloads to be split up across application module, process, or API boundaries. This extension enables applications to create exportable Vulkan memory objects such that the underlying resources can be referenced outside the Vulkan instance that created them.

New Structures

- Extending VkImageCreateInfo:
  - VkExternalMemoryImageCreateInfoNV
- Extending VkMemoryAllocateInfo:
  - VkExportMemoryAllocateInfoNV

New Enum Constants

- VK_NV_EXTERNAL_MEMORY_EXTENSION_NAME
- VK_NV_EXTERNAL_MEMORY_SPEC_VERSION
- Extending VkStructureType:
  - VK_STRUCTURE_TYPE_EXPORT_MEMORY_ALLOCATE_INFO_NV
  - VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_IMAGE_CREATE_INFO_NV

Issues

1) If memory objects are shared between processes and APIs, is this considered aliasing according to the rules outlined in the Memory Aliasing section?

RESOLVED: Yes, but strict exceptions to the rules are added to allow some forms of aliasing in these cases. Further, other extensions may build upon these new aliasing rules to define specific support
usage within Vulkan for imported native memory objects, or memory objects from other APIs.

2) Are new image layouts or metadata required to specify image layouts and layout transitions compatible with non-Vulkan APIs, or with other instances of the same Vulkan driver?

**RESOLVED**: No. Separate instances of the same Vulkan driver running on the same GPU should have identical internal layout semantics, so applications have the tools they need to ensure views of images are consistent between the two instances. Other APIs will fall into two categories: Those that are Vulkan compatible (a term to be defined by subsequent interoperability extensions), or Vulkan incompatible. When sharing images with Vulkan incompatible APIs, the Vulkan image must be transitioned to the `VK_IMAGE_LAYOUT_GENERAL` layout before handing it off to the external API.

Note this does not attempt to address cross-device transitions, nor transitions to engines on the same device which are not visible within the Vulkan API. Both of these are beyond the scope of this extension.

**Examples**

```c
// TODO: Write some sample code here.
```

**Version History**

- Revision 1, 2016-08-19 (James Jones)
  - Initial draft

**VK_NV_external_memory_capabilities**

**Name String**

`VK_NV_external_memory_capabilities`

**Extension Type**

Instance extension

**Registered Extension Number**

56

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

**Deprecation state**

- Deprecated by `VK_KHR_external_memory_capabilities` extension
  - Which in turn was promoted to Vulkan 1.1
Contact
  • James Jones cubanismo

Other Extension Metadata

Last Modified Date
  2016-08-19

IP Status
  No known IP claims.

Interactions and External Dependencies
  • Interacts with Vulkan 1.1.
  • Interacts with VK_KHR_dedicated_allocation.
  • Interacts with VK_NV_dedicated_allocation.

Contributors
  • James Jones, NVIDIA

Description

Applications may wish to import memory from the Direct 3D API, or export memory to other Vulkan instances. This extension provides a set of capability queries that allow applications determine what types of win32 memory handles an implementation supports for a given set of use cases.

New Commands
  • vkGetPhysicalDeviceExternalImageFormatPropertiesNV

New Structures
  • VkExternalImageFormatPropertiesNV

New Enums
  • VkExternalMemoryFeatureFlagBitsNV
  • VkExternalMemoryHandleTypeFlagBitsNV

New Bitmasks
  • VkExternalMemoryFeatureFlagsNV
  • VkExternalMemoryHandleTypeFlagsNV

New Enum Constants
  • VK_NV_EXTERNAL_MEMORY_CAPABILITIES_EXTENSION_NAME
Issues

1) Why do so many external memory capabilities need to be queried on a per-memory-handle-type basis?

**RESOLVED**: This is because some handle types are based on OS-native objects that have far more limited capabilities than the very generic Vulkan memory objects. Not all memory handle types can name memory objects that support 3D images, for example. Some handle types cannot even support the deferred image and memory binding behavior of Vulkan and require specifying the image when allocating or importing the memory object.

2) Does the `VkExternalImageFormatPropertiesNV` struct need to include a list of memory type bits that support the given handle type?

**RESOLVED**: No. The memory types that do not support the handle types will simply be filtered out of the results returned by `vkGetImageMemoryRequirements` when a set of handle types was specified at image creation time.

3) Should the non-opaque handle types be moved to their own extension?

**RESOLVED**: Perhaps. However, defining the handle type bits does very little and does not require any platform-specific types on its own, and it is easier to maintain the bitmask values in a single extension for now. Presumably more handle types could be added by separate extensions though, and it would be midly weird to have some platform-specific ones defined in the core spec and some in extensions.

Version History

- Revision 1, 2016-08-19 (James Jones)
  - Initial version

VK_NV_external_memory_win32

Name String

`VK_NV_external_memory_win32`

Extension Type

Device extension

Registered Extension Number

58

Revision

1

Ratification Status

Not ratified
Extension and Version Dependencies

VK_NV_external_memory

Deprecation state

• Deprecated by VK_KHR_external_memory_win32 extension

Contact

• James Jones @cubanismo

Other Extension Metadata

Last Modified Date

2016-08-19

IP Status

No known IP claims.

Contributors

• James Jones, NVIDIA
• Carsten Rohde, NVIDIA

Description

Applications may wish to export memory to other Vulkan instances or other APIs, or import memory from other Vulkan instances or other APIs to enable Vulkan workloads to be split up across application module, process, or API boundaries. This extension enables win32 applications to export win32 handles from Vulkan memory objects such that the underlying resources can be referenced outside the Vulkan instance that created them, and import win32 handles created in the Direct3D API to Vulkan memory objects.

New Commands

• vkGetMemoryWin32HandleNV

New Structures

• Extending VkMemoryAllocateInfo:
  ◦ VkExportMemoryWin32HandleInfoNV
  ◦ VkImportMemoryWin32HandleInfoNV

New Enum Constants

• VK_NV_EXTERNAL_MEMORY_WIN32_EXTENSION_NAME
• VK_NV_EXTERNAL_MEMORY_WIN32_SPEC_VERSION

• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_EXPORT_MEMORY_WIN32_HANDLE_INFO_NV
Issues

1) If memory objects are shared between processes and APIs, is this considered aliasing according to the rules outlined in the Memory Aliasing section?

**RESOLVED:** Yes, but strict exceptions to the rules are added to allow some forms of aliasing in these cases. Further, other extensions may build upon these new aliasing rules to define specific support usage within Vulkan for imported native memory objects, or memory objects from other APIs.

2) Are new image layouts or metadata required to specify image layouts and layout transitions compatible with non-Vulkan APIs, or with other instances of the same Vulkan driver?

**RESOLVED:** No. Separate instances of the same Vulkan driver running on the same GPU should have identical internal layout semantics, so applications have the tools they need to ensure views of images are consistent between the two instances. Other APIs will fall into two categories: Those that are Vulkan compatible (a term to be defined by subsequent interoperability extensions), or Vulkan incompatible. When sharing images with Vulkan incompatible APIs, the Vulkan image must be transitioned to the **VK_IMAGE_LAYOUT_GENERAL** layout before handing it off to the external API.

Note this does not attempt to address cross-device transitions, nor transitions to engines on the same device which are not visible within the Vulkan API. Both of these are beyond the scope of this extension.

3) Do applications need to call `CloseHandle()` on the values returned from `vkGetMemoryWin32HandleNV` when `handleType` is `VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT_NV`?

**RESOLVED:** Yes, unless it is passed back in to another driver instance to import the object. A successful get call transfers ownership of the handle to the application, while an import transfers ownership to the associated driver. Destroying the memory object will not destroy the handle or the handle's reference to the underlying memory resource.

Examples

```c
//
// Create an exportable memory object and export an external
// handle from it.
//

// Pick an external format and handle type.
static const VkFormat format = VK_FORMAT_R8G8B8A8_UNORM;
static const VkExternalMemoryHandleTypeFlagsNV handleType =
    VK_EXTERNAL_MEMORY_HANDLE_TYPE_OPAQUE_WIN32_BIT_NV;

extern VkPhysicalDevice physicalDevice;
extern VkDevice device;

VkPhysicalDeviceMemoryProperties memoryProperties;
```
VkExternalImageFormatPropertiesNV properties;
VkExternalMemoryImageCreateInfoNV externalMemoryImageCreateInfo;
VkDedicatedAllocationImageCreateInfoNV dedicatedImageCreateInfo;
VkImageCreateInfo imageCreateInfo;
VkImage image;
VkMemoryRequirements imageMemoryRequirements;
uint32_t numMemoryTypes;
uint32_t memoryType;
VkExportMemoryAllocateInfoNV exportMemoryAllocateInfo;
VkDedicatedAllocationMemoryAllocateInfoNV dedicatedAllocationInfo;
VkMemoryAllocateInfo memoryAllocateInfo;
VkDeviceMemory memory;
VkResult result;
HANDLE memoryHnd;

// Figure out how many memory types the device supports
vkGetPhysicalDeviceMemoryProperties(physicalDevice,
    &memoryProperties);
numMemoryTypes = memoryProperties.memoryTypeCount;

// Check the external handle type capabilities for the chosen format
// Exportable 2D image support with at least 1 mip level, 1 array
// layer, and VK_SAMPLE_COUNT_1_BIT using optimal tiling and supporting
// texturing and color rendering is required.
result = vkGetPhysicalDeviceExternalImageFormatPropertiesNV(
    physicalDevice,
    format,
    VK_IMAGE_TYPE_2D,
    VK_IMAGE_TILING_OPTIMAL,
    VK_IMAGE_USAGE_SAMPLED_BIT
    | VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT,
    0,
    handleType,
    &properties);

if ((result != VK_SUCCESS) ||
    !(properties.externalMemoryFeatures &
    VK_EXTERNAL_MEMORY_FEATURE_EXPORTABLE_BIT_NV)) {
    abort();
}

// Set up the external memory image creation info
memset(&externalMemoryImageCreateInfo,
    0, sizeof(externalMemoryImageCreateInfo));
externalMemoryImageCreateInfo.sType =
    VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_IMAGE_CREATE_INFO_NV;
externalMemoryImageCreateInfo.handleTypes = handleType;
if (properties.externalMemoryFeatures &
    VK_EXTERNAL_MEMORY_FEATURE_DEDICATED_ONLY_BIT_NV) {
    memset(&dedicatedImageCreateInfo, 0, sizeof(dedicatedImageCreateInfo));
dedicatedImageCreateInfo.sType =
    VK_STRUCTURE_TYPE_DEDICATED_ALLOCATION_IMAGE_CREATE_INFO_NV;
}
VK_STRUCTURE_TYPE_DEDICATED_ALLOCATION_IMAGE_CREATE_INFO_NV;

    dedicatedImageCreateInfo.dedicatedAllocation = VK_TRUE;
    externalMemoryImageCreateInfo.pNext = &dedicatedImageCreateInfo;
}

// Set up the core image creation info
memset(&imageCreateInfo, 0, sizeof(imageCreateInfo));
imageCreateInfo.sType = VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO;
imageCreateInfo.pNext = &externalMemoryImageCreateInfo;
imageCreateInfo.format = format;
imageCreateInfo.extent.width = 64;
imageCreateInfo.extent.height = 64;
imageCreateInfo.extent.depth = 1;
imageCreateInfo.mipLevels = 1;
imageCreateInfo.arrayLayers = 1;
imageCreateInfo.samples = VK_SAMPLE_COUNT_1_BIT;
imageCreateInfo.tiling = VK_IMAGE_TILING_OPTIMAL;
imageCreateInfo.usage = VK_IMAGE_USAGE_SAMPLED_BIT |
    VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT;
imageCreateInfo.sharingMode = VK_SHARING_MODE_EXCLUSIVE;
imageCreateInfo.initialLayout = VK_IMAGE_LAYOUT_UNDEFINED;

vkCreateImage(device, &imageCreateInfo, NULL, &image);

vkGetImageMemoryRequirements(device,
        image,
        &imageMemoryRequirements);

// For simplicity, just pick the first compatible memory type.
for (memoryType = 0; memoryType < numMemoryTypes; memoryType++) {
    if ((1 << memoryType) & imageMemoryRequirements.memoryTypeBits) {
        break;
    }
}

// At least one memory type must be supported given the prior external
// handle capability check.
assert(memoryType < numMemoryTypes);

// Allocate the external memory object.
memset(&exportMemoryAllocateInfo, 0, sizeof(exportMemoryAllocateInfo));
exportMemoryAllocateInfo.sType = VK_STRUCTURE_TYPE_EXPORT_MEMORY_ALLOCATE_INFO_NV;
exportMemoryAllocateInfo.handleTypes = handleType;
if (properties.externalMemoryFeatures &
    VK_EXTERNAL_MEMORY_FEATURE_DEDICATED_ONLY_BIT_NV) {
    memset(&dedicatedAllocationInfo, 0, sizeof(dedicatedAllocationInfo));
    dedicatedAllocationInfo.sType = VK_STRUCTURE_TYPE_DEDICATED_ALLOCATION_MEMORY_ALLOCATE_INFO_NV;
    dedicatedAllocationInfo.image = image;
    exportMemoryAllocateInfo.pNext = &dedicatedAllocationInfo;
}
memset(&memoryAllocateInfo, 0, sizeof(memoryAllocateInfo));
memoryAllocateInfo.sType = VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO;
memoryAllocateInfo.pNext = &exportMemoryAllocateInfo;
memoryAllocateInfo.allocationSize = imageMemoryRequirements.size;
memoryAllocateInfo.memoryTypeIndex = memoryType;

vkAllocateMemory(device, &memoryAllocateInfo, NULL, &memory);

if (!(properties.externalMemoryFeatures & VK_EXTERNAL_MEMORY_FEATURE_DEDICATED_ONLY_BIT_NV)) {
    vkBindImageMemory(device, image, memory, 0);
}

// Get the external memory opaque FD handle
vkGetMemoryWin32HandleNV(device, memory, &memoryHnd);

---

**Version History**

- Revision 1, 2016-08-11 (James Jones)
  - Initial draft

**VK_NV_fragment_shader_barycentric**

**Name String**

VK_NV_fragment_shader_barycentric

**Extension Type**

Device extension

**Registered Extension Number**

204

**Revision**

1

**Ratification Status**

Not ratified

**Extension and Version Dependencies**

VK_KHR_get_physical_device_properties2

**Deprecation state**

- Promoted to VK_KHR_fragment_shader_barycentric extension

**Contact**

- Pat Brown [nvpbrown](mailto:nvpbrown)
**Other Extension Metadata**

**Last Modified Date**  
2018-08-03

**IP Status**  
No known IP claims.

**Interactions and External Dependencies**

- This extension requires `SPV_NV_fragment_shader_barycentric`
- This extension provides API support for `GL_NV_fragment_shader_barycentric`

**Contributors**

- Pat Brown, NVIDIA
- Daniel Koch, NVIDIA

**Description**

This extension adds support for the following SPIR-V extension in Vulkan:

- `SPV_NV_fragment_shader_barycentric`

The extension provides access to three additional fragment shader variable decorations in SPIR-V:

- `PerVertexNV`, which indicates that a fragment shader input will not have interpolated values, but instead must be accessed with an extra array index that identifies one of the vertices of the primitive producing the fragment
- `BaryCoordNV`, which indicates that the variable is a three-component floating-point vector holding barycentric weights for the fragment produced using perspective interpolation
- `BaryCoordNoPerspNV`, which indicates that the variable is a three-component floating-point vector holding barycentric weights for the fragment produced using linear interpolation

When using GLSL source-based shader languages, the following variables from `GL_NV_fragment_shader_barycentric` maps to these SPIR-V built-in decorations:

- `in vec3 gl_BaryCoordNV;` → `BaryCoordNV`
- `in vec3 gl_BaryCoordNoPerspNV;` → `BaryCoordNoPerspNV`

GLSL variables declared using the `__pervertexNV` GLSL qualifier are expected to be decorated with `PerVertexNV` in SPIR-V.

**Promotion to **`VK_KHR_fragment_shader_barycentric`**

All functionality in this extension is included in `VK_KHR_fragment_shader_barycentric`, with the suffix changed to KHR.
New Structures

- Extending `VkPhysicalDeviceFeatures2`, `VkDeviceCreateInfo`:
  - `VkPhysicalDeviceFragmentShaderBarycentricFeaturesNV`

New Enum Constants

- `VK_NV_FRAGMENT_SHADER_BARYCENTRIC_EXTENSION_NAME`
- `VK_NV_FRAGMENT_SHADER_BARYCENTRIC_SPEC_VERSION`

Extending `VkStructureType`:

- `VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_FRAGMENT_SHADER_BARYCENTRIC_FEATURES_NV`

New Built-In Variables

- `BaryCoordNV`
- `BaryCoordNoPerspNV`

New SPIR-V Decorations

- `PerVertexNV`

New SPIR-V Capabilities

- `FragmentBarycentricNV`

Issues

(1) The `AMD_shader_explicit_vertex_parameter` extension provides similar functionality. Why write a new extension, and how is this extension different?

**RESOLVED**: For the purposes of Vulkan/SPIR-V, we chose to implement a separate extension due to several functional differences.

First, the hardware supporting this extension can provide a three-component barycentric weight vector for variables decorated with `BaryCoordNV`, while variables decorated with `BaryCoordSmoothAMD` provide only two components. In some cases, it may be more efficient to explicitly interpolate an attribute via:

```c
float value = (baryCoordNV.x * v[0].attrib +
               baryCoordNV.y * v[1].attrib +
               baryCoordNV.z * v[2].attrib);
```

instead of

```c
float value = (baryCoordSmoothAMD.x * (v[0].attrib - v[2].attrib) +
               baryCoordSmoothAMD.y * (v[1].attrib - v[2].attrib) +
               baryCoordSmoothAMD.z * v[2].attrib);
```
Additionally, the semantics of the decoration `BaryCoordPullModelAMD` do not appear to map to anything supported by the initial hardware implementation of this extension.

This extension provides a smaller number of decorations than the AMD extension, as we expect that shaders could derive variables decorated with things like `BaryCoordNoPerspCentroidAMD` with explicit attribute interpolation instructions. One other relevant difference is that explicit per-vertex attribute access using this extension does not require a constant vertex number.

(2) Why do the built-in SPIR-V decorations for this extension include two separate built-ins `BaryCoordNV` and `BaryCoordNoPerspNV` when a “no perspective” variable could be decorated with `BaryCoordNV` and `NoPerspective`?

**RESOLVED:** The SPIR-V extension for this feature chose to mirror the behavior of the GLSL extension, which provides two built-in variables. Additionally, it is not clear that it's a good idea (or even legal) to have two variables using the “same attribute”, but with different interpolation modifiers.

**Version History**

- Revision 1, 2018-08-03 (Pat Brown)
  - Internal revisions

**VK_NV_glsl_shader**

**Name String**

- `VK_NV_glsl_shader`

**Extension Type**

- Device extension

**Registered Extension Number**

- 13

**Revision**

- 1

**Ratification Status**

- Not ratified

**Extension and Version Dependencies**

**Deprecation state**

- `Deprecated` without replacement

**Contact**

- Piers Daniell [pdaniell-nv](mailto:pdaniell-nv)
Other Extension Metadata

Last Modified Date
2016-02-14

IP Status
No known IP claims.

Contributors
• Piers Daniell, NVIDIA

Description
This extension allows GLSL shaders written to the GL_KHR_vulkan_gls1 extension specification to be used instead of SPIR-V. The implementation will automatically detect whether the shader is SPIR-V or GLSL, and compile it appropriately.

Deprecation
Functionality in this extension is outside of the scope of Vulkan and is better served by a compiler library such as glslang. No new implementations will support this extension, so applications **should** not use it.

New Enum Constants

• \texttt{VK_NV_GLSL_SHADER_EXTENSION_NAME}
• \texttt{VK_NV_GLSL_SHADER_SPEC_VERSION}
• Extending \texttt{VkResult}:
  ◦ \texttt{VK_ERROR_INVALID_SHADER_NV}

Examples

Example 1
Passing in GLSL code

```c
char const vss[] =
    "#version 450 core\n"
   "layout(location = 0) in vec2 aVertex;\n"
   "layout(location = 1) in vec4 aColor;\n"
   "out vec4 vColor;\n"
   "void main()\n"
   "{\n"
   "   vColor = aColor;\n"
   "   gl_Position = vec4(aVertex, 0, 1);\n"
   "}\n"
;
VkShaderModuleCreateInfo vertexShaderInfo = {
```

4891
VK_STRUCTURE_TYPE_SHADER_MODULE_CREATE_INFO;
vertexShaderInfo.codeSize = sizeof vss;
vertexShaderInfo.pCode = vss;
VkShaderModule vertexShader;
vkCreateShaderModule(device, &vertexShaderInfo, 0, &vertexShader);

Version History

- Revision 1, 2016-02-14 (Piers Daniell)
  - Initial draft

VK_NV_win32_keyed_mutex

Name String

VK_NV_win32_keyed_mutex

Extension Type

Device extension

Registered Extension Number

59

Revision

2

Ratification Status

Not ratified

Extension and Version Dependencies

VK_NV_external_memory_win32

Deprecation state

- Promoted to VK_KHR_win32_keyed_mutex extension

Contact

- Carsten Rohde crohde

Other Extension Metadata

Last Modified Date

2016-08-19

IP Status

No known IP claims.

Contributors

- James Jones, NVIDIA
Carsten Rohde, NVIDIA

Description

Applications that wish to import Direct3D 11 memory objects into the Vulkan API may wish to use the native keyed mutex mechanism to synchronize access to the memory between Vulkan and Direct3D. This extension provides a way for an application to access the keyed mutex associated with an imported Vulkan memory object when submitting command buffers to a queue.

New Structures

- Extending `VkSubmitInfo`, `VkSubmitInfo2`:
  - `VkWin32KeyedMutexAcquireReleaseInfoNV`

New Enum Constants

- `VK_NV_WIN32_KEYED_MUTEX_EXTENSION_NAME`
- `VK_NV_WIN32_KEYED_MUTEX_SPEC_VERSION`

- Extending `VkStructureType`:
  - `VK_STRUCTURE_TYPE_WIN32_KEYED_MUTEX_ACQUIRE_RELEASE_INFO_NV`

Examples

```c
// Import a memory object from Direct3D 11, and synchronize
// access to it in Vulkan using keyed mutex objects.

extern VkPhysicalDevice physicalDevice;
extern VkDevice device;
extern HANDLE sharedNtHandle;

static const VkFormat format = VK_FORMAT_R8G8B8A8_UNORM;
static const VkExternalMemoryHandleTypeFlagsNV handleType =
  VK_EXTERNAL_MEMORY_HANDLE_TYPE_D3D11_IMAGE_BIT_NV;

VkPhysicalDeviceMemoryProperties memoryProperties;
VkExternalImageFormatPropertiesNV properties;
VkExternalMemoryImageCreateInfoNV externalMemoryImageCreateInfo;
VkImageCreateInfo imageCreateInfo;
VkImage image;
VkMemoryRequirements imageMemoryRequirements;
uint32_t numMemoryTypes;
uint32_t memoryType;
VkImportMemoryWin32HandleInfoNV importMemoryInfo;
VkMemoryAllocateInfo memoryAllocateInfo;
VkDeviceMemory mem;
VkResult result;
```
// Figure out how many memory types the device supports
vkGetPhysicalDeviceMemoryProperties(physicalDevice,
    &memoryProperties);
numMemoryTypes = memoryProperties.memoryTypeCount;

// Check the external handle type capabilities for the chosen format
// Importable 2D image support with at least 1 mip level, 1 array
// layer, and VK_SAMPLE_COUNT_1_BIT using optimal tiling and supporting
// texturing and color rendering is required.
result = vkGetPhysicalDeviceExternalImageFormatPropertiesNV(
    physicalDevice,
    format,
    VK_IMAGE_TYPE_2D,
    VK_IMAGE_TILING_OPTIMAL,
    VK_IMAGE_USAGE_SAMPLED_BIT |
    VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT,
    0,
    handleType,
    &properties);

if ((result != VK_SUCCESS) ||
    !(properties.externalMemoryFeatures &
        VK_EXTERNAL_MEMORY_FEATURE_IMPORTABLE_BIT_NV)) {
    abort();
}

// Set up the external memory image creation info
memset(&externalMemoryImageCreateInfo,
    0, sizeof(externalMemoryImageCreateInfo));
externalMemoryImageCreateInfo.sType =
    VK_STRUCTURE_TYPE_EXTERNAL_MEMORY_IMAGE_CREATE_INFO_NV;
externalMemoryImageCreateInfo.handleTypes = handleType;

// Set up the core image creation info
memset(&imageCreateInfo, 0, sizeof(imageCreateInfo));
imageCreateInfo.sType = VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO;
imageCreateInfo.pNext = &externalMemoryImageCreateInfo;
imageCreateInfo.format = format;
imageCreateInfo.extent.width = 64;
imageCreateInfo.extent.height = 64;
imageCreateInfo.extent.depth = 1;
imageCreateInfo.mipLevels = 1;
imageCreateInfo.arrayLayers = 1;
imageCreateInfo.samples = VK_SAMPLE_COUNT_1_BIT;
imageCreateInfo.tiling = VK_IMAGE_TILING_OPTIMAL;
imageCreateInfo.usage = VK_IMAGE_USAGE_SAMPLED_BIT |
    VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT;
imageCreateInfo.sharingMode = VK_SHARING_MODE_EXCLUSIVE;
imageCreateInfo.initialLayout = VK_IMAGE_LAYOUT_UNDEFINED;

vkCreateImage(device, &imageCreateInfo, NULL, &image);
vkGetImageMemoryRequirements(device,
    image,
    &imageMemoryRequirements);

// For simplicity, just pick the first compatible memory type.
for (memoryType = 0; memoryType < numMemoryTypes; memoryType++) {
    if ((1LL << memoryType) & imageMemoryRequirements.memoryTypeBits) {
        break;
    }
}

// At least one memory type must be supported given the prior external
// handle capability check.
assert(memoryType < numMemoryTypes);

// Allocate the external memory object.
memset(&exportMemoryAllocateInfo, 0, sizeof(exportMemoryAllocateInfo));
exportMemoryAllocateInfo.sType = VK_STRUCTURE_TYPE_EXPORT_MEMORY_ALLOCATE_INFO_NV;
importMemoryInfo.handleTypes = handleType;
importMemoryInfo.handle = sharedNtHandle;
memset(&memoryAllocateInfo, 0, sizeof(memoryAllocateInfo));
memoryAllocateInfo.sType = VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO;
memoryAllocateInfo.pNext = &exportMemoryAllocateInfo;
memoryAllocateInfo.allocationSize = imageMemoryRequirements.size;
memoryAllocateInfo.memoryTypeIndex = memoryType;

vkAllocateMemory(device, &memoryAllocateInfo, NULL, &mem);

vkBindImageMemory(device, image, mem, 0);
...

const uint64_t acquireKey = 1;
const uint32_t timeout = INFINITE;
const uint64_t releaseKey = 2;

VkWin32KeyedMutexAcquireReleaseInfoNV keyedMutex =
    { VK_STRUCTURE_TYPE_WIN32_KEYED_MUTEX_ACQUIRE_RELEASE_INFO_NV };

keyedMutex.acquireCount = 1;
keyedMutex.pAcquireSyncs = &mem;
keyedMutex.pAcquireKeys = &acquireKey;
keyedMutex.acquireTimeoutMilliseconds = &timeout;
keyedMutex.releaseCount = 1;
keyedMutex.pReleaseSyncs = &mem;
keyedMutex.pReleaseKeys = &releaseKey;

VkSubmitInfo submit_info = { VK_STRUCTURE_TYPE_SUBMIT_INFO, &keyedMutex };
submit_info.commandBufferCount = 1;
submit_info.pCommandBuffers = &cmd_buf;
vkQueueSubmit(queue, 1, &submit_info, VK_NULL_HANDLE);

Version History

- Revision 2, 2016-08-11 (James Jones)
  ◦ Updated sample code based on the NV external memory extensions.
  ◦ Renamed from NVX to NV extension.
  ◦ Added Overview and Description sections.
  ◦ Updated sample code to use the NV external memory extensions.

- Revision 1, 2016-06-14 (Carsten Rohde)
  ◦ Initial draft.

VK_VALVE_mutable_descriptor_type

Name String

VK_VALVE_mutable_descriptor_type

Extension Type

Device extension

Registered Extension Number

352

Revision

1

Ratification Status

Not ratified

Extension and Version Dependencies

VK_KHR_maintenance3

Deprecation state

- Promoted to VK_EXT_mutable_descriptor_type extension

Special Use

- D3D support

Contact

- Joshua Ashton 🌐Joshua-Ashton
- Hans-Kristian Arntzen 🌐HansKristian-Work

Other Extension Metadata
**Description**

This extension allows applications to reduce descriptor memory footprint by allowing a descriptor to be able to mutate to a given list of descriptor types depending on which descriptor types are written into, or copied into a descriptor set.

The main use case this extension intends to address is descriptor indexing with `VK_DESCRIPTOR_BINDING_VARIABLE_DESCRIPTOR_COUNT_BIT` where the descriptor types are completely generic, as this means applications can allocate one large descriptor set, rather than having one large descriptor set per descriptor type, which significantly bloats descriptor memory usage and causes performance issues.

This extension also adds a mechanism to declare that a descriptor pool, and therefore the descriptor sets that are allocated from it, reside only in host memory; as such these descriptors can only be updated/copied, but not bound.

These features together allow much more efficient emulation of the raw D3D12 binding model. This extension is primarily intended to be useful for API layering efforts.

**New Structures**

- `VkMutableDescriptorTypeListVALVE`
- Extending `VkDescriptorSetLayoutCreateInfo, VkDescriptorPoolCreateInfo`:
  - `VkMutableDescriptorTypeCreateInfoVALVE`
- Extending `VkPhysicalDeviceFeatures2, VkDeviceCreateInfo`:
  - `VkPhysicalDeviceMutableDescriptorTypeFeaturesVALVE`

**New Enum Constants**

- `VK_VALVE_MUTABLE_DESCRIPTOR_TYPE_EXTENSION_NAME`
- `VK_VALVE_MUTABLE_DESCRIPTOR_TYPE_SPEC_VERSION`
- Extending `VkDescriptorPoolCreateFlagBits`:
  - `VK_DESCRIPTOR_POOL_CREATE_HOST_ONLY_BIT_VALVE`
- Extending `VkDescriptorSetLayoutCreateFlagBits`:
  - `VK_DESCRIPTOR_SET_LAYOUT_CREATE_HOST_ONLY_POOL_BIT_VALVE`
• Extending VkDescriptorType:
  ◦ VK_DESCRIPTOR_TYPE_MUTABLE_VALVE

• Extending VkStructureType:
  ◦ VK_STRUCTURE_TYPE_MUTABLE_DESCRIPTOR_TYPE_CREATE_INFO_VALVE
  ◦ VK_STRUCTURE_TYPE_PHYSICAL_DEVICE_MUTABLE_DESCRIPTOR_TYPE_FEATURES_VALVE

Version History

• Revision 1, 2020-12-01 (Joshua Ashton, Hans-Kristian Arntzen)
  ◦ Initial specification, squashed from public draft.
Appendix F: Vulkan Roadmap Milestones

Roadmap milestones are intended to be supported by mid-to-high-end smartphones, tablets, laptops, consoles, and desktop devices.

Each milestone indicates support for a set of extensions, features, limits, and formats across these devices, and should be supported by all such new hardware shipping by the end of the target year or shortly thereafter.

Roadmap 2022

The Roadmap 2022 milestone is intended to be supported by newer mid-to-high-end devices shipping in 2022 or shortly thereafter across mainstream smartphone, tablet, laptops, console and desktop devices.

Required API versions

This profile requires Vulkan 1.3.

Required Features

The following core optional features are required to be supported:

- Vulkan 1.0 Optional Features
  - fullDrawIndexUint32
  - imageCubeArray
  - independentBlend
  - sampleRateShading
  - drawIndirectFirstInstance
  - depthClamp
  - depthBiasClamp
  - samplerAnisotropy
  - occlusionQueryPrecise
  - fragmentStoresAndAtomics
  - shaderStorageImageExtendedFormats
  - shaderUniformBufferArrayDynamicIndexing
  - shaderSampledImageArrayDynamicIndexing
  - shaderStorageBufferArrayDynamicIndexing
  - shaderStorageImageArrayDynamicIndexing

- Vulkan 1.1 Optional Features
  - samplerYcbcrConversion
• Vulkan 1.2 Optional Features
  ◦ samplerMirrorClampToEdge
  ◦ descriptorIndexing
  ◦ shaderUniformTexelBufferArrayDynamicIndexing
  ◦ shaderStorageTexelBufferArrayDynamicIndexing
  ◦ shaderUniformBufferArrayNonUniformIndexing
  ◦ shaderSampledImageArrayNonUniformIndexing
  ◦ shaderStorageBufferArrayNonUniformIndexing
  ◦ shaderUniformTexelBufferArrayNonUniformIndexing
  ◦ descriptorBindingSampledImageUpdateAfterBind
  ◦ descriptorBindingStorageImageUpdateAfterBind
  ◦ descriptorBindingStorageBufferUpdateAfterBind
  ◦ descriptorBindingUniformTexelBufferUpdateAfterBind
  ◦ descriptorBindingStorageTexelBufferUpdateAfterBind
  ◦ descriptorBindingUpdateUnusedWhilePending
  ◦ descriptorBindingPartiallyBound
  ◦ descriptorBindingVariableDescriptorCount
  ◦ runtimeDescriptorArray
  ◦ scalarBlockLayout

Required Limits

The following core increased limits are required

Table 99. Vulkan 1.0 Limits

<table>
<thead>
<tr>
<th>Limit Name</th>
<th>Unsupported Limit</th>
<th>Core Limit</th>
<th>Profile Limit</th>
<th>Limit Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>maxImageDimension1D</td>
<td>-</td>
<td>4096</td>
<td>8192</td>
<td>min</td>
</tr>
<tr>
<td>maxImageDimension2D</td>
<td>-</td>
<td>4096</td>
<td>8192</td>
<td>min</td>
</tr>
<tr>
<td>maxImageDimensionCube</td>
<td>-</td>
<td>4096</td>
<td>8192</td>
<td>min</td>
</tr>
<tr>
<td>maxImageArrayLayers</td>
<td>-</td>
<td>256</td>
<td>2048</td>
<td>min</td>
</tr>
<tr>
<td>maxUniformBufferRange</td>
<td>-</td>
<td>16384</td>
<td>65536</td>
<td>min</td>
</tr>
<tr>
<td>bufferImageGranularity</td>
<td>-</td>
<td>131072</td>
<td>4096</td>
<td>max</td>
</tr>
<tr>
<td>maxPerStageDescriptorSamplers</td>
<td>-</td>
<td>16</td>
<td>64</td>
<td>min</td>
</tr>
<tr>
<td>Limit Name</td>
<td>Unsupported Limit</td>
<td>Core Limit</td>
<td>Profile Limit</td>
<td>Limit Type¹</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>-------------------</td>
<td>------------</td>
<td>---------------</td>
<td>-------------</td>
</tr>
<tr>
<td>maxPerStageDescriptorUniformBuffers</td>
<td>-</td>
<td>12</td>
<td>15</td>
<td>min</td>
</tr>
<tr>
<td>maxPerStageDescriptorStorageBuffers</td>
<td>-</td>
<td>4</td>
<td>30</td>
<td>min</td>
</tr>
<tr>
<td>maxPerStageDescriptorSampledImages</td>
<td>-</td>
<td>16</td>
<td>200</td>
<td>min</td>
</tr>
<tr>
<td>maxPerStageDescriptorStorageImages</td>
<td>-</td>
<td>4</td>
<td>16</td>
<td>min</td>
</tr>
<tr>
<td>maxPerStageResources</td>
<td>-</td>
<td>128</td>
<td>200</td>
<td>min</td>
</tr>
<tr>
<td>maxDescriptorSetSamplers</td>
<td>-</td>
<td>96</td>
<td>576</td>
<td>min, n × PerStage</td>
</tr>
<tr>
<td>maxDescriptorSetUniformBuffers</td>
<td>-</td>
<td>72</td>
<td>90</td>
<td>min, n × PerStage</td>
</tr>
<tr>
<td>maxDescriptorSetStorageBuffers</td>
<td>-</td>
<td>24</td>
<td>96</td>
<td>min, n × PerStage</td>
</tr>
<tr>
<td>maxDescriptorSetSampledImages</td>
<td>-</td>
<td>96</td>
<td>1800</td>
<td>min, n × PerStage</td>
</tr>
<tr>
<td>maxDescriptorSetStorageImages</td>
<td>-</td>
<td>24</td>
<td>144</td>
<td>min, n × PerStage</td>
</tr>
<tr>
<td>maxFragmentCombinedOutputResources</td>
<td>-</td>
<td>4</td>
<td>16</td>
<td>min</td>
</tr>
<tr>
<td>maxComputeWorkGroupInvocations</td>
<td>-</td>
<td>128</td>
<td>256</td>
<td>min</td>
</tr>
<tr>
<td>maxComputeWorkGroupSize</td>
<td>-</td>
<td>(128,128,64)</td>
<td>(256,256,64)</td>
<td>min</td>
</tr>
<tr>
<td>subTexelPrecisionBits</td>
<td>-</td>
<td>4</td>
<td>8</td>
<td>min</td>
</tr>
<tr>
<td>mipmapPrecisionBits</td>
<td>-</td>
<td>4</td>
<td>6</td>
<td>min</td>
</tr>
<tr>
<td>maxSamplerLodBias</td>
<td>-</td>
<td>2</td>
<td>14</td>
<td>min</td>
</tr>
<tr>
<td>pointSizeGranularity</td>
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<td>1.0</td>
<td>0.125</td>
<td>max, fixed point increment</td>
</tr>
<tr>
<td>linewidthGranularity</td>
<td>0.0</td>
<td>1.0</td>
<td>0.5</td>
<td>max, fixed point increment</td>
</tr>
<tr>
<td>standardSampleLocations</td>
<td>-</td>
<td>-</td>
<td>VK_TRUE</td>
<td>implementation-dependent</td>
</tr>
<tr>
<td>maxColorAttachments</td>
<td>-</td>
<td>4</td>
<td>7</td>
<td>min</td>
</tr>
</tbody>
</table>

Table 100. Vulkan 1.1 Limits
<table>
<thead>
<tr>
<th>Limit Name</th>
<th>Unsupported Limit</th>
<th>Core Limit</th>
<th>Profile Limit</th>
<th>Limit Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>subgroupSize</td>
<td>-</td>
<td>1/4</td>
<td>4</td>
<td>implementation-dependent</td>
</tr>
<tr>
<td>subgroupSupportedStages</td>
<td>-</td>
<td>VK_SHADER_STAGE_COMPUTE_BIT</td>
<td>VK_SHADER_STAGE_COMPUTE_BIT</td>
<td>implementation-dependent</td>
</tr>
<tr>
<td>subgroupSupportedOperations</td>
<td>-</td>
<td>VK_SUBGROUP_FEATURE_BASIC_BIT</td>
<td>VK_SUBGROUP_FEATURE_BASIC_BIT</td>
<td>implementation-dependent</td>
</tr>
</tbody>
</table>

Table 101. Vulkan 1.2 Limits

<table>
<thead>
<tr>
<th>Limit Name</th>
<th>Unsupported Limit</th>
<th>Core Limit</th>
<th>Profile Limit</th>
<th>Limit Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>shaderSignedZeroInfNanPreserveFloat16</td>
<td>-</td>
<td>-</td>
<td>VK_TRUE</td>
<td>implementation-dependent</td>
</tr>
<tr>
<td>shaderSignedZeroInfNanPreserveFloat32</td>
<td>-</td>
<td>-</td>
<td>VK_TRUE</td>
<td>implementation-dependent</td>
</tr>
<tr>
<td>maxPerStageDescriptorUpdateAfterBindInputAttachments</td>
<td>0</td>
<td>4</td>
<td>7</td>
<td>min</td>
</tr>
</tbody>
</table>

Table 102. Vulkan 1.3 Limits
<table>
<thead>
<tr>
<th>Limit Name</th>
<th>Unsupported Limit</th>
<th>Core Limit</th>
<th>Profile Limit</th>
<th>Limit Type</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>maxSubgroupSize</code></td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>min</td>
</tr>
</tbody>
</table>

**Required extensions**

The following extensions are **required**

`VK_KHR_global_priority`
Appendix G: API Boilerplate

This appendix defines Vulkan API features that are infrastructure required for a complete functional description of Vulkan, but do not logically belong elsewhere in the Specification.

Vulkan Header Files

Vulkan is defined as an API in the C99 language. Khronos provides a corresponding set of header files for applications using the API, which may be used in either C or C++ code. The interface descriptions in the specification are the same as the interfaces defined in these header files, and both are derived from the `vk.xml` XML API Registry, which is the canonical machine-readable description of the Vulkan API. The Registry, scripts used for processing it into various forms, and documentation of the registry schema are available as described at [https://registry.khronos.org/vulkan/#apiregistry](https://registry.khronos.org/vulkan/#apiregistry).

Language bindings for other languages can be defined using the information in the Specification and the Registry. Khronos does not provide any such bindings, but third-party developers have created some additional bindings.

Vulkan Combined API Header `vulkan.h` (Informative)

Applications normally will include the header `vulkan.h`. In turn, `vulkan.h` always includes the following headers:

- `vk_platform.h`, defining platform-specific macros and headers.
- `vulkan_core.h`, defining APIs for the Vulkan core and all registered extensions other than window system-specific and provisional extensions, which are included in separate header files.

In addition, specific preprocessor macros defined at the time `vulkan.h` is included cause header files for the corresponding window system-specific and provisional interfaces to be included, as described below.

Vulkan Platform-Specific Header `vk_platform.h` (Informative)

Platform-specific macros and interfaces are defined in `vk_platform.h`. These macros are used to control platform-dependent behavior, and their exact definitions are under the control of specific platforms and Vulkan implementations.

Platform-Specific Calling Conventions

On many platforms the following macros are empty strings, causing platform- and compiler-specific default calling conventions to be used.

`VKAPI_ATTR` is a macro placed before the return type in Vulkan API function declarations. This macro controls calling conventions for C++11 and GCC/Clang-style compilers.

`VKAPI_CALL` is a macro placed after the return type in Vulkan API function declarations. This macro controls calling conventions for MSVC-style compilers.
VKAPI_PTR is a macro placed between the '(' and '* in Vulkan API function pointer declarations. This macro also controls calling conventions, and typically has the same definition as VKAPI_ATTR or VKAPI_CALL, depending on the compiler.

With these macros, a Vulkan function declaration takes the form of:

```
VKAPI_ATTR <return_type> VKAPI_CALL <command_name>(<command_parameters>);
```

Additionally, a Vulkan function pointer type declaration takes the form of:

```
typedef <return_type> (VKAPI_PTR *PFN_<command_name>)(<command_parameters>);
```

Platform-Specific Header Control

If the VK_NO_STDINT_H macro is defined by the application at compile time, extended integer types used by the Vulkan API, such as uint8_t, must also be defined by the application. Otherwise, the Vulkan headers will not compile. If VK_NO_STDINT_H is not defined, the system <stdint.h> is used to define these types. There is a fallback path when Microsoft Visual Studio version 2008 and earlier versions are detected at compile time.

If the VK_NO_STDDEF_H macro is defined by the application at compile time, size_t, must also be defined by the application. Otherwise, the Vulkan headers will not compile. If VK_NO_STDDEF_H is not defined, the system <stddef.h> is used to define this type.

Vulkan Core API Header vulkan_core.h

Applications that do not make use of window system-specific extensions may simply include vulkan_core.h instead of vulkan.h, although there is usually no reason to do so. In addition to the Vulkan API, vulkan_core.h also defines a small number of C preprocessor macros that are described below.

Vulkan Header File Version Number

VK_HEADER_VERSION is the version number of the vulkan_core.h header. This value is kept synchronized with the patch version of the released Specification.

```
// Provided by VK_VERSION_1_0
// Version of this file
#define VK_HEADER_VERSION 265
```

VK_HEADER_VERSION_COMPLETE is the complete version number of the vulkan_core.h header, comprising the major, minor, and patch versions. The major/minor values are kept synchronized with the complete version of the released Specification. This value is intended for use by automated tools to identify exactly which version of the header was used during their generation.

Applications should not use this value as their VkApplicationInfo::apiVersion. Instead applications
should explicitly select a specific fixed major/minor API version using, for example, one of the
\texttt{VK\_API\_VERSION\_\_\_*} values.

\begin{verbatim}
// Provided by VK\_VERSION\_1\_0
// Complete version of this file
#define VK\_HEADER\_VERSION\_COMPLETE VK\_MAKE\_API\_VERSION(0, 1, 3, VK\_HEADER\_VERSION)
\end{verbatim}

\texttt{VK\_API\_VERSION} is now commented out of \texttt{vulkan\_core.h} and \textbf{cannot} be used.

\begin{verbatim}
// Provided by VK\_VERSION\_1\_0
// DEPRECATED: This define has been removed. Specific version defines (e.g.
// VK\_API\_VERSION\_1\_0), or the VK\_MAKE\_API\_VERSION macro, should be used instead.
// #define VK\_API\_VERSION VK\_MAKE\_API\_VERSION(0, 1, 0, 0) // Patch version should
// always be set to 0
\end{verbatim}

\textbf{Vulkan Handle Macros}

\texttt{VK\_DEFINE\_HANDLE} defines a \textit{dispatchable handle} type.

\begin{verbatim}
// Provided by VK\_VERSION\_1\_0
#define VK\_DEFINE\_HANDLE(object) typedef struct object\_T* object;
\end{verbatim}

- \textit{object} is the name of the resulting C type.

The only dispatchable handle types are those related to device and instance management, such as \texttt{VkDevice}.

\texttt{VK\_DEFINE\_NON\_DISPATCHABLE\_HANDLE} defines a \textit{non-dispatchable handle} type.

\begin{verbatim}
// Provided by VK\_VERSION\_1\_0

#ifndef VK\_DEFINE\_NON\_DISPATCHABLE\_HANDLE
#if (VK\_USE\_64\_BIT\_PTR\_DEFINES==1)
#define VK\_DEFINE\_NON\_DISPATCHABLE\_HANDLE(object) typedef struct object\_T object;
#else
#define VK\_DEFINE\_NON\_DISPATCHABLE\_HANDLE(object) typedef uint64_t object;
#endif
#endif
\end{verbatim}

- \textit{object} is the name of the resulting C type.

Most Vulkan handle types, such as \texttt{VkBuffer}, are non-dispatchable.

\begin{note}
\textit{Note}
\end{note}
The `vulkan_core.h` header allows the `VK_DEFINE_NON_DISPATCHABLE_HANDLE` and `VK_NULL_HANDLE` definitions to be overridden by the application. If `VK_DEFINE_NON_DISPATCHABLE_HANDLE` is already defined when `vulkan_core.h` is compiled, the default definitions for `VK_DEFINE_NON_DISPATCHABLE_HANDLE` and `VK_NULL_HANDLE` are skipped. This allows the application to define a binary-compatible custom handle which may provide more type-safety or other features needed by the application. Applications must not define handles in a way that is not binary compatible - where binary compatibility is platform dependent.

`VK_NULL_HANDLE` is a reserved value representing a non-valid object handle. It may be passed to and returned from Vulkan commands only when specifically allowed.

```c
// Provided by VK_VERSION_1_0

#ifndef VK_DEFINE_NON_DISPATCHABLE_HANDLE
    #if (VK_USE_64_BIT_PTR_DEFINES==1)
        #if (defined(__cplusplus) && (__cplusplus >= 201103L)) || (defined(_MSVC_LANG) && (_MSVC_LANG >= 201103L))
            #define VK_NULL_HANDLE nullptr
        #else
            #define VK_NULL_HANDLE ((void*)0)
        #endif
    #else
        #define VK_NULL_HANDLE 0ULL
    #endif
#else
    #define VK_NULL_HANDLE 0
#endif
```

`VK_USE_64_BIT_PTR_DEFINES` defines whether the default non-dispatchable handles are declared using either a 64-bit pointer type or a 64-bit unsigned integer type.

`VK_USE_64_BIT_PTR_DEFINES` is set to '1' to use a 64-bit pointer type or any other value to use a 64-bit unsigned integer type.

```c
// Provided by VK_VERSION_1_0

#ifndef VK_USE_64_BIT_PTR_DEFINES
    #if defined(__LP64__) || defined(_WIN64) || (defined(__x86_64__) && !defined(__ILP32__)) || defined(_M_X64) || defined(__ia64) || defined(_M_IA64) || defined(__aarch64__) || defined(__powerpc64__)
        #define VK_USE_64_BIT_PTR_DEFINES 1
    #else
        #define VK_USE_64_BIT_PTR_DEFINES 0
    #endif
#endif
```
The `vulkan_core.h` header allows the `VK_USE_64_BIT_PTR_DEFINES` definition to be overridden by the application. This allows the application to select either a 64-bit pointer type or a 64-bit unsigned integer type for non-dispatchable handles in the case where the predefined preprocessor check does not identify the desired configuration.

This macro was introduced starting with the Vulkan 1.2.174 headers, and its availability can be checked at compile time by requiring `VK_HEADER_VERSION >= 174`.

It is not available if you are using older headers, such as may be shipped with an older Vulkan SDK. Developers requiring this functionality may wish to include a copy of the current Vulkan headers with their project in this case.

### Window System-Specific Header Control (Informative)

To use a Vulkan extension supporting a platform-specific window system, header files for that window system must be included at compile time, or platform-specific types must be forward-declared. The Vulkan header files are unable to determine whether or not an external header is available at compile time, so platform-specific extensions are provided in separate headers from the core API and platform-independent extensions, allowing applications to decide which ones they need to be defined and how the external headers are included.

Extensions dependent on particular sets of platform headers, or that forward-declare platform-specific types, are declared in a header named for that platform. Before including these platform-specific Vulkan headers, applications must include both `vulkan_core.h` and any external native headers the platform extensions depend on.

As a convenience for applications that do not need the flexibility of separate platform-specific Vulkan headers, `vulkan.h` includes `vulkan_core.h`, and then conditionally includes platform-specific Vulkan headers and the external headers they depend on. Applications control which platform-specific headers are included by #defining macros before including `vulkan.h`.

The correspondence between platform-specific extensions, external headers they require, the platform-specific header which declares them, and the preprocessor macros which enable inclusion by `vulkan.h` are shown in the following table.

<table>
<thead>
<tr>
<th>Extension Name</th>
<th>Window System Name</th>
<th>Platform-specific Header</th>
<th>Required External Headers</th>
<th>Controlling <code>vulkan.h</code> Macro</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_KHR_android_surface</td>
<td>Android</td>
<td><code>vulkan_android.h</code></td>
<td>None</td>
<td><code>VK_USE_PLATFORM_ANDROID_KHR</code></td>
</tr>
<tr>
<td>VK_KHR_wayland_surface</td>
<td>Wayland</td>
<td><code>vulkan_wayland.h</code></td>
<td><code>&lt;wayland-client.h&gt;</code></td>
<td><code>VK_USE_PLATFORM_WAYLAND_KHR</code></td>
</tr>
<tr>
<td>Extension Name</td>
<td>Window System Name</td>
<td>Platform-specific Header</td>
<td>Required External Headers</td>
<td>Controlling Macro</td>
</tr>
<tr>
<td>---------------------------------------------------</td>
<td>--------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>VK_KHR_win32_surface,</td>
<td>Microsoft Windows</td>
<td>vulkan_win32.h</td>
<td>&lt;windows.h&gt;</td>
<td>VK_USE_PLATFORM_WIN32_KHR</td>
</tr>
<tr>
<td>VK_KHR_external_memory_win32,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_KHR_win32_keyed_mutex,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_KHR_external_semaphore_win32,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_KHR_external_fence_win32,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_NV_external_memory_win32,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_KHR_win32_keyed_mutex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_KHR_xcb_surface</td>
<td>X11 Xcb</td>
<td>vulkan_xcb.h</td>
<td>&lt;xcb/xcb.h&gt;</td>
<td>VK_USE_PLATFORM_XCB_KHR</td>
</tr>
<tr>
<td>VK_KHR_xlib_surface</td>
<td>X11 Xlib</td>
<td>vulkan_xlib.h</td>
<td>&lt;X11/Xlib.h&gt;</td>
<td>VK_USE_PLATFORM_XLIB_KHR</td>
</tr>
<tr>
<td>VK_EXT_directfb_surface</td>
<td>DirectFB</td>
<td>vulkan_directfb.h</td>
<td>&lt;directfb/directfb.h&gt;</td>
<td>VK_USE_PLATFORM_DIRECTFB_EXT</td>
</tr>
<tr>
<td>VK_EXT_acquire_xlib_display</td>
<td>X11 XRANDR</td>
<td>vulkan_xlib_xrandr.h</td>
<td>&lt;X11/Xlib.h&gt;, &lt;X11/extensions/Xr andr.h&gt;</td>
<td>VK_USE_PLATFORM_XLIB_XRANDR_EXT</td>
</tr>
<tr>
<td>VK_GGP_stream_descriptor_surface,</td>
<td>Google Games Platform</td>
<td>vulkan_ggp.h</td>
<td>&lt;ggp_c/vulkan_types.h&gt;</td>
<td>VK_USE_PLATFORM_GGP</td>
</tr>
<tr>
<td>VK_GGP_frame_token</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VK_MVK_ios_surface</td>
<td>iOS</td>
<td>vulkan_ios.h</td>
<td>None</td>
<td>VK_USE_PLATFORM_IOS_MVK</td>
</tr>
<tr>
<td>VK_MVK_macos_surface</td>
<td>macOS</td>
<td>vulkan_macos.h</td>
<td>None</td>
<td>VK_USE_PLATFORM_MACOS_MVK</td>
</tr>
<tr>
<td>VK_NN_vi_surface</td>
<td>VI</td>
<td>vulkan_vi.h</td>
<td>None</td>
<td>VK_USE_PLATFORM_VI_NN</td>
</tr>
<tr>
<td>VK_FUCHSIA_imagepipe_surface</td>
<td>Fuchsia</td>
<td>vulkan_fuchsia.h</td>
<td>&lt;zircon/types.h&gt;</td>
<td>VK_USE_PLATFORM_FUCHSIA</td>
</tr>
<tr>
<td>VK_EXT_metal_surface</td>
<td>Metal on CoreAnimation</td>
<td>vulkan_metal.h</td>
<td>None</td>
<td>VK_USE_PLATFORM_METAL_EXT</td>
</tr>
<tr>
<td>VK_QNX_screen_surface</td>
<td>QNX Screen</td>
<td>vulkan_screen.h</td>
<td>&lt;screen/screen.h&gt;</td>
<td>VK_USE_PLATFORM_SCREEN_QNX</td>
</tr>
</tbody>
</table>

Note

This section describes the purpose of the headers independently of the specific underlying functionality of the window system extensions themselves. Each extension name will only link to a description of that extension when viewing a specification built with that extension included.
Provisional Extension Header Control (Informative)

Provisional extensions should not be used in production applications. The functionality defined by such extensions may change in ways that break backwards compatibility between revisions, and before final release of a non-provisional version of that extension.

Provisional extensions are defined in a separate provisional header, vulkan_beta.h, allowing applications to decide whether or not to include them. The mechanism is similar to window system-specific headers: before including vulkan_beta.h, applications must include vulkan_core.h.

Note
Sometimes a provisional extension will include a subset of its interfaces in vulkan_core.h. This may occur if the provisional extension is promoted from an existing vendor or EXT extension and some of the existing interfaces are defined as aliases of the provisional extension interfaces. All other interfaces of that provisional extension which are not aliased will be included in vulkan_beta.h.

As a convenience for applications, vulkan.h conditionally includes vulkan_beta.h. Applications can control inclusion of vulkan_beta.h by #defining the macro VK_ENABLE_BETA_EXTENSIONS before including vulkan.h.

Note
Starting in version 1.2.171 of the Specification, all provisional enumerants are protected by the macro VK_ENABLE_BETA_EXTENSIONS. Applications needing to use provisional extensions must always define this macro, even if they are explicitly including vulkan_beta.h. This is a minor change to behavior, affecting only provisional extensions.

Note
This section describes the purpose of the provisional header independently of the specific provisional extensions which are contained in that header at any given time. The extension appendices for provisional extensions note their provisional status, and link back to this section for more information. Provisional extensions are intended to provide early access for bleeding-edge developers, with the understanding that extension interfaces may change in response to developer feedback. Provisional extensions are very likely to eventually be updated and released as non-provisional extensions, but there is no guarantee this will happen, or how long it will take if it does happen.

Video Std Headers

Performing video coding operations usually involves the application having to provide various parameters, data structures, or other syntax elements specific to the particular video compression standard used, and the associated semantics are covered by the specification of those.

The interface descriptions of these are available in the header files derived from the video.xml XML
file, which is the canonical machine-readable description of data structures and enumerations that are associated with the externally-provided video compression standards.

Table 104. Video Std Headers

<table>
<thead>
<tr>
<th>Video Std Header Name</th>
<th>Description</th>
<th>Header File</th>
<th>Related Extensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>vulkan_video_codecs_common</td>
<td>Codec-independent common definitions</td>
<td><code>&lt;vk_video/vulkan_video_codecs_common.h&gt;</code></td>
<td></td>
</tr>
<tr>
<td>vulkan_video_codec_h264std</td>
<td>ITU-T H.264 common definitions</td>
<td><code>&lt;vk_video/vulkan_video_codec_h264std.h&gt;</code></td>
<td>VK_KHR_video_decode_h264, VK_EXT_video_encode_h264</td>
</tr>
<tr>
<td>vulkan_video_codec_h264std_decode</td>
<td>ITU-T H.264 decode-specific definitions</td>
<td><code>&lt;vk_video/vulkan_video_codec_h264std_decode.h&gt;</code></td>
<td>VK_KHR_video_decode_h264</td>
</tr>
<tr>
<td>vulkan_video_codec_h264std_encode</td>
<td>ITU-T H.264 encode-specific definitions</td>
<td><code>&lt;vk_video/vulkan_video_codec_h264std_encode.h&gt;</code></td>
<td>VK_EXT_video_encode_h264</td>
</tr>
<tr>
<td>vulkan_video_codec_h265std</td>
<td>ITU-T H.265 common definitions</td>
<td><code>&lt;vk_video/vulkan_video_codec_h265std.h&gt;</code></td>
<td>VK_KHR_video_decode_h265, VK_EXT_video_encode_h265</td>
</tr>
<tr>
<td>vulkan_video_codec_h265std_decode</td>
<td>ITU-T H.265 decode-specific definitions</td>
<td><code>&lt;vk_video/vulkan_video_codec_h265std_decode.h&gt;</code></td>
<td>VK_KHR_video_decode_h265</td>
</tr>
<tr>
<td>vulkan_video_codec_h265std_encode</td>
<td>ITU-T H.265 encode-specific definitions</td>
<td><code>&lt;vk_video/vulkan_video_codec_h265std_encode.h&gt;</code></td>
<td>VK_EXT_video_encode_h265</td>
</tr>
</tbody>
</table>
Appendix H: Invariance

The Vulkan specification is not pixel exact. It therefore does not guarantee an exact match between images produced by different Vulkan implementations. However, the specification does specify exact matches, in some cases, for images produced by the same implementation. The purpose of this appendix is to identify and provide justification for those cases that require exact matches.

Repeatability

The obvious and most fundamental case is repeated issuance of a series of Vulkan commands. For any given Vulkan and framebuffer state vector, and for any Vulkan command, the resulting Vulkan and framebuffer state must be identical whenever the command is executed on that initial Vulkan and framebuffer state. This repeatability requirement does not apply when using shaders containing side effects (image and buffer variable stores and atomic operations), because these memory operations are not guaranteed to be processed in a defined order.

The repeatability requirement does not apply for rendering done using a graphics pipeline that uses \texttt{VK_RASTERIZATION\_ORDER\_RELAXED\_AMD}.

One purpose of repeatability is avoidance of visual artifacts when a double-buffered scene is redrawn. If rendering is not repeatable, swapping between two buffers rendered with the same command sequence may result in visible changes in the image. Such false motion is distracting to the viewer. Another reason for repeatability is testability.

Repeatability, while important, is a weak requirement. Given only repeatability as a requirement, two scenes rendered with one (small) polygon changed in position might differ at every pixel. Such a difference, while within the law of repeatability, is certainly not within its spirit. Additional invariance rules are desirable to ensure useful operation.

Multi-pass Algorithms

Invariance is necessary for a whole set of useful multi-pass algorithms. Such algorithms render multiple times, each time with a different Vulkan mode vector, to eventually produce a result in the framebuffer. Examples of these algorithms include:

- “Erasing” a primitive from the framebuffer by redrawing it, either in a different color or using the XOR logical operation.
- Using stencil operations to compute capping planes.

Invariance Rules

For a given Vulkan device:

\textbf{Rule 1} For any given Vulkan and framebuffer state vector, and for any given Vulkan command, the resulting Vulkan and framebuffer state must be identical each time the command is executed on that initial Vulkan and framebuffer state.
Rule 2 Changes to the following state values have no side effects (the use of any other state value is not affected by the change):

Required:

- Color and depth/stencil attachment contents
- Scissor parameters (other than enable)
- Write masks (color, depth, stencil)
- Clear values (color, depth, stencil)

Strongly suggested:

- Stencil parameters (other than enable)
- Depth test parameters (other than enable)
- Blend parameters (other than enable)
- Logical operation parameters (other than enable)

Corollary 1 Fragment generation is invariant with respect to the state values listed in Rule 2.

Rule 3 The arithmetic of each per-fragment operation is invariant except with respect to parameters that directly control it.

Corollary 2 Images rendered into different color attachments of the same framebuffer, either simultaneously or separately using the same command sequence, are pixel identical.

Rule 4 Identical pipelines will produce the same result when run multiple times with the same input. The wording “Identical pipelines” means VkPipeline objects that have been created with identical SPIR-V binaries and identical state, which are then used by commands executed using the same Vulkan state vector. Invariance is relaxed for shaders with side effects, such as performing stores or atomics.

Rule 5 All fragment shaders that either conditionally or unconditionally assign FragCoord.z to FragDepth are depth-invariant with respect to each other, for those fragments where the assignment to FragDepth actually is done.

If a sequence of Vulkan commands specifies primitives to be rendered with shaders containing side effects (image and buffer variable stores and atomic operations), invariance rules are relaxed. In particular, rule 1, corollary 2, and rule 4 do not apply in the presence of shader side effects.

The following weaker versions of rules 1 and 4 apply to Vulkan commands involving shader side effects:

Rule 6 For any given Vulkan and framebuffer state vector, and for any given Vulkan command, the contents of any framebuffer state not directly or indirectly affected by results of shader image or buffer variable stores or atomic operations must be identical each time the command is executed on that initial Vulkan and framebuffer state.

Rule 7 Identical pipelines will produce the same result when run multiple times with the same input.
as long as:

- shader invocations do not use image atomic operations;
- no framebuffer memory is written to more than once by image stores, unless all such stores write the same value; and
- no shader invocation, or other operation performed to process the sequence of commands, reads memory written to by an image store.

Note

The OpenGL specification has the following invariance rule: Consider a primitive \( p' \) obtained by translating a primitive \( p \) through an offset \((x, y)\) in window coordinates, where \( x \) and \( y \) are integers. As long as neither \( p' \) nor \( p \) is clipped, it must be the case that each fragment \( f' \) produced from \( p' \) is identical to a corresponding fragment \( f \) from \( p \) except that the center of \( f' \) is offset by \((x, y)\) from the center of \( f \).

This rule does not apply to Vulkan and is an intentional difference from OpenGL.

When any sequence of Vulkan commands triggers shader invocations that perform image stores or atomic operations, and subsequent Vulkan commands read the memory written by those shader invocations, these operations must be explicitly synchronized.

**Tessellation Invariance**

When using a pipeline containing tessellation evaluation shaders, the fixed-function tessellation primitive generator consumes the input patch specified by an application and emits a new set of primitives. The following invariance rules are intended to provide repeatability guarantees. Additionally, they are intended to allow an application with a carefully crafted tessellation evaluation shader to ensure that the sets of triangles generated for two adjacent patches have identical vertices along shared patch edges, avoiding “cracks” caused by minor differences in the positions of vertices along shared edges.

**Rule 1** When processing two patches with identical outer and inner tessellation levels, the tessellation primitive generator will emit an identical set of point, line, or triangle primitives as long as the pipeline used to process the patch primitives has tessellation evaluation shaders specifying the same tessellation mode, spacing, vertex order, and point mode decorations. Two sets of primitives are considered identical if and only if they contain the same number and type of primitives and the generated tessellation coordinates for the vertex numbered \( m \) of the primitive numbered \( n \) are identical for all values of \( m \) and \( n \).

**Rule 2** The set of vertices generated along the outer edge of the subdivided primitive in triangle and quad tessellation, and the tessellation coordinates of each, depend only on the corresponding outer tessellation level and the spacing decorations in the tessellation shaders of the pipeline.

**Rule 3** The set of vertices generated when subdividing any outer primitive edge is always symmetric. For triangle tessellation, if the subdivision generates a vertex with tessellation coordinates of the form \((0, x, 1-x)\), \((x, 0, 1-x)\), or \((x, 1-x, 0)\), it will also generate a vertex with coordinates of exactly \((0, 1-x, x)\), \((1-x, 0, x)\), or \((1-x, x, 0)\).
Rule 4 The set of vertices generated when subdividing outer edges in triangular and quad tessellation must be independent of the specific edge subdivided, given identical outer tessellation levels and spacing. For example, if vertices at (x, 1 - x, 0) and (1-x, x, 0) are generated when subdividing the w = 0 edge in triangular tessellation, vertices must be generated at (x, 0, 1-x) and (1-x, 0, x) when subdividing an otherwise identical v = 0 edge. For quad tessellation, if vertices at (x, 0) and (1-x, 0) are generated when subdividing the v = 0 edge, vertices must be generated at (0, x) and (0, 1-x) when subdividing an otherwise identical u = 0 edge.

Rule 5 When processing two patches that are identical in all respects enumerated in rule 1 except for vertex order, the set of triangles generated for triangle and quad tessellation must be identical except for vertex and triangle order. For each triangle n1 produced by processing the first patch, there must be a triangle n2 produced when processing the second patch each of whose vertices has the same tessellation coordinates as one of the vertices in n1.

Rule 6 When processing two patches that are identical in all respects enumerated in rule 1 other than matching outer tessellation levels and/or vertex order, the set of interior triangles generated for triangle and quad tessellation must be identical in all respects except for vertex and triangle order. For each interior triangle n1 produced by processing the first patch, there must be a triangle n2 produced when processing the second patch each of whose vertices has the same tessellation coordinates as one of the vertices in n1. A triangle produced by the tessellator is considered an interior triangle if none of its vertices lie on an outer edge of the subdivided primitive.

Rule 7 For quad and triangle tessellation, the set of triangles connecting an inner and outer edge depends only on the inner and outer tessellation levels corresponding to that edge and the spacing decorations.

Rule 8 The value of all defined components of TessCoord will be in the range [0, 1]. Additionally, for any defined component x of TessCoord, the results of computing 1.0-x in a tessellation evaluation shader will be exact. If any floating-point values in the range [0, 1] fail to satisfy this property, such values must not be used as tessellation coordinate components.
Appendix I: Lexicon

This appendix defines terms, abbreviations, and API prefixes used in the Specification.

Glossary

The terms defined in this section are used consistently throughout the Specification and may be used with or without capitalization.

Accessible (Descriptor Binding)

A descriptor binding is accessible to a shader stage if that stage is included in the `stageFlags` of the descriptor binding. Descriptors using that binding can only be used by stages in which they are accessible.

Acquire Operation (Resource)

An operation that acquires ownership of an image subresource or buffer range.

Active (Descriptor Type)

When a descriptor with `mutable` type is updated with `vkUpdateDescriptorSets`, the active descriptor type changes. When the descriptor is consumed by shaders, it is the active descriptor type which determines validity, i.e. `VkDescriptorSetLayoutBinding::descriptorType` is replaced with the active descriptor type. A mismatch in active descriptor type and consumption by shader is considered an undefined descriptor.

Active (Transform Feedback)

Transform feedback is made active after `vkCmdBeginTransformFeedbackEXT` executes and remains active until `vkCmdEndTransformFeedbackEXT` executes. While transform feedback is active, data written to variables in the output interface of the last pre-rasterization shader stage of the graphics pipeline are captured to the bound transform feedback buffers if those variables are decorated for transform feedback.

Adjacent Vertex

A vertex in an adjacency primitive topology that is not part of a given primitive, but is accessible in geometry shaders.

Active Object (Ray Tracing)

A primitive or instance in a ray tracing acceleration structure which has a corresponding ID, and is not `inactive` (meaning that it is visible to rays).

Advanced Blend Operation

Blending performed using one of the blend operation enums introduced by the `VK_EXT_blend_operation_advanced` extension. See Advanced Blending Operations.

Alias (API type/command)

An identical definition of another API type/command with the same behavior but a different name.
Aliased Range (Memory)
A range of a device memory allocation that is bound to multiple resources simultaneously.

Allocation Scope
An association of a host memory allocation to a parent object or command, where the allocation’s lifetime ends before or at the same time as the parent object is freed or destroyed, or during the parent command.

Aspect (Image)
Some image types contain multiple kinds (called “aspects”) of data for each pixel, where each aspect is used in a particular way by the pipeline and may be stored differently or separately from other aspects. For example, the color components of an image format make up the color aspect of the image, and can be used as a framebuffer color attachment. Some operations, like depth testing, operate only on specific aspects of an image.

Attachment (Render Pass)
A zero-based integer index name used in render pass creation to refer to a framebuffer attachment that is accessed by one or more subpasses. The index also refers to an attachment description which includes information about the properties of the image view that will later be attached.

Availability Operation
An operation that causes the values generated by specified memory write accesses to become available for future access.

Available
A state of values written to memory that allows them to be made visible.

Axis-aligned Bounding Box
A box bounding a region in space defined by extents along each axis and thus representing a box where each edge is aligned to one of the major axes.

Back-Facing
See Facingness.

Batch
A single structure submitted to a queue as part of a queue submission command, describing a set of queue operations to execute.

Backwards Compatibility
A given version of the API is backwards compatible with an earlier version if an application, relying only on valid behavior and functionality defined by the earlier specification, is able to correctly run against each version without any modification. This assumes no active attempt by that application to not run when it detects a different version.

Binary Semaphore
A semaphore with a boolean payload indicating whether the semaphore is signaled or unsignaled. Represented by a VkSemaphore object created with a semaphore type of
**Binding (Memory)**

An association established between a range of a resource object and a range of a memory object. These associations determine the memory locations affected by operations performed on elements of a resource object. Memory bindings are established using the `vkBindBufferMemory` command for non-sparse buffer objects, using the `vkBindImageMemory` command for non-sparse image objects, and using the `vkQueueBindSparse` command for sparse resources.

**Blend Constant**

Four floating point (RGBA) values used as an input to blending.

**Blending**

Arithmetic operations between a fragment color value and a value in a color attachment that produce a final color value to be written to the attachment.

**Buffer**

A resource that represents a linear array of data in device memory. Represented by a `VkBuffer` object.

**Buffer Device Address**

A 64-bit value used in a shader to access buffer memory through the `PhysicalStorageBuffer` storage class.

**Buffer View**

An object that represents a range of a specific buffer, and state controlling how the contents are interpreted. Represented by a `VkBufferView` object.

**Built-In Variable**

A variable decorated in a shader, where the decoration makes the variable take values provided by the execution environment or values that are generated by fixed-function pipeline stages.

**Built-In Interface Block**

A block defined in a shader containing only variables decorated with built-in decorations, and is used to match against other shader stages.

**Clip Coordinates**

The homogeneous coordinate space in which vertex positions (`Position` decoration) are written by pre-rasterization shader stages.

**Clip Distance**

A built-in output from pre-rasterization shader stages defining a clip half-space against which the primitive is clipped.

**Clip Volume**

The intersection of the view volume with all clip half-spaces.
Color Attachment
A subpass attachment point, or image view, that is the target of fragment color outputs and blending.

Color Fragment
A unique color value within a pixel of a multisampled color image. The fragment mask will contain indices to the color fragment.

Color Renderable Format
A VkFormat where VK_FORMAT_FEATURE_COLOR_ATTACHMENT_BIT is set in one of the following, depending on the image's tiling:

- VkFormatProperties::linearTilingFeatures
- VkFormatProperties::optimalTilingFeatures or a VkFormat where VK_FORMAT_FEATURE_2_LINEAR_COLOR_ATTACHMENT_BIT_NV is set in VkFormatProperties::linearTilingFeatures
- VkDrmFormatModifierPropertiesEXT::drmFormatModifierTilingFeatures

Combined Image Sampler
A descriptor type that includes both a sampled image and a sampler.

Command Buffer
An object that records commands to be submitted to a queue. Represented by a VkCommandBuffer object.

Command Pool
An object that command buffer memory is allocated from, and that owns that memory. Command pools aid multithreaded performance by enabling different threads to use different allocators, without internal synchronization on each use. Represented by a VkCommandPool object.

Compatible Allocator
When allocators are compatible, allocations from each allocator can be freed by the other allocator.

Compatible Image Formats
When formats are compatible, images created with one of the formats can have image views created from it using any of the compatible formats. Also see Size-Compatible Image Formats.

Compatible Queues
Queues within a queue family. Compatible queues have identical properties.

Complete Mipmap Chain
The entire set of mip levels that can be provided for an image, from the largest application specified mip level size down to the minimum mip level size. See Image Mip Level Sizing.

Completed Operation
A deferred operation whose corresponding command has been executed to completion. See
Deferred Host Operations

Component (Format)
A distinct part of a format. Color components are represented with R, G, B, and A. Depth and stencil components are represented with D and S. Formats can have multiple instances of the same component. Some formats have other notations such as E or X which are not considered a component of the format.

Compressed Texel Block
An element of an image having a block-compressed format, comprising a rectangular block of texel values that are encoded as a single value in memory. Compressed texel blocks of a particular block-compressed format have a corresponding width, height, and depth defining the dimensions of these elements in units of texels, and a size in bytes of the encoding in memory.

Constant Integral Expressions
A SPIR-V constant instruction whose type is OpTypeInt. See Constant Instruction in section 2.2.1 “Instructions” of the Khronos SPIR-V Specification.

Cooperative Matrix
A SPIR-V type where the storage for and computations performed on the matrix are spread across a set of invocations such as a subgroup.

Corner-Sampled Image
A VkImage where unnormalized texel coordinates are centered on integer values instead of half-integer values. Specified by setting the VK_IMAGE_CREATE_CORNER_SAMPLED_BIT_NV bit on VkImageCreateInfo::flags at image creation.

Coverage Index
The index of a sample in the coverage mask.

Coverage Mask
A bitfield associated with a fragment representing the samples that were determined to be covered based on the result of rasterization, and then subsequently modified by fragment operations or the fragment shader.

Cull Distance
A built-in output from pre-rasterization shader stages defining a cull half-space where the primitive is rejected if all vertices have a negative value for the same cull distance.

Cull Volume
The intersection of the view volume with all cull half-spaces.

Decode Output Picture
A video picture resource used to store the result of a video decode operation.

Decoded Picture Buffer
An indexed set of reference pictures used by a video session. Abbreviated as DPB.
Decoded Picture Buffer Slot
An entry within a DPB that can be associated with a particular reference picture.

Decoded Picture Buffer Slot Index
The index of a DPB slot within its encompassing DPB.

Decoration (SPIR-V)
Auxiliary information such as built-in variables, stream numbers, invariance, interpolation type, relaxed precision, etc., added to variables or structure-type members through decorations.

Deferrable Command
A command which allows deferred execution of host-side work. See Deferred Host Operations.

Deferrable Operation
A single logical item of host-side work which can be deferred. Represented by the VkDeferredOperationKHR object. See Deferred Host Operations.

Deprecated (feature)
A feature is deprecated if it is no longer recommended as the correct or best way to achieve its intended purpose.

Depth/Stencil Attachment
A subpass attachment point, or image view, that is the target of depth and/or stencil test operations and writes.

Depth/Stencil Format
A VkFormat that includes depth and/or stencil components.

Depth/Stencil Image (or ImageView)
A VkImage (or VkImageView) with a depth/stencil format.

Depth/Stencil Resolve Attachment
A subpass attachment point, or image view, that is the target of a multisample resolve operation from the corresponding depth/stencil attachment at the end of the subpass.

Derivative Group
A set of fragment or compute shader invocations that cooperate to compute derivatives, including implicit derivatives for sampled image operations.

Descriptor
Information about a resource or resource view written into a descriptor set that is used to access the resource or view from a shader.

Descriptor Binding
An entry in a descriptor set layout corresponding to zero or more descriptors of a single descriptor type in a set. Defined by a VkDescriptorSetLayoutBinding structure.
Descriptor Pool
An object that descriptor sets are allocated from, and that owns the storage of those descriptor sets. Descriptor pools aid multithreaded performance by enabling different threads to use different allocators, without internal synchronization on each use. Represented by a `VkDescriptorPool` object.

Descriptor Set
An object that resource descriptors are written into via the API, and that can be bound to a command buffer such that the descriptors contained within it can be accessed from shaders. Represented by a `VkDescriptorSet` object.

Descriptor Set Layout
An object defining the set of resources (types and counts) and their relative arrangement (in the binding namespace) within a descriptor set. Used when allocating descriptor sets and when creating pipeline layouts. Represented by a `VkDescriptorSetLayout` object.

Device
The processor(s) and execution environment that perform tasks requested by the application via the Vulkan API.

Device Group
A set of physical devices that support accessing each other's memory and recording a single command buffer that can be executed on all the physical devices.

Device Index
A zero-based integer that identifies one physical device from a logical device. A device index is valid if it is less than the number of physical devices in the logical device.

Device Mask
A bitmask where each bit represents one device index. A device mask value is valid if every bit that is set in the mask is at a bit position that is less than the number of physical devices in the logical device.

Device Memory
Memory accessible to the device. Represented by a `VkDeviceMemory` object.

Device-Level Command
Any command that is dispatched from a logical device, or from a child object of a logical device.

Device-Level Functionality
All device-level commands and objects, and their structures, enumerated types, and enumerants. Additionally, physical-device-level functionality defined by a device extension is also considered device-level functionality.

Device-Level Object
Logical device objects and their child objects. For example, `VkDevice`, `VkQueue`, and `VkCommandBuffer` objects are device-level objects.
Device-Local Memory
Memory that is connected to the device, and may be more performant for device access than host-local memory.

Direct Drawing Commands
*Drawing commands* that take all their parameters as direct arguments to the command (and not sourced via structures in buffer memory as the *indirect drawing commands*). Includes `vkCmdDrawMultiIndexedEXT`, `vkCmdDrawMultiEXT`, `vkCmdDrawMeshTasksNV`, `vkCmdDrawMeshTasksEXT`, `vkCmdDraw`, and `vkCmdDrawIndexed`.

Disjoint
*Disjoint planes* are *image planes* to which memory is bound independently. A *disjoint image* consists of multiple *disjoint planes*, and is created with the `VK_IMAGE_CREATE_DISJOINT_BIT` bit set.

Dispatchable Command
A non-global command. The first argument to each dispatchable command is a dispatchable handle type.

Dispatchable Handle
A handle of a pointer handle type which may be used by layers as part of intercepting API commands.

Dispatching Commands
Commands that provoke work using a compute pipeline. Includes `vkCmdDispatch` and `vkCmdDispatchIndirect`.

Drawing Commands

Duration (Command)
The *duration* of a Vulkan command refers to the interval between calling the command and its return to the caller.

Dynamic Storage Buffer
A storage buffer whose offset is specified each time the storage buffer is bound to a command buffer via a descriptor set.

Dynamic Uniform Buffer
A uniform buffer whose offset is specified each time the uniform buffer is bound to a command buffer.
buffer via a descriptor set.

**Dynamically Uniform**

See *Dynamically Uniform* in section 2.2 “Terms” of the Khronos SPIR-V Specification.

**Encode Input Picture**

A video picture resource used as the input of a video encode operation.

**Element**

Arrays are composed of multiple elements, where each element exists at a unique index within that array. Used primarily to describe data passed to or returned from the Vulkan API.

**Explicitly-Enabled Layer**

A layer enabled by the application by adding it to the enabled layer list in `vkCreateInstance` or `vkCreateDevice`.

**Event**

A synchronization primitive that is signaled when execution of previous commands completes through a specified set of pipeline stages. Events can be waited on by the device and polled by the host. Represented by a `VkEvent` object.

**Executable State (Command Buffer)**

A command buffer that has ended recording commands and can be executed. See also Initial State and Recording State.

**Execution Dependency**

A dependency that guarantees that certain pipeline stages’ work for a first set of commands has completed execution before certain pipeline stages’ work for a second set of commands begins execution. This is accomplished via pipeline barriers, subpass dependencies, events, or implicit ordering operations.

**Execution Dependency Chain**

A sequence of execution dependencies that transitively act as a single execution dependency.

**Explicit chroma reconstruction**

An implementation of sampler $Y'CbCr$ conversion which reconstructs reduced-resolution chroma samples to luma resolution and then separately performs texture sample interpolation. This is distinct from an implicit implementation, which incorporates chroma sample reconstruction into texture sample interpolation.

**Extension Scope**

The set of objects and commands that can be affected by an extension. Extensions are either device scope or instance scope.

**Extending Structure**

A structure type which may appear in the `pNext` chain of another structure, extending the functionality of the other structure. Extending structures may be defined by either core API versions or extensions.
External Handle
A resource handle which has meaning outside of a specific Vulkan device or its parent instance. External handles may be used to share resources between multiple Vulkan devices in different instances, or between Vulkan and other APIs. Some external handle types correspond to platform-defined handles, in which case the resource may outlive any particular Vulkan device or instance and may be transferred between processes, or otherwise manipulated via functionality defined by the platform for that handle type.

External synchronization
A type of synchronization required of the application, where parameters defined to be externally synchronized must not be used simultaneously in multiple threads.

Facingness (Polygon)
A classification of a polygon as either front-facing or back-facing, depending on the orientation (winding order) of its vertices.

Facingness (Fragment)
A fragment is either front-facing or back-facing, depending on the primitive it was generated from. If the primitive was a polygon (regardless of polygon mode), the fragment inherits the facingness of the polygon. All other fragments are front-facing.

Fence
A synchronization primitive that is signaled when a set of batches or sparse binding operations complete execution on a queue. Fences can be waited on by the host. Represented by a VkFence object.

Flat Shading
A property of a vertex attribute that causes the value from a single vertex (the provoking vertex) to be used for all vertices in a primitive, and for interpolation of that attribute to return that single value unaltered.

Format Features
A set of features from VkFormatFeatureFlagBits that a VkFormat is capable of using for various commands. The list is determined by factors such as VkImageTiling.

Fragment
A rectangular framebuffer region with associated data produced by rasterization and processed by fragment operations including the fragment shader.

Fragment Area
The width and height, in pixels, of a fragment.

Fragment Density
The ratio of fragments per framebuffer area in the x and y direction.

Fragment Density Texel Size
The (w,h) framebuffer region in pixels that each texel in a fragment density map applies to.
Fragment Input Attachment Interface
Variables with UniformConstant storage class and a decoration of InputAttachmentIndex that are statically used by a fragment shader's entry point, which receive values from input attachments.

Fragment Mask
A lookup table that associates color samples with color fragment values.

Fragment Output Interface
A fragment shader entry point's variables with Output storage class, which output to color and/or depth/stencil attachments.

Frame (Video)
A multi-dimensional array of luma samples and an optional multi-dimensional array of chroma samples.

Fragment Tile Image Interface
A fragment shader entry point's variables with TileImageEXT storage class and a decoration of Location, which are used to read values from color attachments.

Framebuffer
A collection of image views and a set of dimensions that, in conjunction with a render pass, define the inputs and outputs used by drawing commands. Represented by a VkFramebuffer object.

Framebuffer Attachment
One of the image views used in a framebuffer.

Framebuffer Coordinates
A coordinate system in which adjacent pixels' coordinates differ by 1 in x and/or y, with (0,0) in the upper left corner and pixel centers at half-integers.

Framebuffer-Space
Operating with respect to framebuffer coordinates.

Framebuffer-Local
A framebuffer-local dependency guarantees that only for a single framebuffer region, the first set of operations happens-before the second set of operations.

Framebuffer-Global
A framebuffer-global dependency guarantees that for all framebuffer regions, the first set of operations happens-before the second set of operations.

Framebuffer Region
A framebuffer region is a set of sample (x, y, layer, sample) coordinates that is a subset of the entire framebuffer.

Front-Facing
See Facingness.
**Full Compatibility**

A given version of the API is fully compatible with another version if an application, relying only on valid behavior and functionality defined by either of those specifications, is able to correctly run against each version without any modification. This assumes no active attempt by that application to not run when it detects a different version.

**Global Command**

A Vulkan command for which the first argument is not a dispatchable handle type.

**Global Workgroup**

A collection of local workgroups dispatched by a single dispatching or single mesh task drawing command.

**Handle**

An opaque integer or pointer value used to refer to a Vulkan object. Each object type has a unique handle type.

**Happen-after, happens-after**

A transitive, irreflexive and antisymmetric ordering relation between operations. An execution dependency with a source of A and a destination of B enforces that B happens-after A. The inverse relation of happens-before.

**Happen-before, happens-before**

A transitive, irreflexive and antisymmetric ordering relation between operations. An execution dependency with a source of A and a destination of B enforces that A happens-before B. The inverse relation of happens-after.

**Helper Invocation**

A fragment shader invocation that is created solely for the purposes of evaluating derivatives for use in non-helper fragment shader invocations, and which does not have side effects.

**Host**

The processor(s) and execution environment that the application runs on, and that the Vulkan API is exposed on.

**Host Mapped Device Memory**

Device memory that is mapped for host access using `vkMapMemory`.

**Host Mapped Foreign Memory**

Memory owned by a foreign device that is mapped for host access.

**Host Memory**

Memory not accessible to the device, used to store implementation data structures.

**Host-Accessible Subresource**

A buffer, or a linear image subresource in either the `VK_IMAGE_LAYOUT_PREINITIALIZED` or `VK_IMAGE_LAYOUT_GENERAL` layout. Host-accessible subresources have a well-defined addressing scheme which can be used by the host.
Host-Local Memory
Memory that is not local to the device, and may be less performant for device access than device-local memory.

Host-Visible Memory
Device memory that can be mapped on the host and can be read and written by the host.

ICD
Installable Client Driver. An ICD is represented as a VkPhysicalDevice.

Identically Defined Objects
Objects of the same type where all arguments to their creation or allocation functions, with the exception of pAllocator, are
1. Vulkan handles which refer to the same object or
2. identical scalar or enumeration values or
3. Host pointers which point to an array of values or structures which also satisfy these three constraints.

Image
A resource that represents a multi-dimensional formatted interpretation of device memory. Represented by a VkImage object.

Image Subresource
A specific mipmap level, layer, and set of aspects of an image.

Image Subresource Range
A set of image subresources that are contiguous mipmap levels and layers.

Image View
An object that represents an image subresource range of a specific image, and state controlling how the contents are interpreted. Represented by a VkImageView object.

Immutable Sampler
A sampler descriptor provided at descriptor set layout creation time for a specific binding. This sampler is then used for that binding in all descriptor sets allocated with the layout, and it cannot be changed.

Implicit chroma reconstruction
An implementation of sampler Y′CbCr conversion which reconstructs the reduced-resolution chroma samples directly at the sample point, as part of the normal texture sampling operation. This is distinct from an explicit chroma reconstruction implementation, which reconstructs the reduced-resolution chroma samples to the resolution of the luma samples, then filters the result as part of texture sample interpolation.

Implicitly-Enabled Layer
A layer enabled by a loader-defined mechanism outside the Vulkan API, rather than explicitly by the application during instance or device creation.
**Inactive Object (Ray Tracing)**

A primitive or instance in a ray tracing acceleration structure which has a corresponding ID, but which will never report an intersection with any ray.

**Index Buffer**

A buffer bound via `vkCmdBindIndexBuffer` which is the source of index values used to fetch vertex attributes for a `vkCmdDrawIndexed` or `vkCmdDrawIndexedIndirect` command.

**Indexed Drawing Commands**

*Drawing commands* which use an *index buffer* as the source of index values used to fetch vertex attributes for a drawing command. Includes `vkCmdDrawIndexed`, `vkCmdDrawIndexedIndirectCount`, `vkCmdDrawIndexedIndirectCountKHR`, `vkCmdDrawIndexedIndirectCountAMD`, `vkCmdDrawMultiIndexedEXT`, and `vkCmdDrawIndexedIndirect`.

**Indirect Commands**

Drawing or dispatching commands that source some of their parameters from structures in buffer memory. Includes `vkCmdDrawIndirect`, `vkCmdDrawIndexedIndirect`, `vkCmdDrawIndirectCount`, `vkCmdDrawIndexedIndirectCount`, `vkCmdDrawIndirectCountKHR`, `vkCmdDrawIndexedIndirectCountKHR`, `vkCmdDrawIndexedIndirectCountAMD`, `vkCmdDrawIndexedIndirectCountAMD`, `vkCmdDrawMeshTasksIndirectNV`, `vkCmdDrawMeshTasksIndirectCountNV`, `vkCmdDrawMeshTasksIndirectCountEXT`, and `vkCmdDispatchIndirect`.

**Indirect Commands Layout**

A definition of a sequence of commands, that are generated on the device via `vkCmdPreprocessGeneratedCommandsNV` and `vkCmdExecuteGeneratedCommandsNV`. Each sequence is comprised of multiple `VkIndirectCommandsTokenTypeNV`, which represent a subset of traditional command buffer commands. Represented as `VkIndirectCommandsLayoutNV`.

**Indirect Drawing Commands**

*Drawing commands* that source some of their parameters from structures in buffer memory. Includes `vkCmdDrawIndirect`, `vkCmdDrawIndirectCount`, `vkCmdDrawIndexedIndirectCount`, `vkCmdDrawIndexedIndirectCountKHR`, `vkCmdDrawIndexedIndirectCountKHR`, `vkCmdDrawIndexedIndirectCountAMD`, `vkCmdDrawIndexedIndirectCountAMD`, `vkCmdDrawMeshTasksIndirectNV`, `vkCmdDrawMeshTasksIndirectCountNV`, `vkCmdDrawMeshTasksIndirectCountEXT`, `vkCmdDrawMeshTasksIndirectCountEXT`, and `vkCmdDrawIndexedIndirect`.

**Initial State (Command Buffer)**

A command buffer that has not begun recording commands. See also Recording State and Executable State.

**Inline Uniform Block**

A descriptor type that represents uniform data stored directly in descriptor sets, and supports read-only access in a shader.
**Input Attachment**

A descriptor type that represents an image view, and supports unfiltered read-only access in a shader, only at the fragment’s location in the view.

**Instance**

The top-level Vulkan object, which represents the application’s connection to the implementation. Represented by a `VkInstance` object.

**Instance-Level Command**

Any command that is dispatched from an instance, or from a child object of an instance, except for physical devices and their children.

**Instance-Level Functionality**

All instance-level commands and objects, and their structures, enumerated types, and enumerants.

**Instance-Level Object**

High-level Vulkan objects, which are not physical devices, nor children of physical devices. For example, `VkInstance` is an instance-level object.

**Instance (Memory)**

In a logical device representing more than one physical device, some device memory allocations have the requested amount of memory allocated multiple times, once for each physical device in a device mask. Each such replicated allocation is an instance of the device memory.

**Instance (Resource)**

In a logical device representing more than one physical device, buffer and image resources exist on all physical devices but can be bound to memory differently on each. Each such replicated resource is an instance of the resource.

**Internal Synchronization**

A type of synchronization required of the implementation, where parameters not defined to be externally synchronized may require internal mutexing to avoid multithreaded race conditions.

**Invocation (Shader)**

A single execution of an entry point in a SPIR-V module. For example, a single vertex’s execution of a vertex shader or a single fragment’s execution of a fragment shader.

**Invocation Group**

A set of shader invocations that are executed in parallel and that must execute the same control flow path in order for control flow to be considered dynamically uniform.

**Invocation Repack Instruction**

A ray tracing shader call instruction where the implementation may change the set of invocations that are executing.

**Join (Deferred Host Operations)**

The act of instructing a thread to participate in the execution of a deferred operation. See
Deferred Host Operations.

Linear Color Attachment
A color attachment with linear tiling

Linear Resource
A resource is linear if it is one of the following:

- a VkBuffer
- a VkImage created with VK_IMAGE_TILING_LINEAR
- a VkImage created with VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT and whose Linux DRM format modifier is DRM_FORMAT_MOD_LINEAR
- a VkAccelerationStructureNV

Because a VkAccelerationStructureKHR resource does not have memory bound to it directly, it is considered neither linear nor non-linear. However, the VkBuffer on which a VkAccelerationStructureKHR resource is placed is a linear resource.

A resource is non-linear if it is one of the following:

- a VkImage created with VK_IMAGE_TILING_OPTIMAL
- a VkImage created with VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT and whose Linux DRM format modifier is not DRM_FORMAT_MOD_LINEAR

Linux DRM Format Modifier
A 64-bit, vendor-prefixed, semi-opaque unsigned integer describing vendor-specific details of an image's memory layout. In Linux graphics APIs, modifiers are commonly used to specify the memory layout of externally shared images. An image has a modifier if and only if it is created with tiling equal to VK_IMAGE_TILING_DRM_FORMAT_MODIFIER_EXT. For more details, refer to the appendix for extension VK_EXT_image_drm_format_modifier.

Local Workgroup
A collection of compute shader invocations invoked by a single dispatching command, which share data via WorkgroupLocal variables and can synchronize with each other.

Logical Device
An object that represents the application’s interface to the physical device. The logical device is the parent of most Vulkan objects. Represented by a VkDevice object.

Logical Operation
Bitwise operations between a fragment color value and a value in a color attachment, that produce a final color value to be written to the attachment.

Lost Device
A state that a logical device may be in as a result of unrecoverable implementation errors, or other exceptional conditions.
Mappable
See Host-Visible Memory.

Memory Dependency
A memory dependency is an execution dependency which includes availability and visibility operations such that:

• The first set of operations happens-before the availability operation
• The availability operation happens-before the visibility operation
• The visibility operation happens-before the second set of operations

Memory Domain
A memory domain is an abstract place to which memory writes are made available by availability operations and memory domain operations. The memory domains correspond to the set of agents that the write can then be made visible to. The memory domains are host, device, shader, workgroup instance (for workgroup instance there is a unique domain for each compute workgroup) and subgroup instance (for subgroup instance there is a unique domain for each subgroup).

Memory Domain Operation
An operation that makes the writes that are available to one memory domain available to another memory domain.

Memory Heap
A region of memory from which device memory allocations can be made.

Memory Type
An index used to select a set of memory properties (e.g. mappable, cached) for a device memory allocation.

Mesh Shading Pipeline
A graphics pipeline where the primitives are assembled explicitly in the shader stages. In contrast to the primitive shading pipeline where input primitives are assembled by fixed function processing.

Mesh Tasks Drawing Commands
Drawing commands which create shader invocations organized in workgroups for drawing mesh tasks. Includes vkCmdDrawMeshTasksNV, vkCmdDrawMeshTasksIndirectNV, and vkCmdDrawMeshTasksIndirectCountNV, vkCmdDrawMeshTasksEXT, vkCmdDrawMeshTasksIndirectEXT, and vkCmdDrawMeshTasksIndirectCountEXT.

Minimum Mip Level Size
The smallest size that is permitted for a mip level. For conventional images this is 1x1x1. For corner-sampled images, this is 2x2x2. See Image Mip Level Sizing.

Mip Tail Region
The set of mipmap levels of a sparse residency texture that are too small to fill a sparse block, and that must all be bound to memory collectively andopaquely.
Multi-planar

A multi-planar format (or “planar format”) is an image format consisting of more than one plane, identifiable with a _2PLANE or _3PLANE component to the format name and listed in Formats requiring sampler Y′C_bC_a conversion for VK_IMAGE_ASPECT_COLOR_BIT image views. A multi-planar image (or “planar image”) is an image of a multi-planar format.

Non-Dispatchable Handle

A handle of an integer handle type. Handle values may not be unique, even for two objects of the same type.

Non-Indexed Drawing Commands

Drawing commands for which the vertex attributes are sourced in linear order from the vertex input attributes for a drawing command (i.e. they do not use an index buffer). Includes vkCmdDraw, vkCmdDrawIndirectCount, vkCmdDrawIndirectCountKHR, vkCmdDrawIndirectCountAMD, vkCmdDrawMultiEXT, and vkCmdDrawIndirect.

Normalized

A value that is interpreted as being in the range [0,1] as a result of being implicitly divided by some other value.

Normalized Device Coordinates

A coordinate space after perspective division is applied to clip coordinates, and before the viewport transformation converts them to framebuffer coordinates.

Obsoleted (feature)

A feature is obsolete if it can no longer be used.

Opaque Capture Address

A 64-bit value representing the device address of a buffer or memory object that is expected to be used by trace capture/replay tools in combination with the bufferDeviceAddress feature.

Overlapped Range (Aliased Range)

The aliased range of a device memory allocation that intersects a given image subresource of an image or range of a buffer.

Ownership (Resource)

If an entity (e.g. a queue family) has ownership of a resource, access to that resource is well-defined for access by that entity.

Packed Format

A format whose components are stored as a single texel block in memory, with their relative locations defined within that element.

Passthrough Geometry Shader

A geometry shader which uses the PassthroughNV decoration on a variable in its input interface. Output primitives in a passthrough geometry shader always have the same topology as the input primitive and are not produced by emitting vertices.
Payload
Importable or exportable reference to the internal data of an object in Vulkan.

Per-View
A variable that has an array of values which are output, one for each view that is being generated. A mesh shader which uses the PerViewNV decoration on a variable in its output interface.

Peer Memory
An instance of memory corresponding to a different physical device than the physical device performing the memory access, in a logical device that represents multiple physical devices.

Physical Device
An object that represents a single device in the system. Represented by a VkPhysicalDevice object.

Physical-Device-Level Command
Any command that is dispatched from a physical device.

Physical-Device-Level Functionality
All physical-device-level commands and objects, and their structures, enumerated types, and enumerants.

Physical-Device-Level Object
Physical device objects. For example, VkPhysicalDevice is a physical-device-level object.

Pipeline
An object controlling how graphics or compute work is executed on the device. A pipeline includes one or more shaders, as well as state controlling any non-programmable stages of the pipeline. Represented by a VkPipeline object.

Pipeline Barrier
An execution and/or memory dependency recorded as an explicit command in a command buffer, that forms a dependency between the previous and subsequent commands.

Pipeline Cache
An object that can be used to collect and retrieve information from pipelines as they are created, and can be populated with previously retrieved information in order to accelerate pipeline creation. Represented by a VkPipelineCache object.

Pipeline Layout
An object defining the set of resources (via a collection of descriptor set layouts) and push constants used by pipelines that are created using the layout. Used when creating a pipeline and when binding descriptor sets and setting push constant values. Represented by a VkPipelineLayout object.

Pipeline Library
A pipeline that cannot be directly used, instead defining a set of shaders and shader groups
which will be linked into other pipelines.

**Pipeline Stage**
A logically independent execution unit that performs some of the operations defined by an action command.

**Pipeline Trace Ray Instruction**
A ray tracing instruction which traces a ray into an acceleration structure when using ray tracing pipelines. One of OpTraceNV, OpTraceRayMotionNV, OpTraceMotionNV, OpTraceRayKHR.

**pNext Chain**
A set of structures chained together through their pNext members.

**Planar**
See multi-planar.

**Plane**
An image plane is part of the representation of an image, containing a subset of the color components necessary to represent the texels in the image and with a contiguous mapping of coordinates to bound memory. Most images consist only of a single plane, but some formats spread the components across multiple image planes. The host-accessible properties of each image plane are accessible for a linear layout using vkGetImageSubresourceLayout. If a multi-planar image is created with the VK_IMAGE_CREATE_DISJOINT_BIT bit set, the image is described as disjoint, and its planes are therefore bound to memory independently.

**Point Sampling (Rasterization)**
A rule that determines whether a fragment sample location is covered by a polygon primitive by testing whether the sample location is in the interior of the polygon in framebuffer-space, or on the boundary of the polygon according to the tie-breaking rules.

**Potential Format Features**
The union of all VkFormatFeatureFlagBits that the implementation supports for a specified VkFormat, over all supported image tilings. For Android external formats the VkFormatFeatureFlagBits is provided by the implementation. For QNX Screen external formats the VkFormatFeatureFlagBits is provided by the implementation.

**Pre-rasterization**
Operations that execute before rasterization, and any state associated with those operations.

**Presentable image**
A VkImage object obtained from a VkSwapchainKHR used to present to a VkSurfaceKHR object.

**Preserve Attachment**
One of a list of attachments in a subpass description that is not read or written by the subpass, but that is read or written on earlier and later subpasses and whose contents must be preserved through this subpass.
Primary Command Buffer
A command buffer that can execute secondary command buffers, and can be submitted directly to a queue.

Primitive Shading Pipeline
A graphics pipeline where input primitives are assembled by fixed function processing. It is the counterpart to mesh shading.

Primitive Topology
State controlling how vertices are assembled into primitives, e.g. as lists of triangles, strips of lines, etc.

Promoted (feature)
A feature from an older extension is considered promoted if it is made available as part of a new core version or newer extension with wider support.

Protected Buffer
A buffer to which protected device memory can be bound.

Protected-capable Device Queue
A device queue to which protected command buffers can be submitted.

Protected Command Buffer
A command buffer which can be submitted to a protected-capable device queue.

Protected Device Memory
Device memory which can be visible to the device but must not be visible to the host.

Protected Image
An image to which protected device memory can be bound.

Provisional
A feature is released provisionally in order to get wider feedback on the functionality before it is finalized. Provisional features may change in ways that break backwards compatibility, and thus are not recommended for use in production applications.

Provoking Vertex
The vertex in a primitive from which flat shaded attribute values are taken. This is generally the “first” vertex in the primitive, and depends on the primitive topology.

Push Constants
A small bank of values writable via the API and accessible in shaders. Push constants allow the application to set values used in shaders without creating buffers or modifying and binding descriptor sets for each update.

Push Constant Interface
The set of variables with PushConstant storage class that are statically used by a shader entry point, and which receive values from push constant commands.
**Push Descriptors**
Descriptors that are written directly into a command buffer rather than into a descriptor set. Push descriptors allow the application to set descriptors used in shaders without allocating or modifying descriptor sets for each update.

**Descriptor Update Template**
An object specifying a mapping from descriptor update information in host memory to elements in a descriptor set, which helps enable more efficient descriptor set updates.

**Query Pool**
An object containing a number of query entries and their associated state and results. Represented by a `VkQueryPool` object.

**Queue**
An object that executes command buffers and sparse binding operations on a device. Represented by a `VkQueue` object.

**Queue Family**
A set of queues that have common properties and support the same functionality, as advertised in `VkQueueFamilyProperties`.

**Queue Operation**
A unit of work to be executed by a specific queue on a device, submitted via a queue submission command. Each queue submission command details the specific queue operations that occur as a result of calling that command. Queue operations typically include work that is specific to each command, and synchronization tasks.

**Queue Submission**
Zero or more batches and an optional fence to be signaled, passed to a command for execution on a queue. See the Devices and Queues chapter for more information.

**Ray Tracing Command**
Commands that provoke work using a ray tracing pipeline. Includes `vkCmdTraceRaysNV`, `vkCmdTraceRaysKHR`, and `vkCmdTraceRaysIndirectKHR`.

**Reconstructed Picture**
A video picture resource reconstructed from a compressed bitstream using video decode or encode operations that can be used as a reference picture by future video decode or encode operations with the same video session.

**Recording State (Command Buffer)**
A command buffer that is ready to record commands. See also Initial State and Executable State.

**Reference Picture**
A video picture resource used by video decode and encode operations to provide predictions of the values of samples in the subsequently decoded or encoded pictures.
**Reference Picture Metadata**
Opaque state associated with a DPB slot, maintained by a video session.

**Release Operation (Resource)**
An operation that releases ownership of an image subresource or buffer range.

**Render Pass**
An object that represents a set of framebuffer attachments and phases of rendering using those attachments. Represented by a `VkRenderPass` object.

**Render Pass Instance**
A use of a render pass in a command buffer.

**Required Extensions**
Extensions that **must** be enabled alongside extensions dependent on them (see Extension Dependencies).

**Reset (Command Buffer)**
Resetting a command buffer discards any previously recorded commands and puts a command buffer in the initial state.

**Residency Code**
An integer value returned by sparse image instructions, indicating whether any sparse unbound texels were accessed.

**Resolve Attachment**
A subpass attachment point, or image view, that is the target of a multisample resolve operation from the corresponding color attachment at the end of the subpass.

**Retired Swapchain**
A swapchain that has been used as the `oldSwapchain` parameter to `vkCreateSwapchainKHR`. Images cannot be acquired from a retired swapchain, however images that were acquired (but not presented) before the swapchain was retired **can** be presented.

**Sample Index**
The index of a sample within a **single set of samples**.

**Sample Shading**
Invoking the fragment shader multiple times per fragment, with the covered samples partitioned among the invocations.

**Sampled Image**
A descriptor type that represents an image view, and supports filtered (sampled) and unfiltered read-only access in a shader.

**Sampler**
An object containing state controlling how sampled image data is sampled (or filtered) when accessed in a shader. Also a descriptor type describing the object. Represented by a `VkSampler`
Secondary Command Buffer
A command buffer that can be executed by a primary command buffer, and must not be submitted directly to a queue.

Self-Dependency
A subpass dependency from a subpass to itself, i.e. with srcSubpass equal to dstSubpass. A self-dependency is not automatically performed during a render pass instance, rather a subset of it can be performed via vkCmdPipelineBarrier during the subpass.

Semaphore
A synchronization primitive that supports signal and wait operations, and can be used to synchronize operations within a queue or across queues. Represented by a VkSemaphore object.

Shader
Instructions selected (via an entry point) from a shader module, which are executed in a shader stage.

Shader Call
An instruction which may cause execution to continue in a different shader stage.

Shader Code
A stream of instructions used to describe the operation of a shader.

Shader Group
A set of Shader Stages that are part of a VkPipeline containing multiple of such sets. This allows the device to make use of all the shader groups from the bound pipeline independently.

Shader Module
A collection of shader code, potentially including several functions and entry points, that is used to create shaders in pipelines. Represented by a VkShaderModule object.

Shader Stage
A stage of the graphics or compute pipeline that executes shader code.

Shading Rate
The ratio of the number of fragment shader invocations generated in a fully covered framebuffer region to the size (in pixels) of that region.

Shading Rate Image
An image used to establish the shading rate for a framebuffer region, where each pixel controls the shading rate for a corresponding framebuffer region.

Shared presentable image
A presentable image created from a swapchain with VkPresentModeKHR set to either VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR or VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR.
Side Effect
A store to memory or atomic operation on memory from a shader invocation.

Single-plane format
A format that is not multi-planar.

Size-Compatible Image Formats
When a compressed image format and an uncompressed image format are size-compatible, it means that the texel block size of the uncompressed format must equal the texel block size of the compressed format.

Sparse Block
An element of a sparse resource that can be independently bound to memory. Sparse blocks of a particular sparse resource have a corresponding size in bytes that they use in the bound memory.

Sparse Image Block
A sparse block in a sparse partially-resident image. In addition to the sparse block size in bytes, sparse image blocks have a corresponding width, height, and depth defining the dimensions of these elements in units of texels or compressed texel blocks, the latter being used in case of sparse images having a block-compressed format.

Sparse Unbound Texel
A texel read from a region of a sparse texture that does not have memory bound to it.

SRT
A decomposition of a spatial transform separating out scale, rotation, and translation which has better linear interpolation properties for representing motion.

Static Use
An object in a shader is statically used by a shader entry point if any function in the entry point’s call tree contains an instruction using the object. A reference in the entry point’s interface list does not constitute a static use. Static use is used to constrain the set of descriptors used by a shader entry point.

Storage Buffer
A descriptor type that represents a buffer, and supports reads, writes, and atomics in a shader.

Storage Image
A descriptor type that represents an image view, and supports unfiltered loads, stores, and atomics in a shader.

Storage Texel Buffer
A descriptor type that represents a buffer view, and supports unfiltered, formatted reads, writes, and atomics in a shader.

Subgroup
A set of shader invocations that can synchronize and share data with each other efficiently. In
compute shaders, the *local workgroup* is a superset of the subgroup.

**Subgroup Mask**
A bitmask for all invocations in the current subgroup with one bit per invocation, starting with the least significant bit in the first vector component, continuing to the last bit (less than **SubgroupSize**) in the last required vector component.

**Subpass**
A phase of rendering within a render pass, that reads and writes a subset of the attachments.

**Subpass Dependency**
An execution and/or memory dependency between two subpasses described as part of render pass creation, and automatically performed between subpasses in a render pass instance. A subpass dependency limits the overlap of execution of the pair of subpasses, and *can* provide guarantees of memory coherence between accesses in the subpasses.

**Subpass Description**
Lists of attachment indices for input attachments, color attachments, depth/stencil attachment, resolve attachments, depth/stencil resolve, and preserve attachments used by the subpass in a render pass.

**Subset (Self-Dependency)**
A subset of a self-dependency is a pipeline barrier performed during the subpass of the self-dependency, and whose stage masks and access masks each contain a subset of the bits set in the identically named mask in the self-dependency.

**Texel Block**
A single addressable element of an image with an uncompressed **VkFormat**, or a single compressed block of an image with a compressed **VkFormat**.

**Texel Block Size**
The size (in bytes) used to store a texel block of a compressed or uncompressed image.

**Texel Coordinate System**
One of three coordinate systems (normalized, unnormalized, integer) defining how texel coordinates are interpreted in an image or a specific mipmap level of an image.

**Tile Image**
A per-tile view of a framebuffer attachment. If the **VK_EXT_shader_tile_image** extension is enabled, the framebuffer is considered to be divided into tiles.

**Timeline Semaphore**
A semaphore with a strictly increasing 64-bit unsigned integer payload indicating whether the semaphore is signaled with respect to a particular reference value. Represented by a **VkSemaphore** object created with a semaphore type of **VK_SEMAPHORE_TYPE_TIMELINE**.

**Uniform Texel Buffer**
A descriptor type that represents a buffer view, and supports unfiltered, formatted, read-only
Uniform Buffer
A descriptor type that represents a buffer, and supports read-only access in a shader.

Units in the Last Place (ULP)
A measure of floating-point error loosely defined as the smallest representable step in a floating-point format near a given value. For the precise definition see Precision and Operation of SPIR-V instructions or Jean-Michel Muller, “On the definition of ulp(x)”, RR-5504, INRIA. Other sources may also use the term “unit of least precision”.

Unnormalized
A value that is interpreted according to its conventional interpretation, and is not normalized.

Unprotected Buffer
A buffer to which unprotected device memory can be bound.

Unprotected Command Buffer
A command buffer which can be submitted to an unprotected device queue or a protected-capable device queue.

Unprotected Device Memory
Device memory which can be visible to the device and can be visible to the host.

Unprotected Image
An image to which unprotected device memory can be bound.

User-Defined Variable Interface
A shader entry point's variables with Input or Output storage class that are not built-in variables.

Vertex Input Attribute
A graphics pipeline resource that produces input values for the vertex shader by reading data from a vertex input binding and converting it to the attribute's format.

Vertex Stream
A vertex stream is where the last pre-rasterization shader stages outputs vertex data, which then goes to the rasterizer, is captured to a transform feedback buffer, or both. Geometry shaders can emit primitives to multiple independent vertex streams. Each vertex emitted by the geometry shader is directed at one of the vertex streams.

Validation Cache
An object that can be used to collect and retrieve validation results from the validation layers, and can be populated with previously retrieved results in order to accelerate the validation process. Represented by a VkValidationCacheEXT object.

Variable-Sized Descriptor Binding
A descriptor binding whose size will be specified when a descriptor set is allocated using this layout.
**Vertex Input Binding**
A graphics pipeline resource that is bound to a buffer and includes state that affects addressing calculations within that buffer.

**Vertex Input Interface**
A vertex shader entry point’s variables with **Input** storage class, which receive values from vertex input attributes.

**Video Bitstream Buffer**
A resource that represents a linear array of data in device memory storing encoded video data. Represented by a `VkBuffer` object.

**Video Coding Scope**
A series of subsequent commands recorded into a command buffer starting with a `vkCmdBeginVideoCodingKHR` command and ending with a `vkCmdEndVideoCodingKHR` command that encompasses a set of video decode or encode operations.

**Video Coding Operations**
Any operations recorded into a command buffer within a video coding scope, including video decode and encode operations.

**Video Decode Operation**
An operation consuming data from a video bitstream buffer and zero or more reference pictures, and producing data to a decode output picture and an optional reconstructed picture.

**Video Encode Operation**
An operation consuming data from an encode input picture and zero or more reference pictures, and producing data to a video bitstream buffer and an optional reconstructed picture.

**Video Picture Resource**
A resource that represents a multi-dimensional formatted interpretation of device memory to be used with a video session as a decode output picture, encode input picture, reconstructed picture, and/or reference picture. It **may** contain metadata associated with a particular video session it is used with. Represented by a `VkImage` object and referred to using `VkImageView` objects created from it.

**Video Session**
A resource that represents and maintains the state needed to perform video decode or encode operations. Represented by a `VkVideoSessionKHR` object.

**Video Session Parameters**
A resource that stores preprocessed codec-specific parameters used with a compatible video session in video codec operations. Represented by a `VkVideoSessionParametersKHR` object.

**Video Transcoding**
The process of using the outputs of video decoding operations as inputs in video encoding operations.
View Mask
When multiview is enabled, a view mask is a property of a subpass controlling which views the rendering commands are broadcast to.

View Volume
A subspace in homogeneous coordinates, corresponding to post-projection x and y values between -1 and +1, and z values between 0 and +1.

Viewport Transformation
A transformation from normalized device coordinates to framebuffer coordinates, based on a viewport rectangle and depth range.

Visibility Operation
An operation that causes available values to become visible to specified memory accesses.

Visible
A state of values written to memory that allows them to be accessed by a set of operations.

Common Abbreviations
The abbreviations and acronyms defined in this section are sometimes used in the Specification and the API where they are considered clear and commonplace.

Src
Source

Dst
Destination

Min
Minimum

Max
Maximum

Rect
Rectangle

Info
Information

LOD
Level of Detail

Log
Logarithm
Video-Specific Abbreviations

The following abbreviations and acronyms are used in the context of video decode and encode operations to refer to commonly used video compression terms in their usual abbreviated form:

**AVC**
Advanced Video Coding

**Bipred**
Bidirectional Prediction

**CABAC**
Context-Adaptive Binary Arithmetic Coding

**CAVLC**
Context-Adaptive Variable-Length Coding

**CBR**
Constant Bit Rate
CTB
  Coding Tree Block

Diff
  Difference

DPB
  Decoded Picture Buffer

GOP
  Group Of Pictures

HDR
  High Dynamic Range

HEVC
  High Efficiency Video Coding

HRD
  Hypothetical Reference Decoder

IDC
  Indicator

IDR
  Instantaneous Decoder Refresh

MB
  Macroblock

MV
  Motion Vector

NALU
  Network Abstraction Layer Unit

PCM
  Pulse-Code Modulation

Pic
  Picture

Pred
  Prediction

PPS
  Picture Parameter Set
**Prefixes**

Prefixes are used in the API to denote specific semantic meaning of Vulkan names, or as a label to avoid name clashes, and are explained here:

**VK/Vk/vk**
Vulkan namespace
All types, commands, enumerants and defines in this specification are prefixed with these two characters.

**PFN/pfn**
Function Pointer
Denotes that a type is a function pointer, or that a variable is of a pointer type.

**p**
Pointer
Variable is a pointer.

**vkCmd**
Commands that record commands in command buffers
These API commands do not result in immediate processing on the device. Instead, they record the requested action in a command buffer for execution when the command buffer is submitted to a queue.

**s**
Structure
Used to denote the `VK_STRUCTURE_TYPE*` member of each structure in `sType`
Appendix J: Credits (Informative)

Vulkan 1.3 is the result of contributions from many people and companies participating in the Khronos Vulkan Working Group, as well as input from the Vulkan Advisory Panel.

Members of the Working Group, including the company that they represented at the time of their most recent contribution, are listed in the following section. Some specific contributions made by individuals are listed together with their name.

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